UNIVERSIDAD POLITÉCNICA DE MADRID
ESCUELA TÉCNICA SUPERIOR DE INGENIEROS INDUSTRIALES

ESSAYS ON MARINE RESOURCES CONSERVATION:
Macroeconomics and national accounting

TESIS DOCTORAL

Laura Recuero Virto

Doctora por la Escuela de Economía de Toulouse

2017

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2017

Tribunal nombrado por el Mgfco.y Excmo. Sr. Rector de la Universidad Politécnica de Madrid,
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Calificación: _____

The views expressed in this thesis are our own and do not necessarily reflect those of the Technical University of Madrid or of the French Ministry of Foreign Affairs and International Development.

ACKNOWLEDGEMENTS

I am extremely grateful to my thesis supervisor, Carlos Romero, who has always been very supportive and available for discussion. I am endeavoured for his suggestions throughout the thesis and I hope we will be able to continue exchanging ideas in the near future. I would like to thank as well the members of the administration of the Technical University of Madrid who have always been very helpful regarding official requirements and deadlines.

In terms of collaborations with other researchers, I would like to thank Denis Couvet from the *Museum National d'Histoire Naturelle* in Paris for his enlightening ideas for chapter two. I thank Frédéric Ducarme from the same institution for his guidance concerning coral reefs management presented in chapter three. I am endeavoured as well to Jean-Louis Weber from the University of Nottingham and member of the European Environment Agency's Scientific Committee, and to Mathilde Jeantil from the *Ecole Normale Supérieure de Cachan* for their contribution to the elaboration and distribution of the survey used in chapter six.

Concerning chapters two, four and five, I would like to thank Steven Durlauf and Grigoris Emvalomatis for insightful thoughts and suggestions as well as for providing me data and econometric programs that were shared during the '2nd Advanced summer school in economics and econometrics' at the University of Crete in Rethymno held on the 19th-26th of August 2007. I would also like to thank Enrique Moral-Benito and Steven Poelhekke for suggestions and providing data. I would also like to thank participants at the *Séminaire du Centre International de Recherche sur l'Environnement et le Développement* (CIRED) held on the 29th January 2017 and at the *Séminaire Développement Durable Environnement et Economie Publique* (DDEEP-EconomiX, Paris Nanterre) held on the 31st January 2017 for their comments and suggestions.

Concerning chapter three, I would like to thank Adrien Comte, Ophélie Darses, François Henry, Yann Kervinio, Daniela Miteva, Linwood Pendleton, Diane Vaschalde and Tibor Vegh for insightful thoughts and suggestions as well as to the participants at the seminar on 'Coastal blue carbon: What scope for mitigation projects currently?' organised by the French Ministry of Foreign Affairs and International Development and *l'Unité Mixte de Recherche Aménagement des Usages des Ressources et des Espaces marins et littoraux, Centre de droit et d'économie de la mer*, on the 8th of June 2015 in Paris.

Concerning chapter six, I would like to thank the anonymous reviewer from the French Association of Environmental and Resource Economists (FAERE) and from Ecological Economics for the very useful comments and suggestions which help us improve the quality of our chapter. I would also like to thank Philippe Puydarrieux and Ophélie Darses from the Ministry of Ecology, Sustainable Development and Energy and to Glenn-Marie Lange and Sofia Ahlroth from the World Bank for insightful thoughts and suggestions. A preliminary version of this chapter was presented at the weekly 'inter' seminar at the *Museum National d'Histoire Naturelle* in Paris on the 4th December 2014, I thank Anne-Caroline Prevot and Clément Feger for their comments during that seminar. The chapter was also presented at the 'International workshop on opportunities and obstacles for natural capital accounting' organised by the French Ministry of Foreign Affairs and International Development and the WWF in Brussels held on the 27th January 2015, I also thank participants for their comments. In particular, we would like to thank Ben Milligan, Günter Mitlacher Jan-Erik Petersen and Robert Smith.

Last but not least, I would like to thank my family for their constant support and understanding. A special thought for all those who are no longer between us.

Paris, 2017
Virto

Laura Recuero

SUMMARY

In this thesis, we explore macroeconomic and accounting frameworks to motivate the integration of marine and coastal ecosystems within the basic infrastructure required to sustain economic activity. In the first chapter, we put forward the reasons for developing such framework. In the second chapter, we analyse whether renewable and non-renewable natural capital are robust determinants of economic growth. We find some evidence of an indirect negative impact of renewable natural capital on economic growth through human fertility. This is particularly the case for countries with higher levels of human development, where fertility rates would be still rising in the second-phase of the demographic transition. These results suggest that we find evidence of the ‘Malthusian trap’ where the resource abundance would encourage population growth, which would eventually bring the per capita supply of resources back to its original level. In contrast, the share of non-renewable natural capital in wealth has a direct positive impact on economic growth in countries with lower income inequality and higher institutional quality. This result reflects the effect of capital accumulation in the domestic economy, as capacity constraints are relaxed.

In the third chapter, we highlight the mechanisms through which the ocean and coasts play a key role on climate regulation, and on the reduction of greenhouse gas emissions, with climate change mitigation interventions in coasts having returns in the short-term. We show that climate change mitigation projects in coasts can play a significant role within overall mitigation efforts, and we share a country-taxonomy for mangrove countries according to their climate change mitigation potential and their break-even carbon price to identify priority areas for intervention. Based on these results, in the fourth chapter, we focus on the determinants of economic growth in countries with high exposure to coastal risks and with high coastal climate change mitigation potential. This is due to the potential synergies between nature-based adaptation and mitigation strategies. In the fifth chapter, we examine countries with high marine biodiversity, through the extension of coral reef resources. Compared to a worldwide data set, macroeconomic policies and natural capital are additional determinants of economic growth in these three types of coastal countries. There is strong historical evidence on the role of macroeconomic policies and non-renewable natural resources in trade flows and economic growth in coastal countries. Both factors, together with demography, highlight the pressures that coastal areas are subject to such as construction and public works, population growth and urbanisation. Besides these results, we find that education plays an important role in countries with marine biodiversity. In particular, diversifying away from natural capital wealth by investing in education and, more generally, in intangible capital can enhance economic growth, particularly in countries with very high levels of marine biodiversity.

Finally, in the sixth chapter, based on a survey for statistical offices, ministries and independent experts worldwide, we find that there is very little use of natural capital accounts for public policy decisions and, more so, in developing countries. The most relevant obstacles are the lack of political support by key people and institutional leadership being unable to promote policy use by other ministries. Concerning developing countries, the factor which is considered as the most relevant in preventing the use of natural capital accounts for policy making is the stage of development of the country. A key result of the survey is the need to evaluate the value-added of natural capital accounts with respect to official statistics.

Key-words – Marine natural capital, economic growth, accounting, climate change.

JEL classification – Q0, Q23, Q28, Q38, Q54, Q58

RESUMEN

En esta tesis, exploramos los marcos macroeconómicos y contables para motivar la integración de los ecosistemas marinos y costeros dentro de la infraestructura básica necesaria para sostener la actividad económica. En el primer capítulo, explicamos las razones por las que desarrollamos este tema. En el segundo capítulo, analizamos si el capital natural renovable y no renovable son determinantes sólidos del crecimiento económico. Encontramos alguna evidencia de un impacto indirecto negativo del capital natural renovable sobre el crecimiento económico a través de la fertilidad humana. Este es el caso en particular de los países con mayores niveles de desarrollo humano, donde las tasas de fecundidad seguirían aumentando en la segunda fase de la transición demográfica. Estos resultados sugieren que encontramos evidencia de la ‘trampa malthusiana’, donde la abundancia de recursos estimularía el crecimiento de la población, lo que eventualmente traería la producción per cápita de recursos a su nivel original. En cambio, el aporte del capital natural no renovable en la riqueza nacional tiene un impacto positivo directo en el crecimiento económico en países con menor desigualdad de ingresos y mayor calidad institucional. Este resultado refleja el efecto de la acumulación de capital en la economía nacional, una vez que las restricciones de capacidad se relajan.

En el tercer capítulo, destacamos los mecanismos a través de los cuales el océano y las costas desempeñan un papel clave en la regulación del clima y en la reducción de las emisiones de gases de efecto invernadero, las intervenciones para la mitigación del cambio climático en las costas teniendo retornos a corto plazo. En base a los datos sobre los manglares, demostramos que los proyectos de mitigación del cambio climático en las costas pueden desempeñar un papel importante dentro de los esfuerzos globales de mitigación y compartimos una taxonomía de países en función de su potencial de mitigación del cambio climático y del precio de carbono equilibrado para identificar áreas prioritarias de intervención. Sobre la base de estos resultados, en el cuarto capítulo nos centramos en los factores determinantes del crecimiento económico en los países con alta exposición a los riesgos costeros y con alto potencial de mitigación de los efectos del cambio climático a nivel costero, dadas las posibles sinergias entre las estrategias de adaptación y de mitigación basadas en la naturaleza. En el quinto capítulo, examinamos países con alta biodiversidad marina, a través de la extensión de los arrecifes de coral. En comparación con una base de datos mundial, las políticas macroeconómicas y el capital natural son determinantes adicionales del crecimiento económico en estos tipos de países costeros. Existen fuertes evidencias históricas sobre el papel de las políticas macroeconómicas y los recursos naturales no renovables en los flujos comerciales y en el crecimiento económico en los países costeros. Ambos factores, junto con la demografía, destacan las presiones a las que están sujetas las zonas costeras como la construcción y las obras públicas, el crecimiento de la población y el urbanismo. Además de estos resultados, encontramos que la educación juega un papel importante en los países con biodiversidad marina. En particular, la diversificación de la riqueza de capital natural mediante la inversión en educación y, más generalmente, en capital intangible puede aumentar el crecimiento económico, especialmente en países con niveles muy altos de biodiversidad marina.

Por último, en el sexto capítulo, basándonos en una encuesta realizada a miembros de las oficinas de estadística, ministerios, así como a expertos independientes a nivel mundial, constatamos que se hace un uso muy escaso de las cuentas de capital natural para conformar las políticas públicas, sobre todo en los países en desarrollo. Los obstáculos más relevantes son la falta de apoyo político de las personas clave y la falta de liderazgo institucional que no puede promover el uso por otros ministerios. En lo que respecta a los países en desarrollo, el factor que se considera más relevante para explicar el escaso uso de las cuentas de capital natural es la etapa en la que se encuentra el desarrollo del país. Un resultado clave derivado de la encuesta realizada es la necesidad de evaluar el valor agregado de las cuentas de capital natural con respecto a las estadísticas.

Palabras clave - Capital natural marino, crecimiento económico, contabilidad, cambio climático.

Clasificación JEL - Q0, Q23, Q28, Q38, Q54, Q58

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1. INTRODUCTION

The scale and nature of the combined challenges of climate change and resource scarcity, among other planetary boundaries, require new macroeconomic as well as microeconomic responses (Daly and Farley, 2004).¹ In particular, some researchers argue that there is a need to derive a fully consistent macroeconomic framework in which it is possible to maintain economic stability, ensure full employment, and yet remain within the ecological constraints and resource limits of a finite planet (Jackson, 2009 and Jackson and Victor, 2013).

Regarding accounting frameworks, in order to better understand the impact of our economic activities on the environment, it is important to develop complementary natural capital accounts (Weber, 2012). This would allow measuring the contribution of natural assets and associated service flows to our economy and well-being, and help monitor the changes in natural capital. However, more work is required with regard to economic valuation, both for monetary and non-monetary approaches (Petersen and Gocheva, 2015). Moreover, physical accounting approaches need to be completed first as they provide a necessary platform on which to build economic valuation. A key conclusion hence to emerge from ongoing work is that future efforts to develop natural capital accounting, particularly concerning ecosystem services, should be targeted and purpose-driven (French Ministry of Foreign Affairs and International Development, MAEDI and WWF, 2014).

The methodologies for ecosystem services accounting for marine habitats are at its early stages. As in the case of terrestrial habitats, the development of ecosystem services accounting is far behind that of satellite asset accounts. At the European level, the Marine Strategy Framework Directive (Directive 2008/56/EC) approved in 2008 requests Member States to take the necessary measures to reduce the impacts of activities on the environment to achieve or maintain good environmental status in the marine environment by 2020 which will imply, among other activities, developing environmental accounting.

Within this initiative, Valuing ecosystem services in the Western Channel (VALMER) is a 4.7 million euro project co-funded by the European Regional Development Fund, which aims to examine how improved marine ecosystem services assessment can support effective and informed marine management and planning. Regarding developing countries, a guidance note on measuring and valuing coastal protection services of mangroves and coral reefs is also underway through the World Bank's WAVES project.

In sum, new macroeconomic frameworks and the associated accounting methodologies, are still being developed. In addition, full endorsement by policy makers to integrate these frameworks and to develop the accounts remains a challenge (WWF, 2015b). There has been little progress as well to make use of some already existing natural capital accounts for policy decisions (Laurans *et al.*, 2013 and Ekins, 2015). This work aims at motivating the need to develop appropriate macroeconomic and accounting frameworks to fully integrate marine habitats within the basic infrastructure required to sustain economic activity.

We propose first to bring some light from an empirical standpoint to the role of natural capital on economic growth distinguishing direct and indirect impacts of renewable and non-renewable natural capital. This analysis also enables us to have a baseline model to compare the results of a world-wide data sets with those of coastal countries with certain specificities. Indeed, we then focus on the economic growth determinants in coastal countries with climate change adaptation needs and mitigation potential, and in countries with high marine biodiversity. We previously explore the potential of coastal vegetated habitats in climate change mitigation. Secondly, we explore why natural capital accounting is rarely used to inform policy decisions through a survey across a large sample of experts from developed and developing

¹See Rockström *et al.* (2009) for a set of nine planetary boundaries.

countries. In this survey, we do not make an explicit reference to marine assets and services. While few countries have developed natural capital accounts, even less have constructed the specific type based on marine assets and services.

1.1. Natural capital and macroeconomic frameworks

Many economic growth models are estimated using panel data to multiply the number of observations. Since the variation of growth rates at annual frequency rates may give very misleading information about the long-term growth process, we average data over five year periods based on Durlauf and Quah (1999).² Using a worldwide sample of countries from 1960 to 2009, our analysis on the role of natural capital on economic growth is based on the augmented Solow model with a set of new growth theories (Solow, 1956 and Durlauf et al., 2005, 2008a).

We work with the following set of new growth theoretical frameworks: Demography, macroeconomic policy, regional heterogeneity, religion, natural capital, geography, fractionalisation and institutions. Our eight classes of growth theories include both proximate and fundamental theories.³ A fundamental theory (religion, natural capital, geography, fractionalisation and institutions) can be eschewed if it is endogenous with respect to a proximate theory that is also included in the model space. We thus develop estimations for proximate and fundamental theories together, and then only for fundamental theories to test the robustness of fundamental theories. The latter may only influence indirectly economic growth through proximate theories.

From an econometric perspective, regression analyses show that a large number of variables are correlated with economic growth but are far from implying the direction of causation. The lack of agreed theoretical bases for empirical work and for a reduced form to apply in empirical analyses, has led researchers to abandon any a priori models and to let the data show which variables are correlated with economic growth through model uncertainty (Capolupo, 2009). In order to estimate accurately the role of the so-called new growth theories such as natural capital in determining economic growth, Durlauf *et al.* (2005, 2008a) and Sala-i-Martin *et al.* (2004) propose the Bayesian Model Averaging (BMA) methodology.⁴

There is indeed a problem of model uncertainty when performing economic growth estimations that account for new growth theories (Brock and Durlauf, 2001, Brock *et al.*, 2003). That is, there is theory uncertainty since the statement that a theory is relevant does not preclude others from being relevant as well. Moreover, there is specification uncertainty since new growth theories do not translate naturally into specific regressors. To deal with model uncertainty, we hence employ the BMA estimator.

Starting with Durlauf and Johnson (1995), many researchers have also explored whether there is evidence of multiple growth regimes focusing on different variables in order to divide the sample and using several methodologies.⁵ That is, they analyse whether there is a common

² We have replicated the analysis with 10 year periods but the sample size is too small given the nature of our data (presence of heteroskedasticity and serial correlation). Even though averaging over the longest time horizon possible should better deal with eliminating business cycle effects that probably dominate per capita income fluctuations at higher frequencies, it comes at the cost of reducing the sample size (Durlauf *et al.*, 2008b). In turn, when the sample size is too limited and the number of explanatory variables large, estimation methods can be of limited use to distinguish robust from irrelevant variables.

³ The determinants derived from a neoclassical growth model are sometimes called proximate determinants because they are thought to be the most established drivers of economic growth. The term 'proximate' also reflects the ease with which these determinants can be influenced by policy measures. Fundamental determinants depend on slow-moving fundamental growth (Durlauf *et al.*, 2008b).

⁴ Fernandez *et al.* (2001) show the superiority of BMA over other techniques in selecting regressors to explain cross-country growth.

⁵ See Owen *et al.* (2007) and Konte (2013) for a summary on how the question of multiple growth regimes has been addressed in numerous works focusing on different theories such as neoclassical,

growth regime for the whole sample under conditional convergence or whether there is a growth process with multiple growth regimes in which economies with similar conditions tend to converge to one another (Durlauf and Johnson, 1995). That is, even after controlling for structural heterogeneity there is a role for initial conditions in explaining variation in cross-country growth behaviour.⁶ Konte (2013), for instance, allows for multiple growth regimes and finds that democracy helps a given country to belong to the blessed regimes in terms of natural resources while education has no effect.

We apply a preliminary analysis to the augmented Solow model to explore whether there are multiple convergence regimes. To analyse whether there are multiple convergence regimes we proceed in two steps. Based on Durlauf and Johnson (1995), we use the Classification Analysis and Regression Tree (CART) model applied to Solow variables to identify those that are most likely to provide a more ‘reasonable’ separation of observations. We then perform preliminary estimations for the full sample and for the identified sub-samples, and we test the hypothesis that all the countries in the sample follow the same convergence dynamics through a Chow test. This test enables to derive whether we should perform our economic growth regressions on one sample or whether we should work with several sub-samples.

We apply this methodology to three different analyses. First, we analyse the role of natural capital on economic growth distinguishing renewable from non-renewable natural capital. Secondly, we focus on the specific role of marine biotic natural capital on economic growth. Thirdly, we explore the economic growth determinants in coastal countries with climate change mitigation potential and adaptation needs. We previously explore the potential of coastal vegetated habitats in climate change mitigation.

Renewable and non-renewable natural capital

The concept of ‘natural capital’ aims to underline the role of nature on supporting the economy and human well-being. Natural capital includes both renewable natural capital, including ecosystems and their associated services, biodiversity, air and water, and non-renewable natural capital (mineral deposits and fossil fuels). Both types of natural capital provide people with exploitable resources (Petersen and Gocheva, 2015). In our work, we use a definition based on a subset of renewable and non-renewable natural capital to derive a cross-country analysis (World Bank, 2006). For renewable natural capital we take into account the extent of timber and non-timber forest resources, protected areas, cropland and pastureland. For non-renewable natural capital, we consider subsoil assets (oil, natural gas, hard and soft coal and minerals).

The dependence of the world population on natural capital is a much disputed subject. Dependence on natural capital has been sometimes argued to negatively affect economic growth, under the so-called ‘natural resource curse’ hypothesis. In this case, higher levels of natural capital can benefit a minority who controls access to natural resources by developing an extractive (often poorly functioning) political regime (Acemoglu and Robinson, 2012). There is an alternative hypothesis whereby abundance replaces dependence and positively affects economic growth (Brunnschweiler and Bulte, 2008). This latter hypothesis is closer to the basic tenet that humans are highly reliant on a finite and non-growing ecosystem (Daly and Farley, 2004).⁷

Natural capital is steadily decreasing. In regards to renewable natural capital, Costanza et al. (2014) estimate, for instance, that the loss of ecosystem services between 1997 and 2011

geography, demography and institutions. There are a number of studies that employ a wide variety of statistical methods in attempting to identify multiple growth regimes (Durlauf *et al.*, 2005).

⁶Note that multiple regimes may represent evidence of multiple steady-states as well as evidence of non-linearity in the growth process.

⁷ See Rockström *et al.* (2009) for a set of nine planetary boundaries.

was between 4 and 18 per cent of the 1997 value. Using ecosystem productivity data, the loss is estimated at around 10 per cent, with large geographic differences, within and between countries, the three top ones being Tunisia, Haiti and Libya with a loss higher than 40 per cent (Sutton et al., 2016). Concerning non-renewable natural capital, the available amount of this type of capital is limited compared to the potential demand of a growing and increasingly affluent society (Andersson and Råde, 2002). For fossil energy carriers oil and gas are most scarce, and for metals platinum, gold and rhodium are least abundant (Goedkoop et al., 2008 and Wegener Sleeswijk et al., 2008).⁸

Within such a context of natural capital depletion, the efforts hence costs of financing natural capital conservation, although not sufficient to avoid losses, are significant. For example, the resources currently being allocated to preserve and maintain biodiversity (around USD 50 billion per year) would, at best, cover one third of the lowest needs estimate. Current finance to protect biodiversity is mainly government-funded, insufficient and poorly distributed (MAEDI, 2014). As protection costs of natural capital are far from negligible from a financial and from a political standpoint, local people are often reluctant to such protection, in the absence of strong socio-economic arguments in favour of such protection. Thus, it is crucial to estimate, in a comprehensible manner for all stake-holders, the social importance of such protection.⁹

Our goal is to estimate the contribution of renewable and non-renewable natural capital to economic growth, our hypothesis being that these two types of natural capital affect growth in a different manner. Renewable natural capital, beyond contributing to food provisioning, provide local climate regulation, air and water quality, natural hazards mitigation, hence contribute indirectly but strongly to local wealth, security, quality of social relationships, health and aesthetics (MEA, 2005). Therefore, renewable natural capital may have a rather large indirect economic contribution to economic growth, particularly through health, security, and more generally human well-being (MEA, 2005), that should be stronger than the impact of non-renewable natural capital.

Non-renewable natural capital can be a source of immediate financial wealth, but can have adverse social (Acemoglu and Robinson, 2012) and environmental effects through pollution. Moreover, it can also be exchanged through international trade, an advantage of such trade being that the negative local effects of extraction associated with pollution are avoided. Companies, and indirectly governments, can choose the territory where they develop their activities based on labour and environmental costs which depend on social and environmental regulations, avoiding countries where natural resources are more protected which leads to spillage effects (Barbier, 2014).

Therefore, to understand how natural capital contributes to economic growth, there is a need to distinguish direct and indirect effects, as well as to integrate the effect of trade between territories and countries, as such trade might obscure the impact of natural capital, especially if rich countries import natural resources from poor countries (Lenzen et al., 2012). In this regard, a comparison on a restricted set of countries shows that natural capital depreciation has been higher in poor countries compared to richer countries (Barbier, 2014), although accounting for economic growth suggests that poor countries presently compensate by higher capital growth, while rich countries do not (Barbier, 2015). Besides, there might be social differences within a

⁸Some authors consider that 80 per cent of fossil energy reserves identified should not be used, to contain climate change (McGlade and Ekins, 2015). In regards to mineral resources, the amount of reserves identified usually increases with improvements in production costs so that scarcity cannot be assessed based on presently identified reserves, phosphate being a possible exception (Reynolds, 1999).

⁹This is the reason why the notion of ecosystem services was developed (Daily *et al.* 1997) and the associated monetary value was estimated (Costanza *et al.*, 1997) although the exact meaning of giving a monetary value to ecosystem services for which there are no markets has been questioned.

country where poor people might be highly dependent on local (renewable) natural resources, while rich people might be more dependent on global (non-renewable) natural resources, often imported from distant countries.

When renewable and non-renewable natural capital are distinguished, there are at least two types of difficulties to solve in regards to renewable natural capital. Firstly, there is a need to identify the benefits of natural capital which might depend on human life-styles, representations and values (Chan et al., 2012). Secondly, there is a need to identify the natural entities necessary to provide these benefits. For example, biologists barely know how biological diversity (genetic and species diversity) affects the quantity and quality of ecosystem services. For non-renewable resources, the discount rate and the degree of substitutability are critical parameters to be introduced in the framework, to consider their relationships with human wellbeing. The ongoing development of natural capital accounts should enable to develop this area of research to better measure the relationship between the environment and economic activities (Weber, 2014).

To our knowledge, this is a first attempt to have a better understanding of the role natural capital's dependence and abundance, distinguishing direct and indirect effects in renewable and non-renewable natural capital. To test these direct and indirect effects, we compare the relevance of proximate and fundamental theories to explain economic growth when the sample is divided according to different country typologies based on investment in physical capital, income per capita, income inequality, human development and institutional quality.

Early macroeconometric models uncover a negative relationship between resource dependence and economic growth. In their analysis, Sachs and Warner (1995) find evidence that resource rich countries underperform resource poor countries regarding export-led growth, after controlling for a number of other factors. Most of the analyses in the late 1990s and early 2000s also find evidence of such a negative relationship, whereby authors often use cross-sectional regressions and frequently proxy resource dependence through the share of primary products exports in total exports or in the gross domestic product (van der Ploeg, 2010). These analyses were mostly inspired by the difficulties of countries rich in non-renewable resources to transform this source of wealth on economic development (van der Ploeg, 2010 and Ross, 2014).

Many of these studies attempt to explain the causes of such a negative relationship although there is no universally accepted theory of the curse of natural resources (Sachs and Warner, 2001 and Torres et al., 2013). Many potential causes of the negative relationship between resource dependence and economic growth have been proposed. The crowding-out of manufacturing activities and the temporarily loss in learning-by-doing, the political capture of rent, the unsustainable government policies, the poor investment in human resources, economic shocks, the low institutional quality, the armed conflicts, the lack of effective definition of property rights and the high transaction costs, or the volatility of world resource prices.¹⁰

Since about the mid-2000s however, there are a number of analyses that challenge the existence of a resource curse by providing evidence of a non-negative impact of natural resources on economic growth (Dinh and Dinh, 2016). For instance, several papers suggest that the negative relationship between natural resource dependence and economic growth can be reversed if institutional quality is high enough (Boschini et al., 2013). Natural resource-dependent countries constitute both growth losers and growth winners, and some authors argue that the main difference between the success cases and the cases of failure would lie in the quality of institutions and in the political economy (Melhum et al., 2006 and Torvik, 2009).

Lederman and Maloney (2002) argue that the negative effect of natural resources on economic growth may be due to the use of inadequate indicators for natural resources and to

¹⁰ See Frankel (2010) and Torres *et al.* (2013) for an exhaustive review of this literature.

international heterogeneity in the impact of natural resources on economic growth. Concerning the use of inadequate indicators, the adverse effect of resource dependence on institutional quality and economic growth would be particularly strong for easily appropriable ‘point-source’ rents with concentrated production and revenues and large rents such as minerals, oil and plantation crops (coffee, sugar, banana, tobacco) compared to agriculture (rice, wheat, animals) whose rents are more dispersed and less easily appropriated by state institutions.¹¹¹² Cross-country regressions suggest that natural resources stimulate corruption amongst bureaucrats and politicians (Ades and Di Tella, 1999).

In addition, although natural resource dependence (measured by the share of exports of primary products in the gross domestic product and by other indicators in relative terms) may retard economic growth, natural resource abundance (often measured by per capita values of production and amount of reserves and stocks) may also be positively correlated or have no significant impact on economic growth.¹³ Gylfason (2011) finds that higher natural capital assets per capita enhance economic growth, while a large ratio of natural capital assets in national wealth has the reverse effect.

Ding and Field (2005) find similar results to Gylfason (2011) but they are contingent on the type of model used. According to Cerny and Filer (2007), although a large ratio of natural capital assets in national wealth is associated with slow economic growth, there is no evidence that natural capital assets per capita are negatively related to growth. The supposed (negative) link between resource dependence and economic growth would arise because of the inherent relationship between slow growth and a small non-resource sector caused by other undetermined characteristics of the economy.

According to Stijns (2005) the data on fuel and minerals reserves shows that natural resource abundance has not been a significant structural determinant of economic growth between 1970 and 1989, probably because of the existence of both positive and negative transmission channels. When a natural resource has high transportation costs, then its physical availability within the economy is important for the development of industries (De Long and Williamson, 1994 and Bardini, 1997). Coal and iron ore deposits were a prerequisite for the development of a steel industry in the 19th century, for instance.

Van der Ploeg (2010) does not find evidence of an impact of neither resource exports in the gross domestic product nor subsoil assets in economic growth, and he concludes that this is due to the divergent impact of these variables on growth depending on the degree of volatility in the country. Concerning production dependence, Hall and Jones (1999) and Sala-i-Martin et al. (2004) find instead a positive relationship between the mining share in gross domestic product and economic growth. In Sala-i-Martin et al. (2004) though, mining requires conditioning on other variables to show its full impact. According to the previous review hence, we should contribute to the literature by enabling to have a better understanding of the role natural capital’s dependence and abundance, in the particular case when we distinguish renewable and non-renewable natural capital. It also enables us to have a baseline model to compare the results of a world-wide data sets with those of coastal countries with certain specificities (high coastal climate change adaptation needs and mitigation potential, and high marine biodiversity).

Coastal blue carbon: Climate change mitigation potential

¹¹ See van der Ploeg (2010) for a more detailed discussion.

¹² Regarding as well the choice of natural resource indicators, when Lederman and Maloney (2008) use net exports of primary products per worker as a natural resource indicator, Sachs and Warner’s (1995) negative impact of natural resources on economic growth based on gross exports of primary products in the gross domestic product disappears due to the possibility of re-exportation.

¹³ Alternative definitions are considered in the academic literature. Norman (2009), for instance, defines resource abundance as the share of resources stocks in the gross domestic product or as resource stocks in per capita terms and resource intensity as the rate of resource exports in the gross domestic product.

The ocean and coasts represent the largest carbon sink on Earth, removing approximately 2 Gton CO₂ per year, about a quarter of anthropogenic emissions (Duarte, 2014). They remove over half of all the biological carbon captured in the world. In relative terms, once deforestation is taken into account, the net land carbon uptake is smaller than that of the ocean and coasts. The term “blue carbon” was then recently coined to refer to the potential of the ocean and coasts ecosystems carbon to mitigate climate change. The most relevant coastal ecosystems for climate change mitigation, the so-called “coastal blue carbon”, are mainly mangroves, seagrass meadows and tidal-marshes (Nellemann *et al.*, 2009).¹⁴

The ocean is a natural carbon sink, that contains 50 times more carbon than the atmosphere, and that is exchanging large amounts of CO₂ with the atmosphere every year (Bopp *et al.*, 2015). In the past decades, the ocean has slowed down the rate of climate change by absorbing about 30 per cent of anthropogenic emissions (Sabine *et al.*, 2004). Thus, the ocean plays a crucial role in climate change mitigation, as well as in climate regulation. It is the largest carbon reservoir on Earth, way beyond coasts.

The absorption of anthropogenic CO₂ by the ocean is the result of physical-chemical processes and marine biology through the co-called solubility and biological pumps (Mcleod *et al.*, 2011). The solubility pump is related to the CO₂ solubility in seawater and the thermal stratification of the ocean. Cold and deep water are generally rich in dissolved inorganic carbon. The biological pump refers to the ability of plankton for up taking CO₂ from the surface waters through photosynthesis. A portion of the biomass produced is transferred through this process to the deep ocean.

Changes in any of these physical, chemical and biological processes may increase or decrease the rate of climate change, although knowledge of such interconnections is limited, and the precautionary principle generally prevails.¹⁵ Furthermore, even though the ocean plays a key role as a major carbon sink, its integration within climate change discussions remains weak (Ocean and climate, 2015). Among the 18 regional sea conventions, only the Barcelona Convention for the Mediterranean Sea integrates the climate change dimension. There is no framework structure for intergovernmental cooperation on ocean governance.¹⁶ The ocean has only recently been given some attention in negotiations under the United Nations Framework Convention on Climate Change (UNFCCC).

Besides, only carbon buried in marine and coastal sediments can be considered long-term marine carbon storage. The long-term residence of the bulk of anthropogenic CO₂ in the ocean is uncertain, as this carbon does not penetrate deep enough to remain in the ocean over extended time scales (Mcleod *et al.*, 2011). In contrast, coastal blue carbon is typically stored for thousands of years in sediments. In addition, coastal blue carbon supports intense carbon burial rates, while the bulk of the carbon stored in the ocean is in intermediate and in deep layers (Duarte *et al.*, 2005).

Moreover, changes in physical, chemical and biological processes may impact carbon storage in the ocean in the long-term. In contrast, short-term and medium-term effects on carbon storage are possible when acting at the local and regional levels to maintain and restore coastal blue carbon.¹⁷ In sum, because of the high complexity of the ocean ecosystems, the absence of intergovernmental cooperation on the governance of high seas, the long-term carbon-

¹⁴ Macroalgae are also included in coastal blue carbon but so far have received less attention from policy makers and researchers.

¹⁵ For example, primary productivity of phytoplankton could be stimulated by adding nutrients such as iron to surface waters. There is currently no consensus on the efficiency of such methods, which are limited to a few field experiments (Bopp *et al.*, 2015).

¹⁶ The UN Convention on the Law of the Sea (UNCLOS) is not a decision-making body but an open-ended informal consultative process.

¹⁷ Besides, coastal blue carbon plays an important role not only for climate change mitigation, but also for climate change adaptation through the protection against coastal erosion and extreme climate events.

intensive storage capacity in coasts, and the ability to obtain results in the short and medium-term when intervening on coasts, the remainder of the document focuses only on coastal blue carbon.

Nevertheless, uncertainties in the land use conversion rates and in the fate of ecosystem carbon upon conversion and few historical and present data on coastal blue carbon ecosystems may certainly reduce the attractiveness of coastal ecosystems for financial markets in the short-term (Crooks *et al.*, 2011). For mangroves and tidal-marshes, there is some evidence that a large percentage of the carbon in the biomass and sediments comes from the atmosphere and is returned to the atmosphere. And yet, is the total carbon stored both in mangroves and tidal-marshes large enough to be meaningful as a mitigation tool against climate change? Do we have enough information on mangroves and tidal-marshes distribution and evolution to derive policy options for conservation and restoration?

Beyond being scientifically-backed and identifying a meaningful scale to apply mitigation policies, political support and adequate institutional design are essential for coastal blue carbon projects to develop successfully. On the political stance, there are prominent challenges to implement climate change mitigation programs in the ocean and coastal areas and, more broadly, to develop programs on ocean and coastal governance. Certain emerging and OECD countries and developing nations in Africa and among the Small Island Developing States (SIDS) consider the ocean and coastal zones as areas for economic development. In such terms, attempts to progress on international regulation for the protection of the ocean and coasts can be rejected by some advanced countries and accepted by African and SIDS countries to the extent that their economic development based upon maritime activities is preserved.

In terms of the institutional design, few market-oriented and incentive schemes have been developed for marine resources for the time being. Indeed, in many marine ecosystems, there are fuzzy property rights, difficulties in assessing the scale of service obtained and risks of elite capture (Mohammed, 2014). Inequitable benefit distribution and difficulties in identifying sustainable financing mechanisms have also hampered the ability to use these mechanisms (Mohammed, 2011). Since recently though, there is growing interest on the design of market mechanisms as means to protect the coasts by generating revenue, and some of these mechanisms can be applied to coastal blue carbon.

Given the scientific body of knowledge, the scope for scaling-up projects for significant mitigation policies, the political support and the role of institutions, we explore whether and how coastal blue carbon schemes can be developed. We focus on the extent to which these schemes are relevant alternative tools for climate change mitigation. We seek to develop a country-taxonomy and to identify factors that should be considered to complement such taxonomy. Such analysis could be helpful to guide policy decisions to prioritise investments. Overall, this analysis is not about whether coastal blue carbon protection can provide economic incentives strong enough to substantially curtail habitat loss rates and contribute to conservation, but whether it has a significant and operational role in the short-term for climate change mitigation in some countries.

Coastal countries with climate change mitigation potential and adaptation needs

Many of the climate change impacts of economic activity are important to the coastal environment. These include inundation of wetlands, bleaching of coral reefs, changing oceanographic processes that affect marine productivity, and the loss of marine habitats and biodiversity (Patterson and Glavovic, 2008). Sea level rise however, will have the greatest impact on coastal ecosystems. The impact of sea level rise is likely to affect tens of millions of people and cost billions of dollars on a global scale in the next century (Darwin and Tol, 2001).

In line with our previous discussion, coastal vegetated habitats are increasingly attracting the attention of researchers and policy makers due to their role in climate change mitigation and adaptation. These habitats, in particular, seagrasses, salt-marshes, macroalgae,

and mangroves contribute to almost 50 per cent of carbon burial in marine sediments despite occupying only 0,2 per cent of the ocean surface (Duarte *et al.*, 2013). About 25 per cent to 50 per cent of the area covered by vegetated coastal habitats has however already been lost in the past 50 years. The soil carbon stock in coastal areas is one order of magnitude lower than that under terrestrial forests, but can yet play an important role on the global carbon cycle (Fourqurean *et al.*, 2012).

These habitats also raise the seafloor, buffering the impacts of rising sea level and wave action associated with climate change. The role of nature-based solutions for coastal protection can be very significant. Only for coasts, the total global adaptation costs (beach nourishment, port upgrades and capital and maintenance on river and sea dikes) for a scenario of no additional sea-level rise ranges from \$10,4 billion/yr in the 2010s to \$9,5 billion/yr in the 2040s (Nicholls *et al.*, 2010). About two-thirds of the total adaptation cost for coastal protection comes from sea dikes, increasing to over 90 per cent when maintenance costs are considered. Mangrove forests, for instance, can be alternative solutions to the construction of costly sea dikes that damage ecosystems (Berrenstein, 2012).

Beyond climate change, there are other economic drivers of change that affect coastal systems. It is estimated, as already mentioned, that more than two billion people and nearly half of the world's major cities are found within 50 km of coastlines (Brown *et al.*, 2008, and MEA, 2005). In addition, there is a momentum in coastal agglomeration growth since economic growth and geographical agglomeration are mutually reinforcing processes (Martin and Ottaviano, 2001). Moreover, the world economy has expanded six-fold between 1950 and 2000, with some sectors such as coastal tourism, fishing, energy, minerals and agriculture, having a disproportionate impact on the coastal environment (Patterson and Glavovic, 2008). Concerning tourism, it is world's largest and fastest growing industry which has expanded 65 times between 1950 and 2000 in terms of tourism numbers (CBD/UNEP, 2005 and Rekacewicz, UNEP/GRID-Arendal, 2001). Tourism infrastructure developments alone are a major cause of habitat loss in Mediterranean coastal ecosystems (WWF Global Marine Programme, 2006).

On the other hand, as previously explained, at least three billion people are thought to depend on marine and coastal biodiversity for their livelihoods (SCBD, 2009). Furthermore, while people living in coastal areas experience higher wellbeing than those living in inland areas, the acute vulnerability of coastal systems to degradation puts coastal inhabitants at greater relative risk (Agardy, 2004). In addition, within coastal development processes, certain coastal communities are politically and economically marginalised, particularly in the developing world, whereby wealth disparity and poverty may reinforce coastal degradation. A key question is then how to reach an equilibrium between coastal development and ecosystem conservation. In fact, development and conservation should be both seen as part of the same basic infrastructure needed to deliver essential services in coastal areas (Emerton, 2014).

It is only with the rising awareness of the international community about the climate change mitigation potential in coastal areas that vegetated coastal habitats have been devoted attention beyond the biological conservation community (Duarte *et al.*, 2008). The characterisation of vegetated coastal areas as global public goods in the climate change discussions, has multiplied almost by four the production of academic works on this matter between 2005 and 2012 (Duarte, 2013). However, there is still a need to raise awareness, particularly at the local level, on the benefits of mitigation and adaptation policies since local managers will commonly opt for (expensive) hard adaptation measures and on-land mitigation options. Besides, local communities will be much more concerned about (local) adaptation risks than about (global) mitigation needs.

In this work, we aim at bringing some light on economic growth determinants in countries with relatively high coastal adaptation needs and mitigation potential. This analysis can usefully inform how to put in place development strategies that can play an effective role on economic development, including the integrated management of coastal development. The new economic geography relying on the role of large agglomerations with increasing returns to scale

could also be useful to account for the weight of natural coastal infrastructure in supporting economic activities (Krugman, 1998, Emerton, 2014). If we explore the determinants of economic growth in coastal countries, Smith (1976) already stressed the relationship between the geographical location, international trade and economic growth. The rapid development of civilizations around the Mediterranean basin was helped by the relative ease of sea-based trade in the region (Braudel, 1972, McNeill, 1974, Jones, 1981 and Crosby, 1986).

There are several reasons that explain the higher income in coastal countries compared to landlocked countries. With a data set on 43 developing countries for the period 1965-1990, Radelet and Sachs (1998) find, for instance, that the cost of freight and insurance for landlocked developing countries was on average 50 per cent higher than for coastal economies, which had a negative impact on economic growth. Moreover, countries with a longer coastline are likely to have more ports, a larger share of the population with relatively easy access to the sea, and a larger share of economic activity grounded in international trade. Bloom and Sachs (1998), Masters and Sachs (2001) and Bloom *et al.* (2003) find that coastline length is a positive and significant determinant of economic growth.

Gallup *et al.* (1998) also find that higher coastal population density is associated with faster economic growth during 1965-1990.¹⁸ Population density on the coast is likely to be associated with an increased division of labour, with increasing returns to scale in infrastructure, and with falling rates of population growth as incomes per household rise.¹⁹ In addition, Gallup *et al.* (1998) find with 149 developed and developing countries in 1995 that more ocean-accessible regions in the world are more urbanised. Radelet and Sachs (1998) find that almost all fast-growing developing countries have based their rapid growth in the period after 1965 on labour-intensive assembly-type industries.

Almost without exception, large export processing zones are located in coastal economies, near good port facilities, and close to markets in the U.S., Japan, or Europe. There are also geographical effects on economic policy choices. A coastal economy, for example, may face a higher elasticity of output response with respect to trade taxes than a landlocked economy (Gallup *et al.*, 1998). The early liberalizers, on the whole, were the coastal economies. In sum, high levels of GDP per capita in coastal countries are associated with low transport costs, economies of agglomeration, liberal economic policy choices and a coastal population.

Besides international trade, natural hazards may also play a role in economic growth in coastal countries, particularly in those with high exposure to coastal risks. Growth empirics do not provide a definite answer on the relationship between natural disasters and economic growth (Cavallo *et al.*, 2013). According to neoclassical growth models, the destruction of capital stock is unlikely to affect the rate of technological progress but it may boost short-run economic growth (Shadnam, 2014). In endogenous growth models, natural disasters may increase economic growth by increasing investment and productivity of capital stock (Caballero and Hammour, 1994). Climatic disasters have sometimes been found to have a positive impact on economic growth through the relationship between the increasing frequency of these events and the total factor productivity (Cuaresma *et al.*, 2008 and Skidmore and Taya, 2002). Other authors find that extreme weather events impact negatively economic growth, particularly in the short-run and when the frequency of the events passes some threshold (Mechler, 2004 and Hallegatte *et al.*, 2007). Overall, higher temperatures and more climate extreme events tend to be associated with lower rates of growth, at least in developing countries (Bowen *et al.*, 2012).

Little attention has been paid to explore the impact of biodiversity on economic growth. The bulk of the studies on biodiversity and economic growth have instead focused on the reversed causality, that is, the (negative) impact that economic growth can have on biodiversity

¹⁸ The relationship between population density and economic growth is positive when taking the country as unit of analysis (Sachs and Warner, 1995).

¹⁹ There is a negative and significant relationship between population growth and economic growth (see, for instance, Kormendi and Meguire, 1985).

(Antoci *et al.*, 2004). Many analyses explore whether the environmental Kuznets curve exists, where a U-shaped relationship between the per capita wealth and the proportion of species conserved is expected (McPherson and Nieswiadomy, 2005, and Mills and Wait, 2009). Biodiversity is often found to be one of the classes of environmental problems where economic growth on its own is unlikely to result in a turning point towards a more sustainable and secure environmental future (Dietz and Adger, 2003).

In sum, high levels of GDP per capita in coastal countries are associated with low transport costs, economies of agglomeration, liberal economic policy choices and a coastal population. Besides, the empirical relationship between natural disasters and economic growth is yet not clearly established and few analyses have been undertaken to understand the impact of biodiversity in economic growth.

Marine renewable natural capital

A good proxy for measuring marine biodiversity is the extent of coral reefs. The ‘rainforests of the ocean’, coral reefs, are biodiversity hotspots that make up less than one per cent of the marine environment but are home to about 25 per cent of the ocean’s marine life. Coral reefs are known as one of the most complex and species-rich ecosystems in the world, with vital connections to many other ecosystems and a global-scale importance. They play a central role in many ecosystem services, such as coastal protection, water chemical balance, CO₂ cycles and marine biomass and biodiversity production (Hicks and Cinner, 2014). However, marine biodiversity is threatened. About 50 per cent of the area covered by coral reefs has been lost in the past 30 years, and an estimated 83 per cent of reefs have lost more than half of their expected fish biomass (WWF, 2015a and MacNeil *et al.*, 2015).

Direct human pressure has been proved to be the major threat on these ecosystems, and this threat is still increasing. It is indeed estimated that more than two billion people and nearly half of the world’s major cities are found within 50 km of coastlines (Brown *et al.*, 2008, and MEA, 2005). On the other hand, at least three billion people are thought to depend on marine and coastal biodiversity for their livelihoods (SCBD, 2009). A key question is then how to reach an equilibrium between coastal development and ecosystem conservation. Development and conservation could be both seen as part of the same basic infrastructure needed to deliver essential services in coastal areas (Emerton, 2014), but a number of more or less hidden trade-offs are to be taken in account in such complex socio-ecosystems (Daw *et al.*, 2015).

Though coral ecosystems are nowadays highly studied, surveyed and monitored, and many consensual scientific advices have been formulated (Worm *et al.*, 2009), they are still globally decreasing. Not only that but many coral countries have not set up so far proper regulation measures to address this trend (Hughes *et al.*, 2012). Even in developed countries with high environmental awareness such as Australia or the US, the coral cover has dramatically decreased by the end of the twentieth century (De’ath *et al.*, 2012). There are many different threats on coral reefs, and if some of them are partly natural (ecological succession, diseases, predators and cyclones), their effect is strongly increased by human influence.

This human influence consists of many different types of pressures. These pressures can be indirect and diffuse, such as global change, or direct and local, such as pollution (Carpenter *et al.*, 2008). Due to global threats, perturbations like massive bleaching are now observed worldwide. Local threats include most notably pollution, overpopulation, overfishing or even direct reef destruction through construction works, destructive fishing gears or limestone exploitation. It is commonly considered that small-scale threats such as destructive fishing, watershed-based pollution, or direct extractions are more closely linked to developing countries (in particular, in the “Coral Triangle” in South-East Asia or in East Africa), whereas long-term stressors such as shifts in water quality or species assemblage are more linked to rich countries (such as the US, outer sea France and Japan).

Other local threats like coastal development, marine pollution or coral bleaching seem to affect both developing and developed countries as soon as coasts get populated (WRI, 2011). Some early agro-industrialized countries have been experiencing coral loss for many tens of years, especially in the Caribbean where the current coral cover is alarming (Mumby *et al.*, 2007), whereas in other parts of the world such as Maldives the coral ecosystems had kept a healthy state until the 1980s, but now suffer from the same large-scale stressors (Andréfouët, 2012). These latter areas have scope to set up adequate policies to protect and benefit from the shrinking but yet important size of coral cover.

A major reasons why marine biodiversity is highly threatened is that their social importance is poorly recognized. In general market mechanisms do not capture the non-monetary values of coastal and marine ecosystems services delivered by coral reefs, and so they are rarely considered when resource management decisions are made (Mohammed, 2012). In addition to this, the need to develop a comprehensive macroeconomic framework and the associated the accounting guidelines is prominent in order to mainstream these ecosystem services amongst economic activities (Jackson, 2009, Victor and Jackson, 2013 and Weber, 2014). There have already been some efforts on marine and coastal valuation that have enabled to raise awareness among the population and policy makers on the weight of marine and coastal ecosystem services in local economic activities such as tourism (Pascal, 2010). The valuation and accounting guidelines remain nevertheless largely behind those developed for terrestrial ecosystem services.

Rather than examining the putative role of marine biodiversity on economic growth which, in any case, should be better addressed through microeconomic analyses, we want to examine the specific determinants of growth in this type of countries.²⁰ To our knowledge, this is a first attempt to have a better understanding of the determinants of economic growth in countries with relatively high marine biodiversity.

1.2. Natural capital accounting

The concept of natural capital can be described as the components of the natural environment that can be used to generate income, goods or services (Barbier, 2011). It underlines the role of nature in supporting the economy and human well-being (Pearce *et al.*, 1989). Natural capital can be categorised as geophysical capital (abiotic goods and services) and ecosystem capital (biotic goods and ecosystem services) (Milligan *et al.*, 2014; Petersen and Gocheva, 2015).²¹ Ecosystem services, in particular, can be defined as the outcome of biological, geochemical and physical processes and components that take place within an ecosystem and that are accessible to people (Weber, 2011; Maynard *et al.*, 2015).²² According to the Common International Classification of Ecosystem Services (CICES), three broad categories of ecosystem services can be identified, namely: provisioning, regulation and maintenance, and cultural services (MA, 2005; Weber, 2011).²³

²⁰ Besides our data identifying countries with high marine biodiversity, coral reefs (square-km), is in physical units compared to our data on the natural capital determinants in monetary units. Some preliminary regressions on economic growth showed that, in any case, the variable coral reefs had no significant explanatory power on economic growth as one could expect. The effects of marine biodiversity are better captured through microeconomic analyses (see, for instance, McClanahan *et al.*, 2008).

²¹ Some key features of natural capital goods and services are their depletability (or not) and their capacity (or not) to renew or self-maintain. In neoclassical economic theory, goods and services overlap since the value of the good or asset stock is derived from the net present value of expected future benefits (monetary terms) (Weber, 2014a).

²² Ecosystem services have not yet been given an exact definition (Weber, 2014b).

²³ There is no clear-cut boundary between natural capital nor ecosystem services categories (see Milligan *et al.*, 2014 and Petersen and Gocheva, 2005 for more details).

There is no single agreed-upon definition of natural capital or (economic-)environmental accounting (Hetch, 2000; Weber, 2014a). We can nevertheless identify some common elements that usually characterise this concept (Hetch, 2000). Firstly, these accounts provide tools to link environmental and economic data which enables joint analyses. Secondly, they have a comprehensive coverage and can be used for macroeconomic and sectoral policy-making, rather than for decisions at the local level. Third, the accounts have time series data produced on a regular basis which enables analyses of trends over time. In this chapter, we broadly define natural capital accounts as ‘the (economic-)environmental accounts that refer to the statistics that can be integrated with national economic accounts which enable to have joint analyses’.

Since the 1970s with some initiatives in Canada, Denmark, France, the Netherlands, Norway and Spain, we have witnessed substantial efforts to develop natural capital accounting (Laurans et al., 2013; Edens, 2013; Weber, 2014a).²⁴ In the recent years, the international natural capital accounting standards have evolved, and many capacity-building partnerships and research programs have been developed.²⁵ Concerning international capital accounting, the United Nations System of Environmental–Economic Accounting Central Framework (SEEA CF) has become in 2012 an international statistical standard that describes stocks and changes in stocks of environmental assets.

The 2012 SEEA Experimental Ecosystem Accounting (EEA) provides the conceptual framework for ecosystem accounting, but does not include an integrated set of accounting tables and provides little guidance on how to implement these accounts (Weber, 2014a). The SEEA EEA defines ecosystem accounting as a coherent and integrated approach to the assessment of the environment through the measurement of ecosystems, and of the flows of services from ecosystems into economic and other human activity. The 2011 EU Framework for Ecosystem Capital Accounting in Europe enables to implement simplified ecosystem capital accounts based on the use of existing data.

The term natural capital accounting is broadly used throughout these initiatives, but not always in an unambiguous way (Weber, 2014a). The usual sense (for instance, its use by the World Bank) relates natural capital both to non-renewable resources of the subsoil and to renewable resources, and to the associated services.²⁶ While proposing no precise definition of natural capital, the SEEA EEA suggests similar coverage for natural assets and services. In the biodiversity strategy of the European Union (EU), natural capital is equivalent to ecosystem capital only. This is the terminology also used in the UNSD/UNEP/CBD project on Advancing Natural Capital Accounting (ANCA) for ecosystem capital. Natural capital can be also understood as an economic production factor or, in a broader sense, covering non-marketed ecosystem services. Capital can refer implicitly or explicitly to the standard economic theory where capital is equal to the value of discounted future benefits; or capital can be defined as physical systems with capacities and resilience.

²⁴ See Edens (2013) and Weber (2015) for a summary of initiatives on natural capital accounting since the 1970s.

²⁵ Some capacity building programs include the 2008 ‘United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries’ (UN-REDD), the 2010 ‘Partnership for Wealth Accounting and the Valuation of Ecosystem Services’ (WAVES) coordinated by the World Bank and the Convention on Biological Diversity ‘Quick Start Package’ on ‘Ecosystem Natural Capital Accounts’ (ENCA). Some research programs include the 2005 Millennium Ecosystem Assessment, the 2008 Commission on Measuring Economic Performance and Social Progress and the 2010 Economics of Ecosystems and Biodiversity Initiative. See Milligan et al. (2014) and Petersen (2015) for a detailed review of accounting standards, capacity-building partnerships and research programs on natural capital accounting.

²⁶ The SEEA CF defines environmental assets as the naturally occurring living and non-living components of the Earth that may provide benefits to humanity. The SEEA EEA proposes accounts which describe the supply of ecosystem services as well as asset accounts for ecosystems (Edens, 2013).

The SEEA CF and the SEEA EEA encompass measurement in both physical and monetary terms, and this is also the scope of this chapter.²⁷ The monetary valuation in the SEEA CF is limited in scope since generally only goods that have a market price are included (Weber, 2014a; Petersen and Gocheva, 2015). Physical accounts are considered the basis of the framework in the SEEA EEA (Weber, 2011). Because ecosystem accounts are deeply rooted into monitoring databases, implementation presently focuses on physical accounts. Measurement in monetary terms for ecosystem accounting is generally dependent on the availability of information in physical terms since there are few observable market values for ecosystems and their services (Weber, 2014a). According to a review of national ecosystem service assessments across the EU Member States, most provisioning services are, or will be, valued using market prices. Most regulating services using methodologies based on costs, are possible. Cultural ecosystem services, which are mainly valued using stated valuation methods, are subject to methodological challenges and lack of data (Brouwer et al., 2013).

There are many challenges related to monetary valuation in natural capital accounting. Adding together supporting services and ecosystem services represents a double counting of the contribution of supporting services.²⁸ To avoid double counting, CICES classification assists in identifying the ‘final outputs’ of ecosystems (Haines-Young and Potschin, 2010). In addition, because there is often lack of resources and time to do monetary valuation studies, the benefit transfer approach extends value estimates for ecosystem services or ecosystem assets to other areas (Pascual et al., 2010). However, the values provided by ecosystem services are often strongly dependent on the local context and on the proximity of other ecosystems (Petersen and Gocheva, 2015). According to the SEEA EEA, the limited data for certain ecosystem services, the variability in methodologies and the lack of common functional variables across studies, limit the use of this approach.

Concerning the monetary valuation of natural capital, the choice of the discount rate, which attributes more relevance to costs and benefits in the present than in the future, is one of the most disputed subjects in economic theory (Russi and ten Brink, 2010). According to the SEEA CF, it is necessary to select marginal, private, market-based discount rates for environmental assets in net present value calculations, to align SEEA values with the system of national accounts. However, lower discount rates are more appropriate to account for intergenerational equity and ethical responsibilities to the world’s poorest that depend directly on natural capital (Gowdy et al., 2009). Although experts agree on the principle of discounting and the formula to be used, they do not agree on the discount rate to be used for the valuation of natural capital (ten Brink et al., 2015).

Another problem related to the monetary valuation of natural capital, is the estimation of exchange values for non-market ecosystem capital, such as many regulation and cultural services.²⁹ The SEEA CF and SEEA EEA use exchange values, not welfare values, similarly to the system of national accounts.³⁰ Accordingly, there is a need to value the quantity of ecosystem services at the market prices that would have prevailed if the services had been freely traded and exchanged. Weber (2011) states that in such cases monetary valuation should be

²⁷ See Petersen and Gocheva (2015) for details on the units of measurement for the different components of the accounts in the SEEA CF and the SEEA EEA.

²⁸ The SEEA EEA argues that peat soils and cultivated biological resources can also be subject to double counting.

²⁹ It is also difficult to give a market value to biodiversity since it is challenging to evaluate the benefits it provides to humans associated, among other features, with social and cultural, ethical and aesthetic values, as well as unexplored or unknown values (Lavorel, 2014).

³⁰ In contrast with exchange values, welfare values include the consumer surplus, that is, the difference between the price consumers are willing to pay for a good or service and the market price. Exchange values do not capture the full benefits derived by the agents participating in a transaction. Natural capital accounts using exchange values are not attempting welfare valuation, and do not replace the need for cost-benefit analyses appraisal of policy changes (ten Brink et al., 2015).

carried out on the basis of restoration costs rather than stated or revealed preferences as the latter are based on subjective evaluations, which make up-scaling and aggregation disputable.³¹

Besides, in general, the methods based on revealed and stated preferences are based on the measurement of changes in individual welfare, and hence prices should be generated through simulated exchanged value or price function approaches (Day, 2013; ten Brink et al., 2015). In addition, if different methodologies are used for monetary valuation, the values obtained for different ecosystem services are not directly comparable and hence difficult to aggregate (Petersen and Gocheva, 2015). Despite these caveats, the use of monetary valuation is often considered useful for communication purposes (Pascal, 2014).³²

Regarding the areas covered by natural capital accounts, at least 33 developed (high-income) countries have experiences, out of which 26 regularly compile at least one account (Edens, 2014).³³ The accounts that are most frequently compiled are physical flows in the input and output in production and consumption, namely air emissions, energy and material flow accounts. They also cover quite often environmental transactions in monetary units, mainly taxes and environmental protection expenditure accounts, and natural capital assets in physical and monetary units, mainly energy, timber and land accounts. Ecosystem services are rarely compiled, with exceptions such as non-timber forest resources in physical units.

There are a large number of pilot projects in developed countries concerning environmental protection expenditure, air emissions and non-timber forest resources accounts which suggests that these areas should be covered in the coming years by more countries. In developing (non-high-income) countries, there are fewer natural capital accounting experiences.³⁴ According to Edens (2014), out of 39 developing countries, 11 have some accounts while 21 have pilot projects. These countries usually develop natural capital asset accounts in physical and monetary units (minerals, energy, fish,...) and, to a lesser extent, physical flows such as water flows. Given these premises, ecosystem services accounts are those with most data gaps both for developed and developing countries. While monitoring databases can enable physical valuation, monetary valuation demands robust primary valuation studies that cover ecosystem services relevant to the decision context which can be very expensive (Hölzinger et al., 2013).

Since setting up natural capital accounts is very demanding in terms of human and financial resources, a relevant question is to which extent and how they are used. Worldwide policy makers were asked, among other things, whether or not they had made use of their natural capital accounts for economic and policy analysis through a survey developed by the UN for the SEEA programme (UN, 2006). Specific components of natural capital accounts were used by some developed countries' line ministries and agencies for planning and policy analysis such as Norway and Sweden (integration of natural capital accounting data with macroeconomic planning tools), Australia (water Act) and the United Kingdom (carbon footprint and sustainable consumption) (Delos Angeles, 2011). The reported uses of natural capital accounting by developing countries are much scarcer.³⁵

There are currently international efforts to support financially and to accompany, from a technical standpoint, some developing countries in the development of natural capital accounts,

³¹ Others argue that restoration costs reflect technological ability rather than the value of ecosystem capital (ten Brink et al., 2015).

³² Accounts in physical units are generally given priority to consider the capacity of ecosystems to deliver services, their resilience and, ultimately, the measurement of ecosystem degradation and enhancement (Weber, 2014a). In current approaches, physical accounts are sitting alongside economic information as a set of satellite accounts (Petersen and Gocheva, 2015).

³³ Developed countries are those with high-income level according to the World Bank classification.

³⁴ Developing countries are those with non-high-income level according to the World Bank classification.

³⁵ See Hetch (2000), Edens (2014) and Milligan et al. (2014) for some additional examples in developed and developing countries.

including ecosystem capital accounts. There is however, no scientific consensus neither on the definition of natural capital, nor on its conceptual relationship with ecosystem services. There are also theoretical and empirical questions about what should be appropriate analytical scales in ecosystem services accounting (EFESE, 2013). The process of creating of ecosystem services accounts has been characterised by tensions between statistics and modelling efforts, and between initiatives that modify the boundaries of the system of national accounts framework and the emergence of multiple systems analyses (Weber, 2015).

Significant progress in the implementation of natural capital accounts is expected given international commitments. In 2010, Parties to the Convention on Biological Diversity (CBD) decided to integrate the values of ecosystem capital in national accounting systems by 2020, under Aichi Target 2 (CBD, 2014). The EU committed to the same goal under the EU Biodiversity Strategy, has given a significant push to natural capital accounting and, in particular, to ecosystem capital accounting (EU, 2011). Under the UN General Assembly 2015 agreement, the Sustainable Development Goals (SDG) target 15.9 requires countries to integrate ecosystem capital values into national and local planning, development processes, poverty reduction strategies and accounts by 2020.

These commitments on natural capital accounts are made in a context of accelerated degradation of ecosystem capital (GRET/CIRAD/CDC Biodiversité, 2014). They seek to foster better management decisions, and are often closely linked to defining financing needs and mechanisms (NRC, 2005; TEEB, 2008). In this context, we propose to explore whether or not natural capital accounting has been used so far to inform public policy decisions, and to identify the obstacles that prevent such usage, if any. We explore the specificities of developed and developing countries. We aim at extending UN (2006) survey's sample beyond statistical offices since the latter may not be well informed of policy uses (Smith, 2015b). A survey conducted recently on 21 countries identified the (lack of) political awareness and will, enabling laws, policies and institutions, and technical knowledge and capacity as the challenges to the advancement and implementation of natural capital accounting (Milligan et al., 2014).

In order to accomplish this purpose, we describe the existing evidence in the academic literature on the obstacles in the use of natural capital accounts for policy decisions. We find six major obstacles: political, structural, institutional, design, data availability and cooperation. Combining these obstacles with the literature and insights from practitioners, we elaborate a survey. The survey was conducted by the French ministry of foreign affairs and international development in a joint effort with the WAVES program from the World Bank and with technical support from the European Environmental Agency (EEA). Survey respondents were experts from statistical offices and ministries and independent experts worldwide, identified as focal points by ongoing natural capital accounting projects such as the SEEA, WAVES and the MAES initiatives. The relatively small sample of experts, with 21 surveys representing a total of 17 countries, prevented us from performing an empirical analysis and our results are based on the description of raw data.

2. THE IMPACT OF RENEWABLE VERSUS NON-RENEWABLE NATURAL CAPITAL ON ECONOMIC GROWTH

2.1. Introduction

The concept of ‘natural capital’ aims to underline the role of nature on supporting the economy and human well-being.³⁶ Natural capital includes both renewable natural capital, including ecosystems and their associated services, biodiversity, air and water, and non-renewable natural capital (mineral deposits and fossil fuels). Both types of natural capital provide people with exploitable resources (Petersen and Gocheva, 2015). In our work, we use a definition based on a subset of renewable and non-renewable natural capital to derive a cross-country analysis (World Bank, 2006). For renewable natural capital we take into account the extent of timber and non-timber forest resources, protected areas, cropland and pastureland. For non-renewable natural capital, we consider subsoil assets (oil, natural gas, hard and soft coal and minerals).

The dependence of the world population on natural capital is nowadays a controversial subject. Dependence on natural capital has been sometimes argued to negatively affect economic growth, under the so-called ‘natural resource curse’ hypothesis. In this case, higher levels of natural capital can benefit a minority who controls access to natural resources by developing an extractive (often poorly functioning) political regime (Acemoglu and Robinson, 2012). There is an alternative hypothesis whereby abundance replaces dependence and positively affects economic growth (Brunnschweiler and Bulte, 2008). This latter hypothesis is closer to the basic tenet that humans are highly reliant on a finite and non-growing ecosystem (Daly and Farley, 2004).³⁷

Natural capital is steadily decreasing. In regards to renewable natural capital, Costanza et al. (2014) estimate, for instance, that the loss of ecosystem services between 1997 and 2011 was between 4 and 18 per cent of the 1997 value. Using ecosystem productivity data, the loss is estimated at around 10 per cent, with large geographic differences, within and between countries, the three top ones being Tunisia, Haiti and Libya with a loss higher than 40 per cent (Sutton et al., 2016). Concerning non-renewable natural capital, the available amount of this type of capital is limited compared to the potential demand of a growing and increasingly affluent society (Andersson and Råde, 2002). For fossil energy carriers oil and gas are most scarce, and for metals platinum, gold and rhodium are least abundant (Goedkoop et al., 2008 and Wegener Sleeswijk et al., 2008).³⁸

Within such a context of natural capital depletion, the efforts hence costs of financing natural capital conservation, although not sufficient to avoid losses, are significant. For example, the resources currently being allocated to preserve and maintain biodiversity (around USD 50 billion per year) would, at best, cover one third of the lowest needs estimate. Current finance to protect biodiversity is mainly government-funded, insufficient and poorly distributed (MAEDI, 2014). As protection costs of natural capital are far from negligible from a financial

³⁶ I would like to thank Steven Durlauf and Grigoris Emvalomatis for insightful thoughts and suggestions as well as data and econometric programs at the 2nd Advanced summer school in economics and econometrics at the University of Crete, Rethymno on the 19th-26th of August 2007. I would also like to thank Enrique Moral-Benito for suggestions and data from Moral-Benito (2012) and Steven Poelhekke for data from van der Ploeg and Poelhekke (2010). I am grateful to the participants at the *Séminaire du Centre International de Recherche sur l'Environnement et le Développement* (CIRED) on the 29th January 2017 and at the *Séminaire Développement Durable Environnement et Economie Publique* (DDEEP-EconomiX, Paris Nanterre) on the 31st January 2017 for their comments and suggestions.

³⁷ See Rockström et al. (2009) for a set of nine planetary boundaries.

³⁸ Some authors consider that 80 per cent of fossil energy reserves identified should not be used, to contain climate change (McGlade and Ekins, 2015). In regards to mineral resources, the amount of reserves identified usually increases with improvements in production costs so that scarcity cannot be assessed based on presently identified reserves, phosphate being a possible exception (Reynolds, 1999).

and from a political standpoint, local people are often reluctant to such protection, in the absence of strong socio-economic arguments in favour of such protection. Thus, it is crucial to estimate, in a comprehensible manner for all stake-holders, the social importance of such protection.³⁹

Our goal in this chapter is to estimate the contribution of renewable and non-renewable natural capital to economic growth. Our main hypothesis in this direction is that these two types of natural capital affect growth in a different manner. Renewable natural capital, beyond contributing to food provisioning, provide local climate regulation, air and water quality, natural hazards mitigation, hence contribute indirectly but strongly to local wealth, security, quality of social relationships, health and aesthetics (MEA, 2005). Therefore, renewable natural capital may have a rather large indirect economic contribution to economic growth, particularly through health, security, and more generally human well-being (MEA, 2005), that should be stronger than the impact of non-renewable natural capital.

On the other hand, non-renewable natural capital can be a source of immediate financial wealth, but can have adverse social (Acemoglu and Robinson, 2012) and environmental effects through pollution. Moreover, it can also be exchanged through international trade, an advantage of such trade being that the negative local effects of extraction associated with pollution are avoided. Companies, and indirectly governments, can choose the territory where they develop their activities based on labour and environmental costs which depend on social and environmental regulations, avoiding countries where natural resources are more protected which leads to spillage effects (Barbier, 2014).

Therefore, to understand how natural capital contributes to economic growth, there is a need to distinguish direct and indirect effects, as well as to integrate the effect of trade-off between territories and countries, as such trade might obscure the impact of natural capital, especially if rich countries import natural resources from poor countries (Lenzen et al., 2012). In this regard, a comparison on a restricted set of countries shows that natural capital depreciation has been higher in poor countries compared to richer countries (Barbier, 2014), although accounting for economic growth suggests that poor countries presently compensate by higher capital growth, while rich countries do not (Barbier, 2015). Besides, there might be social differences within a country where poor people might be highly dependent on local (renewable) natural resources, while rich people might be more dependent on global (non-renewable) natural resources, often imported from distant countries.

When renewable and non-renewable natural capital are distinguished, there are at least two types of difficulties to solve in regards to renewable natural capital. Firstly, there is a need to identify the benefits of natural capital which might depend on human life-styles, representations and values (Chan et al., 2012). Secondly, there is a need to identify the natural entities necessary to provide these benefits. For example, biologists barely know how biological diversity (genetic and species diversity) affects the quantity and quality of ecosystem services. For non-renewable resources, the discount rate and the degree of substitutability are critical parameters to be introduced in the framework, to consider their relationships with human wellbeing. The ongoing development of natural capital accounts should enable to develop this area of research to better measure the relationship between the environment and economic activities (Weber, 2014).

To our knowledge, this is a first attempt to have a better understanding of the role natural capital's dependence and abundance, distinguishing direct and indirect effects in renewable and non-renewable natural capital. To test these direct and indirect effects, we

³⁹This is the reason why the notion of ecosystem services was developed (Daily *et al.* 1997) and the associated monetary value was estimated (Costanza *et al.*, 1997) although the exact meaning of giving a monetary value to ecosystem services for which there are no markets has been questioned.

compare the relevance of proximate and fundamental theories to explain economic growth when the sample is divided according to different country typologies based on investment in physical capital, income per capita, income inequality, human development and institutional quality. Our analysis on the role of natural capital on economic growth controls for the existence of multiple growth regimes under a Bayesian Model Averaging (BMA) method that accounts for theory and specification uncertainty. This work aims at motivating the need to further develop appropriate accounting and macroeconomic frameworks to fully integrate natural capital within the basic infrastructure required to sustain economic activity.

In the following section, we describe the previous empirical literature on the role of natural capital on economic growth and we explain how we attempt to contribute to this literature. In section three, we describe the econometric model and some preliminary analyses to explore whether there are multiple economic growth regimes. We also explain how we compare the relevance of proximate and fundamental theories to explain economic growth. In section three, we also present the data used in our analysis, and share both the preliminary results on the presence of economic growth regimes, and the estimations on the determinants of economic growth under uncertainty. In section four, we conclude and share some future avenues of work. The appendix provides a detailed description of the data and the estimations.

2.2. Natural capital as a determinant of economic growth - What have we learned?

The accounting and macroeconomic frameworks that integrate natural capital are still being developed. In addition, full endorsement by policy makers to develop and to integrate these frameworks remains a challenge (WWF, 2015b).⁴⁰ There has been little progress as well to make use of some existing natural capital accounts on policy decisions (Laurans et al., 2013 and Jeantil et al., 2016). In view of these difficulties, already available analytical tools may offer some information to explore the role of natural capital on economic growth. Besides, as previous empirical results are contradictory, they ought to be integrated in a complete framework.

Early macroeconometric models uncover a negative relationship between resource dependence and economic growth. In their analysis, Sachs and Warner (1995) find evidence that resource rich countries underperform resource poor countries regarding export-led growth, after controlling for a number of other factors. Most of the analyses in the late 1990s and early 2000s also find evidence of such a negative relationship, whereby authors often use cross-sectional regressions and frequently proxy resource dependence through the share of primary products exports in total exports or in the gross domestic product (van der Ploeg, 2010). These analyses were mostly inspired by the difficulties of countries rich in non-renewable resources to transform this source of wealth on economic development (van der Ploeg, 2010 and Ross, 2014).

Many of these studies attempt to explain the causes of such a negative relationship although there is no universally accepted theory explaining the cause of the so-called "curse of natural resources" (Sachs and Warner, 2001 and Torres et al., 2013). Many potential causes of the negative relationship between resource dependence and economic growth have been proposed. The crowding-out of manufacturing activities and the temporarily loss in learning-by-doing, the political capture of rent, the unsustainable government policies, the poor investment in human resources, economic shocks, the low institutional quality, the armed conflicts, the lack of effective property rights and the high transaction costs, or the volatility of world resource prices.⁴¹

⁴⁰ A key conclusion to emerge from ongoing work is that future efforts to develop natural capital accounting should be targeted and purpose-driven (MAEDI and WWF, 2014).

⁴¹ See Frankel (2010) and Torres *et al.* (2013) for an exhaustive review of this literature.

Since about the mid-2000s however, there are a number of analyses that challenge the existence of a resource curse by providing evidence of a non-negative impact of natural resources on economic growth (Dinh and Dinh, 2016). For instance, several papers suggest that the negative relationship between natural resource dependence and economic growth can be reversed if institutional quality is high enough (Boschini et al., 2013). Natural resource-dependent countries constitute both growth losers and growth winners, and some authors argue that the main difference between the success cases and the cases of failure would lie in the quality of institutions and in the political economy (Melhum et al., 2006 and Torvik, 2009).

Lederman and Maloney (2002) argue that the negative effect of natural resources on economic growth may be due to the use of inadequate indicators for natural resources and to international heterogeneity in the impact of natural resources on economic growth. Concerning the use of inadequate indicators, the adverse effect of resource dependence on institutional quality and economic growth would be particularly strong for easily appropriable ‘point-source’ rents with concentrated production and revenues and large rents such as minerals, oil and plantation crops (coffee, sugar, banana, tobacco) compared to agriculture (rice, wheat, animals) whose rents are more dispersed and less easily appropriated by state institutions.⁴²⁴³ Cross-country regressions suggest that natural resources stimulate corruption amongst bureaucrats and politicians (Ades and Di Tella, 1999).

In addition, although natural resource dependence (measured by the share of exports of primary products in the gross domestic product and by other indicators in relative terms) may retard economic growth, natural resource abundance (often measured by per capita values of production and reserves or stocks) may be positively correlated or have no significant impact on economic growth.⁴⁴ Gylfason (2011) finds that higher natural capital assets per capita enhance economic growth, while a large ratio of natural capital assets in national wealth has the reverse effect.

Ding and Field (2005) find similar results to Gylfason (2011) but that are contingent on the type of model used. According to Cerny and Filer (2007) although a large ratio of natural capital assets in national wealth is associated with slow economic growth, there is no evidence that natural capital assets per capita are negatively related to growth. The supposed (negative) link between resource dependence and economic growth would arise because of the inherent relationship between slow growth and a small non-resource sector caused by other undetermined characteristics of the economy.

According to Stijns (2005) the data on fuel and minerals reserves shows that natural resource abundance has not been a significant structural determinant of economic growth between 1970 and 1989, probably because of the existence of both positive and negative transmission channels. When a natural resource has high transportation costs, then its physical availability within the economy is important for the development of industries (De Long and Williamson, 1994 and Bardini, 1997). Coal and iron ore deposits were a prerequisite for the development of a steel industry in the 19th century, for instance.

Van der Ploeg (2010) does not find evidence of an impact of neither resource exports in the gross domestic product nor subsoil assets in economic growth, and he concludes that this is due to the divergent impact of these variables on growth depending on the degree of volatility in

⁴² See van der Ploeg (2010) for a more detailed discussion.

⁴³ Regarding as well the choice of natural resource indicators, when Lederman and Maloney (2008) use net exports of primary products per worker as a natural resource indicator, Sachs and Warner’s (1995) negative impact of natural resources on economic growth based on gross exports of primary products in the gross domestic product disappears due to the possibility of re-exportation.

⁴⁴ Alternative definitions are considered in the academic literature. Norman (2009), for instance, defines resource abundance as the share of resources stocks in the gross domestic product or as resource stocks in per capita terms and resource intensity as the rate of resource exports in the gross domestic product.

the country. Concerning production dependence, Hall and Jones (1999) and Sala-i-Martin et al. (2004) find instead a positive relationship between the mining share in gross domestic product and economic growth. However, Sala-i-Martin et al. (2004) show how mining requires conditioning on other variables to show its full impact.

In terms of the presence of international heterogeneity when analyzing the impact of natural resources on economic growth, the academic literature based on fixed-effects estimations provides evidence that natural resource export dependence variables are not significant determinants of economic growth (Mansano and Rigobon, 2001 and Lederman and Maloney, 2002). However, such fixed-effects methods leave unexplained exactly the long-run cross-country growth variation originally motivating the research (Durlauf and Quah, 1999). To account for international heterogeneity in the effects of the determinants of growth, controlling for mean shifters by including regional dummies can be an alternative to fixed-effects estimations (Lederman and Maloney, 2008).

From an econometric perspective, regression analyses show that a large number of variables are correlated with economic growth but are far from implying the direction of causation. The lack of agreed theoretical bases for empirical work and for a reduced form to apply in empirical analyses, has led researchers to abandon any a priori models and to let the data show which variables are correlated with economic growth through model uncertainty (Capolupo, 2009). In order to estimate accurately the role of the so-called new growth theories such as natural capital in determining economic growth, Durlauf et al. (2005, 2008a) and Sala-i-Martin et al. (2004) propose the above commented BMA methodology.⁴⁵

Starting with Durlauf and Johnson (1995), many researchers have also explored whether there is evidence of multiple growth regimes focusing on different variables in order to divide the sample and using several methodologies.⁴⁶ That is, they analyse whether there is a common growth regime for the whole sample under conditional convergence or whether there is a growth process with multiple growth regimes in which economies with similar conditions tend to converge to one another. Konte (2013), for instance, allows for multiple growth regimes and finds that democracy helps a given country to belong to the blessed regimes in terms of natural resources while education has no effect.

To our knowledge, we propose a first attempt to have a better understanding of the role of renewable and non-renewable natural capital dependence and abundance in economic growth. Using a worldwide sample of countries, we estimate the augmented Solow model including new growth theories, among which the natural capital theory. We control for the existence of multiple convergence regimes under a BMA method that accounts for uncertainty.

2.3. Empirical analysis

Econometric methodology

In section three, we firstly present the baseline model based on the augmented Solow model and a set of new growth theories. Secondly, we explain how we integrate theory and

⁴⁵ Fernandez *et al.* (2001) show the superiority of BMA over other techniques in selecting regressors to explain cross-country growth.

⁴⁶ See Owen *et al.* (2007) and Konte (2013) for a summary on how the question of multiple growth regimes has been addressed in numerous papers focusing on different theories such as neoclassical, geography, demography and institutions. There are a number of studies that employ a wide variety of statistical methods in attempting to identify multiple growth regimes (Durlauf *et al.*, 2005).

specification uncertainty through the BMA. Lastly, we explain how we perform our preliminary analysis on the existence of multiple convergence regimes.

Economic growth model: Baseline with eight fundamental and proximate theories

Many economic growth models are estimated using panel data to multiply the number of observations. Since the variation of growth rates at annual frequency rates may give very misleading information about the long-term growth process, we average data over five year periods.⁴⁷ Based on Durlauf and Quah (1999), we use the following augmented Solow model with a set of new growth theories (Solow, 1956 and Durlauf et al., 2005, 2008a):

$$\log(y_{i,r}) = \gamma_0 \log(y_{i,r-T}) + \gamma_1 \log(s_{i,r}^k) + \gamma_2 \log(s_{i,r}^h) + \gamma_3 \log(n_{i,r} + g + \delta) + z_{i,r} + \alpha_i + \theta_r + \varepsilon_{i,r} \quad [1]$$

$$\gamma_1 = e^{\lambda T} \gamma_2 = (1 - e^{\lambda T}) \frac{\alpha_k}{1 - \alpha_k - \alpha_h} \gamma_3 = (1 - e^{\lambda T}) \frac{\alpha_h}{1 - \alpha_k - \alpha_h} \gamma_4 = -(1 - e^{\lambda T}) \frac{\alpha_k + \alpha_h}{1 - \alpha_k - \alpha_h}$$

where $y_{i,r}$ is the real per capita GDP for country $i = [1, \dots, N]$ across a time period $r = [r, r+T]$, T being 5 years, $s_{i,r}^k$, $s_{i,r}^h$ and $\log(n_{i,r} + g + \delta)$ denote the variables that measure the net factor accumulation in the neoclassical growth theory with the saving rates of physical capital accumulation ($s_{i,r}^k$) and human capital accumulation ($s_{i,r}^h$) and with population growth rates ($n_{i,r}$), the rate of labour augmenting technical progress (g) and the physical capital depreciation rate (δ), $z_{i,r}$ denotes a set of variables proxying eight new growth theories described in the data subsection and in the appendix (Tables 2.8 and 2.9), α_i is a country-specific effect, θ_r is a time-specific effect and $\varepsilon_{i,r}$ is the error term.⁴⁸

Each growth theory can be proxied by several variables (see Table 2.5). Note that typically $g + \delta = 0.05$ (Mankiw *et al.*, 1992). α_k and α_h are the parameters associated with the Cobb-Douglas production function on physical and human capital input variables, such that $\alpha_k > 0$, $\alpha_h > 0$ and $\alpha_k + \alpha_h < 1$. λ is a parameter that denotes the rate of convergence such that $\lambda < 0$. Saving rates of physical capital accumulation and saving rates of human capital accumulation are referred to hereafter as investment in physical capital and schooling, respectively.

We work with the following set of new eight growth theories including both proximate and fundamental theories: Demography, macroeconomic policy, regional heterogeneity for proximate theories, and religion, natural capital, geography, fractionalisation and institutions for fundamental theories (see Table 2.1). The determinants derived from a neoclassical growth model are referred to as proximate determinants because they are thought to be the most established drivers of economic growth. The term ‘proximate’ also reflects the ease with which these determinants can be influenced by policy measures. Fundamental determinants depend instead on slow-moving fundamental growth (Durlauf et al., 2008b). Our economic growth regressions include both proximate and fundamental theories.

Fundamental theories can have direct and/or indirect effects on economic growth. To analyse this matter, we first develop estimations including both proximate and fundamental theories. If fundamental theories are significant in these estimations, this implies that they have

⁴⁷ We have replicated the analysis with 10 year periods but the sample size is too small given the nature of our data (presence of heteroskedasticity and serial correlation). Even though averaging over the longest time horizon possible should better deal with eliminating business cycle effects that probably dominate per capita income fluctuations at higher frequencies, it comes at the cost of reducing the sample size (Durlauf *et al.*, 2008b). In turn, when the sample size is too limited and the number of explanatory variables large, estimation methods can be of limited use to distinguish robust from irrelevant variables.

⁴⁸ We note that in our economic growth regressions we replace the country-specific effect variables by the regional heterogeneity variables included in the new growth theories which enables us to take into account regional heterogeneity while decreasing the number of variables in the regression given the short number of observations typically associated with economic growth estimations.

a direct impact on economic growth. It may also be the case that fundamental theories are not significant in these estimations, and yet may have an indirect impact on economic growth.

To test this hypothesis, we develop estimations only including fundamental theories. If some of the fundamental theories in these latter estimations are significant, while they were not significant in the estimations with proximate and fundamental theories, we can infer that such fundamental theories have an indirect impact on economic growth through proximate theories. In fine, we analyse whether fundamental theories exert a direct influence on economic growth, or an indirect influence through their correlation with proximate theories.

Table 2.1. Proximate and fundamental growth theories

PROXIMATE THEORIES

Demography	Health may contribute to explain differences in income per capita among countries (Shastri and Weil, 2003 and Weil, 2005)
Macroeconomic policy	Inflation, government consumption and terms of trade can impact economic growth (Barro, 1997)
Regional heterogeneity	Countries in different continents may not represent draws from a common growth model (Brock and Durlauf, 2001)

FUNDAMENTAL THEORIES

Religion	Religion beliefs and adherence may influence growth (Barro and McCleary, 2003, Durlauf <i>et al.</i> , 2012)
Natural capital	Natural capital dependence and abundance may impact economic growth (Sachs and Warner, 1995 and Gylfason, 2011)
Geography	Geographical and ecological conditions (climate zone, disease ecology, distance from the coast) can affect economic growth (Sachs, 2003)
Fractionalisation	Ethnic and linguistic heterogeneity can affect economic growth (Alesina <i>et al.</i> , 2003 and Easterly and Levine, 1997)
Institutions	The regulation of entry of new firms, the procedural formalism in courts can impact economic growth (Djankov <i>et al.</i> , 2002, 2003)

Economic growth model: Uncertainty

There is a problem of model uncertainty when performing economic growth estimations that account for new growth theories following the regression model [1] (Brock and Durlauf, 2001, Brock *et al.*, 2003). That is, there is theory uncertainty since the statement that a theory is relevant does not preclude others from being relevant as well. Moreover, there is specification uncertainty since new growth theories do not translate naturally into specific regressors. To deal with model uncertainty, we employ a BMA estimator.

In model averaging models, we treat the growth model as an unobservable variable. To account for this variable, each model specification m in the model space M is associated with a posterior model probability $\mu(m|D) \propto \mu(D|m) \mu(m)$, where D is the available data, $\mu(D|m)$ is the likelihood of the data given the model and $\mu(m)$ is the prior model probability. We set the prior probability that a particular theory is in the true model to 0,5 to reflect non-information across theories (Durlauf *et al.*, 2008a).⁴⁹ The posterior model probability is the probability that model m is the true model given the data and we can hence calculate whether a theory is in the true

⁴⁹ Assigning equal prior probability to each possible model can have odd implications for linear regressions with a large number of potential regressors, though. However, the number of variables we are including is not very large compared to other analyses, since we are building over Durlauf *et al.* (2008a) results.

model by computing $\sum \{m \in M\} \mu(m|D, m \in A)$, where A is the event that at least one proxy variable is in the true model.

Preliminary analysis: Presence of multiple convergence regimes

We apply a preliminary analysis to the augmented Solow model to explore whether there are multiple convergence regimes. The so-called conditional beta-convergence is interpreted as evidence that poorer countries are converging with richer ones after controlling for heterogeneity.⁵⁰ Alternatively, there can be evidence of multiple convergence regimes if there is no single regime model for global convergence (Durlauf and Johnson, 1995). That is, even after controlling for structural heterogeneity there is a role for initial conditions in explaining variation in cross-country growth behaviour.⁵¹

To analyse whether there are multiple convergence regimes we proceed in two steps. Based on Durlauf and Johnson (1995), we use the Classification Analysis and Regression Tree (CART) model applied to Solow variables to identify those that are most likely to provide a more ‘reasonable’ separation of observations. We then perform preliminary estimations for the full sample and for the identified sub-samples, and we test the hypothesis that all the countries in the sample follow the same convergence dynamics through a Chow test. This test enables to derive whether we should perform our economic growth regressions on one sample or whether we should work with several sub-samples.

To perform these preliminary estimations, since the country-specific effect α_i is not distributed independently with respect to $\log(y_{i,r-T})$, we use a fixed-effects method rather than a random effects method. Another alternative is to difference the model to eliminate fixed-effects and then use the Differenced Generalised Method of Moments (DIF-GMM) method developed by Arellano and Bond (1991) to address the contemporaneous correlation between the differenced lagged dependent variable $\log(y_{i,r-T})$ component of $\Delta \log(y_{i,r-T})$ and the $\Delta \varepsilon_{i,r-T}$ component of the new error term:

$$\Delta \log(y_{i,r}) = \gamma_0 \Delta \log(y_{i,r-T}) + \gamma_1 \Delta \log(s_{i,r}^k) + \gamma_2 \Delta \log(s_{i,r}^h) + \gamma_3 \Delta \log(n_{i,r} + g + \delta) + \Delta z_{i,r} + \Delta \theta_r + \Delta \varepsilon_{i,r} \quad [2]$$

We follow the standard approach where lagged values of the potentially endogenous regressors in levels are used as instruments. However, if the explanatory variables are highly persistent, lagged levels can be weak instruments and the estimator can be biased. To check for the consistency of the DIF-GMM results, we propose to compare the estimates of the rate of convergence of the OLS and the within-group models with those of DIF-GMM methods. If the explanatory variables other than lagged output are exogenous then a consistent DIF-GMM parameter estimate should lie between OLS and within-group estimates which are biased in opposite directions (Caselli *et al.*, 1996).

Besides, lagged variables in levels can also be inappropriate instruments if there is serial correlation in the error terms of the growth equation before differencing. For instance, education variables can influence output with a considerable delay. Due to these drawbacks associated with the DIF-GMM method, we estimate as well equation [2] through the system GMM (SYS-GMM) method derived by Arellano and Bover (1995). This estimator uses, in addition to the

⁵⁰ There is evidence against unconditional beta-convergence, where the latter implies that countries that are poorer and have higher marginal productivity of capital should grow faster in the transition to the long-run steady state, independently of structural heterogeneity. In conditional convergence, countries will tend to different levels of income in the long run. There is evidence of unconditional convergence among manufacturing industries rather than entire economies suggesting that the lack of convergence is due to the factors that influence the speed of reallocation from non-convergence to convergence activities (Rodrik, 2012).

⁵¹ Note that multiple regimes may represent evidence of multiple steady-states as well as evidence of non-linearity in the growth process.

moment conditions used in DIF-GMM, instruments in first differences for the equation in levels and offers higher robustness.

Data

The unbalanced panel data set covers 83 countries across different regions in the world for 10 five-year periods from 1960 to 2009 (see appendix for more details). There are some differences in the choice of variables when comparing our work with the study of Durlauf *et al.* (2008a). We include our variables of interest, that is, the share of natural capital in national wealth and the natural capital per capita suggested by Gylfasson (2011).⁵² Natural capital consists on timber resources, non-timber forest resources, protected areas, cropland and pastureland and subsoil assets, where we distinguish renewable (timber, non-timber forest resources, protected areas cropland and pastureland) and non-renewable (oil, natural gas, hard coal, soft coal, coal and minerals) natural capital. National wealth is approximated by the present value of sustainable consumption using a social discount rate of four (World Bank, 2006).

In terms of other differences with respect to Durlauf *et al.* (2008a), we use the average growth rate of real per capita GDP instead of the average growth rate of real per worker GDP since the dataset from Caselli (2005) does not cover our period of study. For the geography theory, we use some variables suggested by Durlauf *et al.* (2005) since those used by Durlauf *et al.* (2008a) were often not available for our sample of countries. For the institutions theory, we use some proxies for individual and minority rights and public sector corruption, instead of expropriation risks since the latter was not available for our period of study. The detailed definition of the variables, their designation and the data sources are given in Tables 2.5-2.6 in the appendix.

Preliminary analysis results

In this section, we summarize the preliminary analysis results in Tables 2.7-2.13 in the appendix. Our preliminary tests reveal that the data shows heteroskedasticity and serial correlation which needs to be taken into account when analyzing the data. Moreover, we find some evidence of the existence of multiple convergence regimes among our panel of countries based on the CART model. Given this result, we develop the regressions on economic growth determinants for the whole sample and for the two sub-samples defined by the cut-off point in the median level of investment in physical capital.

Furthermore, we share the summary statistics and the correlation matrix between proximate and fundamental theories for the full sample and for the two sub-samples according to the cut-off point in the median level of investment in physical capital. When comparing the two sub-samples we can appreciate that the ratio of renewable natural capital in national wealth is larger for countries with investment in physical capital below the median cut-off point than for countries with investment in physical capital above the median cut-off point. The correlation matrix conveys some useful information on the explanatory power of fundamental theories and in particular of the natural capital theory, in the economic growth regression.

In particular, we find some evidence that the influence of the share of renewable natural capital on national wealth may be exerted through neoclassical (population growth rates), demography (life expectancy and fertility rate) and regional heterogeneity (Sub-Saharan Africa) proximate theories, and that the ‘natural capital’ fundamental theory may have no direct

⁵² We acknowledge that this data is subject to certain limitations as described by van der Ploeg and Poelhekke (2010). For instance, the data use the same discount rate of four per cent per annum regardless of the rate of economic growth, and the same remaining lifetime of 20 years and the same elasticity of the cost of extraction independently of the type of resource, country and date. van der Ploeg (2010) also argues that there is a caveat in using World Bank data on resource stocks as a measure of abundance since it is based on rents.

influence on economic growth, particularly so for the sub-sample of countries with lower levels of investment in physical capital. More generally, we analyze whether some fundamental theories (renewable natural capital, but also religion, fractionalization and institutions) have some explanatory power in the economic growth regression, beyond the influence exerted through proximate theories' variables.

Economic growth regression results

In the following lines, we present our findings for the augmented Solow model and eight new growth theories based on equation [1].⁵³ The results for natural capital can be found in Tables 2.14-2.16, those for renewable natural capital in Tables 2.17-2.19, and those for non-renewable natural capital in Tables 2.20-2.22. BMA method results are available in Tables 2.14, 2.17 and 2.20 for the full sample and in Tables 2.15-2.16, 2.18-2.19 and 2.21-2.22 for the two sub-samples defined by the cut-off point in the median level of investment in physical capital.

Tables 2.14-2.22 show results for the case where we include both proximate and fundamental determinants in the model space (columns 1-3) as well as the case where only fundamental growth determinants are in the model space (columns 4-6). Columns 1 and 4 provide the posterior probability that each theory is in the 'true' model under the BMA method. In Tables 2.2 and 2.3 below, we share the summary findings for the BMA posterior inclusion probability results for the natural capital theory and for the full set of eight theories, respectively.

We first discuss our findings on the natural capital theory. Given the prior probability of a theory being in the true model space is set at 0,5, the robustness of a theory will depend on how the data updates this prior through the posterior probability of inclusion of the theory in the true model. In terms of the natural capital theory, the posterior probability of inclusion is lower than the prior of 0,5 when we consider proximate and fundamental theories in Table 2.2 below and in Tables 2.14-2.22 in the appendix. These results appear to contradict previous findings in the empirical literature whereby natural capital is a significant determinant of economic growth (Ding and Field, 2005, Cerny and Filer, 2007 and Gylfason, 2011).

If we drop proximate growth theories from the model space and retain only fundamental growth theories, the posterior probability of inclusion for natural capital as a theory is instead significant for renewable natural capital at 0,605 for the full sample. Our interpretation of these results is that renewable natural capital affects economic growth indirectly through its influence on proximate theories' variables. Our results may indicate that previous findings on the direct contribution of natural capital to economic growth based on standard methods without uncertainty may be fragile.

Table 2.2. Economic growth determinants: BMA posterior inclusion probability results for natural capital

Proximate and fundamental theories			Fundamental theories		
Full	$invest \geq$	$invest <$	Full	$invest \geq$	$invest <$

⁵³ The ratio of observations to independent variables should not fall below five (Bartlett *et al.*, 2001). As in Durlauf *et al.* (2005), we therefore exclude from the BMA regressions the variables which have weaker explanatory power in our regressions with respect to those presented in Table 2.7 (some religion variables: buddhism, catholic, jew and orthodox). We check for multicollinearity whereby additional variables are also excluded from the BMA regressions (some regional heterogeneity variables: East Asia and the Pacific and some institutional variables: liberal democracy, public sector corruption, legal formalism: Check (1), legal formalism: Check (2) and complex).

	sample	3,10	3,10	sample	3,10	3,10
NATURAL CAPITAL	0,250	0,170	0,096	0,227	0,084	0,341
NATURAL CAPITAL (ren)	0,169	0,164	0,221	0,814	0,369	0,734
NATURAL CAPITAL (non-ren)	0,277	0,153	0,079	0,059	0,038	0,124

Note: This table provides the summary results for the natural capital theory for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. Results are reported for the natural capital theory for the aggregated indicator on renewable and non-renewable natural capital, and for renewable and non-renewable natural capital indicators separately. Results are also given for the full sample, and for the sub-samples defined by the median cut-off point in investment in physical capital, *invest*. The text in bold indicates that the variable is a relatively robust determinants of economic growth.

We can rely on our preliminary findings to analyse through which proximate variables natural capital affects economic growth. In our preliminary results, among fundamental theories, renewable natural capital is correlated with neoclassical (population growth rates), demography (fertility rate) and regional heterogeneity (Sub-Saharan Africa) proximate theories (Table 2.13). In turn, for the renewable natural capital regressions, we can see in Table 2.17 that fertility is a robust (and negative) determinant of growth for the full sample. We infer that renewable natural capital contributes to economic growth indirectly through fertility rates.⁵⁴

Beyond the results for the natural capital theory, in Tables 2.3 and 2.14 we can appreciate that the empirically robust new growth theories for the full sample are demography, religion and institutions.⁵⁵ With regards to demography variables, in Table 2.14 we can see that the effect of *fertility* is detrimental to economic growth and significant as in Barro (1991, 1996 and 1997) and Barro and Lee (1994). In terms of the religion theory, the eastern religion matters for economic growth in the sense that the posterior probability of inclusion is also higher than the prior of 0,5 at 0,98. These results confirm previous work in the empirical literature suggesting an important role for religion in growth (Barro and McCleary, 2003). They also confirm the relevance of the eastern religion as a positive determinant of economic growth (Durlauf *et al.*, 2008a).

Our results for institutions point out that executive constraints have a negative and significant impact on economic growth in contrast with the result of Acemoglu *et al.* (2002) where institutions are positively correlated with economic growth. These results may suggest that greater checks and balances may depress growth (Barro, 1994). They may also suggest that to the extent that our measure of executive constraints correlates with political instability, there is significant evidence in the empirical literature of a negative relationship with respect to economic growth.⁵⁶

⁵⁴When the demography variables are included in the fundamentals only model space, the renewable natural capital theory that is found to be a determinant in column 4 of Table 2.2 becomes non relevant with a posterior probability of 0,174 instead of 0,605, while the posterior probability of the demography theory is 1,000. Results are available upon request.

⁵⁵With the exception of the natural capital theory findings, the results of BMA analysis on the remaining determinants of economic growth are very similar for the regression with natural capital (Tables 2.14-2.16) and with renewable (Tables 2.17-2.19) and non-renewable natural capital (Tables 2.20-2.22).

⁵⁶Our executive constraints variable reflects the outcomes of most recent elections as a ‘political institution’ variable (Glaeser *et al.*, 2004). Some authors suggest that this variable cannot be therefore interpreted as reflecting durable rules, procedures or norms. Given such view, Cox and Weingast (2015) find that in terms of moderating succession-related downturns and thereby promoting steadier economic growth, the quality of legislatures measured by the executive’s horizontal accountability is more important than the existence of free and fair elections. In addition, to the extent that elections may correlate with political instability, there is significant evidence of negative relationship with respect to economic growth (see, for instance, Barro, 1991, Barro and Lee, 1994, Sachs and Warner, 1995, Alesina *et al.*, 1996 and Castelli *et al.*, 1996).

Table 2.3. Economic growth determinants: BMA posterior inclusion probability results

	Proximate and fundamental theories			Fundamental theories		
	Full sample	<i>invest</i> ≥ 3,10	<i>invest</i> < 3,10	Full sample	<i>invest</i> ≥ 3,10	<i>invest</i> < 3,10
DEMOGRAPHY	1,000	1,000	0,161			
MACROEC. POLICY	0,028	0,973	0,041			
REGIONAL HETERO.	0,085	0,002	0,384			
RELIGION	0,981	0,980	0,241	1,000	1,000	0,116
NATURAL CAPITAL	0,250	0,170	0,096	0,227	0,084	0,341
GEOGRAPHY	0,056	0,078	0,065	0,035	0,037	0,088
FRACTIONALISATION	0,056	0,092	0,052	0,964	0,992	0,083
INSTITUTIONS	1,000	1,000	0,999	1,000	0,999	1,000

Note: This table provides the summary results for the eight growth theories for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. Results are given for the full sample, and for the sub-samples defined by the median cut-off point in investment in physical capital, *invest*. The text in bold indicates that the variable is a relatively robust determinants of economic growth.

In terms of the fractionalization theory, the associated variables do not appear to matter for economic growth in the sense that the posterior probability of inclusion is lower than the prior of 0,5 at 0,05. These results appear to contradict previous work in the empirical literature suggesting an important role for fractionalisation in growth (Easterly and Levine, 1997 and Alesina *et al.*, 2003). If we drop proximate growth theories from the model space and retain only fundamental growth theories, the posterior probability of inclusion for fractionalisation as a theory is instead very high at 0,96 as the *ethnic* variable is important by our t-statistic rule of thumb as in Durlauf *et al.* (2008a).

One interpretation of these results is that fractionalization affects economic growth indirectly through its influence on proximate variables. In exercises where we included the demography variables in the fundamentals only model space, the fractionalisation variables that were found to be robust determinants in column 4 of Table 2.3 become non-robust with a posterior probability of 0,06.⁵⁷ This is consistent with our preliminary results where, among fundamental theories, fractionalisation is correlated with neoclassical (population growth rates), demography (fertility rate) and regional heterogeneity (Sub-Saharan Africa) variables (Table 2.8). As with the natural capital theory, our results indicate that previous findings on the importance of fractionalisation to economic growth are fragile.

In terms of the neoclassical growth variables, our findings are overall consistent with those in the conditional convergence literature as well as previous studies that have used BMA methods. In Table 2.14, we can see that we find robust evidence of conditional convergence with a negative and significant coefficient on initial income as many previous studies (see, for instance, Barro, 1991, Sachs and Warner, 1995, Barro, 1997 and Easterly and Levine, 1997).

There is no evidence however that investment in physical capital is positively and significantly correlated to economic growth in contrast with previous findings (see, for example, Barro, 1991, Barro and Lee, 1994, Sachs and Warner, 1995, Barro, 1996, Caselli *et al.*, 1996 and Barro, 1997). The effect of schooling is not significant, but this result remains largely consistent with the empirical literature (Durlauf *et al.*, 2008a). In exercises where we drop demography from the model space, we find that population growth rates are negatively though still not significantly related to growth (Mankiw *et al.*, 1992, Kelley and Schmidt, 1995 and Blooms and Sachs, 1998).⁵⁸ This variable is instead significant for the sub-sample with

⁵⁷ Results are available upon request.

⁵⁸ Results are available upon request.

investment in physical capital below the median cut-off point (see Tables 2.15, 2.18 and 2.21).

If we compare the two sub-samples according to the median level of investment in physical capital in Tables 2.3 and 2.15-2.16 with the results for the full sample, we can appreciate two main differences concerning the new growth theories. Firstly, beyond demography, religion and institutions, macroeconomic policy is also a robust determinant of economic growth in the sub-sample with investment in physical capital above the median cut-off point. In particular, in Table 2.15 we can appreciate that inflation is negatively and significantly correlated with economic growth which is consistent with the empirical literature (Barro, 1997 and Bruno and Easterly, 1998). Secondly, the institutions theory is the only robust theory in the sub-sample with investment values below the median cut-off point, even if no specific institutional variable is significant in Table 2.16.

To conclude, we find that the natural capital theory proxied through natural capital wealth dependence and per capita abundance variables is not a robust direct determinant economic growth unlike previous findings using standards methodologies without uncertainty (Ding and Field, 2005, Cerny and Filer, 2007 and Gylfason, 2011). Renewable natural capital affects economic growth indirectly through its influence on proximate theories. This indirect contribution to economic growth is exerted through the demography (fertility) theory.

Otherwise, we find that according to the BMA method the robust direct new growth theories include demography, religion and institutions for the full sample and, in addition, macroeconomic policy for the sub-sample with investment in physical capital above the median cut-off point. Fractionalisation also contributes indirectly to economic growth in the sub-sample with investment in physical capital above the median cut-off point through the demography theory. Our identification of the robust determinants of economic growth in the sub-sample with investment values below the median cut-off point is very poor, only the religion theory being relevant as a direct determinant of economic growth.

2.4. Conclusion

In this work, we aim at bringing some light on whether natural capital is a robust determinant of economic growth, distinguishing the direct and indirect contributions of renewable and non-renewable natural capital. For this matter, we use a data set on 83 countries for the period 1960-2009 to compare the relevance of proximate and fundamental theories to explain economic growth when the sample is divided according to investment in physical capital.

Through this first country typology based on investment in physical capital, we find some evidence that renewable natural capital has a rather indirect impact on economic growth, since it impacts growth only when fundamental theories alone are examined. In particular, we find an indirect negative impact through human development and, more precisely, through fertility rates. The dependency effect (fewer dependent children relative to working adults) and, at longer horizons, the increase in human capital, capital shallowing (Solow, 1956), and the effects of congestion of fixed resources (Malthus, 1798) are the most relevant channels to explain the role reduced fertility of economic growth (Ashraf *et al.*, 2013). In particular, according to the 'Malthusian trap' the resource abundance would encourage population growth, which would eventually bring the per capita supply of resources back to its original level. In contrast, we find neither a direct impact of non-renewable natural capital on economic growth when exploring proximate and fundamental theories together, not an indirect impact when analyzing fundamental theories alone.

Is it possible to find some other impact of renewable and non-renewable natural capital on economic growth through methods that take into account model uncertainty? As we can appreciate in Table 2.4, we can separate the sample according to the levels of investment in physical capital, but also divide it according to income per capita, income inequality, human development and institutional quality median values. Through these additional country

typologies, we find a direct positive impact of natural capital on economic growth in the sub-sample with lower income inequality, since it significantly impacts growth when analysing proximate and fundamental theories together.⁵⁹

Besides, when we analyse separately renewable and non-renewable natural capital, we find relevant differences. In Table 2.4, we can see that renewable natural capital has an indirect impact on economic growth in the sub-samples characterised by lower investment in physical capital, as we have already seen, and also in those characterised by higher human development, since it affects growth solely when fundamental theories alone are explored. In particular, the share of renewable natural capital in wealth is positively correlated with fertility in the sub-sample with higher levels of human development and in turn, fertility affects negatively economic growth.⁶⁰ Hence, in countries with higher human development (higher fertility rates), renewable natural capital has a negative indirect impact on economic growth.

In contrast with previous findings on renewable capital, non-renewable natural capital has a direct impact on economic growth in the sub-samples characterised by lower income inequality and higher institutional quality, given that it affects growth when both proximate and fundamental theories are analysed together. This impact is positive through the non-renewable natural capital in wealth variable in both sub-samples, and significant in the sub-sample characterised by higher institutional quality. This is related to the effect of capital accumulation in the domestic economy, as capacity constraints are relaxed (van der Ploeg and Venables, 2010).⁶¹

Why focusing on income per capita, income inequality, human development and institutional quality to analyse the role of natural capital on economic growth? There are often large differences concerning the share of natural capital on wealth and natural capital per capita according to the high/low level of each of these variables. The level of income per capita, for instance, is strongly correlated with international trade patterns. For example, richer countries may be specialised in services and/or be wealthy enough to protect their natural resources and import them from poorer countries, and as such may depend loosely on their local (renewable) natural capital, like Singapore, Netherlands, Japan and Switzerland which import most of their food.

Income inequality within countries should also be taken into account since different social groups might be differently affected by the loss of natural capital. In particular, the ones who benefit more from economic growth are not necessarily those who are more affected by natural capital degradation (TEEB, 2008). Such context has been often associated with the granting of perverse subsidies (Edenhofer, 2015). Thus, we should distinguish the dependence on local (renewable) and on global (non-renewable) natural capital depending on within country income inequality. In addition, highly polluting activities are increasingly displaced to poor countries. As a result, human development might be an appropriate indicator to examine human dependence on natural capital, as it takes into account health, among other social effects of natural capital. The inverse relationship between dependence on natural capital and education has also been explored (Gylfason, 2001).

Table 2.4. Natural capital as a determinants of economic growth according to different country typologies

Proximate and fundamental theories	Fundamental theories
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⁵⁹ The full set of results are available upon request.

⁶⁰ Note that it seems that our sample of countries characterised by high levels of HDI would be in the second phase of the demographic transition, that is, life expectancy would be rising but fertility rates would be still high.

⁶¹ Many countries find it indeed hard to absorb windfall of foreign exchange, as it takes time for the non-traded sectors to accumulate capital. In the meantime, it is optimal to park the windfall revenue abroad until there is enough capacity to invest in the domestic economy.

	Total	Renewable	Non-renewable	Total	Renewable	Non-renewable
Investment in physical capital						
<i>invest</i> < 3,10	0,096	0,221	0,079	0,341	0,734	0,124
<i>invest</i> ≥ 3,10	0,170	0,164	0,153	0,084	0,369	0,038
Income per capita						
<i>income</i> < 9	0,089	0,061	0,085	0,448	0,159	0,174
<i>income</i> ≥ 9	0,073	0,193	0,193	0,152	0,315	0,070
Income inequality						
GINI < 38,61	0,701	0,273	0,802	0,164	0,186	0,329
GINI ≥ 38,61	0,079	0,096	0,062	0,079	0,056	0,090
Human development						
HDI < 0,628	0,084	0,099	0,074	0,239	0,066	0,326
HDI ≥ 0,628	0,042	0,206	0,451	0,052	0,732	0,121
Institutional quality						
<i>kkz96</i> < 0,07	0,087	0,056	0,079	0,098	0,093	0,060
<i>kkz96</i> ≥ 0,07	0,124	0,383	0,930	0,043	0,187	0,353

Note: This table provides the summary results for the natural capital theories for the growth regression exercise in equation (1) of the text, in particular, the BMA posterior inclusion probability results. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. Results are given for sub-samples whose threshold is defined by the median in investment in physical capital, income per capita, income inequality, human development and institutional quality. The text in bold indicates that the variable is a relatively robust determinants of economic growth.

Furthermore, several authors claim that the negative relationship between natural resource intensity and economic growth can be reversed if institutional quality is high enough (Melhum *et al.*, 2006, Torvik, 2009 and Boschini *et al.*, 2013). Besides, the role of natural capital on economic growth may also depend on the country's history, whether or not it is an ancient colony which gives rise to easily exportable, controllable products such as oil and diamonds rather than cereals, for example (Pomeranz, 2000), the extent of degradation of renewable natural capital, very variable among countries (Sutton *et al.*, 2016), and the relative weight of food and energy in individual income as these are the two major resources which depend on natural capital.

What reasons may explain the lack of a stronger impact of renewable natural capital on economic growth? Some important data components are poorly integrated in natural capital accounts. In regards to biodiversity, for instance, variations of natural capital are usually estimated based on variations of land-uses without accurately including the effect of the loss of biological diversity. Species similarity very much depends on land uses. However, the loss of biodiversity also depends highly on land-use intensity, human population density and road proximity, parameters -or on their effects on biodiversity- that should be introduced in natural capital accounts (Newbold *et al.*, 2016).

This is especially important since such loss in terms of crossing biodiversity safe plenary limits would concern 58 per cent of terrestrial areas, where more than 70 per cent of humans live. Moreover, the different components of natural capital should affect economic growth in widely different ways, depending on their time and spatial effects. For example, cropland has an immediate and local effect, whereas protected areas are supposed to have delayed and global benefits, aspects that should be devoted particular attention.

Finally, we can also mention the limitations described by van der Ploeg and Poelhekke (2010) which are associated with our data on natural capital based on World Bank (2006) to

which we have referred to previously in the data subsection. Including time-varying data on natural capital, and relaxing the stringent constraints on interest rates, cost of extraction and time horizons to exhaustion, would be particularly relevant to verify the robustness of our results. It would also be interesting to explore the separate impacts of each of the renewable and non-renewable natural capital components on economic growth.

Besides the role of data limitations, the impact of natural capital on economic growth may also depend on the timeframe and country sample. Indeed, Aliyev (2011) and Lederman and Maloney (2002) argue that the results on the impact of natural resources in economic growth are contingent on the timeframe selected for the estimation. Aliyev (2011), for instance, finds that Sala-i-Martin *et al.* (2004) findings on the (non-robust) positive impact of the share of mining in GDP on economic growth during the period 1960-1996, no longer hold for the period 1960-2003.

When we compare our results with those of Durlauf *et al.* (2008a) who use a shorter period and a smaller sample of countries, we find different results in terms of the robust determinants of economic growth suggesting that the evidence is contingent on the timeframe and country sample.⁶² Further work based on longer time-series and specific country samples, could enable to provide more evidence on the nature of the effect of natural resources on economic growth in the long-run. Our work and that of Konte (2013) testing whether neoclassical and institutional variables help a given country to belong to a certain economic growth regime with specific implications in terms of natural capital, are some first attempts to develop country typologies. One research question would be then how can countries fall under the classifications that enable to benefit from natural capital.⁶³

⁶²We can compare our results for the period 1960-2009 with respect to those of Durlauf *et al.* (2008a) for the period 1965-1994. The data set used by Durlauf *et al.* (2008a) consists of 57 countries, of which 54 are also present in our work. In particular, both analyses are based on 11 from Asia and Oceania, 13 from Latin America and Caribbean, 19 countries from North America and Europe and 11 from Middle East and Africa. In addition, we include one country from Europe, 14 from Middle East and Africa, seven from Latin America and Caribbean and seven from Asia and Oceania. While Durlauf *et al.* (2008a) find that among new growth theories, macroeconomic policy is a robust determinant, in our BMA analysis for the full sample demography, religion and institutions are instead the robust determinants suggesting that results are contingent on the time frame and country sample.

⁶³ There is lengthy literature on natural capital and economic growth seeking to analyse how to attain the characteristics that enable to have a positive relationship between these two variables, particularly applied to institutional endowments (see, for instance, Omgba, 2015).

2.5. Appendix

Data

The data set constructed for this study contains observations for the period 1960-2009 on 83 countries from the following regions for which we have data on our relevant variables, namely, neoclassical variables, natural capita in wealth and natural capital per capita:

- Latin America and the Caribbean (20): Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Peru, Trinidad and Tobago, Uruguay and Venezuela.
- Middle East and North Africa (10): Bahrain, Brunei, Egypt, Iran, Israel, Jordan, Kuwait, Saudi Arabia, Tunisia and United Arab Emirates.
- Sub-Saharan Africa (15): Cameroun, Congo, Gabon, Ghana, Kenya, Malawi, Mauritius, Mozambique, Senegal, Sierra Leone, South Africa, Sudan, Uganda, Zambia and Zimbabwe.
- East Asia and the Pacific (13): Australia, China, Fiji, Indonesia, Japan, Malaysia, New Zealand, Papua New Guinea, Philippines, Republic of Korea, Singapore, Thailand and Tonga.
- South Asia (5): Bangladesh, India, Maldives, Pakistan and Sri Lanka.
- North America, Europe and Central Asia (20): Austria, Belgium, Canada, Denmark, Finland, France, Greece, Hungary, Italy, Ireland, Norway, Poland, Portugal, Spain, Sweden, Switzerland, The Netherlands, Turkey, United Kingdom and United States.

We have collected data on variables regrouped in five categories: neoclassical, demography, macroeconomic policy, regional heterogeneity, religion, natural capital, geography, fractionalisation, institutions and other. The definition of these variables and the data sources are given below. The choice of the eight growth theories and the associated variables is largely inspired by the work of Durlauf *et al.* (2008a). The analysis of Durlauf *et al.* (2008a) is robust since they built their work over an exhaustive survey of the empirical growth literature which identifies 43 growth theories and 145 regressors. Each of these theories is found to be statistically significant in at least one study (Durlauf *et al.*, 2005). Besides the eight growth theories, we also include a category named ‘other’ to account for some instruments and for time dummy variables.

We do not include variables such as the fraction of primary products in total exports or the fraction of mining in the gross domestic product which have been often used as a proxy of the curse of natural resources (Sachs and Warner, 1996, Sala-i-Martin, 1997a, 1997b, Hall and Jones, 1999 and Sala-i-Martin *et al.*, 2004). Durlauf *et al.* (2008a) already rejected the robustness of these variables. Sala-i-Martin *et al.* (2004), in particular, by using BMA over 67 variables find that the fraction of mining in the gross domestic product is a weak determinant of growth since its significance depends on the prior model size and requires conditioning on other variables to show its full impact.

Table 2.5. Data description

Designation	Source(s)
NEOCLASSICAL	
Growth rates of pc GDP	Average growth rates (constant 2005 USD prices) for the periods 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004, 2005-2009.
Initial income	Logarithm of GDP per capita (constant 2005 USD prices) at 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000 and 2005. The instruments for the initial income include

Population growth rates	the values at 1955, 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, and 2000. Logarithm of average population growth rates plus 0.05 for the periods 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, 2000-2004, 2005-2009. The instruments for populations growth rates include the average values of 1955-1959, 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, 2000-2004.
Investment in physical capital	Logarithm of average ratios over each period of investment in physical capital to GDP for the periods 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, 2000-2004, 2005-2009. The instruments for investment include the average values of 1955-1959, 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, 2000-2004.
Schooling	Logarithm of the ratio of male population enrolled in secondary school to total population in 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000 and 2005.

DEMOGRAPHY

Life Expectancy	Reciprocals of life expectancy at age 1 in 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000, 2005.
Fertility rate	The log (LN) of the total fertility rate in 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000, 2005.

MACROECONOMIC POLICY

Openness	Average ratios for each period of exports plus imports to GDP in 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004, 2005-2009. The instruments include the average values of 1955-1959, 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, 2000-2004.
Government consumption	Average ratios for each period of government consumption to GDP in 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004, 2005-2009.
Inflation	The consumer price inflation rate for the periods 1960-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2009.

REGIONAL HETEROGENEITY

Latin America and Caribbean	Dummy variable.
Sub-Saharan Africa	Idem.
East Asia and the Pacific	Idem.
South-East Asia	Idem.

RELIGION

Buddhism	Buddhism share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the Buddhism share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Catholic	Catholic share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the catholic share in 1900 expressed as a fraction of the population who expressed adherence to

Eastern Religion	some religion. Eastern Religion share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the eastern religion share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Hindu	Hindu share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the Hindu share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Jew	Jew share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the Jew share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Muslim	Muslim share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the Muslim share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Orthodox	Orthodox share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the orthodox share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Other	Other religion share in 1970. The instruments include the other religion share in 1990.
Protestant	Protestant share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the protestant share in 1900 expressed as a fraction of the population who expressed adherence to some religion.

NATURAL CAPITAL

Natural capital in wealth	Time-invariant variable measuring the weight of natural capital in national wealth in 2000.
Natural capital in wealth (renewable)	Time-invariant variable measuring the weight of renewable natural capital in national wealth (crop, pasture land, timber, non-timber forest resources and protected areas) in 2000.
Natural capital in wealth (non-renewable)	Time-invariant variable measuring the weight of non-renewable natural capital (oil, natural gas, hard coal, soft coal, coal and minerals) in national wealth in 2000.
Natural capital per capita	Time-invariant variable measuring natural capital per capita in 2000. The variable is scaled to take values between zero and one.
Natural capital per capita (renewable)	Time-invariant variable measuring renewable natural capital per capita (crop, pasture land, timber, non-timber forest resources and protected areas) in 2000. The variable is scaled to take values between zero and one.
Natural capital per capita (non-renewable)	Time-invariant variable measuring non-renewable natural capital per capita (oil, natural gas, hard coal, soft coal, coal and minerals) in 2000. The variable is scaled to take values between zero and one.

GEOGRAPHY

Coastline	Coastline length in km, scaled to take values between zero and one.
Landlocked	Binary variable where one indicates landlocked country.
FRACTIONALISATION	
Language	Time-invariant measure of linguistic fractionalization that reflects the probability that two randomly selected individuals from a population belong to different groups. The data ranges from zero to one.
Ethnic	Time-invariant measure of ethnic fractionalization that reflects the probability that two randomly selected individuals from the population belong to different groups. The data ranges from zero to one.
INSTITUTIONS	
Liberal democracy	Time variant-index that emphasizes the importance of protecting individual and minority rights against the tyranny of the state and the tyranny of the majority. This is achieved by constitutionally protected civil liberties, strong rule of law, an independent judiciary, and effective checks and balances that, together, limit the exercise of executive power. To make this a measure of liberal democracy, the index also takes the level of electoral democracy into account. This variable is calculated as the average for the periods 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2009. It ranges from zero to one. Higher scores imply a more liberal democracy.
Public sector corruption	Time-variant variables that measures to what extent public sector employees grant favors in exchange for bribes, kickbacks, or other material inducements, and how often they steal, embezzle, or misappropriate public funds or other state resources for personal or family use. This variable is calculated as the average for the periods 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2009. It ranges from zero to one. Higher scores imply a more corruption.
Legal formalism: Check (1)	Time-invariant index of the professionals vs. laymen, written vs. oral elements, legal justification, statutory regulation of evidence, control of superior review, and engagement formalities indices, and the normalized number of independent procedural actions for the case of collection of a check. The index ranges from zero to seven, where seven means a higher level of control or intervention in the judicial process.
Legal formalism: Check (2)	Time-invariant index of formality in legal procedures for collecting on a bounced check, rescaled to lie between zero to one for 2003. Lower scores imply a less legal formality.
Complex	Time-invariant index of complexity in collecting a commercial debt valued at 50% of annual GDP per capita, rescaled to lie between zero and one for 2003. Lower scores imply a less complexity.
KKZ96	Time-invariant composite governance index. It is calculated as the average of six variables: voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law,

Executive constraints	and control of corruption in 1996. It ranges from –2 to 2. Higher values imply better governance. Time varying variable that measures the extent of institutionalized constraints on the decision making powers of chief executives. This variable is calculated as the average for the periods 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2009. This variable ranges from zero to seven where higher values equal a greater extent of institutionalized constraints on the power of chief executives.
OTHER	
Time dummy variables	Dummy variables for 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2009
Colonial (Spain or Portugal)	Binary variable where one indicates that country was colonized by Spain or Portugal.
English legal origin	Binary variable where one indicates that country was colonized by The United Kingdom, and English legal code was transferred.
French legal origin	Binary variable where one indicates that country was colonized by France, Spain, Belgium, Portugal or Germany and French legal code was transferred.
Latitude	The absolute value of the latitude of the capital of the country, scaled to take values between zero and one.
Mineral stocks	Time-invariant variable that takes the value of the logarithm of fuel and 35 non fossil fuel stocks estimated for 1970 at market prices, in US dollars per capita.
System	Time-invariant variable that takes the value of 0 if the country has a presidential system, 1 if it has an assembly-elected president and 2 if it has a parliamentary system (mean value between 1975 and 2010).

Table 2.6. Data sources

Designation	Source(s)
NEOCLASSICAL	
Growth rates of pc GDP	Penn World Tables 7.1
Initial income	Idem
Population growth rates	Idem
Investment in physical capital	Idem
Schooling	Barro and Lee (2014)
DEMOGRAPHY	
Life Expectancy	World Bank
Fertility rate	Idem
MACROECONOMIC POLICY	
Openess	Penn World Tables 7.1
Government consumption	Idem
Inflation	World Bank
REGIONAL HETEROGENEITY	
Latin America and Caribbean	World Bank country classification
Sub-Saharan Africa	Idem

East Asia and the Pacific	Idem
South-East Asia	Idem
RELIGION	
Buddhism	World Christian Encyclopedia (2001)
Catholic	Idem
Eastern Religion	Idem
Hindu	Idem
Jew	Idem
Muslim	Idem
Orthodox	Idem
Other	Idem
Protestant	Idem
NATURAL CAPITAL	
Natural capital in wealth	World Bank
Natural capital in wealth (renewable)	Idem
Natural capital in wealth (non-renewable)	Idem
Natural capital per capita	Idem
Natural capital per capita (renewable)	Idem
Natural capital per capita (non-renewable)	Idem
GEOGRAPHY	
Coastline	UNEP (2015)
Landlocked	Central Intelligence Agency (2009)
FRACTIONALISATION	
Language	Alesina <i>et al.</i> (2003)
Ethnic	Idem
INSTITUTIONS	
Liberal democracy	The QOG Standard Dataset
Public sector corruption	Idem
Legal formalism: Check (1)	Djankov <i>et al.</i> (2003)
Legal formalism: Check (2)	Doing Business, World Bank
Complex	Idem
KKZ96	Kaufmann <i>et al.</i> (2005)
Executive constraints	Polity IV Project, 1946-2013
OTHER	
Time dummy variables	Own construction
Colonial (Spain or Portugal)	Barro and Lee (1994)
English legal origin	Easterly (2001)
French legal origin	La Porta <i>et al.</i> (1999) and Djankov <i>et al.</i> (2003)
Latitude	Djankov <i>et al.</i> (2003)
Mineral stocks	Norman (2009) and van der Ploeg and Poelhekke (2010)
System	Beck <i>et al.</i> (2001)

Descriptive statistics and preliminary results

We share the preliminary analysis results in Tables 2.7-2.13 in this appendix. Firstly, we present the summary statistics and the correlation matrix between the variables that proxy proximate and fundamental economic growth theories. This correlation matrix conveys some information on whether fundamental theories and in particular renewable and non-renewable natural capital, may have some explanatory power in the economic growth regression, beyond the influence exerted through proximate theories.

Secondly, we perform some preliminary tests to prepare the data for the analyses.

Thirdly, we test on our dataset whether there is evidence of multiple convergence regimes among our panel of countries through the CART model. We verify the robustness of these results through the OLS, the fixed-effects and the DIF-GMM and SYS-GMM methods. Finally, we present the summary statistics and the correlation matrix according to the results of the CART model.

We can first see some descriptive statistics. In Table 2.7, we share the summary statistics for all the variables that we used in our estimations. In Table 2.8, we present the correlation matrix between the proximate theories' variables and the variables associated with the fundamental theories, whenever the level of correlation is above or equal to 0,40. The variables associated with four fundamental theories, religion, natural capital (renewable), fractionalisation and institutions, are strongly correlated with variables from all proximate theories except for the macroeconomic policy theory.

In particular, renewable natural capital is correlated with the following proximate theories: demography (fertility) and regional heterogeneity (Sub-Saharan Africa). Building on these results, in the section three we analyse whether the fundamental theories just mentioned (religion, renewable natural capital, fractionalisation and institutions) have some explanatory power in the economic growth regression, beyond the influence exerted through proximate theories' variables.

Before proceeding with the CART model and the economic growth regressions, we perform a series of preliminary tests. We find that our dependent variable is stationary in levels, that panel data is preferred to pool data and that there is presence of heteroskedasticity and serial correlation, and we treat our data accordingly.⁶⁴ We then perform the CART analysis to search for the presence of convergence regimes. The CART analysis identifies subgroups of countries that obey a common linear growth model based on neoclassical variables.

We identify four subgroups according to three different cut-off points by order of relevance: 2,75 and 1,29 for investment in physical capital and -2,47 for population growth rates. The subgroups are: $invest < 1,29$ with 13 observations, $1,29 \leq invest < 2,75$ with 143 observations, $invest \geq 2,75$ and $population < -2,47$ with 610 observations and $invest \geq 2,75$ and $population \geq -2,47$ with 25 observations. To test the robustness of these results, we separate the data according to the subgroups, and we test the hypothesis that all the countries in the sample follow the same convergence dynamics.

Unfortunately, we are unable to compare subgroups according to the CART cut-off points since the number of observations is insufficient in two of the four sub-samples.⁶⁵ To overcome this problem, for the most appropriate variable in the CART analysis given the sub-

⁶⁴ Firstly, through the Fisher unit root test, we find that the dependent variable is stationary in levels. Secondly, we verify whether it is preferable to pool or not the data by testing the appropriateness of random and fixed-effects panel data compared to the pool analysis through the goodness-of-fit results. Panel data is preferred to pool data which implies that the parameters of the equation vary from one period to the other over the ten periods of available data. Thirdly, our data shows heteroskedasticity across panels through the Erilat LM-test and serial correlation through the Baltagi LM-test. The OLS and fixed-effects methods have adjusted standard errors for intragroup correlation which should hence be robust to heteroskedasticity and serial correlation. The GMM method also controls for heteroskedasticity and we test the presence of serial correlation of order one and two. This method assumes there is no second-order autocorrelation in the error term in levels. To perform the 2SLS method for the economic growth regressions, we use Driscoll and Kraay's approach which guarantees that the covariance matrix estimator is consistent, independently of the cross-sectional dimension, in contrast to Parks-Kmenta and the Panel-Corrected Standard Errors (PCSE) approaches, which typically become inappropriate when the cross-sectional dimension of a microeconomic panel gets large (Driscoll and Kraay, 1998).

⁶⁵ With fewer than five cases per group and fewer than 50 groups, standard errors for fixed effects will be too small (increased Type I errors), and random effects (variances) and their standard errors may be underestimated (Hox, 2002, 2010).

groups sample sizes, *invest*, we select a cut-off point at the median value 3,10.⁶⁶ This choice enables us to have over 350 observations in each of the two sub-samples which are sufficient to verify the presence of convergence regimes. We can see in Table A5 that there are no large differences in neoclassical variables when separating the sample according to the CART and median cut-off points.⁶⁷ In Table A6, we therefore explore whether we find evidence of the presence of two convergence regimes after accounting for variation in structural characteristics.

In addition to showing the convergence rate, λ , associated with the explanatory variables estimates of equation [2], Table A6 includes the number of observations actually used, *Observations*, the F and the Wald statistics, *F* and *Wald*, to test the joint significance of the coefficients associated with the dependent and the explanatory variables, the Hansen statistic with the p-value in parentheses, *Hansen*, to test the validity of instruments, the first- and second-order autocorrelation coefficients of the residuals in first differences, *m1* and *m2* and the chow test, *Chow*, which tests the hypothesis that the coefficients of the two sub-samples are the same.⁶⁸

The results of the chow test reveal that we can find evidence of the presence of two convergence regimes according to the OLS and fixed-effects methods. This is consistent with the main findings in the empirical literature (Durlauf *et al.*, 2005). Our global convergence rates are close to those typically estimated in the academic literature and which generally lie between two and three per cent (Barro and Sala-i-Martin, 1992). We can also appreciate in Table A6 that OLS and fixed-effects estimates are biased in opposite directions as expected. Moreover, when dividing the sample according to the cut-off point in investment in physical capital, we find that the rate of convergence is higher for those countries with higher rates of investment and lower for the countries with lower rates of investment.

In Table A6, we can appreciate that the estimates of the convergence rate for the DIF-GMM method do not stand between OLS and fixed-effects estimates. As in the case of Castelli *et al.* (1996), this large sample prediction is not valid raising the question about the validity of the DIF-GMM method. The SYS-GMM method is likely to be more robust in the presence of highly persistence series. Indeed, the estimates of the convergence rate for the SYS-GMM method stand between OLS and fixed-effects estimates. Besides, we can see in Table A6 that there is compliance with the SYS-GMM assumptions. There is no second order serial autocorrelation. In addition, the Hansen test accepts the validity of the instruments.

In Table 2.11, we share the summary statistics above and below the median cut-off point in investment in physical capital for the variables that we use in our economic growth regressions. When comparing the two sub-samples we can appreciate that the ratio of renewable natural capital in national wealth is larger for countries with investment in physical capital below the median cut-off point than for countries with investment in physical capital above the median cut-off point. Otherwise, the most significant differences between the sub-samples with the investment values in physical capital above and below the median cut-off point are those associated with the initial income, fertility rate, openness, inflation, Sub-Saharan Africa, ethnic tensions and institutional endowments (KKZ96).

In Tables 2.12 and 2.13, we present the correlation matrix between the proximate theories' variables and the variables associated with the fundamental theories, whenever the level

⁶⁶ The fact that, given the opportunity to split the sample according to different neoclassical variables, the regression tree shows a preference for investment in physical capital splits suggests that investment in physical capital dominates the other variables in identifying multiple regimes in the data.

⁶⁷ Note that as the cut-off point for investment in physical capital gets closer from the median 3,10 to the CART value 2,75, there are larger differences between the rates of convergence in the sub-samples below and above the cut-off point.

⁶⁸ If DIF-GMM and SYS-GMM generate instruments that grow quadratically with T which can bias the estimates when the number of instruments is too large with respect to the number of observations. The weakness of specification tests is a particular concern for the SYS-GMM whose instruments are only valid under non-trivial assumptions. We should hence take a conservative p-value of the Hansen test (Roodman, 2009).

of correlation is above or equal to 0,40 for the sub-samples above and below the median cut-off point in investment in physical capital. The variables associated with four fundamental theories, religion, natural capital (renewable), fractionalisation and institutions, are strongly correlated with variables from all proximate theories except for the macroeconomic policy theory in the sub-samples both above and below the median cut-off point in investment in physical capital.

In particular, for the sub-sample above the median cut-off point in investment in physical capital, the amount of renewable natural capital is correlated with the demography proximate theory (fertility and life expectancy variables). For the sub-sample below the median cut-off point in investment in physical capital, the amount of renewable natural capital is correlated with neoclassical (population growth rates), demography (fertility), regional heterogeneity (Sub-Saharan Africa) proximate theories. Building on these results, in the section three we analyse whether the fundamental theories just mentioned (religion, renewable natural capital, fractionalisation and institutions) have some explanatory power in the economic growth regression, beyond the influence exerted through proximate theories' variables.

Table 2.7. Summary statistics

Designation	Variable	Obs.	Mean	Median	Std. Dev.	Min.	Max.
NEOCLASSICAL							
Growth rates of pc GDP	<i>growth_pc</i>	797	0,02	0,02	0,03	-0,11	0,12
Initial income	<i>income_in</i>	791	8,55	8,61	1,26	5,65	11,37
Population growth rates	<i>population</i>	830	-2,72	-2,73	0,19	-3,22	-1,56
Investment in phy. capital	<i>invest</i>	791	3,04	3,11	0,52	0,26	4,20
Schooling	<i>school</i>	830	3,21	3,40	0,78	-0,05	4,41
DEMOGRAPHY							
Life Expectancy	<i>life_exp</i>	827	0,02	0,01	0,08	0,01	2,54
Fertility rate	<i>fertility</i>	828	1,28	1,32	0,52	0,01	2,10
MACROECONOMIC POLICY							
Openess	<i>open</i>	793	0,62	0,51	0,45	0,04	4,20
Government consumption	<i>gov_consu</i>	808	0,09	0,08	0,06	0,00	0,41
Inflation	<i>inflation</i>	671	0,23	0,06	1,36	-0,01	24,14
REGIONAL HETEROGENEITY							
Latin America and Caribbean	<i>lac</i>	830	0,24	0,00	0,42	0,00	1,00
Sub-Saharan Africa	<i>ssa</i>	830	0,18	0,00	0,38	0,00	1,00
East Asia and the Pacific	<i>eac</i>	830	0,15	0,00	0,36	0,00	1,00
South-East Asia	<i>sea</i>	830	0,06	0,00	0,23	0,00	1,00
RELIGION							
Buddhism	<i>buddhism</i>	830	0,03	0,00	0,14	0,00	0,92
Catholic	<i>catholic</i>	830	0,36	0,17	0,37	0,00	0,99
Eastern Religion	<i>eastern</i>	830	0,02	0,00	0,07	0,00	0,46
Hindu	<i>hindu</i>	830	0,03	0,00	0,11	0,00	0,77
Jew	<i>jew</i>	830	0,01	0,00	0,09	0,00	0,85
Muslim	<i>muslim</i>	830	0,20	0,01	0,34	0,00	0,99
Orthodox	<i>orthodox</i>	830	0,02	0,00	0,10	0,00	0,94
Other	<i>other</i>	830	0,04	0,00	0,13	-0,42	0,58
Protestant	<i>protestant</i>	830	0,15	0,04	0,24	0,00	1,09
NATURAL CAPITAL							
Natural capital in wealth	<i>natural_w</i>	830	0,27	0,17	0,32	0,00	2,22
Nat. cap. in wealth (ren.)	<i>natural_w_r</i>	830	0,20	0,09	0,23	0,00	1,26
Nat. cap. in wealth (non-ren.)	<i>natural_w_nr</i>	830	0,06	0,01	0,19	0,00	2,21
Natural capital per capita	<i>natural_pc</i>	830	0,11	0,05	0,17	0,00	1,00
Nat. cap. per capita (ren.)	<i>natural_pc_r</i>	830	0,14	0,09	0,15	0,00	1,00

Nat. cap. per capita (non-natural_pc_nr ren.)		830	0,05	0,00	0,16	0,00	1,00
GEOGRAPHY							
Coastline	<i>coastline</i>	830	0,05	0,01	0,13	0,00	1,00
Landlocked	<i>landlock</i>	830	0,09	0,00	0,28	0,00	1,00
FRACTIONALISATION							
Language	<i>language</i>	810	0,34	0,33	0,29	0,00	0,92
Ethnic tensions	<i>ethnic</i>	820	0,42	0,42	0,26	0,00	0,93
INSTITUTIONS							
Liberal democracy	<i>democracy</i>	770	0,43	0,38	0,29	0,02	0,95
Public sector corruption	<i>corruption</i>	770	0,41	0,40	0,29	0,00	0,97
Legal formalism: Check (1)	<i>check(1)</i>	660	3,54	3,39	1,10	1,42	6,01
Legal formalism: Check (2)	<i>check(2)</i>	580	0,42	0,38	0,18	0,09	0,83
Complex	<i>complex</i>	710	0,56	0,53	0,15	0,29	0,86
KKZ96	<i>KKZ96</i>	830	0,28	0,08	0,90	-1,69	1,92
Executive constraints	<i>exe_constr</i>	770	4,73	5,00	2,22	0,80	7,00
OTHER							
Time dummy variables	<i>year_dummy</i>						
Colonial (Spain or Portugal)	<i>colonial</i>	790	0,19	0,00	0,39	0,00	1,00
English legal origin	<i>english</i>	830	0,44	0,00	0,49	0,00	1,00
French legal origin	<i>french</i>	790	0,08	0,00	0,28	0,00	1,00
Latitude	<i>latitude</i>	830	0,27	0,22	0,19	0,01	0,71
Mineral stocks	<i>minerals</i>	780	-6,31	-6,25	2,96	-14,51	0,26
System	<i>system</i>	820	0,89	0,55	0,89	0,00	2,00

Table 2.8. Correlation matrix between proximate and fundamental theories

Fundame. theories	Proximate theories										
	<i>popu.</i>	<i>invest</i>	<i>scho.</i>	<i>life.</i>	<i>fert.</i>	<i>open</i>	<i>gov_.</i>	<i>infl.</i>	<i>lac</i>	<i>ssa</i>	<i>sea</i>
RELIGION											
<i>catholic</i>	-0,16	-0,07	-0,00	0,05	-0,07	-0,09	-0,23	0,13	0,54	-0,22	-0,22
<i>hindu</i>	0,06	0,00	-0,06	-0,00	0,11	-0,09	0,14	-0,02	-0,10	-0,06	0,70
<i>muslim</i>	0,44	-0,11	-0,24	-0,01	0,35	0,21	0,03	-0,03	-0,23	0,07	0,17
<i>other</i>	0,41	-0,14	-0,28	-0,01	0,42	0,03	0,12	-0,01	-0,10	0,73	-0,00
NATURAL CAPITAL											
<i>natural_w</i>	0,53	-0,18	-0,34	-0,02	0,59	-0,03	0,17	0,06	0,13	0,48	0,19
<i>natural_w_r</i>	0,27	-0,23	-0,26	-0,01	0,50	0,01	0,38	0,03	0,06	0,40	0,09
FRACTIONALISATION											
<i>language</i>	0,43	-0,15	-0,20	-0,02	0,41	0,11	0,10	-0,03	-0,32	0,57	0,27
<i>ethnic</i>	0,60	-0,23	-0,30	-0,04	0,61	0,13	0,06	0,11	0,26	0,50	0,09
INSTITUTIONS											
<i>democracy</i>	-0,60	0,08	0,50	0,04	-0,72	-0,11	-0,08	-0,03	-0,22	-0,28	-0,08
<i>corruption</i>	0,55	-0,20	-0,42	-0,02	0,65	0,12	0,08	0,08	0,28	0,32	0,02
<i>check(1)</i>	0,11	-0,09	-0,22	-0,08	0,21	0,07	-0,01	0,13	0,50	-0,16	0,08
<i>check(2)</i>	0,11	-0,09	-0,23	-0,08	0,22	0,08	-0,02	0,13	0,50	-0,17	0,02
<i>KKZ96</i>	-0,63	0,24	0,45	0,03	-0,73	-0,06	-0,14	-0,11	-0,36	-0,38	-0,27
<i>exe_constr</i>	-0,48	0,04	0,47	0,00	-0,57	-0,09	-0,09	-0,00	-0,11	-0,24	0,04

Note: Values are only reported for those variables with a correlation above or equal to 0,40. The correlation matrix with all variables is available upon request to authors.

Table 2.9. Neoclassical variables for CART and median cut-off points

	<i>income_ini</i>	<i>population</i>	<i>invest</i>	<i>school</i>
CART cut-off point				
<i>invest</i> ≥ 2,75	8,82	-2,73	3,22	3,32
<i>invest</i> < 2,75	7,46	-2,64	2,25	2,70
Median cut-off point				
<i>invest</i> ≥ 3,10	8,86	-2,72	3,38	3,29
<i>invest</i> < 3,10	8,23	-2,71	2,66	3,11

Note: The table reports the mean values of the neoclassical variables (initial income, population growth rates, investment in physical capital and schooling) according to the CART and the median cut-off points in the investment in physical capital variable, *invest*. See Tables 2.5-2.6 for more details on data definitions and sources.

Table 2.10. Estimation results for the existence of multiple convergence clubs

	OLS	FE	DIF-GMM	SYS-GMM
Full sample				
λ	-0,002	-0,021	-0,071	-0,012
<i>Observations</i>	791	791	599	678
<i>F</i>	13,45***	4,14***		
<i>Wald</i>			63,89	4.537***
<i>Hansen</i>				32,99
<i>M1</i>			-3,54***	-3,97***
<i>M2</i>			-0,99	-1,69*
Sub-sample: <i>invest</i> ≥ 3,10				
λ	-0,006	-0,021	-0,098	-0,014
<i>Observations</i>	401	401	304	346
<i>F</i>	10,36***	4,60***		
<i>Wald</i>			48,10	2.234***
<i>Hansen</i>				51,45
<i>M1</i>			-2,85***	-3,97***
<i>M2</i>			-0,14	-0,49
Sub-sample: <i>invest</i> < 3,10				
λ	-0,000	-0,015	-0,070	-0,005
<i>Observations</i>	390	390	295	342
<i>F</i>	6,16***	2,72***		
<i>Wald</i>			65,64	8.548***
<i>Hansen</i>				29,85
<i>M1</i>			-2,57**	-3,48***
<i>M2</i>			-1,08	-1,27
Chow test	2,56**	17,34***	-	-

Note : The table reports mean values of the convergence rate, λ , according to four estimation methods (OLS, fixed-effects, DIF-GMM and SYS-GMM). We report the F and the Wald statistics, F and Wald, that test the joint significance of the coefficients associated with the dependent and the explanatory variables, the Hansen statistic with the p-value in parentheses, Hansen, that tests the validity of instruments, the first- and second-order autocorrelation coefficients of the residuals in first differences, m1 and m2, and the chow test, Chow, that tests the null hypothesis that the coefficients of the two sub-samples are the same and hence that there is only one convergence regime. ***/** stand for significance at the one and five per cent levels. In DIF-GMM, we use *french* in levels as additional instrument variable. In SYS-GMM, we use *colonial* and *french* in levels as instruments for the equation in first differences.

Table 2.11. Summary statistics according to the median cut-off point in investment in physical capital

Designation	Variable	<i>invest</i> ≥ 3,10		<i>invest</i> < 3,10	
		Obs.	Mean	Obs.	Mean
NEOCLASSICAL					
Growth rates of pc GDP	<i>growth_pc</i>	407	0,02	390	0,01
Initial income	<i>income_in</i>	401	8,86	390	8,23
Population growth rates	<i>population</i>	440	-2,72	390	-2,71
Investment in physical capital	<i>invest</i>	401	3,38	390	2,66
Schooling	<i>school</i>	440	3,29	390	3,11
DEMOGRAPHY					
Life Expectancy	<i>life_exp</i>	437	0,01	390	0,02
Fertility rate	<i>fertility</i>	438	1,20	390	1,36
MACROECONOMIC POLICY					
Openness	<i>open</i>	404	0,73	389	0,51
Government consumption	<i>gov_consu</i>	418	0,09	390	0,09
Inflation	<i>inflation</i>	353	0,08	318	0,38
REGIONAL HETEROGENEITY					
Latin America and Caribbean	<i>lac</i>	440	0,22	390	0,26
Sub-Saharan Africa	<i>ssa</i>	440	0,11	390	0,25
South-East Asia	<i>sea</i>	440	0,05	390	0,07
RELIGION					
Buddhism	<i>buddhism</i>	440	0,05	390	0,01
Catholic	<i>catholic</i>	440	0,35	390	0,36
Eastern Religion	<i>eastern</i>	440	0,03	390	0,01
Hindu	<i>hindu</i>	440	0,03	390	0,04
Jew	<i>jew</i>	440	0,01	390	0,01
Muslim	<i>muslim</i>	440	0,20	390	0,20
Orthodox	<i>orthodox</i>	440	0,02	390	0,01
Other	<i>other</i>	440	0,01	390	0,06
Protestant	<i>protestant</i>	440	0,14	390	0,15
NATURAL CAPITAL					
Natural capital in wealth	<i>natural_w</i>	440	0,14	390	0,28
Natural capital in wealth (ren.)	<i>natural_w_r</i>	440	0,16	390	0,23
Natural capital in wealth (non-ren.)	<i>natural_w_nr</i>	440	0,08	390	0,04
Natural capital per capita	<i>natural_pc</i>	440	0,12	390	0,08
Natural capital per capita (ren.)	<i>natural_pc_r</i>	440	0,15	390	0,13
Natural capital per capita (non-ren.)	<i>natural_pc_nr</i>	440	0,06	390	0,03
GEOGRAPHY					
Coastline	<i>coastline</i>	440	0,04	390	0,11
FRACTIONALISATION					
Language	<i>language</i>	429	0,31	381	0,38
Ethnic tensions	<i>ethnic</i>	430	0,37	390	0,46
INSTITUTIONS					
Liberal democracy	<i>democracy</i>	376	0,41	364	0,46
Public sector corruption	<i>corruption</i>	376	0,43	364	0,42
Legal formalism: Check (1)	<i>check(1)</i>	301	0,42	279	0,42
Legal formalism: Check (2)	<i>check(2)</i>	348	3,50	312	3,57
Complex	<i>complex</i>	357	0,56	353	0,55

KKZ96	<i>KKZ96</i>	440	0,44	390	0,11
Executive constraints	<i>exe_constr</i>	401	4,73	369	4,72
OTHER					
Time dummy variables	<i>year_dummy</i>				
Colonial (Spain or Portugal)	<i>colonial</i>	412	0,15	378	0,22
English legal origin	<i>english</i>	440	0,42	390	0,46
French legal origin	<i>french</i>	412	0,08	378	0,09
Latitude	<i>latitude</i>	440	0,29	390	0,26
Mineral stocks	<i>minerals</i>	404	-6,09	376	-6,54
System	<i>system</i>	431	1,02	389	0,75

Table 2.12. Correlation matrix between proximate and fundamental theories for countries above the median cut-off point in investment in physical capital

Fundamen . theories	Proximate theories										
	<i>popu.</i>	<i>invest</i>	<i>scho.</i>	<i>life.</i>	<i>fert.</i>	<i>open</i>	<i>gov_.</i>	<i>infl.</i>	<i>lac</i>	<i>ssa</i>	<i>sea</i>
RELIGION											
<i>buddhism</i>	-0,14	0,22	-0,04	0,00	-0,02	0,04	-0,04	-0,10	-0,16	-0,09	0,41
<i>hindu</i>	0,08	-0,01	0,08	0,09	0,09	0,04	0,12	-0,02	-0,08	-0,03	0,75
<i>muslim</i>	0,51	0,34	-0,05	0,14	0,31	0,43	0,00	-0,04	-0,18	0,08	-0,02
<i>other</i>	0,32	0,15	-0,20	0,58	0,36	0,14	0,19	0,09	-0,00	0,72	0,00
NATURAL CAPITAL											
<i>natural_w</i>	0,42	0,25	-0,38	0,62	0,52	0,05	0,16	0,19	0,26	0,38	0,08
<i>natural_w_r</i>	0,10	0,06	-0,17	0,45	0,44	0,04	0,38	0,13	0,20	0,25	0,04
FRACTIONALISATION											
<i>language</i>	0,34	-0,03	-0,15	0,43	0,35	0,21	0,01	-0,02	-0,22	0,44	0,18
<i>ethnic</i>	0,54	0,18	-0,32	0,55	0,57	0,35	0,06	0,21	0,32	0,40	0,05
INSTITUTIONS											
<i>democracy</i>	-0,59	-0,34	0,43	-0,60	-0,69	-0,20	-0,15	-0,23	-0,25	-0,26	-0,04
<i>corruption</i>	0,42	0,20	-0,37	0,50	0,52	0,16	0,11	0,22	0,29	0,20	-0,00
<i>check(2)</i>	0,08	-0,03	-0,22	0,08	0,15	-0,05	0,01	0,13	0,40	-0,17	0,07
<i>KKZ96</i>	-0,57	-0,21	0,35	-0,64	-0,66	-0,16	-0,27	-0,31	-0,43	-0,32	-0,26
<i>exe_constr</i>	-0,50	-0,38	0,46	-0,51	-0,58	-0,13	-0,11	-0,22	-0,16	-0,16	0,07

Note: Values are only reported for those variables with a correlation above or equal to 0,40. The correlation matrix with all variables is available upon request to authors.

Table 2.13. Correlation matrix between proximate and fundamental theories for countries below the median cut-off point in investment in physical capital

Fundamen . theories	Proximate theories										
	<i>popu.</i>	<i>invest</i>	<i>scho.</i>	<i>life.</i>	<i>fert.</i>	<i>open</i>	<i>gov_.</i>	<i>infl.</i>	<i>lac</i>	<i>ssa</i>	<i>sea</i>
RELIGION											
<i>catholic</i>	-0,18	0,05	0,07	0,07	-0,11	-0,01	-0,24	0,19	0,71	-0,29	-0,28
<i>hindu</i>	0,04	0,13	-0,12	-0,01	0,11	-0,20	0,16	-0,03	-0,12	-0,08	0,69
<i>other</i>	0,48	-0,26	-0,32	-0,03	0,46	-0,02	0,09	-0,03	-0,16	0,74	-0,01
<i>protestant</i>	-0,41	0,20	0,37	-0,04	-0,45	0,04	0,04	-0,09	-0,29	-0,05	-0,18
NATURAL CAPITAL											
<i>natural_w</i>	0,60	-0,30	-0,29	-0,05	0,62	-0,05	0,18	0,05	0,00	0,53	0,25
<i>natural_w_r</i>	0,41	-0,30	-0,29	-0,04	0,53	0,09	0,37	0,01	-0,08	0,49	0,11
FRACTIONALISATION											
<i>language</i>	0,49	-0,13	-0,21	-0,04	0,44	0,06	0,17	-0,06	-0,42	0,64	0,33
<i>ethnic</i>	0,61	-0,31	-0,26	-0,08	0,61	-0,02	0,04	0,11	0,18	0,56	0,09
INSTITUTIONS											
<i>democracy</i>	-0,62	0,39	0,56	0,07	-0,77	-0,03	0,00	-0,02	-0,19	-0,29	-0,11
<i>corruption</i>	0,65	-0,41	-0,45	-0,05	0,70	0,16	0,04	0,07	0,25	0,38	0,03
<i>check(1)</i>	0,13	-0,21	-0,23	-0,01	0,26	0,26	-0,06	0,17	0,58	-0,17	0,01
<i>check(2)</i>	0,13	-0,19	-0,21	-0,01	0,26	0,24	-0,04	0,16	0,58	-0,16	0,08
<i>KKZ96</i>	-0,67	0,40	0,51	0,06	-0,77	-0,03	-0,01	-0,11	-0,29	-0,40	0,27
<i>exe_constr</i>	-0,47	0,36	0,48	0,01	-0,58	-0,07	-0,08	0,02	-0,06	-0,31	0,03

Note: Values are only reported for those variables with a correlation above or equal to 0,40. The correlation matrix with all variables is available upon request to authors.

Results

These tables provide results for the growth regression exercise in equation [1] of the text under BMA specification and model uncertainty. The dependent variable is the average growth rate of real per capita GDP corresponding to the periods 1960-64, 1965-69, 1970-74, 1975-79, 1980-84, 1985-89, 1990-94, 1995-99, 2000-04 and 2005-2009. Following Durlauf *et al.* (2008a), we instrument for endogenous variables using earlier or initial values if available with the exception of inflation, religion shares and natural capital under the Two-Stage Least Squares (2SLS) estimation (without uncertainty). For inflation we use as instruments the colonial dummy for Spain or Portugal and British and French legal origins and for religion shares we use the corresponding shares in 1900. Following van der Ploeg and Poelhekke (2010), we use a dummy for presidential system and mineral resource stocks as an instrument for natural capital variables. 2SLS regression results are very similar to the BMA estimation results with uncertainty, results are available upon request. Please refer to the data appendix for details on the variables used.

Table 2.14. BMA estimation results for average growth rates of pc GDP: Full sample

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probability y (#)	Posterior mean	Posterior standard deviation	Posterior inclusion probability y (#)	Posterior mean	Posterior standard deviation
NEOCLASSICAL						
<i>income_in</i>		-0,051*	0,008		-0,014*	0,006
<i>population</i>		-0,016	0,050			
<i>invest</i>		0,018	0,012			
<i>school</i>		-0,012	0,010			
DEMOGRAPHY	1,000					
<i>life_exp</i>		-0,006	0,024			
<i>fertility</i>		-0,159*	0,025			
MACROECONOMIC POLICY	0,028					
<i>open</i>		-0,000	0,001			
<i>gov_cons</i>		-0,000	0,013			
<i>inflation</i>		-0,001	0,000			
REGIONAL HETEROGENEITY	0,085					
<i>lac</i>		0,000	0,001			
<i>ssa</i>		-0,002	0,010			
<i>sea</i>		0,000	0,002			
RELIGION	0,981			1,000		
<i>eastern</i>		0,288*	0,076		0,433*	0,062
<i>hindu</i>		0,001	0,012		0,017	0,039
<i>muslim</i>		0,000	0,004		-0,001	0,007
<i>other</i>		0,001	0,013		0,000	0,011
<i>protestant</i>		-0,003	0,012		-0,003	0,012
NATURAL CAPITAL	0,250			0,227		
<i>natural_w</i>		-0,006	0,018		-0,012	0,026
<i>natural_pc</i>		0,000	0,000		0,000	0,000
GEOGRAPHY	0,056			0,035		
<i>coastline</i>		-0,000	0,004		0,000	0,005
<i>landlocked</i>		-0,001	0,006		-0,000	0,003
FRACTIONALISATION	0,056			0,964		
<i>language</i>		-0,001	0,006		-0,002	0,010
<i>ethnic</i>		-0,000	0,004		-0,089*	0,031
INSTITUTIONS	1,000			1,000		
<i>KKZ96</i>		-0,000	0,002		0,000	0,003
<i>exe_constr</i>		-0,006*	0,003		0,000	0,003
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		640			640	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 2.15. BMA estimation results for average growth rates of pc GDP: *invest* $\geq 3,10$

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probability (#)	Posterior mean	Posterior standard deviation	Posterior inclusion probability (#)	Posterior mean	Posterior standard deviation
NEOCLASSICAL						
<i>income_in</i>		-0,073*	0,010		-0,032*	0,009
<i>population</i>		0,044	0,063			
<i>invest</i>		-0,053	0,033			
<i>school</i>		-0,014	0,015			
DEMOGRAPHY	1,000					
<i>life_exp</i>		0,116	1,485			
<i>fertility</i>		-0,199*	0,031			
MACROECONOMIC POLICY	0,973					
<i>open</i>		-0,001	0,006			
<i>gov_consu</i>		-0,007	0,052			
<i>inflation</i>		-0,303*	0,092			
REGIONAL HETEROGENEITY	0,002					
<i>lac</i>		0,000	0,002			
<i>ssa</i>		-0,000	0,003			
<i>sea</i>		-0,000	0,004			
RELIGION	0,980			1,000		
<i>eastern</i>		0,302*	0,083		0,433*	0,069
<i>hindu</i>		0,037	0,067		0,129	0,102
<i>muslim</i>		-0,000	0,007		-0,008	0,021
<i>other</i>		0,003	0,025		-0,000	0,021
<i>protestant</i>		-0,000	0,008		-0,000	0,007
NATURAL CAPITAL	0,170			0,084		
<i>natural_w</i>		-0,002	0,014		-0,003	0,016
<i>natural_pc</i>		0,000	0,000		0,000	0,000
GEOGRAPHY	0,078			0,037		
<i>coastline</i>		-0,000	0,010		0,000	0,003
<i>landlocked</i>		-0,002	0,010		0,000	0,003
FRACTIONALISATION	0,092			0,992		
<i>language</i>		-0,002	0,012		-0,000	0,009
<i>ethnic</i>		-0,001	0,008		-0,138*	0,036
INSTITUTIONS	1,000			0,999		
<i>KKZ96</i>		-0,000	0,004		0,000	0,004
<i>exe_constr</i>		-0,006	0,004		0,001	0,004
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		338			338	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 2.16. BMA estimation results for average growth rates of pc GDP: *invest* < 3,10

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probability (#)	Posterior mean	Posterior standard deviation	Posterior inclusion probability (#)	Posterior mean	Posterior standard deviation
NEOCLASSICAL						
<i>income_in</i>		0,000	0,012		0,009	0,008
<i>population</i>		-0,151*	0,075			
<i>invest</i>		0,037	0,022			
<i>school</i>		-0,019	0,014			
DEMOGRAPHY	0,161					
<i>life_exp</i>		-0,001	0,011			
<i>fertility</i>		-0,011	0,032			
MACROECONOMIC POLICY	0,041					
<i>open</i>		-0,000	0,002			
<i>gov_consu</i>		-0,000	0,016			
<i>inflation</i>		-0,000	0,001			
REGIONAL HETEROGENEITY	0,384					
<i>lac</i>		-0,000	0,003			
<i>ssa</i>		-0,024	0,036			
<i>sea</i>		0,001	0,008			
RELIGION	0,241			0,116		
<i>eastern</i>		0,017	0,085		0,026	0,111
<i>hindu</i>		0,000	0,007		0,001	0,013
<i>muslim</i>		0,002	0,011		0,000	0,003
<i>other</i>		0,019	0,062		0,000	0,006
<i>protestant</i>		-0,010	0,030		-0,005	0,021
NATURAL CAPITAL	0,096			0,341		
<i>natural_w</i>		-0,003	0,014		-0,023	0,036
<i>natural_pc</i>		0,000	0,000		0,000	0,000
GEOGRAPHY	0,065			0,088		
<i>coastline</i>		0,000	0,006		0,000	0,006
<i>landlocked</i>		-0,001	0,008		-0,002	0,001
FRACTIONALISATION	0,052			0,083		
<i>language</i>		0,000	0,007		-0,000	0,006
<i>ethnic</i>		0,000	0,006		-0,002	0,012
INSTITUTIONS	0,999			1,000		
<i>KKZ96</i>		-0,001	0,006		0,000	0,003
<i>exe_constr</i>		-0,007	0,004		-0,004	0,004
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		308			308	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 2.17. BMA estimation results for average growth rates of pc GDP: Full sample (renewable natural capital)

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probability (#)	Posterior mean	Posterior standard deviation	Posterior inclusion probability (#)	Posterior mean	Posterior standard deviation
NEOCLASSICAL						
<i>income_in</i>		-0,051*	0,008		-0,018*	0,008
<i>population</i>		-0,017	0,049			
<i>invest</i>		0,017	0,012			
<i>school</i>		-0,003	0,010			
DEMOGRAPHY	1,000					
<i>life_exp</i>		-0,007	0,025			
<i>fertility</i>		-0,162*	0,025			
MACROECONOMIC POLICY	0,024					
<i>open</i>		-0,000	0,001			
<i>gov_consu</i>		-0,000	0,010			
<i>inflation</i>		-0,001	0,000			
REGIONAL HETEROGENEITY	0,053					
<i>lac</i>		0,000	0,001			
<i>ssa</i>		-0,001	0,006			
<i>sea</i>		0,000	0,002			
RELIGION	0,943			1,000		
<i>eastern</i>		0,258*	0,089		0,416*	0,063
<i>hindu</i>		0,002	0,013		0,025	0,047
<i>muslim</i>		0,000	0,005		-0,004	0,013
<i>other</i>		0,002	0,015		0,001	0,012
<i>protestant</i>		-0,001	0,008		-0,002	0,010
NATURAL CAPITAL	0,169			0,605		
<i>natural_w_r</i>		-0,015	0,038		-0,082	0,075
<i>natural_pc_r</i>		0,000	0,000		0,000	0,000
GEOGRAPHY	0,074			0,034		
<i>coastline</i>		-0,000	0,004		0,000	0,005
<i>landlocked</i>		-0,001	0,008		-0,000	0,003
FRACTIONALISATION	0,043			0,984		
<i>language</i>		-0,000	0,004		-0,004	0,015
<i>ethnic</i>		-0,000	0,003		-0,084*	0,031
INSTITUTIONS	1,000			1,000		
<i>KKZ96</i>		-0,000	0,004		0,000	0,002
<i>exe_constr</i>		-0,008*	0,003		-0,000	0,003
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		640			640	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 2.18. BMA estimation results for average growth rates of pc GDP: *invest* $\geq$ 3,10 (renewable natural capital)

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probability	Posterior mean	Posterior standard deviation	Posterior inclusion probability	Posterior mean	Posterior standard deviation
	y (#)			y (#)		
NEOCLASSICAL						
<i>income_in</i>		-0,071*	0,010		-0,036*	0,011
<i>population</i>		0,041	0,063			
<i>invest</i>		-0,058	0,032			
<i>school</i>		-0,007	0,015			
DEMOGRAPHY	1,000					
<i>life_exp</i>		0,197	1,621			
<i>fertility</i>		-0,197*	0,031			
MACROECONOMIC POLICY	0,924					
<i>open</i>		-0,000	0,005			
<i>gov_cons</i>		-0,005	0,049			
<i>inflation</i>		-0,275*	0,111			
REGIONAL HETEROGENEITY	0,029					
<i>lac</i>		0,000	0,002			
<i>ssa</i>		-0,000	0,003			
<i>sea</i>		-0,000	0,006			
RELIGION	0,971			1,000		
<i>eastern</i>		0,290*	0,087		0,423*	0,071
<i>hindu</i>		0,060	0,086		0,186	0,104
<i>muslim</i>		-0,001	0,008		-0,017	0,031
<i>other</i>		0,008	0,037		0,003	0,025
<i>protestant</i>		0,000	0,006		-0,001	0,008
NATURAL CAPITAL	0,165			0,378		
<i>natural_w_b</i>		-0,021	0,059		-0,073	0,113
<i>natural_pc_b</i>		0,000	0,000		0,000	0,000
GEOGRAPHY	0,094			0,039		
<i>coastline</i>		0,001	0,014		0,000	0,003
<i>landlocked</i>		-0,003	0,012		0,000	0,014
FRACTIONALISATION	0,076			0,984		
<i>language</i>		-0,002	0,010		-0,001	0,012
<i>ethnic</i>		-0,000	0,007		-0,129*	0,039
INSTITUTIONS	1,000			0,999		
<i>KKZ96</i>		-0,001	0,005		0,000	0,003
<i>exe_constr</i>		-0,008	0,004		-0,001	0,005
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		338			338	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 2.19. BMA estimation results for average growth rates of pc GDP: *invest* < 3,10 (renewable natural capital)

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probability (#)	Posterior mean	Posterior standard deviation	Posterior inclusion probability (#)	Posterior mean	Posterior standard deviation
NEOCLASSICAL						
<i>income_in</i>		-0,006	0,013		0,003	0,009
<i>population</i>		-0,154*	0,086			
<i>invest</i>		0,035	0,022			
<i>school</i>		-0,010	0,014			
DEMOGRAPHY	0,286					
<i>life_exp</i>		-0,002	0,014			
<i>fertility</i>		-0,027	0,051			
MACROECONOMIC POLICY	0,042					
<i>open</i>		-0,000	0,002			
<i>gov_cons</i>		0,001	0,027			
<i>inflation</i>		-0,000	0,000			
REGIONAL HETEROGENEITY	0,218					
<i>lac</i>		0,000	0,003			
<i>ssa</i>		-0,011	0,027			
<i>sea</i>		0,000	0,007			
RELIGION	0,167			0,004		
<i>eastern</i>		0,065	0,050		0,007	0,058
<i>hindu</i>		0,000	0,006		0,000	0,008
<i>muslim</i>		0,024	0,011		0,000	0,021
<i>other</i>		0,012	0,050		0,000	0,005
<i>protestant</i>		-0,007	0,024		-0,001	0,012
NATURAL CAPITAL	0,220			0,524		
<i>natural_w_r</i>		-0,024	0,055		0,076	0,058
<i>natural_pc_r</i>		-0,000	0,000		-0,000	0,000
GEOGRAPHY	0,050			0,057		
<i>coastline</i>		0,000	0,006		-0,001	0,007
<i>landlocked</i>		-0,000	0,006		0,002	0,006
FRACTIONALISATION	0,045			0,089		
<i>language</i>		0,000	0,005		-0,000	0,007
<i>ethnic</i>		0,000	0,005		-0,002	0,012
INSTITUTIONS	0,999			1,000		
<i>KKZ96</i>		-0,005	0,013		0,000	0,003
<i>exe_constr</i>		-0,007	0,004		-0,002	0,004
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		308			308	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 2.20. BMA estimation results for average growth rates of pc GDP: Full sample (non-renewable natural capital)

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probability (#)	Posterior mean	Posterior standard deviation	Posterior inclusion probability (#)	Posterior mean	Posterior standard deviation
NEOCLASSICAL						
<i>income_in</i>		-0,052*	0,008		-0,012*	0,005
<i>population</i>		-0,022	0,050			
<i>invest</i>		0,017	0,012			
<i>school</i>		-0,003	0,010			
DEMOGRAPHY	1,000					
<i>life_exp</i>		-0,007	0,025			
<i>fertility</i>		-0,164*	0,025			
MACROECONOMIC POLICY	0,024					
<i>open</i>		-0,000	0,001			
<i>gov_consu</i>		-0,000	0,009			
<i>inflation</i>		-0,000	0,000			
REGIONAL HETEROGENEITY	0,049					
<i>lac</i>		0,000	0,001			
<i>ssa</i>		-0,001	0,006			
<i>sea</i>		0,000	0,002			
RELIGION	0,958			1,000		
<i>eastern</i>		0,266*	0,084		0,432*	0,062
<i>hindu</i>		0,001	0,012		0,021	0,043
<i>muslim</i>		0,000	0,005		-0,001	0,006
<i>other</i>		0,002	0,015		0,001	0,013
<i>protestant</i>		-0,003	0,011		-0,003	0,013
NATURAL CAPITAL	0,277			0,059		
<i>natural_w_nr</i>		-0,000	0,006		-0,001	0,009
<i>natural_pc_nr</i>		0,000	0,000		0,000	0,000
GEOGRAPHY	0,074			0,036		
<i>coastline</i>		-0,000	0,004		0,000	0,005
<i>landlocked</i>		-0,001	0,008		-0,000	0,003
FRACTIONALISATION	0,044			0,993		
<i>language</i>		-0,000	0,004		-0,001	0,009
<i>ethnic</i>		-0,000	0,004		-0,093*	0,025
INSTITUTIONS	1,000			1,000		
<i>KKZ96</i>		-0,000	0,003		0,000	0,003
<i>exe_constr</i>		-0,007*	0,003		-0,000	0,003
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		640			640	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 2.21. BMA estimation results for average growth rates of pc GDP: $invest \geq 3,10$ (non-renewable natural capital)

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probability y (#)	Posterior mean	Posterior standard deviation	Posterior inclusion probability y (#)	Posterior mean	Posterior standard deviation
NEOCLASSICAL						
<i>income_in</i>		-0,071*	0,010		-0,031*	0,008
<i>population</i>		0,043	0,063			
<i>invest</i>		-0,059	0,032			
<i>school</i>		-0,007	0,015			
DEMOGRAPHY	1,000					
<i>life_exp</i>		0,155	1,513			
<i>fertility</i>		-0,195*	0,031			
MACROECONOMIC POLICY	0,925					
<i>open</i>		-0,001	0,006			
<i>gov_consu</i>		-0,007	0,050			
<i>inflation</i>		-0,275*	0,110			
REGIONAL HETEROGENEITY	0,027					
<i>lac</i>		-0,000	0,002			
<i>ssa</i>		-0,000	0,003			
<i>sea</i>		-0,000	0,004			
RELIGION	0,976			1,000		
<i>eastern</i>		0,294*	0,084		0,428*	0,068
<i>hindu</i>		0,051	0,080		0,169	0,106
<i>muslim</i>		-0,001	0,008		-0,008	0,021
<i>other</i>		0,007	0,034		0,002	0,023
<i>protestant</i>		-0,000	0,006		-0,000	0,007
NATURAL CAPITAL	0,153			0,038		
<i>natural_w_nr</i>		0,004	0,020		0,000	0,007
<i>natural_pc_nr</i>		0,000	0,000		0,000	0,000
GEOGRAPHY	0,093			0,038		
<i>coastline</i>		0,000	0,014		0,000	0,014
<i>landlocked</i>		-0,002	0,012		0,000	0,003
FRACTIONALISATION	0,077			0,993		
<i>language</i>		-0,002	0,010		-0,000	0,009
<i>ethnic</i>		-0,001	0,007		-0,136*	0,036
INSTITUTIONS	1,000			0,999		
<i>KKZ96</i>		-0,001	0,004		0,000	0,004
<i>exe_constr</i>		-0,008*	0,004		-0,001	0,004
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		338			338	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 2.22. BMA estimation results for average growth rates of pc GDP: *invest* < 3,10 (non-renewable natural capital)

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probability	Posterior mean	Posterior standard deviation	Posterior inclusion probability	Posterior mean	Posterior standard deviation
	y (#)			y (#)		
NEOCLASSICAL						
<i>income_in</i>		-0,005	0,013		0,010	0,007
<i>population</i>		-0,154*	0,090			
<i>invest</i>		0,037	0,022			
<i>school</i>		-0,010	0,014			
DEMOGRAPHY	0,317					
<i>life_exp</i>		-0,002	0,015			
<i>fertility</i>		-0,031	0,053			
MACROECONOMIC POLICY	0,039					
<i>open</i>		-0,000	0,002			
<i>gov_consu</i>		0,000	0,017			
<i>inflation</i>		-0,000	0,001			
REGIONAL HETEROGENEITY	0,190					
<i>lac</i>		0,000	0,003			
<i>ssa</i>		-0,009	0,025			
<i>sea</i>		0,000	0,007			
RELIGION	0,181			0,007		
<i>eastern</i>		0,007	0,053		0,012	0,974
<i>hindu</i>		0,000	0,006		0,001	0,009
<i>muslim</i>		0,002	0,012		0,000	0,003
<i>other</i>		0,012	0,050		0,000	0,006
<i>protestant</i>		-0,008	0,026		-0,003	0,016
NATURAL CAPITAL	0,079			0,124		
<i>natural_w_nr</i>		-0,001	0,010		-0,006	0,022
<i>natural_pc_nr</i>		0,000	0,000		0,000	0,000
GEOGRAPHY	0,051			0,068		
<i>coastline</i>		0,000	0,006		0,000	0,006
<i>landlocked</i>		-0,000	0,006		-0,002	0,009
FRACTIONALISATION	0,044			0,095		
<i>language</i>		0,000	0,005		-0,000	0,006
<i>ethnic</i>		-0,000	0,006		0,003	0,014
INSTITUTIONS	0,999			0,999		
<i>KKZ96</i>		-0,005	0,014		0,000	0,003
<i>exe_constr</i>		-0,007	0,004		-0,003	0,004
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		308			308	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

3. COASTAL BLUE CARBON – WHAT SCOPE FOR CLIMATE CHANGE MITIGATION PROJECTS CURRENTLY?

3.1. What is the real scope for coastal blue carbon in climate change mitigation?

The ocean and coasts represent the largest carbon sink on Earth, removing approximately 2 Gton CO₂ per year, about a quarter of anthropogenic emissions (Duarte, 2014).⁶⁹ They remove over half of all the biological carbon captured in the world. In relative terms, once deforestation is taken into account, the net land carbon uptake is smaller than that of the ocean and coasts. The term “blue carbon” was then recently coined to refer to the potential of the ocean and coasts ecosystems carbon to mitigate climate change. The most relevant coastal ecosystems for climate change mitigation, the so-called “coastal blue carbon”, are mainly mangroves, seagrass meadows and tidal-marshes (Nellemann *et al.*, 2009).⁷⁰

The ocean is a natural carbon sink, that contains 50 times more carbon than the atmosphere, and that is exchanging large amounts of CO₂ with the atmosphere every year (Bopp *et al.*, 2015). In the past decades, the ocean has slowed down the rate of climate change by absorbing about 30 per cent of anthropogenic emissions (Sabine *et al.*, 2004). Thus, the ocean plays a crucial role in climate change mitigation, as well as in climate regulation. It is the largest carbon reservoir on Earth, way beyond coasts.

The absorption of anthropogenic CO₂ by the ocean is the result of physical-chemical processes and marine biology through the co-called solubility and biological pumps (McLeod *et al.*, 2011). The solubility pump is related to the CO₂ solubility in seawater and the thermal stratification of the ocean. Cold and deep water are generally rich in dissolved inorganic carbon. The biological pump refers to the ability of plankton for up taking CO₂ from the surface waters through photosynthesis. A portion of the biomass produced is transferred through this process to the deep ocean.

Changes in any of these physical, chemical and biological processes may increase or decrease the rate of climate change, although knowledge of such interconnections is limited, and the precautionary principle generally prevails.⁷¹ Furthermore, even though the ocean plays a key role as a major carbon sink, its integration within climate change discussions remains weak (Ocean and climate, 2015). Among the 18 regional sea conventions, only the Barcelona Convention for the Mediterranean Sea integrates the climate change dimension. There is no framework structure for intergovernmental cooperation on ocean governance.⁷² The ocean has

⁶⁹ I would like to thank Adrien Comte, Ophélie Darses, François Henry, Yann Kervinio, Daniela Miteva, Linwood Pendleton, Diane Vaschalde and Tibor Vegh for insightful thoughts and suggestions as well as participants at the seminar on ‘Coastal blue carbon: What scope for mitigation projects currently?’, organised by the French Ministry of Foreign Affairs and International Development and *l’Unité Mixte de Recherche Aménagement des Usages des Ressources et des Espaces marins et littoraux, Centre de droit et d’économie de la mer*, on the 8th June 2015 in Paris. This work has been submitted on the 26th October 2016 to *Région et Développement* for a special issue on environmental economics. It has a ranking 4 according to the *Centre National de Recherche Scientifique* (CNRS) 2016 classification and a ranking C according to the *Agence d’Evaluation de la Recherche et de l’Enseignement Supérieur* (AERES) 2012 classification.

⁷⁰ Macroalgae are also included in coastal blue carbon but so far have received less attention from policy makers and researchers.

⁷¹ For example, primary productivity of phytoplankton could be stimulated by adding nutrients such as iron to surface waters. There is currently no consensus on the efficiency of such methods, which are limited to a few field experiments (Bopp *et al.*, 2015).

⁷² The UN Convention on the Law of the Sea (UNCLOS) is not a decision-making body but an open-ended informal consultative process.

only recently been given some attention in negotiations under the United Nations Framework Convention on Climate Change (UNFCCC).

Besides, only carbon buried in marine and coastal sediments can be considered long-term marine carbon storage. The long-term residence of the bulk of anthropogenic CO₂ in the ocean is uncertain, as this carbon does not penetrate deep enough to remain in the ocean over extended time scales (McLeod *et al.*, 2011). In contrast, coastal blue carbon is typically stored for thousands of years in sediments. In addition, coastal blue carbon supports intense carbon burial rates, while the bulk of the carbon stored in the ocean is in intermediate and in deep layers (Duarte *et al.*, 2005).

Moreover, changes in physical, chemical and biological processes may impact carbon storage in the ocean in the long-term. In contrast, short-term and medium-term effects on carbon storage are possible when acting at the local and regional levels to maintain and restore coastal blue carbon.⁷³ In sum, because of the high complexity of the ocean ecosystems, the absence of intergovernmental cooperation on the governance of high seas, the long-term carbon-intensive storage capacity in coasts, and the ability to obtain results in the short and medium-term when intervening on coasts, the remainder of the document focuses only on coastal blue carbon.

Nevertheless, uncertainties in the land use conversion rates and in the fate of ecosystem carbon upon conversion and few historical and present data on coastal blue carbon ecosystems may certainly reduce the attractiveness of coastal ecosystems for financial markets in the short-term (Crooks *et al.*, 2011). For mangroves and tidal-marshes, there is some evidence that a large percentage of the carbon in the biomass and sediments comes from the atmosphere and is returned to the atmosphere. And yet, is the total carbon stored both in mangroves and tidal-marshes large enough to be meaningful as a mitigation tool against climate change? Do we have enough information on mangroves and tidal-marshes distribution and evolution to derive policy options for conservation and restoration?

Beyond being scientifically-backed and identifying a meaningful scale to apply mitigation policies, political support and adequate institutional design are essential for coastal blue carbon projects to develop successfully. On the political stance, there are prominent challenges to implement climate change mitigation programs in the ocean and coastal areas and, more broadly, to develop programs on ocean and coastal governance. Certain emerging and OECD countries and developing nations in Africa and among the Small Island Developing States (SIDS) consider the ocean and coastal zones as areas for economic development. In such terms, attempts to progress on international regulation for the protection of the ocean and coasts can be rejected by some advanced countries and accepted by African and SIDS countries to the extent that their economic development based upon maritime activities is preserved.

In terms of the institutional design, few market-oriented and incentive schemes have been developed for marine resources for the time being. Indeed, in many marine ecosystems, there are fuzzy property rights, difficulties in assessing the scale of service obtained and risks of elite capture (Mohammed, 2014). Inequitable benefit distribution and difficulties in identifying sustainable financing mechanisms have also hampered the ability to use these mechanisms (Mohammed, 2011). Since recently though, there is growing interest on the design of market mechanisms as means to protect the coasts by generating revenue, and some of these mechanisms can be applied to coastal blue carbon.

Given the scientific body of knowledge, the scope for scaling-up projects for significant mitigation policies, the political support and the role of institutions, we explore whether and how coastal blue carbon schemes can be developed. We focus on the extent to which these schemes are relevant alternative tools for climate change mitigation. We seek to develop a country-taxonomy and to identify factors that should be considered to complement such

⁷³ Besides, coastal blue carbon plays an important role not only for climate change mitigation, but also for climate change adaptation through the protection against coastal erosion and extreme climate events.

taxonomy. Such analysis could be helpful to guide policy decisions to prioritise investments. Overall, this analysis is not about whether coastal blue carbon protection can provide economic incentives strong enough to substantially curtail habitat loss rates and contribute to conservation, but whether it has a significant and operational role in the short-term for climate change mitigation in some countries.

The remainder of this chapter is organised as follows. In the second section, we analyse whether we have sufficient scientific knowledge and data available to derive policy implications on the role of coastal blue carbon in climate change mitigation. In section three, we explore whether coastal blue carbon can play a significant role among overall climate change mitigation needs. In section four, we look at coastal blue carbon conservation and restoration to derive which actions are more likely to be effective for climate change mitigation. In section five, we put forward some mechanisms that can finance coastal blue carbon projects and in section six, we focus on climate change adaptation programs as a source of funding for coastal blue carbon. In section seven, we analyse the extent to which information is available on governance and socio-economic factors for coastal blue carbon projects. Finally, in section eight, we conclude and in the appendix, we provide some country data and some details on alternative statistics when coastal-specific data is missing.

3.2. Mangroves: Ecosystem with sufficient scientific knowledge and data

There are still large sources of uncertainty in the rates of land use conversion and the fates of ecosystem carbon upon conversion (Duarte, 2014, Pendleton *et al.*, 2012). A key question about carbon is where it comes from and what happens to it when the ecosystem releases it. For instance, corals have not been included in the discussion of coastal blue carbon so far because there is no scientific evidence that the carbon in corals comes from the atmosphere or is released into the atmosphere upon coral death and skeleton dissolution.

In the case of seagrass meadows, scientists ignore whether the carbon released from their sediments when they die, goes into the atmosphere or remains somewhere else nearby or simply contributes to increased ocean acidification. A particular uncertainty that has not yet been resolved neither is the fate of the carbon that erodes from a tidal marsh with a sea-level rise (UNEP and CIFOR, 2014). Besides, tidal-marshes and mangroves found in coastal waters at salinities less than half that of seawater produce methane which needs to be considered when developing the greenhouse-gas accounts of an intervention.

Since we only have sufficient knowledge about the fates of ecosystem carbon upon conversion but also country-level geospatial data for mangroves, this represents the only coastal ecosystem for which we can currently derive analyses on its mitigation potential and identify priority areas. As we can see in the Graph 1, mangroves are mainly limited to tropical and sub-tropical regions, while tidal-marshes mostly occur in temperate areas and seagrass meadows can be found in all continents. A thorough inventory of coastal blue carbon sinks as a whole could nevertheless be twice as large as the mean area considered in current conservative global assessments (Nellemann *et al.*, 2009). This calls for more efforts to be deployed on data collection in the upcoming years.

In sum, we can only develop a country-taxonomy to prioritise action on climate change mitigation for mangrove ecosystems. We nevertheless refer to the other coastal blue carbon ecosystems in the remainder of the chapter to share the potential interest to derive more data and scientific analyses on tidal-marshes and seagrass. The taxonomy on mangrove countries should be understood as a preliminary attempt to provide some guidance on the prioritisation of investments since even for these ecosystems, the scientific understanding of post-conversion rates of carbon dioxide emissions is relatively embryonic, the results presented in this chapter being based on conservative estimations, and there is also some degree of uncertainty on the proportion of mangroves that may be destroyed and on the plantation potential.

Figure 3.1. Global Distribution of Mangroves

Source: Giri *et al.*, 2011.

3.3. Mangroves: Geographically concentrated carbon intensive ecosystems

Coastal ecosystems store large amounts of carbon in the soils beneath them. If released to the atmosphere, the carbon stored in a typical hectare of mangroves could contribute as much to greenhouse-gas emissions as three to five hectares of tropical forest.⁷⁴ However, the total area of mangroves, as well as tidal-marshes, and seagrass meadows is small compared to land in agriculture or terrestrial forests. The three type of ecosystems amount to about 1-2 per cent of the global coverage of forest at 78.9 million hectares, and mangroves alone amount to only about a quarter of that contribution, tidal-marshes to about 7 per cent and seagrass to about 70 per cent. Given the relative small land area they occupy, can mangroves then have a significant impact on climate change mitigation?

Soil organic carbon is the largest carbon pool in coastal blue carbon, averaging 1 400 t CO₂e/ha for mangroves, 917 t CO₂e/ha for tidal-marshes and 500 t CO₂e/ha for seagrass. In the case of mangroves, living biomass can account for 10-50 per cent of the carbon pool (Murray *et al.*, 2011). The annual mitigation potential for mangrove ecosystems on current land-use conversion rates between 0.7 and 2 per cent stands at 0.5-1.44 per cent of global anthropogenic carbon emissions (Friedlingstein *et al.*, 2010). Mangroves are among the most threatened ecosystems in the world (Crow and Carney, 2013). According to Duke *et al.* (2007) and Polidoro *et al.* (2010), mangrove forests may disappear from a functional standpoint in about 100 years. Tidal-marshes and seagrass have similar annual loss rates at 1-2 per cent and 1.2-2 per cent, respectively.

Murray *et al.* (2011), estimate the annual carbon loss for mangroves in the range of 0.09-0.45 Pg CO₂, given both biomass and soil organic carbon.⁷⁵ To put these emissions in perspective, 0.45 Pg CO₂ per year approaches the annual fossil fuel CO₂ emissions of the United Kingdom (the world's ninth ranked country by emissions), while the low estimate of 0.09 Pg CO₂ per year is close to those of Venezuela (ranked 30th). The loss of mangroves ecosystems may contribute an additional 2–8 per cent above the most recent estimates of global emissions from deforestation (5.5 Pg CO₂ per year including freshwater peatlands). Such a mitigation potential through the avoided loss due to mangrove destruction would enable to offset 2.3 to 6.8 per cent of the current fossil fuel emissions, over half of that projected for reducing rainforest

⁷⁴ See Donato *et al.* (2011) for some graphs comparing carbon storage in mangroves vs other tropical ecosystems.

⁷⁵ These estimates are much larger than data from previous studies based only on biomass loss. Indeed, the climate change impact of the destruction of mangroves and salt marshes was assessed at 76 million t CO₂ per year.

deforestation (Nellemann *et al.*, 2009). The upper bound of this contribution would be equivalent to about 10 per cent of the emission reductions needed to keep atmospheric concentrations of carbon dioxide below 450 ppm.

Even if the aggregated annual loss rate of mangroves has a non-negligible impact on carbon emissions, there is a still need to analyse to which extent there is scope for projects that can be scaled-up to achieve significant mitigation impact. Evidence suggests that there is indeed scope for obtaining significant results since much of the mangrove mitigation potential lies in a small group of countries. Almost 80 per cent of mangrove mitigation potential resides in a few countries whose annual total mitigation potential is over three million t CO₂e, over 55 per cent of that potential resides in seven countries with at least 5 million t CO₂e: Indonesia, Mexico, Papua New Guinea, Malaysia, Vietnam, Colombia, and Pakistan (Murray *et al.*, 2011).⁷⁶

If we develop a country-taxonomy according to the annual mangrove climate change mitigation potential and the break-even carbon price, we can infer some conclusions in terms of geographical priorities in policy interventions (see Table 3.1 below, and Tables 3.6-3.7 and Figure 3.3 in the appendix). The break-even carbon price stands for the price at which the financial payment from avoiding carbon releases just offsets the direct and opportunity costs of mangrove protection.⁷⁷ Note that this carbon price does not take into account the value of other ecosystem services, which could lead to higher monetary benefits and is thus conservative (Vasconcelos *et al.*, 2015). Avoiding the destruction of coastal blue carbon ecosystems could be financially attractive at carbon prices above the break-even carbon price. As the carbon price rises, more countries can reduce emissions, and the total mitigation quantity rises.

Table 3.1. Top 25 mangrove countries according to the annual mangrove mitigation potential and the break-even carbon price

		Annual mangrove mitigation potential (million t CO ₂ e/year)		
		Very high (>4)	High (>1,3, <3)	Low (<1,35)
Break-even carbon price (\$/t CO ₂ e)	High (>6)	Papua New Guinea	Colombia, Honduras, Philippines, United States	Brazil, Ecuador, Panama, Thailand, Venezuela,
	Medium (> 3, <6)	Indonesia, Mexico	Gabon, Myanmar, Pakistan, Vietnam	India, Nicaragua, Tanzania
	Low (<3)	Malaysia	Guinea-Bissau, Madagascar, Senegal, Sierra Leone	Cambodia

Source: Author work based on Murray *et al.* (2011).

We can see in Table 3.1 that the countries where the mitigation potential is the largest and the break-even carbon price is relatively low are Indonesia, followed by Mexico, Malaysia and with a higher carbon price, Papua New Guinea. These countries are therefore the most relevant for coastal blue carbon interventions. Other countries where the mitigation potential is still relatively high are Vietnam and Guinea-Bissau, Madagascar, Senegal and Sierra Leone (with a low break-even point for the carbon price) and Gabon, Myanmar and Pakistan (with a moderate break-even point for the carbon price).

⁷⁶ Jardine and Siikamäki (2014) have constructed a global dataset of estimated soil carbon concentrations and stocks.

⁷⁷For each country, the break-even price is the point at which coastal blue carbon value equals the cost of protection. The cost of protection is equivalent to the costs of establishing and managing protected areas plus the average of the opportunity costs derived from World Bank land values and from GTAP land values.

We highlight that in this analysis we are weighting the benefits by the threats of conversion to other uses to evaluate where the additional impacts of a policy would be the greatest. Any concrete policy interventions would need to verify separately. That is, whether the emission reductions would not have occurred, holding everything else constant, without the offset project. The topic of additionally is the most fundamental and contentious issue in the carbon offset market.

So far, the management activities that have led to the majority of mangrove loss include forestry activities (26 per cent) and aquaculture, comprising the construction (and extraction of soil) for shrimp ponds (38 per cent) and fish farms (14 per cent) (Vaiela *et al.*, 2009). The threats mangroves face may differ across the globe and temporarily so more research is needed. For example, in Indonesia, the threats may vary from the creation of shrimp farms (E. Java, Sulawesi and Sumatra), agriculture and salt pans (Java and Sulawesi), oil spills (E. Kalimantan) to general pollution (FAO, 2007). In turn, tidal-marches are disappearing due to agricultural use, industrial or urban use, and reduced sedimentary supply (Coleman *et al.*, 2008). Seagrass meadows are disappearing due to water quality degradation and mechanical damage such as dredging, trawling and anchoring (Murray *et al.*, 2011).

The prioritisation of coastal blue carbon opportunities, including restoration, should include not just carbon but also the co-benefits provided by other ecosystem services. Some of the co-benefits of ecosystem services provided by coastal blue carbon ecosystems are coastal hazard mitigation, shoreline stabilisation and erosion control, safe harbours and sites for maritime industry at shore and offshore, beach production, fisheries production (for instance, commercial fish stocks in tropics often dependent on mangroves as nursery areas) and pollution assimilation, water filtration, maintenance of water quality and hydrological balances (Zorini *et al.*, 2004, Datta *et al.*, 2012, Lau, 2012 and Agardy, 2015).

Adding co-benefits can increase the monetary value resulting from carbon benefits, while having a limited increase in costs. For instance, adding a biodiversity component to carbon projects can add only USD 1/t of CO₂ in costs (Siikamäki *et al.*, 2012). In fact, one of the most powerful arguments for climate-biodiversity co-financing initiatives is the observation it may be possible to achieve significant improvements in biodiversity returns while incurring only relatively small carbon penalties (Venter *et al.*, 2009).

Such co-benefits can be necessary for the financial sustainability of the project. For example, a price of USD 10/t of blue carbon can provide revenues to cover only 80 per cent of the cost of installing and managing the coastal mangrove area in Guinea-Bissau (Vasconcelos *et al.*, 2015). Co-benefits may be also necessary given technical, administrative and institutional constraints (Broadhead, 2011). We note that mangrove forests can differ in their species composition and services provided and hence co-benefits can vary. A recent study finds that the highest diversity of mangrove species as well as the highest number of threatened mangrove species is found around Indonesia, for instance (Pilodoro *et al.*, 2010).

Unfortunately, there are not only co-benefits but also risks associated with the impact of the development of coastal blue carbon on other ecosystem services. The potential trade-offs among mitigation objectives, biodiversity and ecosystem services outcomes, and the needs of the different stakeholders need to be well integrated (Parrott *et al.*, 2012). Planning for mangrove conservation should be done at scales that try to minimize fragmentation, including cross-country coordination where needed. Fragmentation and lack of connectivity generally impoverish the ecosystem structure and functions, including carbon storage and sequestration (see, for instance, Cemin *et al.*, 2012).

Besides, not all impacts on carbon (and biodiversity) are easily anticipated or measured (Parrott *et al.*, 2012). Fire suppression in mangrove ecosystems can lead to increased carbon stocks in the short term, but can be detrimental in the long term for both carbon and biodiversity if the accumulation of fuel leads to large-scale fires. Furthermore, site prioritisation should integrate the expected higher rates of sea-level rise, focusing on the mangrove areas most

resilient to this factor (UNEP and CIFOR, 2014).⁷⁸ Finally, the eventual production of methane in mangroves found in coastal waters at salinities less than half also needs to be accounted for when selecting the area to preserve or restore.

3.4. Coastal blue carbon conservation and restoration

Coastal blue carbon is subject to global loss rates 2 to 15 times larger than that of tropical forests (0.5 per cent per year according to Achard *et al.*, 2002) and the conversion rates associated with coastal blue carbon are accelerating (Waycott *et al.*, 2009). About half of the blue carbon sinks may have been lost, mainly through the loss of coastal blue carbon since the 1940s. More precisely, about 35 per cent of the area once covered by mangroves has been lost globally since the 1940s (Valiela *et al.*, 2001). About 67 and 29 per cent of the area covered by tidal-marshes and seagrass has also been lost, respectively (Lotze *et al.*, 2006, Gedan *et al.*, 2009 and Waycott *et al.* 2009).

Large-scale restoration projects have been already conducted for mangroves, the most important effort being the afforestation of the Mekong Delta forest in Vietnam. However, the majority of mangrove restoration projects often fail (Lewis, 2005). The major cause of ecological failure is the oversimplification of the process of restoration with the reliance on direct planting of a low diversity of mangrove species into a substrate either not appropriate or unprepared hydrologically for mangrove establishment. Inadequate public consultation and local involvement has also been cited as major reasons for failure (Brown and Nurdin Massa, 2013).

Restoring lost tidal-marshes is also possible, and has been largely applied in Europe and in the US. Restoring seagrass meadows is more difficult since it is more costly (Nellemann *et al.*, 2009). In general terms, it is relevant to explore how restored ecosystems compare to protecting existing ecosystems. If the restoration occurs in places that still contain large amounts of soil carbon, then it has a value similar to protecting old ecosystem - as long as the soil carbon would be lost without the restoration. If restoration occurs in a place that does not have carbon rich soils, then its carbon value is very small. Indeed, carbon storage in soil is a slow process. Besides, carbon sequestration capacities appear to be lower in restored areas than in undisturbed ecosystems (Matsui *et al.*, 2012).

Overall, coastal benthic ecosystems conservation is usually preferred to restoration (Crooks, 2015, UNEP and CIFOR, 2014). Given the poor knowledge about the functioning of benthic ecosystems and their complex interactions, the technical difficulties to intervene and the associated costs, there are very few projects to restore these ecosystems. Most projects deal with their protection through the regulation of human activities. The establishment of protected areas can be relatively effective for restoration, but full ecological recovery is slow (Carlier, 2015). Given these premises, geo-engineering solutions are often considered to be insufficiently mature for climate change mitigation in the ocean and coastal areas.⁷⁹

⁷⁸Recognizing the additional requirements for coastal wetland carbon projects, new procedures are proposed under the draft Verified Carbon Standard methodology for Tidal Wetland and Seagrass Restoration. These procedures include guidance on defining project boundaries in settings subject to mobility with sea-level rise.

⁷⁹ Geo-engineering solutions can reduce the concentration of CO₂ in the atmosphere by enhancing the function of the ocean as carbon sink or by storing CO₂ in subsea geological formations. The UNFCCC 17th COP held in Durban on 2011 adopted the modalities and procedures for carbon dioxide capture and storage in geological formations as a Clean development mechanism (CDM), including injection in ocean bed aquifer. Sleipner in Norway (Statoil) has been injecting 1 million tons a year of CO₂ since 1996 into an offshore 'aquifer' 800m below the seabed (IEA, 2008). Moreover, in the context of The Convention for the Protection of the marine Environment of the North-East Atlantic (OSPAR), some amendments have been ratified to enable carbon sequestration. The International Maritime Organisation (IMO) has recently submitted a project on the possibility of modifying the London protocol regarding ocean fertilisation.

Even though conservation is often preferred to restoration, the latter will be difficult to avoid given the extent of lost areas of coastal blue carbon. If we focus on mangroves on the remainder of this section, unfortunately most of the restoration efforts for mangroves have consisted on planting few species of trees for wood or to raise intertidal areas for agriculture, rather than assessing the reasons for the loss of mangroves and working with natural recovery processes. Many failures also result from afforestation attempts in areas that previously did not support mangroves (Erftemeijer and Lewis, 2000).

Lewis and Marshall (1997) have suggested five steps to achieve successful mangrove restoration from an ecological standpoint: understand the species ecology, the hydrological patterns (depth, duration, and frequency of tidal flooding), and the reasons for the loss of mangroves, design a restoration program based on natural volunteer mangrove plants and on local hydrological conditions, and only resort to planting mangroves if the natural regeneration has failed. Institutional, social and economic issues are also relevant to ensure the success of both restoration and conservation projects.

With structural adjustments programs in the 1980s, there was a devolution of power of the central state for the management of mangrove resources through the so-called community-based conservation (Alcorn *et al.*, 2002 and Crow and Carney, 2013). The argument by which the commons would be better managed by state command-and-control to avoid mangrove overexploitation compromised the participation of local communities which traditionally had managed and harvested mangroves (Ostrom, 1999). Following the devolution of power, the state was then no longer responsible for the delivery of services but for the regulation of other local actors responsible for service delivery.

Previous top-down approaches based on state control were not successful in protecting these ecosystems since, among other, there were intense frictions between the state and local communities over the control of the resources, particularly when poor people depended on mangroves for their living, and they were prone to elite capture (Mangora, 2011 and Datta *et al.*, 2012). Besides, there was often state-level failure in the management and enforcement of mangrove policies (Kulindwa *et al.*, 2001).

Without devolution to local communities, lack of technical capacity to translate laws, frequent changes in the administration staff and poor state governance can exacerbate risks and hence the monetary buffer needed per ton of avoided carbon emissions (Vasconcelos *et al.*, 2015). Political interference, conflicting and overlapping jurisdictions and the absence of an authority which coordinates actions, are serious policy problems as well (Mangora, 2012). In such circumstances, building over an indigenous institution may be easier to protect mangrove forests (Verheij *et al.*, 2004).

Where ecological success has been achieved, communities have often actively and formally protected mangroves, with the local government and other stakeholders to ensure the long-term functioning of a system that benefits their livelihoods (Brown and Nurdin Massa, 2013). Community management is more effective when the community has suffered some first-hand loss in mangroves, there are short-term economic benefits, rights of access and use are secured with social capital being strong enough to claim rights to the mangrove resource, and monitoring and sanctions are in place (Sudtongkong and Webb, 2008).

There are some problems associated with the community-based management of mangroves though, with mixed outcomes of success and failure (Datta *et al.*, 2012). The emphasis on economic returns to the local community has threaten in some cases the long-term sustainability of mangroves (Hackel, 1999 and Crow and Carney, 2013). The degree of devolution of the state to local authorities has been very diverse which has led to different conservation outcomes (Datta *et al.*, 2012). There is no one-size-fits-all model, since management solutions will depend, among other, on location, historical functions and user preferences. Most importantly, control by local elites and exclusion of the poorest has often resulted on weak protection of mangroves (Bergquist, 2007).

Independently of having centrally or locally managed mangrove ecosystems, climate change financial mechanisms can enable revenue diversification, avoiding full dependence on local sources for the protection and restoration of coastal blue carbon (Vasconcelos *et al.*, 2015). We note that initial investments of capital and labour have often to be made by the communities, though (Wattage and Madle, 2007).

3.5. Which policy mechanisms can finance coastal blue carbon?

Coastal blue carbon could have the potential to harness large capital flows through regulated climate policy cap-and-trade schemes such as the UNFCCC, the European Union Emission Trading System (EU ETS), and other national and sub-national schemes (Ullman *et al.*, 2012). Through these schemes we can either regulate the maximum permitted coastal blue carbon emissions, or provide an economic incentive to reduce emissions (offsets).

There have already been efforts to include coastal blue carbon in the UNFCCC.⁸⁰ There is, in particular, a market mechanism that is relevant for mangroves, the Clean Development Mechanism (CDM). The CDM allows the Annex I countries to meet part of their emission reduction commitments under the Kyoto Protocol by buying Certified Emission Reduction units from CDM emission reduction projects in developing countries.

CDM procedures have been already approved on carbon dioxide capture and storage in geological formations including oceanic aquifers and on afforestation and reforestation of degraded mangrove ecosystems (Climate focus, 2011). This mechanism however, does not include avoided emissions which are more appropriate for mangroves since most of the carbon lies in soil stocks. In addition, it can be subject to carbon leakage (carbon losses will happen elsewhere), high transaction costs, poor incentives (it does not penalise emission increases), lack of permanence, local resistance and market deflation with the low price of carbon.

Besides this policy mechanism, if mangroves are included in a country's definition of a forest, they are eligible under Reducing Emissions from Deforestation and Forest Degradation (REDD+) for climate credits.⁸¹ REDD+ creates economic incentives to reduce mangrove destruction and degradation and the associated carbon emissions supported by finance from developed countries. Unlike forestry activities for carbon offsets based on sequestration through afforestation and reforestation, REDD+ focuses on avoided emissions.

There are currently some policies in place to protect mangroves that could inform REDD+ projects, the dominant being protected areas. Protected areas could become an important element of mangrove countries' efforts to implement and benefit from REDD+ (Brandon and Wells, 2009). There are similarities between REDD+ projects and integrated conservation and development projects (ICDPs) linked to protected areas.⁸² However, there is almost no evidence whether or not this type of policy is effective in stalling mangrove loss (see McNally *et al.*, 2011 and Miteva *et al.*, 2015 for some exceptions).⁸³

Of the 25 countries with the highest potential for mangrove mitigation, 12 countries, representing three quarters of mangrove ecosystems, have developed or are in the process of developing REDD+ readiness plans. Most of these 12 countries already mention mangroves with regard to deforestation and data collection needs. Despite this progress, this type of

⁸⁰ Since the UNFCCC Sixteenth session of the Conference of the Parties on 2010 (COP16), there is a provision to take action on coastal and marine ecosystems and to integrate them into already existing UNFCCC mechanisms (Murray *et al.*, 2012).

⁸¹ REDD+ should not be considered as a market-based mechanism since it is based on trading allowances between nations (Thomas, 2014).

⁸² Like ICDPs, REDD+ pilot and demonstration projects have generated considerable donor support and very high expectations among stakeholders. Although ICDP projects do not always perform well, and avoidable mistakes continue to be made in their design and implementation.

⁸³ Miteva *et al.* (2015) find that protected areas can be effective in preventing mangrove loss in Indonesia. McNally *et al.* (2011) find similar results for Saadani National Park in Tanzania.

mechanism has very high transaction costs. USD 1.6 billion have been spent for planning and institutional capacity in REDD+, while only USD 97 million have been recorded for sold credits in reduction emissions (Pendleton, 2015). It is also subject to a certain number of caveats such as the lack of definition of what constitutes a forest and forest degradation, and the weak inclusion of local communities. The issues of carbon leakage, additionality and permanence remain unsolved. Overall, the effectiveness of REDD+ is strongly questioned (Seyller *et al.*, 2015 and Sunderlin *et al.*, 2015).

There are other cap-and-trade schemes beyond those under the UNFCCC. The EU ETS excludes forestry credits, however. Besides this regional cap-and-trade scheme, at the national level there are no cap-and-trade regimes yet, and at the sub-national level there are some with that in California being the most relevant for coastal blue carbon (Ullman *et al.*, 2015). Otherwise, voluntary mechanisms for carbon credits are more developed than regulated markets currently but mobilise small amounts of funding, being more appropriate for pilot projects.

Other non-market mechanisms may also finance for coastal blue carbon. Subsidies are an option, for instance, under the UNFCCC Nationally Appropriate Mitigation Actions (NAMAs) for wetlands in developing countries. These are actions that countries may voluntarily undertake to reduce greenhouse gas emissions and that are well suited for mangroves (Herr, 2015). Countries such as Dominican Republic and Honduras have expressed their interest to support coastal blue carbon NAMAs. Finally, regulation can also provide support for coastal blue carbon through carbon offsets requirements or fines for damages (Pendleton, 2015).

The NOAA has recently analyzed whether and how blue carbon benefits could be incorporated into US federal policies (Sutton-Grier *et al.*, 2014, 2015 and Pendleton *et al.*, 2013).⁸⁴ In fact, at national and sub-national levels, there can be market mechanisms that can be valuable for mitigation and adaptation purposes such as compensation or carbon farming to compensate the CO₂ emissions through, for instance, mitigation banking, Payments for Ecosystem Services (PES) to safeguard ecosystems providing multiple services and payments for watershed services to assure water quality and flows (Thomas, 2014 and Agardy, 2015).⁸⁵ Currently, there are no comprehensive financial mechanisms in place to ensure that mangroves are rehabilitated following damage though mangrove insurance could be technically feasible (Bell and Lovelock, 2013).

Mitigation banking is a system of credits and debits to ensure that an ecological loss, especially to wetlands and streams resulting from various papers, is compensated for by the preservation and restoration of wetlands, natural habitats, streams in other areas so that there is no net loss to the environment. In 2008, a US federal rule establishing standards for mitigation banks was implemented, consistently with the Clean Water Act passed in 1972 that made it compulsory to avoid and minimize the impact on designated water bodies and provide compensatory mitigation for unavoidable impacts. The foremost challenge of mitigation banking is the difficulty encountered by regulatory agencies in guaranteeing an ecological equivalent (MAEDI, 2014). Besides, the US experience has denoted that market demand may not meet expectations since it is difficult to distinguish a profitable bank from one that disappoints.

⁸⁴Sutton-Grier *et al.* (2014) determined that it is possible to incorporate carbon services of coastal ecosystems into implementation of the Clean Water Act (CWA), the Coastal Zone Management Act (CZMA), and the Natural Resource Damage Assessment (NRDA) process. Pendleton *et al.* (2013) determined that the Endangered Species Act, National Environmental Policy Act (NEPA), and the Water Resources Development Act and the Proposed Revised Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G) also could include carbon services in their implementation.

⁸⁵Proving additionally remains a challenging task, though.

The international community has mostly focused on PES mechanisms to finance coastal blue carbon although few examples exist in the ocean and coastal context so far, and in terrestrial areas this mechanism has been subject to numerous criticisms. PES mechanisms should increasingly focus on generating co-benefits by either bundling or stacking ecosystem services since otherwise it will be difficult to prevent the development of certain activities such as coastal tourism as well as to avoid the maximization of carbon sequestration through the plantation of monocultures (Lau, 2012). Carbon sequestration could be delivered together with shoreline protection, nursery habitat, biodiversity and water quality.

Mechanisms generating co-benefits will result however on difficulties in quantifying separately services, on larger management and monitoring costs and on higher transaction costs with a larger number of stakeholders (Engel *et al.*, 2008). It is indeed uneasy to clearly define in space and time an ecosystem service of interest, the quality of assets would be easier to quantify (Alongi, 2011 and Thomas, 2014). Besides, monitoring and enforcement costs are high even without taking into account bundling (Muradian *et al.*, 2010). Moreover, PES incentives could erode cultural and ethical motivations to conserve mangroves (Kosoy and Corbera, 2010).

Finally, problems of equity, access and rights over the resource, moral hazard (offsetting carbon will excuse business-as-usual), leakage and additionality must also be addressed (Corbera *et al.*, 2007, Proctor *et al.*, 2009 and Thomas, 2014). In fact, the analysis of the effectiveness of PES mechanisms in Costa Rica and Mexico has demonstrated that they have added relatively limited value to existing community conservation practices and command-and-control measures like deforestation bans and such caveats can apply as well to mangroves (Gordon *et al.*, 2011 and Lovera *et al.*, 2013).

Unfortunately, there are yet additional challenges to integrate coastal ecosystems into the instruments previously discussed in this section. Since accounting guidelines on wetlands have only been recently available to enable the estimation and reporting of anthropogenic greenhouse-gas emissions it may be difficult to establish baselines in coastal blue carbon systems because historical data and current emission factors and loss rates may not be available on the national scale (IPCC, 2014).⁸⁶ Limited data on soil carbon could also substantially undercut the potential for coastal blue carbon revenue (Murray *et al.*, 2011).

Furthermore, current methodologies for measuring carbon sequestration do not include soil carbon whereas most coastal blue carbon is stored in soils. The soil carbon component of mangrove offsets would have to be further developed for its inclusion under REDD+.⁸⁷ The legal or de facto ownership are not always well-established in coastal areas, yet the local definition or pattern of ownership will likely affect the design of payment systems such that not every mechanism will be applicable (Murray *et al.*, 2011). Finally, as previously explained, carbon, biodiversity, institutional and social factors have to be properly integrated and research is still needed on this area.

There are some specificities associated with mangrove forests that need to be appropriately accounted for in projects. Mangroves are dynamic, non-linear, non-equilibrium ecosystems that do not conform to classical concepts of forest development (Lugo, 1980). Net accretion and carbon flux vary over space and time and hence short-term small-scale measurements do not reflect an accurate picture of evolutions in the medium-term (Alongi, 2011). In addition, mature mangrove forests can still be net producers of carbon unlike many terrestrial forests while these mechanisms may focus on young plantations for afforestation (Alongi, 2009), the latter being water-intensive and with lower biodiversity (Jackson *et al.*, 2002). Concerning the fate of carbon, there is about 50 per cent of uncertainty for mangrove

⁸⁶See Emmer (2015) for blue carbon accounting protocols.

⁸⁷ Besides, measuring carbon in seagrass meadows or tidal-marshes on both the national and local scales may be difficult because remote sensing methods, which are helpful for aboveground carbon stocks, are more difficult to apply (Murray and Vegh, 2012).

forests given the limited understanding of the relationship between the dissolved inorganic carbon and the tidal range (Bouillon *et al.*, 2008).

In sum, even though coastal blue carbon could access large potential funding flows through global and regional regulated cap-and-trade regimes, it may take time for these schemes to be mature. Local market-based mechanisms such as PES are still subject to research. In the meantime, non-market instruments such as fines, protection of carbon-rich areas, subsidies and offsets for damages may play an important role for the conservation and restoration of mangroves.⁸⁸ The capacity of the private sector to bring innovative, cost-effective solutions must be weighted by its high cost of capital due to the (high) risks. In any case, instruments should be designed to guarantee an adequate balance between local communities' participation and state regulation.

3.6. Coastal blue carbon and climate change adaptation

Since climate change adaptation is perceived as a major issue at the local level, adaptation projects designed to protect coastal communities could also help protect coastal blue carbon, a global public good whose effects are perceived at the global level and hence receive less local support. Climate change adaptation has the potential to become coastal blue carbon's greatest financing driver. The synergies between climate change adaptation and coastal blue carbon are explained hereafter.

Some evidence on climate change coastal exposure

The major consequences of climate change on the ocean are the melting of glaciers and ice sheets, the sea level rise, the ocean acidification and the potential effects on the thermohaline circulation. Besides, coasts can suffer from extreme weather events (Kreft and Eckstein, 2013). In this section, we aim at better understanding the impact of such environmental changes on human wellbeing with a link to climate adaptation policies and to the role that coastal blue carbon can play to buffer such impacts.

Global studies on the vulnerability of coastal zones to sea-level rise and storm surges are severely hampered by the unavailability of data on coastal protection (Füssel, 2009). As an example, results on population below one meter above sea level (Buys *et al.*, 2007, Dasgupta *et al.*, 2007) and on percentage change in population annually flooded (Hinkel 2008, Klein and Hinkel 2009) show little agreement regarding the most vulnerable countries, and the rank correlation is not significant. While acknowledging these data limitations, coastal protection is the only sector for which our knowledge of adaptation costs (and benefits) has most progressed with a comprehensive coverage (Agrawala and Fankhauser, 2008).

We make use of the coasts at risk exposure index developed by Beck (2014) on the vulnerability of coastal zones to climate change as an imperfect but currently available proxy to enable to derive some policy options for mangrove countries (see Table 3.2 below and Table 3.8 in the appendix). The index describes the share of the population exposed to coastal hazards per country and is calculated by summing up all exposed people per hazard divided by the number of inhabitants per country. It takes two different types of natural hazards into account; it focuses primarily on current and sudden onset hazards, such as storms, floods, storm surges and tsunamis, but also includes the slow onset hazard of sea level rise based on the exposed people to sea level rise by one meter.

Some linkages between coastal blue carbon and climate change adaptation

⁸⁸ The Intended Nationally Determined Contributions (INDC) under the UNFCCC with national pledges for the reduction of greenhouse-gas emissions can provide information on the countries' willingness to make efforts on coastal blue carbon, given that Kyoto protocol parties can elect rewetting and drainage as a Land Use, Land-Use Change and Forestry (LULUCF) reporting activity (Herr, 2015).

Adaptation programmes could provide funding for coastal blue carbon projects, as donors may favour projects that incorporate the need to lower emissions while helping to create more resilient communities and ecosystems. Even more, given that financing mechanisms for coastal blue carbon are yet immature. Besides the role of coastal blue carbon for carbon storage, mangroves provide additional functions such as the buffering of the impacts against storm surges and waves, soil preservation, raising the sea floor and shelter for fish nursery or habitat protection.

Table 3.2. Coasts at Risk in the top 25 mangrove countries: Exposure

Very high	High	Medium	Low	Very low
Philippines	Madagascar	India	Guinea-Bissau	Nicaragua
Vietnam	Indonesia	Papua New Guinea	Colombia	Sierra Leona
Cambodia	Malaysia	Tanzania	Pakistan	
	Gabon	Thailand		
	Myanmar	Honduras		
	Ecuador	Senegal		
	United States	Venezuela		
	Brazil	Mexico		
		Panama		

Legend: As defined by Beck (2014), very low is between 0.0003 - 0.0040, low between 0.0041 - 0.0103, medium between 0.0104 - 0.0228, high between 0.0229 - 0.0704 and very high 0.0705 - 0.5955.

Mangroves can play an important role in reducing risk to communities from coastal disasters (Beck, 2014). Mangroves reduce exposure to coastal hazards and reduce social vulnerability by providing a source of natural capital in the form of fisheries and other mangrove-derived products such as timber harvesting, charcoal making and beekeeping (see Das and Vincent, 2009, for instance). Mangroves can help communities cope with disasters by providing food and fuel in the immediate aftermath and supporting livelihoods during the recovery period and thereafter. The conservation or restoration of mangroves can thus form part of local adaptation strategies aimed at reducing risk from future disasters, which may become more frequent as the climate changes and sea levels rise.

Since mangrove conservation delivers a host of services, these can help refine estimates of the benefits from mangrove conservation. However, very few studies have attempted to quantify these additional benefits and, even fewer, have attempted to perform rigorous economic valuation of the services provided (Vegh *et al.*, 2014). There is a need to carry out research on these co-benefits from mangroves. Depending on the context, the conservation of mangroves can be coupled with development interventions aiming to increase local household/community welfare and to reduce risk to coastal disasters. Local benefits of mangrove protection are more likely to be requested by communities that those benefits perceived at a global scale.

Restoration and ecosystem engineering of coastal blue carbon are examples of positive synergies between climate change mitigation and adaptation measures in coastal areas (IPCC, 2014). In Table 3.3, we can see that amongst the top 25 mangrove countries, those that have high exposure to coastal risk are Cambodia, Philippines and Vietnam, followed by Brazil, Ecuador, Gabon, Indonesia, Madagascar, Malaysia, Myanmar and the US. With the exception of Malaysia, Myanmar and Vietnam, these countries have committed to reduce over 25 per cent of their greenhouse-gas emissions against the business as usual scenario by the year 2030. There would be hence scope for the implementation of programmes that are beneficial both for adaptation and mitigation purposes.

A country classification according to coastal exposure may diverge however, from a country classification according to the costs associated with the optimal coastal adaptation level. Costs can vary substantially from one country to another and hence not all potential damages

will be necessarily addressed. The optimal level of adaptation in the coastal sector is extremely high for most developing regions in the world (De Bruin, 2011). This is because the costs of protecting the land are usually much lower than the costs of losing the land due to sea rise level. In contrast, in some developed countries, in particular, in European countries, there is a lower optimal adaptation level because the costs of protecting are higher than the costs of losing the land.

Table 3.3. Top 25 mangrove countries with very high or high exposure to coastal risk

		Annual mangrove mitigation potential (tCO2e/year)		
		Very high	High	Medium
Break-even carbon price (\$/tCO2e)	High	Papua New Guinea	Colombia, Honduras, Philippines(**), United States(*)	Brazil(*), Ecuador(*), Panama, Thailand, Venezuela
	Medium	Indonesia(*), Mexico	Gabon(*), Myanmar(*), Pakistan, Vietnam(**)	India, Nicaragua, Tanzania
	Low	Malaysia(*)	Guinea-Bissau, Madagascar(*), Senegal, Sierra Leone	Cambodia(**)

Legend: (**) denotes countries very high exposure to coastal risk and (*) denotes countries high exposure to coastal risk.

There is some correlation between the incremental annual costs of adaptation for coastal protection and the break-even carbon price (see Table 3.4). The annual costs of adaptation and the carbon price are the largest for Latin American and the Caribbean and are relatively low for Sub-Saharan Africa. Thus, on a global scale, projects in Sub-Saharan Africa would be less expensive to address compared to other World Bank regions. The South Asia sample is not sufficiently representative since we only have two countries (India, Pakistan) among the mangrove-country sample. The estimates are nevertheless low both for the carbon price and for the adaptation costs. For the case of East Asia and the Pacific, we can put forward that the countries with a high mangrove potential display a large variance in terms of carbon price.

Only for coasts, the global adaptation costs (beach nourishment, port upgrades and capital and maintenance on river and sea dikes) for a scenario of no additional sea-level rise ranges from USD 10.4 billion per year in the 2010s to USD 9.5 billion per year in the 2040s (Nicholls *et al.*, 2010). World Bank regions account for approximately 60 per cent of these costs. Two-thirds of the total adaptation cost comes from sea dikes, increasing to over 90 per cent when maintenance costs are considered (see Table 3.4). Some research points to the importance of mangrove forests as alternative solutions to the construction of expensive sea dikes while preserving ecosystems (Berrenstein, 2012).

The European Union has adopted a strategy on green infrastructure to enable ecosystems to deliver their many services to people and nature. Almere is a pioneer city in The Netherlands where co-benefits between flood resilience and carbon storage, among other services, are taken into account. Although the complementarity between adaptation and mitigation strategies can be substantial, attention needs to be paid in the case of the interventions of multilateral development banks. Since large funds are being allocated for resilience and it is easier to measure project inputs than project effectiveness, development banks tend to choose grey instead of green infrastructure.

Focusing on mitigation alone results in a failure to anticipate the impact of climate change on available forests, which in turn can jeopardise the permanence of carbon storage. One of the priorities in the climate change research agenda is to have a better quantification of trade-offs between population adaptation and carbon objectives as some REDD+ projects may in fact worsen people's vulnerability to multi-stressors, including climate change. Such an analysis is relevant for coastal blue carbon REDD+ projects as well. Besides, we note that projects focusing both on coastal mitigation and adaptation are also subject to other trade-offs given the introduction of exotic species, indigenous rights to coastal lands and accessibility for boats to the sea and, as highlighted above, the use of grey infrastructure versus coastal blue carbon (see Faegin *et al.*, 2010).

Table 3.4. Comparison between break-even carbon prices for the top 25 mangrove countries and adaptation costs for coastal protection

	Break-even carbon price (\$/tCO ₂ e)	Incremental Annual Costs of Adaptation for Coastal Protection for 2020 decade for the Medium SLR Scenario (billion dollars per year at 2005 prices)						Total
		Port upgrade	Beach nourish.	River dikes (capital costs)	River dikes (main. costs)	Sea dikes (capital costs)	Sea dikes (main. costs)	
East Asia and Pacific	4,7	0,18	0,56	0,07	0,01	6,4	1,26	8,48
Latin America and Caribbean	7,1	0,04	0,87	0,25	0,02	7,06	1,37	9,61
South Asia	4,2	0,02	0,24	0,01	0	1,23	0,24	1,74
Sub-Saharan Africa	2,9	0,02	0,79	0,02	0	2,43	0,47	3,73

Legend: Authors based on World Bank (2010). No discounting; high-income countries are excluded.

The aggregate volume of public and private climate finance mobilised by developed countries is estimated to be USD 57.0 billion on average per year in 2013-14 (OECD, 2015). Of this average aggregate estimate, 77 per cent of climate finance is allocated towards climate change mitigation objectives, 16 per cent towards climate change adaptation and 7 per cent to activities that target both. This result is driven by the dominance of mobilised private climate finance towards mitigation-related activities (over 90 per cent). According to other study, funding available in 2012–2013 for mitigation interventions in developing countries amounted to USD 39.1 billion, whereas that for adaptation was USD 3.4 billion (Pavageau and Tiani, 2014).

The estimates suggest that tens of billions of dollars per year will be needed for adaptation in developing countries (Lipinski and McGray, 2010). However, specific ranges are broad and the newest studies suggest that real costs could be substantially higher.⁸⁹ Overall, estimates remain extremely uncertain due to the unknown effects of climate change and to the broad assumptions that must be made in calculating global costs. Among the different sectors, coastal zones have the highest adaptation costs, followed by infrastructure (World Bank, 2010).

⁸⁹ Parry *et al.* (2009) estimate costs could be three times greater than the UNDP estimate, for instance.

Mitigation costs can be broadly estimated as being two to seven times larger than adaptation costs, although there are large variances (World Bank, 2010).⁹⁰ Besides, the incremental financing requirements for new projects tend to be much higher than the lifetime costs reported in mitigation costs models. The difference could be as much as a factor of three. Yet, there is a rationale to pledge for additional funding for adaptation in developing countries which seek to tackle coastal challenges given the synergies between coastal climate change mitigation and adaptation policies, and the little maturity of coastal blue carbon mitigation mechanisms.

3.7. Lack of information on sector specific governance and socio-economic factors

The need to have a better understanding of the trade-offs and synergies between climate change mitigation and adaptation policies within and among sectors, as well as between other ecosystem services, should further motivate developing and implementing marine and coastal resource management tools such as Marine Spatial Planning (MSP), Integrated Coastal Management (ICM) and Marine Protected Areas (MPA). In the recent years, the body of knowledge about the development of objectives and indicators for marine ecosystem-based management for previous tools has substantially progressed.

International organisations such as the International Oceanographic Commissions (IOC), the International Union for Conservation of Nature (IUCN) and the World Wide Fund for Nature (WWF) have supported the development of marine indicators that include governance and socio-economic components that were largely ignored prior to 2003 (Fisheries and Oceans Canada, 2003). However, none of the initiatives, to our knowledge, has implemented the indicator reporting systems.

Arguably, the development of marine and coastal resource management tools is a difficult task given the high complexity and poor understanding of many of the functions and processes of marine ecosystems. The task is even more complex once multiple-level and multiple-sector institutions requirements and economic and social factors of the people who use the resources of the ocean and coasts are taken into account. Developing objectives and indicators in such a context requires a high level of political commitment, with strong scientific and administrative support and a substantial allocation of funds.

Given the little availability of data, we can only use proxies to derive some information about the country's engagement on the marine sector (see Table 3.5). For instance, according to the IOC, various countries have started to use marine spatial management to achieve sustainable use and biodiversity conservation in the ocean and in coastal areas. Of the top 25 mangrove countries in Table 3.1, only Philippines and the US are developing MSP initiatives. MSP is developing rapidly in many areas, especially the EU, US and Australia, leaving aside most of the countries with high potential for coastal blue carbon policies concerning mangroves. If we now consider MPA as identified by The Marine Conservation Institute's project MPAtlas, there are four countries among the top 25 mangrove economies that have MPAs: Brazil, Malaysia, Senegal and the US.

Achieving ICM along its different dimensions (inter-sectoral, intra-governmental, spatial, cross-disciplinary, and international) is perhaps among the most difficult challenge in managing the ocean and coasts (Cicin-Sain and Knecht, 1998). Training and research are then key pillars to support the effective development of ICM. We can take into account among top mangrove countries those that have i) university degree programs offering a specialization in

⁹⁰ It is important to distinguish between mitigation costs (the incremental costs of a low-carbon project over its lifetime) and incremental investment needs (the additional financing requirement created as a result of the project). Because many clean investments have high up-front capital costs, followed later by savings in operating costs, the incremental financing requirements tend to be higher than the lifetime costs reported in mitigation models. The difference could be as much as a factor of three.

ICM: Malaysia, Mexico, Thailand and the US; and ii) research centres doing work related to ICM: Brazil, India, Indonesia, Malaysia, Mexico, Philippines, Senegal, Thailand and the US (Cicin-Sain *et al.*, 2000).

A better ex-ante understanding of the governance and socio-economic factors associated with a marine ecosystem, would enable to better prepare project appraisal. We can at least infer from the previous paragraphs that there are some countries amongst the top 25 mangrove countries that are, to some extent, familiar with marine policies and/or marine research and training. They may be hence more politically receptive and institutionally knowledgeable concerning coastal blue carbon projects.

Table 3.5. Top 25 mangrove countries with MSP, MPA and ICM training and research

		Annual mangrove mitigation potential (t CO ₂ e/year)		
		Very high	High	Medium
Break-even carbon price (\$/tCO₂e)	High	Papua New Guinea	Colombia, Honduras, Philippines (1, 3), United States (1, 2, 3)	Brazil (2, 3), Ecuador, Panama, Thailand (3), Venezuela
	Medium	Indonesia (3), Mexico (3)	Gabon, Myanmar, Pakistan, Vietnam	India (3), Nicaragua, Tanzania
	Low	Malaysia (2, 3)	Guinea-Bissau, Madagascar, Senegal (2, 3), Sierra Leone	Cambodia

Legend: (1) denotes countries with MSP, (2) denotes countries with MPAs and (3) denotes countries with ICZ training and research.

The previous argument diverges from conditioning the allocation of funds to governance requirements. Some authors argue that the quality of institutions is the deep fundamental factor that determines which countries experience good performance (Barro, 1991 and North, 1994). As such, some International Financial Institutions (IFIs) argue it is not useful to recommend good macroeconomic or microeconomic policies, if the institutional structure is not there to support them.

The development of specific indicators diverges substantially from using already available indexes on non-marine related governance and socio-economic indicators often used by the international community when analysing the ocean and coasts (Comte and Pendleton, 2014).⁹¹ Non-marine specific data can provide some indirect data to inform (to some extent) project appraisal in the absence of marine tools.

In terms of non-marine specific data, for instance, among the top 25 mangrove countries, we have a sample with countries with high dependence to natural resources and low institutional endowments and countries with medium-low dependence to natural resources and higher institutional endowments (see Figure 3.2 below and Table 3.10 in the appendix). This type of information only provides a very preliminary broad picture that needs to be complemented with macro and microeconomic data relevant to the project.

3.8. Conclusion

In this chapter, we have explored whether and how coastal blue carbon policy mechanisms can be currently developed. We focus on the extent to which these mechanisms are relevant alternative tools for climate change mitigation. This analysis is not about whether

⁹¹ See, for instance, the coasts at risk indicator or the proposal made by Fussler (2009).

coastal blue carbon protection can provide economic incentives strong enough to substantially curtail existing rates of ecosystem loss and contribute to conservation, but whether it has a significant and operational role in the short-term for climate change mitigation in specific countries.

Figure 3.2. Top 22 mangrove countries and governance

Source: Author calculations based on World Bank (1997) for natural capital % total wealth (2005) and on World Bank Governance indicators (2008). In red, a country has medium-low dependence on natural resources when natural capital as a percentage of total wealth is <21; In blue, high dependence. Cambodia, Myanmar and Tanzania are excluded because of lack of data.

We find that mangroves are the only coastal ecosystem for which we have sufficient scientific knowledge and data to establish priorities for climate change mitigation. This type of coastal blue carbon ecosystem can play a significant role on climate change mitigation since mangroves are carbon-intensive ecosystems that are geographically concentrated and that are among the most threatened ecosystems in the world. We put forward a country-taxonomy according to the climate change mitigation potential and the break-even carbon price for the top 25 mangrove countries, and we identify factors that should be considered to further develop such taxonomy such as co-benefits, but also risks, among other, due to trade-offs between carbon, biodiversity and social objectives.

We empathise that coastal blue carbon conservation is more effective than restoration, but that the latter will be difficult to avoid given the extent of loss of mangrove forests. Concerning financing and management mechanisms, due to the time it may take to include coastal blue carbon in market schemes and to avoid the associated side-effects and unforeseen events, fines, protection of carbon-rich areas, subsidies and offsets for damages may play an important role for the conservation and restoration of mangroves. The capacity of the private sector to bring innovative, cost-effective solutions must be weighted by its high cost of capital due to the (high) risks. In any case, instruments should be designed to guarantee an adequate balance between local communities' participation and state regulation. Overall, coastal blue carbon schemes are yet to be fully developed and scaled-up.

There are important potential linkages between climate change adaptation and coastal blue carbon. Among the different sectors, coastal zones have the highest adaptation costs and the bulk of the coastal adaptation costs are related to sea dikes. Interestingly, some research points to the role of mangrove forests as an alternative solution to the construction of sea-dikes that can be cost-effective and less damaging for ecosystems. Within this context, there are

several economies among the top 25 mangrove countries that have high exposure to coastal risk and that have committed to reduce over 25 per cent of their greenhouse-gas emissions against the business as usual scenario by the year 2030 (Brazil, Cambodia, Ecuador, Gabon, Indonesia, Madagascar, Philippines and the US). Although the complementarity between adaptation and mitigation strategies can be substantial, attention needs to be paid in the case of the interventions of multilateral development banks. Since large funds are being allocated for resilience and it is easier to measure project inputs than project effectiveness, development banks tend to choose grey instead of green infrastructure.

Finally, we provide some information about the extent to which the top 25 mangrove countries are familiar with marine policies and marine research and training. Certain countries such as the US, Senegal, Brazil, Malaysia and Philippines and, to a lesser extent, Indonesia, Mexico and Thailand stand out in this kind of analysis. A better ex-ante understanding of the governance and socio-economic factors associated with coastal ecosystems would enable to better prepare project appraisal. In the absence of such coastal-specific data, proxies are often used by the international community. In our sample of mangrove countries, we can see, for instance, that we have with countries with high dependence to natural resources and low institutional endowments and countries with medium-low dependence to natural resources and higher institutional endowments. Such information can only provide a very preliminary broad picture that needs to be complemented with macro and microeconomic data relevant to the project.

3.9. Appendix 1

Tables and graph

Table 3.6. Top 25 mangrove countries according to the annual mangrove mitigation potential (million t CO₂ e/year)

	Annual mangrove mitigation potential (million t CO ₂ e/year)	Classification
Indonesia	30679644	Very high
Mexico	8137233	Very high
Papua New Guinea	4570866	Very high
Malaysia	4181896	Very high
Vietnam	2564008	High
Colombia	2261764	High
Pakistan	2026638	High
United States	1953947	High
Guinea-Bissau	1832201	High
Myanmar	1790324	High
Philippines	1762242	High
Sierra Leone	1716291	High
Gabon	1698338	High
Honduras	1631183	High
Madagascar	1539227	High
Senegal	1342843	High
India	1133760	Medium
Venezuela	1124822	Medium
Panama	1056887	Medium
Tanzania	755870	Medium
Ecuador	684104	Medium
Nicaragua	681651	Medium
Brazil	872828	Medium
Cambodia	692276	Medium
Thailand	603800	Medium

Source: Author work based on Murray *et al.* (2011).

Table 3.7. Top 25 mangrove countries according to the break-even carbon price (\$/tCO₂ e)

	Break-even carbon price (\$/t CO ₂ e)	Classification
Senegal	1,7	Low
Cambodia	2,14	Low
Guinea-Bissau	2,16	Low
Malaysia	2,34	Low
Sierra Leone	2,6	Low
Madagascar	2,73	Low
Tanzania	3,35	Medium
Myanmar	3,78	Medium
Indonesia	4,04	Medium
India	4,1	Medium
Pakistan	4,46	Medium
Mexico	4,74	Medium
Gabon	4,9	Medium
Nicaragua	5,13	Medium
Vietnam	5,32	Medium
Ecuador	6,53	High
Thailand	6,53	High
Papua New Guinea	6,58	High
Venezuela	6,83	High
Philippines	6,9	High
Brazil	6,98	High
Honduras	7,83	High
Panama	7,95	High
United States	8,34	High
Colombia	11,31	High

Source: Author work based on Murray *et al.* (2011).

Legend: The mitigation potential is discounted to the present with a 10% rate as well as scaled down to represent only lands at risk from conversion to agriculture, aquaculture, or wood harvests.

Table 3.8. Exposure to coastal risks in the top 25 mangrove countries

	Coasts at risk: Exposure	Ranking
Philippines	0,2095	Very high
Vietnam	0,1445	Very high
Cambodia	0,1333	Very high
Madagascar	0,0558	High
Indonesia	0,0520	High
Malaysia	0,0422	High
Gabon	0,0393	High
Myanmar	0,0393	High
Ecuador	0,0342	High
United States	0,0240	High
Brazil	0,0232	High
India	0,0227	Medium
Papua New Guinea	0,0214	Medium
Tanzania	0,0189	Medium
Thailand	0,0197	Medium
Honduras	0,0150	Medium
Senegal	0,0115	Medium
Venezuela	0,0158	Medium
Mexico	0,0136	Medium
Panama	0,0129	Medium
Guinea-Bissau	0,0099	Low
Colombia	0,0087	Low
Pakistan	0,0053	Low
Nicaragua	0,0036	Very low
Sierra Leona	0,0035	Very low

Source: Author work based on Beck (2014).

Table 3.9. Natural resources in the top 22 mangrove countries

	Natural capital % total wealth	Natural capital per capita (US\$)	Dependence per total wealth
Papua N. Guinea	95,3	8 569	Very high
Gabon	71,9	42 065	Very high
Guinea-Bissau	55,6	2 078	Very high
Madagascar	54,9	1 918	Very high
Ecuador	51,4	22 454	Very high
Honduras	47,3	12 012	Very high
Venezuela	43,7	30 567	Very high
Vietnam	38,7	3 630	Very high
Sierra Leone	33,8	1 363	High
Pakistan	27,4	3 355	High
India	25,6	2 704	High
Nicaragua	24,1	4 730	High
Indonesia	24,9	4 926	High
Thailand	20,6	7 810	Medium
Malaysia	19,6	12 750	Medium
Brazil	18,9	14 978	Medium
Philippines	17,6	3 468	Medium
Colombia	13,9	7 614	Medium
Senegal	11,8	1 621	Medium
Panama	10,5	7 944	Medium
Mexico	5,0	6 641	Low
United States	1,8	13 822	Low

Source: Author work calculations based on World Bank (1997) for 2005 data.

Legend: A country has low dependence on natural resources when natural capital as a percentage of total wealth is <21; high dependence, otherwise. We exclude Ecuador, Gabon and Venezuela from the high dependence sample since we consider these countries as outliers given their ratios of natural capita per capita. Cambodia, Myanmar and Tanzania are excluded because of lack of data.

Figure 3.3. Top 25 mangrove countries by break-even carbon price

Source: Based on Murray *et al.* (2011).

Legend: The curve represents the mobile mean.

3.10. Appendix 2

Non-marine specific indicators for the top 25 mangrove countries – Example

While economic growth is positively correlated with natural capital per capita or natural capital abundance, it is instead negatively correlated with natural capital as percentage of total wealth or natural capital dependence (Gylfason and Gylfi, 2006). A casual look at countries displayed following the World Bank income classification supports this argument (see Table 3.10). Once we disaggregate the data on the top 25 mangrove countries depending on the level of dependence of mangrove countries on natural capital as a percentage of total wealth, about half of the sample is characterised by upper-middle income countries with a low dependence on natural resources (14.1 per cent) and a relatively high ratio of natural capital per capita (USD 8 307). The other half of the sample is characterised by low and lower-middle income countries with a high dependence on natural resources (44.7 per cent) and a relatively low ratio of natural capital per capita (USD 4 731). This may have implications for the structure of the economy and its associated institutional endowments since natural capital dependence tends to crowd out, among other factors, social, physical, human and financial capital (Gylfason, 2001).

Table 3.10. Natural resources in the top 22 mangrove countries: Classification

	Natural capital per capita (USD)	Natural capital % total wealth
Low income	2 316	35,5
Lower middle income	4 357	25,5
Upper middle income	14 104	16,6
High income: OECD	10 946	1,9
Mangrove : All	9 864	32,1
Mangrove: Medium-low dependence on natural resources	8 186	13,3
Mangrove: Very high-high dependence on natural resources	10 797	45,7
Mangrove: Very high-high dependence on natural resources(*)	4 528	42,8

Source: Author work calculations based on World Bank (1997) for 2005 data.

Legend: A country has medium-low dependence on natural resources when natural capital as a percentage of total wealth is <21; high dependence, otherwise. (*): We exclude Ecuador, Gabon and Venezuela from the high dependence sample since we consider these countries as outliers given their ratios of natural capital per capita. Cambodia, Myanmar and Tanzania are excluded because of lack of data.

4. ECONOMIC GROWTH DETERMINANTS IN COUNTRIES WITH HIGH COASTAL CLIMATE CHANGE ADAPTATION NEEDS AND MITIGATION POTENTIAL

4.1. Introduction

Many of the climate change impacts of economic activities are important to the coastal environment. These include inundation of wetlands which affects coastal ecosystems, bleaching of coral reefs, changing oceanographic processes that affect marine productivity, and the loss of marine habitats and biodiversity (Patterson and Glavovic, 2008).⁹² Sea level rise however, will have the greatest impact on coastal ecosystems. The impact of sea level rise is likely to affect tens of millions of people and cost billions of dollars on a global scale in the next century (Darwin and Tol, 2001).

Coastal vegetated habitats are increasingly attracting the attention of researchers and policy makers due to their role in climate change adaptation and mitigation. These habitats, in particular, seagrasses, salt-marshes, macroalgae and mangroves contribute to almost 50 per cent of carbon burial in marine sediments despite occupying only 0,2 per cent of the ocean surface (Duarte *et al.*, 2013). Nevertheless, about 25 to 50 per cent of the area covered by vegetated coastal habitats has already been lost in the past 50 years. The carbon stock in soil in coastal areas is one order of magnitude lower than that under terrestrial forests, but can play an important role on the global carbon cycle since coastal areas can support intense burial rates and keep the carbon stored for thousands of years in sediments (Fourqurean *et al.*, 2012).

The coastal habitats also raise the seafloor, buffering the impacts of rising sea level and wave action associated with climate change. The role of nature-based solutions for coastal protection can be very significant. Only for coasts, the total global adaptation costs (beach nourishment, port upgrades and capital and maintenance on river and sea dikes) for a scenario of no additional sea-level rise ranges from USD 10,4 billion per year in the 2010s to USD 9,5 billion per year in the 2040s (Nicholls *et al.*, 2010). About two-thirds of the total adaptation costs for coastal protection come from sea dikes, increasing to over 90 per cent when maintenance costs are considered. Mangrove forests, for instance, can be alternative solutions to the construction of expensive sea dikes that damage ecosystems (Berrenstein, 2012). The European Union has adopted a strategy on green infrastructure to enable ecosystems to deliver their many services, among which adaptation and mitigations services, to people and nature.

Beyond climate change, there are other economic drivers of change that affect coastal systems. It is estimated that more than two billion people and nearly half of the world's major cities are found within 50 km of coastlines (Brown *et al.*, 2008, and MEA, 2005). There is a momentum in coastal agglomeration growth since economic growth and geographical agglomeration are mutually reinforcing processes (Martin and Ottaviano, 2001). The world economy has already expanded six-fold between 1950 and 2000, with some sectors such as coastal tourism, fishing, energy, minerals and agriculture, having a disproportionate impact on the coastal environment (Patterson and Glavovic, 2008). Concerning tourism, it is the world's largest and fastest growing industry which has expanded 65 times between 1950 and 2000 in

⁹²I would like to thank Steven Durlauf and Grigoris Emvalomatis for insightful thoughts and suggestions as well as for data and econometric programs shared at the 2nd Advanced summer school in economics and econometrics at the University of Crete, Rethymno on the 19th-26th of August 2007. I would also like to thank Enrique Moral-Benito for suggestions and data from Moral-Benito (2012), and Steven Poelhekke for data from van der Ploeg and Poelhekke (2010). I am grateful to the participants at the *Séminaire du Centre International de Recherche sur l'Environnement et le Développement* (CIRED) on the 29th January 2017 and at the *Séminaire Développement Durable Environnement et Economie Publique* (DDEEP-EconomiX, Paris Nanterre) on the 31st January 2017 for their comments and suggestions on the methodology and data.

terms of tourism numbers (CBD/UNEP, 2005 and Rekacewicz and UNEP/GRID-Arendal, 2001). Tourism infrastructure developments alone are a major cause of habitat loss in Mediterranean coastal ecosystems (WWF Global Marine Programme, 2006).

On the other hand, at least three billion people are thought to depend on marine and coastal biodiversity for their livelihoods (SCBD, 2009). Furthermore, while people living in coastal areas experience higher wellbeing than those living in inland areas, the acute vulnerability of coastal systems to degradation puts coastal inhabitants at greater relative risk (Agardy, 2004). In addition, within coastal development processes, certain coastal communities are politically and economically marginalised, particularly in the developing world, whereby wealth disparity and poverty may reinforce coastal degradation. A key question is then how to reach an equilibrium between coastal development and ecosystem conservation in the context of climate change. Development and conservation should be both seen as part of the same basic infrastructure needed to deliver essential services in coastal areas (Emerton, 2014).

An underlying problem to preserve coastal ecosystems is that market valuations do not capture the non-monetary values of their services, and so they are rarely considered when resource management decisions are made (Mohammed, 2012). Accounting guidelines and comprehensive macroeconomic frameworks should be developed to mainstream these ecosystem services among other economic activities. There have already been some efforts on marine and coastal valuation that have enabled to raise awareness among the population and policy makers on the weight of marine and coastal ecosystem services in local economic activities such as tourism (Vo *et al.*, 2012). The valuation and accounting guidelines remain nevertheless largely behind those developed for terrestrial ecosystem services.

It is only with the rising awareness of the international community about the climate change mitigation potential in coastal areas that vegetated coastal habitats have been devoted attention beyond the biological conservation community (Duarte *et al.*, 2008). The characterisation of vegetated coastal areas as global public goods in the climate change discussions, has multiplied almost by four the production of academic papers on this matter between 2005 and 2012 (Duarte, 2013). However, there is still a need to raise awareness, particularly at the local level, on the benefits of nature-based adaptation and mitigation solutions to address climate change since local managers will commonly opt for (expensive) hard adaptation measures and on-land mitigation options (UICN France, 2016). Nature-based solutions are solutions that build upon ecosystems in order to meet challenges, such as addressing climate change.

To our knowledge, this is a first attempt to explore the economic growth determinants in countries with high climate change coastal adaptation needs and coastal mitigation potential, given the potential synergies between nature-based adaptation and mitigation strategies. This analysis can inform how to put in place development strategies that can play an effective role on economic development, including the integrated management of coastal development. This work aims at motivating the need to further develop appropriate accounting and macroeconomic frameworks to fully integrate coastal habitats within the basic infrastructure required to sustain economic activity.

In the following section, we describe the previous empirical literature on the determinants of economic growth in coastal countries, and we explain how we attempt to contribute to this literature. In section three, we describe the econometric model and some preliminary analyses. We present the data used in our analysis and share both the preliminary results and the estimations on the determinants of economic growth under uncertainty. In section four, we conclude and share some future avenues of work. The appendix provides a detailed description of the data and the estimations.

4.2. Economic growth determinants in countries with high coastal climate change adaptation needs and mitigation potential: What have we learned so far?

The scale and nature of the combined challenges of climate change and resource scarcity require new accounting and macroeconomic frameworks (Weber, 2014 and Daly and Farley, 2004).⁹³ In addition, full endorsement by policy makers to develop and to integrate these frameworks remains a challenge (WWF, 2015b). There has been little progress as well to make use of some existing natural capital accounts on policy decisions (Laurans *et al.*, 2013 and Jeantil *et al.*, 2016). In view of these difficulties, already available analytical tools may offer some information to explore the role of coastal ecosystems services in countries with adaptation needs and mitigation potential.

If we explore the determinants of economic growth in coastal countries, we must cite the pioneer work by Smith (1976) where the relationship between the geographical location and international trade is analyzed. The rapid development of civilizations around the Mediterranean basin was due to the relative ease of sea-based trade in the region (Braudel, 1972, McNeill, 1974, Jones, 1981 and Crosby, 1986). Relatedly, there is large evidence of the positive relationship between trade statistics and economic growth through, for instance, the fraction of exports and total trade in the gross domestic product (GDP) (Frankel and Romer, 1999 and Alcalá and Ciccone, 2004). The geographical advantage has changed over time though, as technology has evolved with railroads, automobiles, air transport and telecommunications, reducing the advantages of the coastline relative to the hinterland.

Yet, coastal countries are still outperforming landlocked countries. Landlocked countries outside of Western and Central Europe which are strongly integrated, have an average income less than half compared to that of the non-European coastal countries (Easterly and Levine, 2001). There are several reasons that explain the higher income in coastal countries compared to landlocked countries. With a data set on 43 developing countries for the period 1965-1990, Radelet and Sachs (1998) find, for instance, that the cost of freight and insurance for landlocked developing countries was on average 50 per cent higher than for coastal economies, which had a negative impact on economic growth. Moreover, countries with a longer coastline are likely to have more ports, a larger share of the population with relatively easy access to the sea and a larger share of economic activity grounded in international trade. Blooms and Sachs (1998), Masters and Sachs (2001) and Bloom *et al.* (2003) find that coastline length is a positive and significant determinant of economic growth.

Gallup *et al.* (1998) find that higher coastal population density is associated with faster economic growth during 1965-1990, while higher interior population density is associated with lower economic growth.⁹⁴ Population density on the coast is likely to be associated with an increased division of labour, with increasing returns to scale in infrastructure and with falling rates of population growth as incomes per household rise.⁹⁵ Population density in the hinterland is likely to be associated with diminishing returns with few opportunities for absorbing population through manufacturing and international trade and with high rates of population

⁹³ In particular, some researchers argue that there is a need to derive a fully consistent macroeconomic framework in which it is possible to maintain economic stability, ensure full employment, and yet remain within the ecological constraints and resource limits of a finite planet (Jackson, 2009 and Victor and Jackson, 2013). More work is also required with regard to economic valuation, both for monetary and non-monetary approaches (Petersen and Gocheva, 2015). Moreover, physical accounting approaches need to be completed first as they provide a necessary platform on which to build economic valuation. A key conclusion to emerge from ongoing work is that future efforts to develop accounting frameworks should be targeted and purpose-driven (MAEDI and WWF, 2014).

⁹⁴ The relationship between population density and economic growth is positive when taking the country as unit of analysis (Sachs and Warner, 1995).

⁹⁵ There is a negative and significant relationship between population growth and economic growth (see, for instance, Kormendi and Meguire, 1985).

growth, and may therefore show Malthusian dynamics. Fleisher and Chen (1996) find that one reason that despite a higher rate of investment relative to GDP, the interior provinces in China have not grown more rapidly than their coastal counterparts in recent years is that the productivity of investment in the interior is not as high as in the coastal region.

When Gallup *et al.* (1998) identify geographical regions that are not conducive to modern economic growth, they find that many of these regions have high population density and rapid population increase. Current population growth tends to be highest in the more remote regions, mainly because population growth is negatively related to mother's education and because agriculture has been the principle driving force behind the population distribution. The mismatch between the geographical location for high population densities and the geographical location for modern economic growth designates the regions of mass poverty far from the coast in Asia and Africa. Furthermore, much of the population increase in the next thirty years is likely to take place in these geographically disadvantaged regions.

Despite the concentration of high population densities in the hinterland, there is evidence economies of agglomeration in the coastal regions which favour growth through, among other, the migration from the hinterland to the coast (Krugman, 1998). Gallup *et al.* (1998) find with 149 developed and developing countries in 1995 that more ocean-accessible regions in the world are more urbanised. Radelet and Sachs (1998) find that almost all fast-growing developing countries have based their rapid growth in the period after 1965 on labour-intensive assembly-type industries. Almost without exception, export processing zones are located in coastal economies, near good port facilities, and close to markets in the US, Japan or Europe.

There are also geographical effects on economic policy choices. A coastal economy, for example, may face a higher elasticity of output response with respect to trade taxes than a landlocked economy (Gallup *et al.*, 1998). As a result, a revenue-maximizing landlocked country may choose harsh trade taxes while a coastal country would not. The early liberalizers, on the whole, were the coastal economies. Relatedly, there is evidence of the positive relationship between friendly trade policies and economic growth through the growth and the level of openness indices, and through the years that an economy has been trading (Sachs and Warner, 1995, Harrison, 1996, Sala-i-Martin, 1997 and Wacziarg and Welch, 2003). Trading tariffs are negatively though non-significantly correlated with economic growth (Barro and Lee, 1994).

Besides international trade, natural hazards may also play a role in economic growth in coastal countries, particularly in those with high exposure to coastal risks. Growth empirics do not provide a definite answer on the relationship between natural disasters and economic growth (Cavallo *et al.*, 2013). According to neoclassical growth models, the destruction of capital stock is unlikely to affect the rate of technological progress but it may boost short-run economic growth (Shadnam, 2014). In endogenous growth models, natural disasters may increase economic growth by increasing investment and productivity of capital stock (Caballero and Hammour, 1994). Climatic disasters have sometimes been found to have a positive impact on economic growth through the relationship between the increasing frequency of these events and the total factor productivity (Cuaresma *et al.*, 2008 and Skidmore and Toya, 2002). Other authors find that extreme weather events impact negatively economic growth, particularly in the short-run and when the frequency of the events passes some threshold (Mechler, 2004 and Hallegatte *et al.*, 2007). Overall, higher temperatures and more climate extreme events tend to be associated with lower rates of growth, at least in developing countries (Bowen *et al.*, 2012).

Moreover, scant attention has been paid to explore the role of biodiversity in economic growth. For instance, in the second chapter of this thesis I analyzed separately the renewable and non-renewable components of natural capital, finding that renewable capital has some indirect negative impact on economic growth through health proxies. Besides some exceptions, the bulk of the studies on biodiversity and economic growth have instead focused on the reversed causality, that is, the (negative) impact that economic growth can have on biodiversity

(Antoci *et al.*, 2004). Many analyses explore whether the environmental Kuznets curve exists, where a U-shaped relationship between the per capita wealth and the proportion of species conserved is expected (McPherson and Nieswiadomy, 2005, and Mills and Wait, 2009). Biodiversity is often found to be one of the class of environmental problems where economic growth on its own is unlikely to result in a turning point towards a more sustainable and secure environmental future (Dietz and Adger, 2003).

In sum, high levels of GDP per capita in coastal countries are associated with low transport costs, economies of agglomeration, liberal economic policy choices and a coastal population. Besides, the empirical relationship between natural disasters and economic growth is yet not clearly established and few analyses have been undertaken to understand the impact of biodiversity in economic growth. From an econometric perspective, regression analyses show that a large number of variables are correlated with economic growth but are far from implying the direction of causation. The lack of agreed theoretical bases for empirical work and for a reduced form to apply in empirical analyses, has led researchers to abandon any a priori models and to let the data show which variables are correlated with economic growth through model uncertainty (Capolupo, 2009). In order to estimate accurately the role of the so-called new growth theories such as natural capital in determining economic growth, Durlauf *et al.* (2005, 2008a) and Sala-i-Martin *et al.* (2004) propose the BMA methodology.⁹⁶

To our knowledge, we propose a first attempt to have a better understanding of the determinants of economic growth in countries that are concerned with climate change mitigation and adaptation policies at the coastal level, given the potential synergies between nature-based adaptation and mitigation strategies. We estimate the augmented Solow model including new growth theories, among which the natural capital theory, under a BMA method that accounts for uncertainty

4.3. Empirical analysis

Econometric methodology

In section three, we firstly present the baseline model based on the augmented Solow model and a set of new growth theories. Secondly, we explain how we integrate theory and specification uncertainty through the BMA. Lastly, we explain how we perform our preliminary analysis.⁹⁷

Economic growth model: Baseline with eight fundamental and proximate theories

Many economic growth models are estimated using panel data to multiply the number of observations. Since the variation of growth rates at annual frequency rates may give very misleading information about the long-term growth process, we average data over five year periods.⁹⁸ Based on Durlauf and Quah (1999), we use the following augmented Solow model with a set of new growth theories (Solow, 1956 and Durlauf *et al.*, 2005, 2008a):

⁹⁶ Fernandez *et al.* (2001) show the superiority of BMA over other techniques in selecting regressors to explain cross-country growth.

⁹⁷ Starting with Durlauf and Johnson (1995), many researchers have also explored whether there is evidence of multiple growth regimes focusing on different variables in order to divide the sample and using several methodologies. That is, they analyse whether there is a common growth regime for the whole sample under conditional convergence or whether there is a growth process with multiple growth regimes in which economies with similar conditions tend to converge to one another. Because our samples are too small, we do not perform among our preliminary tests, an analysis to explore whether there are multiple convergence regimes.

⁹⁸ We have replicated the analysis with 10 year periods but the sample size is too small given the nature of our data (presence of heteroskedasticity and serial correlation). Even though averaging over the longest time horizon possible should better deal with eliminating business cycle effects that probably dominate per capita income fluctuations at higher frequencies, it comes at the cost of reducing the sample size

$$\log(y_{i,r}) = \gamma_0 \log(y_{i,r-T}) + \gamma_1 \log(s_{i,r}^k) + \gamma_2 \log(s_{i,r}^h) + \gamma_3 \log(n_{i,r} + g + \delta) + z_{i,r} + \alpha_i + \theta_r + \varepsilon_{i,r} \quad [1]$$

$$\gamma_1 = e^{\lambda T} \gamma_2 = (1 - e^{\lambda T}) \frac{\alpha_k}{1 - \alpha_k - \alpha_h} \gamma_3 = (1 - e^{\lambda T}) \frac{\alpha_h}{1 - \alpha_k - \alpha_h} \gamma_4 = -(1 - e^{\lambda T}) \frac{\alpha_k + \alpha_h}{1 - \alpha_k - \alpha_h}$$

where $y_{i,r}$ is the real per capita GDP for country $i = [1, \dots, N]$ across a time period $r = [r, r+T]$, T being 5 years, $s_{i,r}^k$, $s_{i,r}^h$ and $\log(n_{i,r} + g + \delta)$ denote the variables that measure the net factor accumulation in the neoclassical growth theory with the saving rates of physical capital accumulation ($s_{i,r}^k$) and human capital accumulation ($s_{i,r}^h$) and with population growth rates ($n_{i,r}$), the rate of labour augmenting technical progress (g) and the physical capital depreciation rate (δ), $z_{i,r}$ denotes a set of variables proxying eight new growth theories described in the data subsection and in the appendix (Tables 4.7 and 4.8), α_i is a country-specific effect, θ_r is a time-specific effect and $\varepsilon_{i,r}$ is the error term.⁹⁹

Each growth theory can be proxied by several variables (see Table 4.4). Note that typically $g + \delta = 0.05$ (Mankiw *et al.*, 1992). α_k and α_h are the parameters associated with the Cobb-Douglas production function on physical and human capital input variables, such that $\alpha_k > 0$, $\alpha_h > 0$ and $\alpha_k + \alpha_h < 1$. λ is a parameter that denotes the rate of convergence such that $\lambda < 0$. Saving rates of physical capital accumulation and saving rates of human capital accumulation are referred to hereafter as investment in physical capital and schooling, respectively.

We work with the following set of new eight growth theories including both proximate and fundamental theories: Demography, macroeconomic policy, regional heterogeneity for proximate theories, and religion, natural capital, geography, fractionalisation and institutions for fundamental theories (see Table 4.1). The determinants derived from a neoclassical growth model are referred to as proximate determinants because they are thought to be the most established drivers of economic growth. The term ‘proximate’ also reflects the ease with which these determinants can be influenced by policy measures. Fundamental determinants depend instead on slow-moving fundamental growth (Durlauf *et al.*, 2008b). Our economic growth regressions include both proximate and fundamental theories.

Fundamental theories can have direct and/or indirect effects on economic growth. To analyse this matter, we first develop estimations including both proximate and fundamental theories. If fundamental theories are significant in these estimations, this implies that they have a direct impact on economic growth. It may also be the case that fundamental theories are not significant in these estimations, and yet may have an indirect impact on economic growth.

To test this hypothesis, we develop estimations only including fundamental theories. If some of the fundamental theories in these latter estimations are significant, while they were not significant in the estimations with proximate and fundamental theories, we can infer that such fundamental theories have an indirect impact on economic growth through proximate theories. In fine, we analyse whether fundamental theories exert a direct influence on economic growth, or an indirect influence through their correlation with proximate theories.

Economic growth model: Uncertainty

(Durlauf *et al.*, 2008b). In turn, when the sample size is too limited and the number of explanatory variables large, estimation methods can be of limited use to distinguish robust from irrelevant variables.

⁹⁹ We note that in our economic growth regressions we replace the country-specific effect variables by the regional heterogeneity variables included in the new growth theories which enables us to take into account regional heterogeneity while decreasing the number of variables in the regression given the short number of observations typically associated with economic growth estimations.

There is a problem of model uncertainty when performing economic growth estimations that account for new growth theories following the regression model [1] (Brock and Durlauf, 2001, Brock *et al.*, 2003). That is, there is theory uncertainty since the statement that a theory is relevant does not preclude others from being relevant as well. Moreover, there is specification uncertainty since new growth theories do not translate naturally into specific regressors. To deal with model uncertainty, we employ a BMA estimator.

Table 4.1. Proximate and fundamental growth theories

PROXIMATE THEORIES

Demography	Health may contribute to explain differences in income per capita among countries (Shastry and Weil, 2003 and Weil, 2005)
Macroeconomic policy	Inflation, government consumption and terms of trade can impact economic growth (Barro, 1997)
Regional heterogeneity	Countries in different continents may not represent draws from a common growth model (Brock and Durlauf, 2001)

FUNDAMENTAL THEORIES

Religion	Religion beliefs and adherence may influence growth (Barro and McCleary, 2003, Durlauf <i>et al.</i> , 2012)
Natural capital	Natural capital dependence and abundance may impact economic growth (Sachs and Warner, 1995 and Gylfason, 2011)
Geography	Geographical and ecological conditions (climate zone, disease ecology, distance from the coast) can affect economic growth (Sachs, 2003)
Fractionalisation	Ethnic and linguistic heterogeneity can affect economic growth (Alesina <i>et al.</i> , 2003 and Easterly and Levine, 1997)
Institutions	The regulation of entry of new firms, the procedural formalism in courts can impact economic growth (Djankov <i>et al.</i> , 2002, 2003)

In model averaging models, we treat the growth model as an unobservable variable. To account for this variable, each model specification m in the model space M is associated with a posterior model probability $\mu(m|D) \propto \mu(D|m) \mu(m)$, where D is the available data, $\mu(D|m)$ is the likelihood of the data given the model and $\mu(m)$ is the prior model probability. We set the prior probability that a particular theory is in the true model to 0,5 to reflect non-information across theories (Durlauf *et al.*, 2008a).¹⁰⁰ The posterior model probability is the probability that model m is the true model given the data and we can hence calculate whether a theory is in the true model by computing $\sum \{m \in M\} \mu(m|D, m \in A)$, where A is the event that at least one proxy variable is in the true model.

Data

The unbalanced panel data set covers 67 countries across different regions in the world for 10 five-year periods from 1960 to 2009 (see appendix for more details). The data includes 27 countries with very high exposure to coastal risks, 27 countries with high exposure to coastal risk and 23 mangrove countries with very high annual mangrove mitigation potential, (see Tables 4.4-4.6 in the appendix).

¹⁰⁰Assigning equal prior probability to each possible model can have odd implications for linear regressions with a large number of potential regressors, though. However, the number of variables we are including is not very large compared to other analyses, since we are building over Durlauf *et al.* (2008a) results.

We use the coasts at risk exposure index on the vulnerability of coastal zones to climate change as an imperfect but currently available proxy to enable to derive the data set.¹⁰¹ The index describes the share of the population exposed to coastal hazards per country and is calculated by summing up all exposed people per hazard divided by the number of inhabitants per country (Beck, 2014). It takes two different types of natural hazards into account; it focuses primarily on current and sudden onset hazards, such as storms, floods, storm surges and tsunamis, but also includes the slow onset hazard of sea level rise based on the exposed people to sea level rise by one meter.

Since we only have country-level geospatial data for mangroves, this represents the only coastal habitat for which we can currently derive analyses on their mitigation potential and identify priority areas with precision.¹⁰² The annual mitigation potential for mangrove habitats at current conversion rates would enable to offset 2,3 to 6,8 per cent of the current fossil fuel emissions, over half of that projected for reducing rainforest deforestation (Nellemman *et al.*, 2009). Evidence suggests that there is scope for obtaining significant mitigation since much of the mangrove mitigation potential lies in a small group of countries. Almost 80 per cent of mangrove mitigation potential resides in a few countries whose annual mitigation potential is over 3 million t CO₂e, 55 per cent of that potential resides in seven countries with at least five million t CO₂e (Murray *et al.*, 2011).

The choice of the eight growth theories and the associated variables is largely inspired by the work of Durlauf *et al.* (2008a).¹⁰³ Besides the eight growth theories, we also include a category named ‘other’ to account for some instruments and for time dummy variables. There are some differences in the choice of variables when comparing our work with the study of Durlauf *et al.* (2008a). In particular, we use the average growth rate of real per capita GDP instead of the average growth rate of real per worker GDP since the dataset from Caselli (2005) does not cover our period of study.

For the geography theory, we use some variables suggested by Durlauf *et al.* (2005) since those used by Durlauf *et al.* (2008a) were often not available for our sample of countries. For the institutions theory, we use some proxies for individual and minority rights and public sector corruption, instead of expropriation risks since the latter was not available for our period of study. Moreover, we include variables on natural capital suggested by Gylfason (2011). The detailed definition of the variables, their designation and the data sources are given in Tables 4.7-4.8 in the appendix.

Preliminary results

¹⁰¹Global studies on the vulnerability of coastal zones to sea-level rise and storm surges are severely hampered by the unavailability of data on coastal protection at the global level (Füssel, 2009). As an example, results on population below one meter above sea level (Buys *et al.*, 2007 and Dasgupta *et al.*, 2007) and on percentage change in population annually flooded (Hinkel, 2008 and Klein and Hinkel, 2009) show little agreement regarding the most vulnerable countries. While acknowledging these data limitations, coastal protection is the only sector for which our knowledge of adaptation costs (and benefits) has most progressed with a comprehensive coverage (Agrawala and Fankhauser, 2008).

¹⁰²Besides data availability constraints, there are still large sources of uncertainty in the rates of land use conversion and the fates of coastal vegetated ecosystem carbon upon conversion (Duarte, 2014, Pendleton *et al.*, 2012). A key question about carbon is where it comes from and what happens to it when the ecosystem releases it. In the case of seagrass meadows, for instance, scientists ignore whether the carbon released from sediments when seagrass dies goes into the atmosphere or remains somewhere else nearby or simply contributes to increased ocean acidification.

¹⁰³The analysis of Durlauf *et al.* (2008a) is robust since they built their work over an exhaustive survey of the empirical growth literature which identifies 43 growth theories and 145 regressors. Each of these theories is found to be statistically significant in at least one study (Durlauf *et al.*, 2005).

In this section, we summarise the preliminary analysis results in Tables 4.9-4.12 in the appendix. We perform some preliminary tests which have revealed that the data shows heteroskedasticity and serial correlation which needs to be taken into account in our analyses. Furthermore, we present the summary statistics and the correlation matrix between proximate and fundamental theories for countries with very high and high exposure to coastal risks and for countries with high coastal climate change mitigation potential. The correlation matrix conveys some useful information on the explanatory power of fundamental theories in the economic growth regression. It may be the case that the influence of some of the fundamental theories (religion, natural capital, fractionalisation and institutions) is exerted through proximate theories, and that these fundamental theories have no direct impact on economic growth in both type of samples of countries.

Economic growth regression results

In the following lines, we present our findings for the augmented Solow model and eight new growth theories based on equation [1].¹⁰⁴ Tables 4.13 and 4.14 show BMA results for the case where we include both proximate and fundamental determinants in the model space (columns 1-3) as well as the case where only fundamental growth determinants are in the model space (columns 4-6). Columns 1 and 4 provide the posterior probability that each theory is in the ‘true’ model under the BMA method. In Tables 4.2 and 4.3 below, we share the summary findings for the BMA posterior inclusion probability and for the BMA posterior mean results for countries with very high and high exposure to coastal risks and for countries with high coastal climate change mitigation potential. In Tables 4.15 and 4.16 in the appendix, we share the equivalent findings for countries with very high exposure to coastal risks and for countries with high exposure to coastal risks.

Given the prior probability of a theory being in the true model space is set at 0,5, the robustness of a theory will depend on how the data updates this prior through the posterior probability of inclusion of the theory in the true model. In Tables 4.2 and A10-A11, we can appreciate that the robust new growth theories both for countries with high exposure to coastal risks and for countries with high coastal climate change mitigation potential include demography, macroeconomic policy and natural capital.¹⁰⁵ With regards to demography variables, in Tables 4.3 and A10-A11, we can see that the effect of *fertility* is detrimental to economic growth and significant as in Barro (1991, 1996 and 1997) and Barro and Lee (1994). This finding contrasts with Gallup *et al.* (1998)’s results on population density but may be explained by our unit of analysis which is the country, instead of coastal regions.

Concerning macroeconomic policy, *inflation* is negatively and significantly correlated with economic growth, in line with previous findings (Barro, 1997 and Bruno and Easterly, 1998). Besides, this result backs the relevance of macroeconomic policy in coastal countries due to the role of international trade (Gallup *et al.*, 1998). In terms of natural capital, the share of natural capital in wealth is negatively and significantly correlated with economic growth, which is consistent with the findings of Ding and Field (2005) and Cerny and Filer (2007). That is, a

¹⁰⁴ The ratio of observations to independent variables should not fall below five (Bartlett *et al.*, 2001). As in Durlauf *et al.* (2005), we therefore exclude from the BMA regressions the variables which have weaker explanatory power in our regressions with respect to those presented in Table 4.9 (some religion variables: buddhism, catholic, jew and orthodox). We check for multicollinearity whereby additional variables are also excluded from the BMA regressions (some regional heterogeneity variables: East Asia and the Pacific and some institutional variables: liberal democracy, public sector corruption, legal formalism: Check (1), legal formalism: Check (2) and complex).

¹⁰⁵ When we perform the analysis separating countries with very high and with high exposure to coastal risks, we observe that the results are very similar compared to the ones we obtain with one unique sample covering both countries with very and high exposure to coastal risks. The results are available in Tables 4.15 and 4.16 in the appendix. We have also replicated the analyses in Table 4.2, separating the natural capital variables on renewable and non-renewable natural capital sub-components and the results remain the same. They are available upon request.

too large dependence on natural capital has a negative impact on economic growth, there is a need to diversify by investing in intangible capital (Gylfason, 2011). Besides, in contrast to Blooms and Sachs (1998), Masters and Sachs (2001) and Bloom *et al.* (2003), we find that geography and, in particular, coastline length has no significant impact on economic growth which may be due to the fact that we have a more homogeneous sample.

Table 4.2. Economic growth determinants for different country typologies (I): BMA posterior inclusion probability results

	Proximate and fundamental theories		Fundamental theories	
	High adaptation needs	High mitigation potential	High adaptation needs	High mitigation potential
DEMOGRAPHY	1,000	0,980		
MACROEC. POLICY	1,000	0,999		
REGIONAL HETERO.	0,320	0,089		
RELIGION	0,062	0,264	1,000	0,524
NATURAL CAPITAL	0,964	0,999	1,000	1,000
GEOGRAPHY	0,048	0,086	0,053	0,089
FRACTIONALISATION	1,000	0,624	0,999	0,189
INSTITUTIONS	1,000	0,366	1,000	0,836

Note: This table provides the summary results for the posterior inclusion probability for the eight growth theories for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 54 countries with very high and high exposure to coastal risks and 23 countries with high annual mangrove mitigation potential.

In terms of the neoclassical growth variables, our findings are consistent with those in the conditional convergence literature as well as previous studies that have used BMA methods. In Table 4.3, we can see that we find robust evidence of conditional convergence with a negative and significant coefficient on initial income as many previous studies (see, for instance, Barro, 1991, Sachs and Warner, 1995, Barro, 1997 and Easterly and Levine, 1997). There is also evidence that investment in physical capital is positively and significantly correlated to economic growth in line with previous findings (see, for example, Barro, 1991, Barro and Lee, 1994, Sachs and Warner, 1995, Barro, 1996, Caselli *et al.*, 1996 and Barro, 1997). The effect of schooling is not significant, but this result remains largely consistent with the literature (Durlauf *et al.*, 2008a). In exercises where we drop demography from the model space, we find that population growth rates are negatively and significantly related to growth (Mankiw *et al.*, 1992, Kelley and Schmidt, 1995 and Blooms and Sachs, 1998).¹⁰⁶

Besides these results, we find that fractionalisation and institutions are additional robust determinants of economic growth in countries with high exposure to coastal risks. Concerning the fractionalisation theory, the *language* variable is significant and negative in Table 4.3 in line with previous analyses (Easterly and Levine, 1997 and Alesina *et al.*, 2003). These results are consistent with previous work in the empirical literature suggesting an important role for fractionalisation in economic growth (Easterly and Levine, 1997 and Alesina *et al.*, 2003). More diversity can lead to more conflicts and less communication, even controlling for the latter it also leads to higher productivity (Alesina and La Ferrara, 2005).

Our results for institutions point out that executive constraints have a negative and significant impact on economic growth in contrast with the result of Acemoglu *et al.* (2002) where institutions are positively correlated with economic growth. These results may suggest that greater checks and balances may depress growth (Barro, 1994). They may also suggest that

¹⁰⁶ Results are available upon request.

to the extent that our measure of executive constraints correlates with political instability, there is significant evidence in the empirical literature of a negative relationship with respect to economic growth.¹⁰⁷

Table 4.3. Economic growth determinants for different country typologies (I): BMA posterior mean results

	Proximate and fundamental theories		Fundamental theories	
	High adaptation needs	High mitigation potential	High adaptation needs	High mitigation potential
NEOCLASSICAL				
<i>income_ini</i>	-	-	-	-
<i>invest</i>	+	+	NA	NA
DEMOGRAPHY				
<i>fertility</i>	-	-	NA	NA
MACROEC. POLICY				
<i>inflation</i>	NS	-	NA	NA
RELIGION				
<i>eastern</i>	NS	NS	+	+
NATURAL CAPITAL				
<i>natural_w</i>	NS	NS	-	NS
FRACTIONALISATION				
<i>language</i>	-	NS	-	NS
INSTITUTIONS				
<i>exe_constr</i>	-	NS	NS	NS

Note: This table provides the summary results for the posterior mean for the eight growth theories for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 54 countries with very high and high exposure to coastal risks and 23 mangrove countries with high annual mangrove mitigation potential. ‘+’ stands for a positive and significant impact on average growth rates of pc GDP, ‘-’ stands for a negative and significant impact, ‘NS’ stands for a non-significant impact and ‘NA’ stands for non-applicable.

Otherwise, we find that the religion theory is only a determinant of economic growth when analysing fundamental theories alone for countries with high exposure to coastal risks. The associated variables to the religion theory do not appear to matter for economic growth in the sense that the posterior probability of inclusion is lower than the prior of 0,5 when accounting for proximate and fundamental theories (see Table 4.2). These results appear to contradict previous work in the empirical literature suggesting an important role for religion in growth (Barro and McCleary, 2003).

If we drop proximate growth theories from the model space and retain only fundamental growth theories, the posterior probability of inclusion for religion as a theory is very high at 1,00 for countries with high exposure to coastal risks as the eastern religion variable is

¹⁰⁷Our executive constraints variable reflects the outcomes of most recent elections as a ‘political institution’ variable (Glaeser *et al.*, 2004). Some authors suggest that this variable cannot be therefore interpreted as reflecting durable rules, procedures or norms. Given such view, Cox and Weingast (2015) find that in terms of moderating succession-related downturns and thereby promoting steadier economic growth, the quality of legislatures measured by the executive’s horizontal accountability is more important than the existence of free and fair elections. In addition, to the extent that elections may correlate with political instability, there is significant evidence of negative relationship with respect to economic growth (see, for instance, Barro, 1991, Barro and Lee, 1994, Sachs and Warner, 1995, Alesina *et al.*, 1996 and Castelli *et al.*, 1996).

important by our t-statistic rule of thumb as in Durlauf *et al.* (2008a). One interpretation of these results is hence at religion affects economic growth indirectly through its influence on proximate variables.¹⁰⁸ This is consistent with our preliminary results where, among fundamental theories, religion is correlated with neoclassical, demography and regional heterogeneity variables (Table 4.10). As in Durlauf *et al.* (2008a), our results indicate that previous findings on the direct importance of religion to economic growth are fragile.

To conclude, we find that according to the BMA method the robust direct new growth theories include demography, macroeconomic policy and natural capital both for countries with high exposure to coastal risks and for countries with high coastal climate change mitigation potential. In addition, initial income and investment in physical capital are also significant variables in explaining economic growth.

4.4. Conclusion

In this thesis in general and in this chapter in particular, we aim at bringing some light on the determinants of economic growth in countries with high exposure to coastal risks and with high coastal climate change mitigation potential, given the potential synergies between nature-based adaptation and mitigation strategies. We use a data set on 67 countries for the period 1960-2009, and we take into account theory and specification uncertainty and confirm the presence of multiple growth regimes.

We find evidence that the neoclassical (initial income and investment in physical capital), demography, macroeconomic policy and natural capital are the robust determinants of economic growth both in countries with high exposure to coastal risks and with high coastal climate change mitigation potential. These results suggest that a country's capacity to deal with climate adaptation and mitigation policies relying on nature based-solutions is associated with factors that impact economic growth. There is strong historical evidence on the relationship between demography, macroeconomic policies and non-renewable natural resources, and trade flows and economic growth in coastal countries. These factors highlight the pressures that coastal areas are subject to such as construction and public works, population growth and urbanisation. Our results are particularly relevant for Brazil, Cambodia, Ecuador, Gabon, Indonesia, Madagascar, Malaysia, Myanmar, Philippines, United States and Vietnam, which have both high exposure to coastal risks and high coastal climate change mitigation potential.

Growth-oriented macroeconomic policies can exert great pressure on natural resources as it was the case, for instance, in Indonesia (Dahuri and Dutton, 2000). In fact, policies with inflationary impacts such as increases in money supply and government expenditures, and decreases in taxes, cause the aggregate demand to grow. Despite higher prices of consumer goods and higher demand for labour in the formal sector, wages need not increase when there is labour surplus. Hence, expansionary policies may place more pressure on coastal resources and ecosystems and lead to faster depletion and degradation (Francisco and Sajise, 1992). In addition, greater government consumption can lead to lower economic growth because resources are diverted from more productive investments, as those needed to sustain economic activity in coastal areas.

In terms of natural capital, we find that the share of natural capital in wealth is negatively and significantly correlated with economic growth. That is, a too large dependence on natural capital has a negative impact on economic growth, and there is a need to diversify the sources of wealth by investing in intangible capital (Gylfason, 2011). This negative effect of natural capital dependence on economic growth may be partly related to the export of non-renewable resources and the associated 'resource curse' problems (see, for instance, van der Ploeg, 2010 and Ross, 2014). Depending on institutional factors, the type of indicators (export

¹⁰⁸ We should note that in exercises where we included the demography variables in the fundamentals only model space, the religion variables that were found to be robust determinants in column 4 of Table 4.3 become non-robust with a posterior probability of 0,3611. Results are available upon request.

dependence versus stock abundance) and other sources of heterogeneity, this negative relationship can be reversed (Dinh and Dinh, 2016). In our analysis, this result, in any case, brings to the forefront the relevance of coastal areas for exports in this kind of countries, and the pressures that these areas may be subject to.

Many studies show a clear and direct antagonism between demography and natural capital, as an increasing population increases the anthropogenic pressure on ecosystems (Cinner *et al.*, 2009a and Bond Estes *et al.*, 2012), through direct exploitation as well as indirect effects such as uncontrolled sewage or farming runoffs. Hence, in countries with high levels of natural capital and high demographic growth, natural capital can be wasted for short-term gain rather than used in a more sustainable way for long-term benefit (Larrère and Larrère, 1997), jeopardizing the expected growth. In terms of policies, short-term gain is still often preferred to ecosystem services management (MEA, 2005). Moreover, according to the ‘Malthusian trap’ the resource abundance would encourage population growth, which would eventually bring the per capita supply of resources back to its original level (Malthus, 1798).

Many of the world's coasts are becoming increasingly urban, with strong increases in coastal population, which in turn damages coastal ecosystems. At the same time, most coastal cities' current defences against storm surges and flooding have already high exposure to current climate conditions (Nicholls *et al.*, 2008). Global flood damage for large coastal cities could cost \$1 trillion a year if cities do not take steps to adapt (Hallegatte *et al.*, 2013). Nature-based solutions can serve in this context as climate adaptation and mitigation tools that produce additional co-benefits for societal well-being, thereby being relevant investment options for sustainable urban planning (Kabisch *et al.*, 2016). Ecosystem-based approaches have the potential to be more cost-effective, particularly in the long-run, compared to grey infrastructure solutions.

Higher level of awareness amongst policy makers and the general public are necessary, governments having a guiding role in acting as a motivating actor to foster these actions at the local level (Naumann *et al.*, 2011). Besides, given the little maturity of coastal climate change mitigation mechanisms and the fact that coastal areas have the highest climate change adaptation costs, there is a rationale to pledge for additional funding for climate change adaptation, in favor of both coastal climate change adaptation and mitigation (Ullman *et al.*, 2012).¹⁰⁹

¹⁰⁹ Only for coasts, the global adaptation costs (beach nourishment, port upgrades and capital and maintenance on river and sea dikes) for a scenario of no additional sea-level rise ranges from USD 10.4 billion per year in the 2010s to USD 9.5 billion per year in the 2040s (Nicholls *et al.*, 2010). Two-thirds of the total adaptation cost comes from sea dikes, increasing to over 90 per cent when maintenance costs are considered.

4.5. Appendix

Data

The data set constructed for this study contains observations for the period 1960-2009 on the following coastal countries listed in Tables 4.4-4.6 for which we have sufficient data on neoclassical variables.¹¹⁰ We have data on 27 countries with very high exposure to coastal risks, 27 countries with high exposure to coastal risks and 23 mangrove countries with high annual mangrove mitigation potential. Our sample has in total 68 countries of which 45 countries have only exposure to coastal risks, 13 have only very high annual mangrove mitigation potential and 10 have both exposure to coastal risks and very high annual mangrove mitigation potential.

Table 4.4. Countries with very high exposure to coastal risks

Countries	Coasts at risk: Exposure
Saint Kitts and Nevis	0,5955
Antigua and Barbuda	0,5893
Tonga	0,5108
Brunei Darussalam	0,2818
Fiji	0,2568
Vanuatu	0,2392
Philippines	0,2095
Japan	0,2080
Netherlands	0,2036
Bangladesh	0,1878
Seychelles	0,1776
Bahamas	0,1717
Belize	0,1685
Kiribati	0,1558
Mauritius	0,1548
Vietnam	0,1445
Samoa	0,1409
Guyana	0,1352
Cambodia	0,1333
Suriname	0,1146
Jamaica	0,1135
Djibouti	0,0869
Grenada	0,0832
Saint Vincent and the Grenadines	0,0820
Solomon Islands	0,0799
Saint Lucia	0,0768
Cuba	0,0739

Source: Author work based on Beck (2014).

¹¹⁰ The following countries were excluded from the analysis because of lack of data: Myanmar and Guinea-Bissau.

Table 4.5. Countries with high exposure to coastal risks

Countries	Coasts at risk: Exposure
Barbados	0,0704
Australia	0,0676
Cape Verde	0,0629
Bahrain	0,0604
Dominican Republic	0,0585
Madagascar	0,0558
Cameroon	0,0541
Ireland	0,0523
Republic of Korea	0,0522
Indonesia	0,0520
New Zealand	0,0484
Haiti	0,0478
Chile	0,0452
Malaysia	0,0422
Sri Lanka	0,0413
Peru	0,0399
Gabon	0,0393
Myanmar*	0,0393
Ecuador	0,0342
Maldives	0,0323
Denmark	0,0298
Canada	0,0271
Egypt	0,0258
United States	0,0240
Singapore	0,0239
Congo	0,0233
United Kingdom	0,0233
Brazil	0,0232

Note: (*) indicates the countries that have been excluded from the analysis due to lack of sufficient data.

Source: Author work based on Beck (2014).

Table 4.6. Top 25 mangrove countries according to the annual mangrove mitigation potential

Countries	Discounted annual mangrove mitigation potential (million tCO₂e/year)
Indonesia	30.679.644
Mexico	8.137.233
Papua New Guinea	4.570.866
Malaysia	4.181.896
Vietnam	2.564.008
Colombia	2.261.764
Pakistan	2.026.638
United States	1.953.947
Guinea-Bissau*	1.832.201
Myanmar*	1.790.324
Philippines	1.762.242
Sierra Leone	1.716.291
Gabon	1.698.338
Honduras	1.631.183
Madagascar	1.539.227
Senegal	1.342.843
India	1.133.760
Venezuela	1.124.822
Panama	1.056.887
Tanzania	755.870
Ecuador	684.104
Nicaragua	681.651
Brazil	872.828
Cambodia	692.276
Thailand	603.800

Note: (*) indicates the countries that have been excluded from the analysis due to lack of sufficient data.

Source: Author work based on Murray *et al.* (2011).

We have collected data on variables regrouped in five categories: neoclassical, demography, macroeconomic policy, regional heterogeneity, religion, natural capital, geography, fractionalisation, institutions and other. The definition of these variables and the data sources are given below.

Table 4.7. Data description

Designation	Source(s)
NEOCLASSICAL	
Growth rates of pc GDP	Average growth rates (constant 2005 USD prices) for the periods 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004 and 2005-2009.
Initial income	Logarithm of real GDP per capita (constant 2005 USD prices) at 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000 and 2005. The instruments for the initial income include the values at 1955, 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995 and 2000.
Population growth rates	Logarithm of average population growth rates plus 0.05 for the periods 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, 2000-2004 and 2005-2009. The instruments for populations growth rates include the average values of 1955-1959, 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995 and 2000-2004.
Investment in physical capital	Logarithm of average ratios over each period of investment in physical capital to GDP for the periods 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, 2000-2004 and 2005-2009. The instruments for investment include the average values of 1955-1959, 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995 and 2000-2004.
Schooling	Logarithm of the ratio of male population enrolled in secondary school to total population in 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000 and 2005.
DEMOGRAPHY	
Life Expectancy	Reciprocals of life expectancy at age 1 in 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000 and 2005.
Fertility rate	The log (LN) of the total fertility rate in 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000 and 2005.
MACROECONOMIC POLICY	
Openness	Average ratios for each period of exports plus imports to GDP in 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004 and 2005-2009. The instruments include the average values of 1955-1959, 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995 and 2000-

Government consumption	2004. Average ratios for each period of government consumption to GDP in 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004 and 2005-2009.
Inflation	The consumer price inflation rate for the periods 1960-1969, 1970-1979, 1980-1989, 1990-1999 and 2000-2009.
REGIONAL HETEROGENEITY	
Latin America and Caribbean	Dummy variable.
Sub-Saharan Africa	Idem.
South-East Asia	Idem.
RELIGION	
Buddhism	Buddhism share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the Buddhism share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Catholic	Catholic share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the catholic share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Eastern Religion	Eastern Religion share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the eastern religion share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Hindu	Hindu share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the Hindu share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Jew	Jew share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the Jew share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Muslim	Muslim share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the Muslim share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Orthodox	Orthodox share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the orthodox share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Other	Other religion share in 1970. The instruments include the other religion share in 1990.
Protestant	Protestant share in 1970 expressed as a fraction of the

population who expressed adherence to some religion. The instruments include the protestant share in 1900 expressed as a fraction of the population who expressed adherence to some religion.

NATURAL CAPITAL	
Natural capital in wealth	Time-invariant variable measuring the weight of natural capital in total wealth in 2000.
Natural capital per capita	Time-invariant variable measuring natural capital per capita in 2000. The variable is scaled to take values between zero and one.
GEOGRAPHY	
Coastline	Coastline length in km, scaled to take values between zero and one.
FRACTIONALISATION	
Language	Time-invariant measure of linguistic fractionalization that reflects the probability that two randomly selected individuals from a population belong to different groups. The data ranges from zero to one.
Ethnic	Time-invariant measure of ethnic fractionalization that reflects the probability that two randomly selected individuals from the population belong to different groups. The data ranges from zero to one.
INSTITUTIONS	
Liberal democracy	Time variant-index that emphasizes the importance of protecting individual and minority rights against the tyranny of the state and the tyranny of the majority. This is achieved by constitutionally protected civil liberties, strong rule of law, an independent judiciary, and effective checks and balances that, together, limit the exercise of executive power. To make this a measure of liberal democracy, the index also takes the level of electoral democracy into account. This variable is calculated as the average for the periods 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2009. It ranges from zero to one. Higher scores imply a more liberal democracy.
Public sector corruption	Time-variant variables that measures to what extent public sector employees grant favours in exchange for bribes, kickbacks, or other material inducements, and how often they steal, embezzle, or misappropriate public funds or other state resources for personal or family use. This variable is calculated as the average for the periods 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2009. It ranges from zero to one. Higher scores imply a more corruption.
Legal formalism: Check (1)	Time-invariant index of the professionals vs. laymen, written vs. oral elements, legal justification, statutory regulation of evidence, control of superior review, and engagement formalities indices, and the normalized number of independent procedural actions for the case of

	collection of a check. The index ranges from zero to seven, where seven means a higher level of control or intervention in the judicial process.
Legal formalism: Check (2)	Time-invariant index of formality in legal procedures for collecting on a bounced check, rescaled to lie between zero to one for 2003. Lower scores imply a less legal formality.
Complex	Time-invariant index of complexity in collecting a commercial debt valued at 50% of annual GDP per capita, rescaled to lie between zero and one for 2003. Lower scores imply a less complexity.
KKZ96	Time-invariant composite governance index. It is calculated as the average of six variables: voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption in 1996. It ranges from -2 to 2. Higher values imply better governance.
Executive constraints	Time varying variable that measures the extent of institutionalized constraints on the decision making powers of chief executives. This variable is calculated as the average for the periods 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2009. This variable ranges from zero to seven where higher values equal a greater extent of institutionalized constraints on the power of chief executives.
OTHER	
Time dummy variables	Dummy variables for 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2009
Colonial (Spain or Portugal)	Binary variable where one indicates that country was colonized by Spain or Portugal.
English legal origin	Binary variable where one indicates that country was colonized by The United Kingdom, and English legal code was transferred.
French legal origin	Binary variable where one indicates that country was colonized by France, Spain, Belgium, Portugal or Germany and French legal code was transferred.
Latitude	The absolute value of the latitude of the capital of the country, scaled to take values between zero and one.
Mineral stocks	Time-invariant variable that takes the value of the logarithm of fuel and 35 non fossil fuel stocks estimated for 1970 at market prices, in US dollars per capita.
System	Time-invariant variable that takes the value of 0 if the country has a presidential system, 1 if it has an assembly-elected president and 2 if it has a parliamentary system (mean value between 1975 and 2010).

Table 4.8. Data sources

Designation	Source(s)
NEOCLASSICAL	
Growth rates of pc GDP	Penn World Tables 7.1
Initial income	Idem
Population growth rates	Idem
Investment in physical capital	Idem
Schooling	Barro and Lee (2014)
DEMOGRAPHY	
Life Expectancy	World Bank
Fertility rate	Idem
MACROECONOMIC POLICY	
Openness	Penn World Tables 7.1
Government consumption	Idem
Inflation	World Bank
REGIONAL HETEROGENEITY	
Latin America and Caribbean	World Bank country classification
Sub-Saharan Africa	Idem
South-East Asia	Idem
RELIGION	
Buddhism	World Christian Encyclopaedia (2001)
Catholic	Idem
Eastern Religion	Idem
Hindu	Idem
Jew	Idem
Muslim	Idem
Orthodox	Idem
Other	Idem
Protestant	Idem
NATURAL CAPITAL	
Natural capital in wealth	World Bank
Natural capital per capita	Idem
GEOGRAPHY	
Coastline	UNEP (2015)
FRACTIONALISATION	
Language	Alesina <i>et al.</i> (2003)
Ethnic	Idem
INSTITUTIONS	
Liberal democracy	The QOG Standard Dataset
Public sector corruption	Idem
Legal formalism: Check (1)	Djankov <i>et al.</i> (2003)
Legal formalism: Check (2)	Doing Business, World Bank
Complex	Idem
KKZ96	Kaufmann <i>et al.</i> (2005)
Executive constraints	Polity IV Project, 1946-2013
OTHER	
Time dummy variables	Own construction
Colonial (Spain or Portugal)	Barro and Lee (1994)
English legal origin	Easterly (2001)

French legal origin	La Porta <i>et al.</i> (1999), and Djankov <i>et al.</i> (2003)
Latitude	Djankov <i>et al.</i> (2003)
Mineral stocks	Norman (2009) and van der Ploeg and Poelhekke (2010)
System	Beck <i>et al.</i> (2001)

Descriptive statistics and preliminary results

We share the preliminary analysis results in Tables 4.9-A.12. Firstly, we present the summary statistics and the correlation matrix between the variables that proxy proximate and fundamental economic growth theories. This correlation matrix conveys some information on whether fundamental theories, may have some explanatory power in the economic growth regression, beyond the influence exerted through proximate theories. Secondly, we perform some preliminary tests to prepare the data for the preliminary exploration and the economic growth regressions.

We can see some descriptive statistics below. In Tables 4.9 and 4.10, we share the summary statistics for all the variables that we used in our estimations for countries with very high and high exposure to coastal risks and for countries with high coastal climate change mitigation potential, respectively. The countries with very high and high exposure to coastal risks have higher values regarding neoclassical variables (higher initial income, education and investment in physical capital), fewer language and ethnic fractionalisation and slightly higher values in terms of institutional endowments, as compared to countries with high coastal climate change mitigation potential.

In Tables 4.11 and 4.12, we present the correlation matrix between the proximate theories' variables and the variables associated with the fundamental theories, whenever the level of correlation is above or equal to 0,40. The variables associated with four fundamental theories, religion, natural capital, fractionalisation and institutions, are strongly correlated with variables from all proximate theories except for the macroeconomic policy theory. The correlation between the institutions theory and some proximate theories is particularly strong for the sample countries with very high and high exposure to coastal risks. Building on these results, we analyse whether the fundamental theories just mentioned (religion, natural capital, fractionalisation and institutions) have some explanatory power in the economic growth regression, beyond the influence exerted through proximate theories' variables.

We finally perform a series of preliminary tests. We find that our dependent variable is stationary in levels, that panel data is preferred to pool data and that there is presence of heteroskedasticity and serial correlation, and we treat our data accordingly.¹¹¹

¹¹¹ Firstly, through the Fisher unit root test, we find that the dependent variable is stationary in levels. Secondly, we verify whether it is preferable to pool or not the data by testing the appropriateness of random and fixed-effects panel data compared to the pool analysis through the goodness-of-fit results. Panel data is preferred to pool data which implies that the parameters of the equation vary from one period to the other over the ten periods of available data. Thirdly, our data shows heteroskedasticity across panels through the Erhat LM-test and serial correlation through the Baltagi LM-test. The OLS and fixed-effects methods have adjusted standard errors for intragroup correlation which should hence be robust to heteroskedasticity and serial correlation. The GMM method also controls for heteroskedasticity and we test the presence of serial correlation of order one and two. This method assumes there is no second-order autocorrelation in the error term in levels. To perform the 2SLS method for the economic growth regressions, we use Driscoll and Kraay's approach which guarantees that the covariance matrix estimator is consistent, independently of the cross-sectional dimension, in contrast to Parks-Kmenta and the Panel-Corrected Standard Errors (PCSE) approaches, which typically become inappropriate when the cross-sectional dimension of a microeconomic panel gets large (Driscoll and Kraay, 1998).

Table 4.9. Summary statistics: Countries with high coastal climate change adaptation needs

Designation	Variable	Obs.	Median	Mean	Std. Dev.	Min.	Max.
NEOCLASSICAL							
Growth rates of pc GDP	<i>growth_pc</i>	498	0,02	0,02	0,03	-0,08	0,13
Initial income	<i>income_in</i>	498	8,56	8,60	1,14	6,28	11,37
Population growth rates	<i>population</i>	540	-2,77	-2,76	0,15	-3,15	-2,19
Investment	<i>invest</i>	498	3,11	3,04	0,55	0,69	4,39
Schooling	<i>school</i>	390	3,53	3,39	1,13	6,28	11,37
DEMOGRAPHY							
Life Expectancy	<i>life_exp</i>	521	0,01	0,01	0,00	0,01	0,04
Fertility rate	<i>fertility</i>	521	1,38	1,31	0,47	0,07	2,03
MACROECONOMIC POLICY							
Openness	<i>open</i>	498	0,71	0,77	0,49	0,04	4,20
Government consumption	<i>gov_cons</i>	519	0,09	0,12	0,09	0,00	0,65
Inflation	<i>inflation</i>	408	0,05	0,20	1,12	-0,01	16,67
REGIONAL HETEROGENEITY							
Latin America and Caribbean	<i>lac</i>	540	0,00	0,33	0,47	0,00	1,00
Sub-Saharan Africa	<i>ssa</i>	540	0,00	0,14	0,35	0,00	1,00
South-East Asia	<i>sea</i>	540	0,00	0,05	0,22	0,00	1,00
RELIGION							
Buddhism	<i>buddhism</i>	540	0,00	0,05	0,17	0,00	0,87
Catholic	<i>catholic</i>	540	0,19	0,31	0,32	0,00	0,97
Eastern Religion	<i>eastern</i>	540	0,00	0,03	0,08	0,00	0,45
Hindu	<i>hindu</i>	540	0,00	0,03	0,09	0,00	0,45
Jew	<i>jew</i>	540	0,00	0,00	0,00	0,00	0,03
Muslim	<i>muslim</i>	540	0,00	0,13	0,27	0,00	0,99
Orthodox	<i>orthodox</i>	540	0,00	0,00	0,02	0,00	0,14
Other	<i>other</i>	540	0,01	0,03	0,08	-0,16	0,49
Protestant	<i>protestant</i>	540	0,13	0,23	0,25	0,00	0,90
NATURAL CAPITAL							
Natural capital in wealth	<i>natural_w</i>	420	0,14	0,27	0,40	0,00	2,21
Natural capital per capita	<i>natural_pc</i>	420	0,06	0,10	0,14	0,00	0,78
GEOGRAPHY							
Coastline	<i>coastline</i>	530	0,00	0,06	0,16	0,00	1,00
FRACTIONALISATION							
Language	<i>language</i>	480	0,24	0,30	0,25	0,00	0,88
Ethnic tensions	<i>ethnic</i>	530	0,32	0,36	0,25	0,00	0,87
INSTITUTIONS							
Liberal democracy	<i>democracy</i>	376	0,37	0,42	0,30	0,02	0,95
Public sector corruption	<i>corruption</i>	376	0,42	0,42	0,31	0,00	0,95
Legal formalism: Check (1)	<i>check(1)</i>	220	0,33	0,37	0,17	0,09	0,76
Legal formalism: Check (2)	<i>check(2)</i>	280	3,01	3,15	1,04	1,41	5,60
Complex	<i>complex</i>	280	0,49	0,53	0,15	0,29	0,82
KKZ96	<i>KKZ96</i>	540	0,08	0,23	0,84	-1,35	1,92
Executive constraints	<i>exe_constr</i>	365	5,00	4,64	2,23	0,75	7,00
OTHER							
Time dummy variables	<i>year_dummy</i>						
Colonial (Spain or Portugal)	<i>colonial</i>	420	0,00	0,11	0,32	0,00	1,00

English legal origin	<i>english</i>	530	1,00	0,52	0,49	0,00	1,00
French legal origin	<i>french</i>	420	0,00	0,14	0,35	0,00	1,00
Latitude	<i>latitude</i>	540	0,17	0,21	0,16	0,01	0,66
Mineral stocks	<i>minerals</i>	380	-6,15	-6,28	3,18	-14,51	-1,35
System	<i>system</i>	480	1,12	1,10	0,86	0,00	2,00

Note: Data for 54 countries with very high and high exposure to coastal risks.

Table 4.10. Summary statistics: Countries with high coastal climate change mitigation potential

Designation	Variable	Obs.	Median	Mean	Std. Dev.	Min.	Max.
NEOCLASSICAL							
Growth rates of pc GDP	<i>growth_pc</i>	226	0,02	0,02	0,03	-0,10	0,12
Initial income	<i>income_in</i>	225	7,78	7,87	1,01	5,94	10,65
Population growth rates	<i>population</i>	230	-2,65	-2,68	0,10	-3,22	-2,46
Investment	<i>invest</i>	225	3,01	2,96	0,48	1,15	4,20
Schooling	<i>school</i>	220	2,85	2,80	0,78	-0,23	4,11
DEMOGRAPHY							
Life Expectancy	<i>life_exp</i>	230	0,01	0,01	0,00	0,01	0,04
Fertility rate	<i>fertility</i>	230	1,64	1,52	0,38	0,43	2,01
MACROECONOMIC POLICY							
Openness	<i>open</i>	226	0,53	0,62	0,44	0,07	2,06
Government consumption	<i>gov_cons</i>	228	0,08	0,10	0,07	0,02	0,41
Inflation	<i>inflation</i>	182	0,07	0,24	1,31	0,00	16,67
REGIONAL HETEROGENEITY							
Latin America and Caribbean	<i>lac</i>	230	0,00	0,34	0,47	0,00	1,00
Sub-Saharan Africa	<i>ssa</i>	230	0,00	0,21	0,41	0,00	1,00
South-East Asia	<i>sea</i>	230	0,00	0,08	0,28	0,00	1,00
RELIGION							
Buddhism	<i>buddhism</i>	230	0,00	0,10	0,26	0,00	0,92
Catholic	<i>catholic</i>	230	0,22	0,42	0,39	0,00	0,94
Eastern Religion	<i>eastern</i>	230	0,00	0,02	0,07	0,00	0,25
Hindu	<i>hindu</i>	230	0,00	0,03	0,15	0,00	0,76
Jew	<i>jew</i>	230	0,00	0,00	0,00	0,00	0,03
Muslim	<i>muslim</i>	230	0,02	0,17	0,28	0,00	0,96
Orthodox	<i>orthodox</i>	230	0,00	0,00	0,00	0,00	0,02
Other	<i>other</i>	230	0,01	0,06	0,14	-0,16	0,49
Protestant	<i>protestant</i>	230	0,03	0,07	0,10	0,00	0,39
NATURAL CAPITAL							
Natural capital in wealth	<i>natural_w</i>	200	0,30	0,33	0,20	0,02	0,88
Natural capital per capita	<i>natural_pc</i>	200	0,04	0,06	0,06	0,00	0,26
GEOGRAPHY							
Coastline	<i>coastline</i>	230	0,02	0,07	0,11	0,00	0,50
FRACTIONALISATION							
Language	<i>language</i>	230	0,35	0,41	0,31	0,01	0,89
Ethnic tensions	<i>ethnic</i>	230	0,55	0,54	0,19	0,18	0,87
INSTITUTIONS							
Liberal democracy	<i>democracy</i>	218	0,27	0,32	0,20	0,02	0,88
Public sector corruption	<i>corruption</i>	218	0,63	0,58	0,24	0,02	0,97
Legal formalism: Check (1)	<i>check(1)</i>	160	0,47	0,50	0,17	0,22	0,83
Legal formalism: Check (2)	<i>check(2)</i>	170	3,90	4,04	1,08	2,34	6,00
Complex	<i>complex</i>	220	0,62	0,60	0,14	0,29	0,82

KKZ96	<i>KKZ96</i>	230	-0,37	-0,24	0,54	-1,16	1,61
Executive constraints	<i>exe_constr</i>	220	4,00	4,17	1,92	0,75	7,00
OTHER							
Time dummy variables	<i>year_dummy</i>						
Colonial (Spain or Portugal)	<i>colonial</i>	200	0,00	0,40	0,49	0,00	1,00
English legal origin	<i>english</i>	230	0,00	0,34	0,47	0,00	1,00
French legal origin	<i>french</i>	200	0,00	0,10	0,30	0,00	1,00
Latitude	<i>latitude</i>	230	0,14	0,14	0,09	0,01	0,42
Mineral stocks	<i>minerals</i>	210	-7,22	-6,99	2,26	-11,59	-2,90
System	<i>system</i>	230	0,00	0,58	0,75	0,00	2,00

Note: Data for 23 countries with high annual mangrove mitigation potential.

Table 4.11. Correlation matrix between proximate and fundamental theories: Countries with high coastal climate change adaptation needs

Fundamen. theories	Proximate theories									
	<i>popu.</i>	<i>invest</i>	<i>scho.</i>	<i>life.</i>	<i>fert.</i>	<i>open</i>	<i>gov_.</i>	<i>infl.</i>	<i>lac</i>	<i>sea</i>
RELIGION										
<i>buddhism</i>	-0,30	0,32	0,19	-0,11	-0,15	-0,01	-0,09	-0,06	-0,23	0,74
<i>catholic</i>	0,38	-0,01	-0,24	0,26	0,36	-0,18	-0,26	0,23	0,65	-0,18
<i>hindu</i>	0,05	0,22	0,12	0,04	0,08	0,37	-0,00	-0,06	-0,22	0,90
<i>muslim</i>	0,44	-0,24	-0,31	0,43	0,33	0,40	0,17	-0,04	-0,29	-0,04
<i>protestant</i>	-0,50	-0,10	0,36	-0,47	-0,51	-0,15	0,09	-0,11	-0,30	-0,20
NATURAL CAPITAL										
<i>natural_w</i>	0,48	0,16	-0,37	0,38	0,44	0,05	-0,08	0,03	0,32	-0,00
FRACTIONALISATION										
<i>ethnic</i>	0,38	0,01	-0,27	0,33	0,36	0,05	-0,08	0,16	0,40	0,03
INSTITUTIONS										
<i>democracy</i>	-0,69	0,05	0,59	-0,74	-0,79	-0,36	-0,02	-0,05	-0,32	-0,11
<i>corruption</i>	0,64	-0,14	-0,59	0,65	0,65	0,33	0,06	0,10	0,40	-0,03
<i>check(1)</i>	0,45	-0,01	-0,39	0,58	0,57	0,02	-0,22	0,16	0,44	0,11
<i>check(2)</i>	0,42	-0,00	-0,31	0,49	0,54	0,02	-0,24	0,16	0,48	0,13
<i>complex</i>	0,48	-0,02	-0,42	0,60	0,61	0,03	-0,21	0,16	0,46	0,13
<i>KKZ96</i>	-0,58	-0,00	0,56	-0,66	-0,71	-0,21	-0,05	-0,16	-0,56	-0,26
<i>exe_constr</i>	-0,62	0,12	0,57	-0,72	-0,66	-0,16	-0,04	-0,06	-0,19	0,01

Note: Data for 54 countries with very high and high exposure to coastal risks. Values are only reported for those variables with a correlation above or equal to 0,40. The correlation matrix with all variables is available upon request to authors.

Table 4.12. Correlation matrix between proximate and fundamental theories: Countries with high coastal climate change mitigation potential

Fundamen. theories	Proximate theories										
	<i>popu.</i>	<i>invest</i>	<i>scho.</i>	<i>life.</i>	<i>fert.</i>	<i>open</i>	<i>gov_.</i>	<i>infl.</i>	<i>lac</i>	<i>ssa</i>	<i>sea</i>
RELIGION											
<i>buddhism</i>	-0,37	0,41	-0,14	-0,06	-0,18	0,17	-0,10	-0,05	-0,25	-0,09	-0,12
<i>catholic</i>	0,04	0,02	0,13	-0,32	-0,00	-0,01	-0,10	0,12	0,86	-0,26	-0,42
<i>hindu</i>	0,00	-0,00	-0,04	0,31	0,05	-0,21	0,23	-0,05	-0,26	-0,09	0,71
<i>jew</i>	-0,35	-0,09	0,38	-0,30	-0,44	-0,24	0,09	-0,03	-0,19	-0,09	-0,13
<i>muslim</i>	0,40	-0,32	-0,26	0,42	0,37	0,09	0,05	-0,07	-0,51	0,55	0,33
<i>orthodox</i>	-0,37	-0,08	0,36	-0,27	-0,42	-0,32	0,06	-0,04	-0,16	-0,12	-0,05
<i>protestant</i>	-0,35	-0,08	0,41	-0,34	-0,46	-0,16	0,18	0,01	-0,18	-0,18	-0,16
NATURAL CAPITAL											
<i>natural_pc</i>	-0,20	0,31	0,17	-0,34	-0,26	-0,10	-0,12	0,07	0,51	-0,28	-0,36
FRACTIONALISATION											
<i>language</i>	0,27	-0,05	-0,17	0,41	0,27	0,20	0,14	-0,16	-0,83	0,20	0,42
INSTITUTIONS											
<i>democracy</i>	-0,27	-0,19	0,37	-0,27	-0,54	-0,25	0,09	0,13	-0,00	0,06	0,06
<i>corruption</i>	0,09	0,20	-0,47	0,27	0,29	0,18	-0,11	0,04	0,03	0,17	-0,14
<i>check(1)</i>	0,39	-0,16	-0,13	0,07	0,34	0,22	0,18	-0,11	0,53	0,19	-0,04
<i>check(2)</i>	0,37	-0,18	-0,18	0,08	0,35	0,25	0,17	-0,09	0,51	0,19	-0,19
<i>complex</i>	0,40	-0,18	-0,24	0,15	0,33	0,33	0,20	-0,09	0,31	0,31	-0,30
<i>KKZ96</i>	-0,35	0,15	0,44	-0,41	-0,50	0,08	0,01	-0,04	-0,25	-0,19	-0,32
<i>exe_constr</i>	-0,23	-0,07	0,43	-0,26	-0,46	-0,18	-0,04	0,02	-0,01	-0,16	0,22

Note: Data for 23 countries with high annual mangrove mitigation potential. Values are only reported for those variables with a correlation above or equal to 0,40. The correlation matrix with all variables is available upon request to authors.

Results

These tables provide results for the growth regression exercise in equation [1] of the text under BMA regressions with theory and specification uncertainty. The dependent variable is the average growth rate of real per capita GDP corresponding to the periods 1960-64, 1965-69, 1970-74, 1975-79, 1980-84, 1985-89, 1990-94, 1995-99, 2000-04 and 2005-2009. Following Durlauf *et al.* (2008a), we instrument for endogenous variables using earlier or initial values if available with the exception of inflation, religion shares and natural capital under the Two-Stage Least Squares (2SLS) regressions (without uncertainty). For inflation we use as instruments the colonial dummy for Spain or Portugal and British and French legal origins and for religion shares we use the corresponding shares in 1900. Following van der Ploeg and Poelhekke (2010) we used a dummy for presidential system and mineral resource stocks as an instrument for natural capital variables. The 2SLS regression results are very similar to the BMA regression results with uncertainty and are available upon request. Please refer to the data appendix for details on the variables used.

Table 4.13. BMA estimation results for average growth rates of pc GDP: Countries with high coastal climate change adaptation needs

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probability	Posterior mean	Posterior standard deviation	Posterior inclusion probability	Posterior mean	Posterior standard deviation
	y (#)			y (#)		
NEOCLASSICAL						
<i>income_in</i>		-0,077*	0,013		-0,019*	0,008
<i>population</i>		0,055	0,076			
<i>invest</i>		0,069*	0,023			
<i>school</i>		-0,003	0,016			
DEMOGRAPHY	1,000					
<i>life_exp</i>		0,039	1,805			
<i>fertility</i>		-0,252*	0,036			
MACROECONOMIC POLICY	1,000					
<i>open</i>		0,001	0,007			
<i>gov_consu</i>		-0,173	0,304			
<i>inflation</i>		-0,007	0,004			
REGIONAL HETEROGENEITY	0,320					
<i>lac</i>		-0,000	0,004			
<i>ssa</i>		0,000	0,004			
<i>sea</i>		-0,025	0,042			
RELIGION	0,062			1,000		
<i>buddhism</i>		-0,002	0,016		0,002	0,015
<i>eastern</i>		0,003	0,023		0,391*	0,069
<i>muslim</i>		-0,000	0,007		-0,007	0,022
<i>protestant</i>		-0,000	0,006		-0,002	0,013
NATURAL CAPITAL	0,964			1,000		
<i>natural_w</i>		-0,041	0,028		-0,041*	0,020
<i>natural_pc</i>		-0,011	0,045		-0,000	0,029
GEOGRAPHY	0,048			0,053		
<i>coastline</i>		-0,000	0,008		0,000	0,009
FRACTIONALISATION	1,000			0,999		
<i>language</i>		-0,072*	0,030		-0,066*	0,028
<i>ethnic</i>		0,002	0,014		-0,004	0,017
INSTITUTIONS	1,000			1,000		
<i>KKZ96</i>		0,000	0,003		0,000	0,002
<i>exe_constr</i>		-0,017*	0,005		0,002	0,004
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		403			403	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 54 countries with very high and high exposure to coastal risks. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 4.14. BMA estimation results for average growth rates of pc GDP: Countries with high coastal climate change mitigation potential

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probability y (#)	Posterior mean	Posterior standard deviation	Posterior inclusion probability y (#)	Posterior mean	Posterior standard deviation
NEOCLASSICAL						
<i>income_in</i>		-0,072*	0,024		-0,057	0,033
<i>population</i>		0,353	0,263			
<i>invest</i>		0,071*	0,034			
<i>school</i>		-0,002	0,031			
DEMOGRAPHY	0,980					
<i>life_exp</i>		-4,365	7,676			
<i>fertility</i>		-0,215*	0,071			
MACROECONOMIC POLICY	0,999					
<i>open</i>		0,001	0,008			
<i>gov_consu</i>		-0,015	0,086			
<i>inflation</i>		-0,012*	0,006			
REGIONAL HETEROGENEITY	0,089					
<i>lac</i>		-0,000	0,007			
<i>ssa</i>		-0,003	0,026			
<i>sea</i>		0,002	0,015			
RELIGION	0,264			0,524		
<i>buddhism</i>		0,001	0,012		0,029	0,059
<i>eastern</i>		0,105	0,211		0,232	0,277
<i>muslim</i>		-0,064	0,131		-0,059	0,093
<i>protestant</i>		0,007	0,051		-0,000	0,060
NATURAL CAPITAL	0,999			1,000		
<i>natural_w</i>		-0,085	0,089		-0,028	0,075
<i>natural_pc</i>		0,097	0,326		0,422	0,376
GEOGRAPHY	0,086			0,089		
<i>coastline</i>		-0,004	0,032		-0,005	0,038
FRACTIONALISATION	0,624			0,189		
<i>language</i>		0,002	0,016		0,001	0,013
<i>ethnic</i>		0,132	0,140		0,027	0,074
INSTITUTIONS	0,366			0,836		
<i>KKZ96</i>		0,008	0,026		0,085	0,050
<i>exe_constr</i>		-0,003	0,006		-0,001	0,004
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		208			208	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 23 countries with high annual mangrove mitigation potential. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 4.15. Economic growth determinants for different country typologies (II): BMA posterior inclusion probability results

	Proximate and fundamental theories		Fundamental theories	
	<i>Very high adaptation needs</i>	<i>High adaptation needs</i>	<i>Very high adaptation needs</i>	<i>High adaptation needs</i>
DEMOGRAPHY	1,000	0,998		
MACROEC. POLICY	1,000	1,000		
REGIONAL HETERO.	0,771	0,111		
RELIGION	0,341	0,636	0,923	1,000
NATURAL CAPITAL	1,000	0,220	1,000	0,139
GEOGRAPHY	0,176	0,085	0,319	0,167
FRACTIONALISATION	0,427	0,998	0,228	1,000
INSTITUTIONS	1,000	0,364	1,000	0,056

Note: This table provides the summary results for the posterior inclusion probability for the eight growth theories for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 27 countries with very high exposure to coastal risks and 27 countries with high exposure to coastal risk.

Table 4.16. Economic growth determinants for different country typologies (II): BMA posterior mean results

	Proximate and fundamental theories		Fundamental theories	
	<i>Very high adaptation needs</i>	<i>High adaptation needs</i>	<i>Very high adaptation needs</i>	<i>High adaptation needs</i>
NEOCLASSICAL				
<i>income_ini</i>	NS	-	-	-
<i>invest</i>	NS	NS	NA	NA
DEMOGRAPHY				
<i>fertility</i>	NS	-	NA	NA
MACROEC. POLICY				
<i>inflation</i>	NS	-	NA	NA
RELIGION				
<i>eastern</i>	NS	NS	NA	+
FRACTIONALISATION				
<i>language</i>	NS	NS	NS	NS

Note: This table provides the summary results for the posterior mean for the eight growth theories for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 27 countries with very high exposure to coastal risks and 27 countries with high exposure to coastal risk. ‘+’ stands for a positive and significant impact on average growth rates of pc GDP, ‘-’ stands for a negative and significant impact, ‘NS’ stands for a non-significant impact and ‘NA’ stands for non-applicable.

5. THE DETERMINANTS OF ECONOMIC GROWTH IN COUNTRIES WITH HIGH MARINE BIODIVERSITY

5.1. Introduction

A good proxy for marine biodiversity is the extent achieved by coral reefs. The ‘rainforests of the ocean’, coral reefs, are biodiversity hotspots that make up less than one per cent of the marine environment but are home to about 25 per cent of the ocean’s marine life.¹¹² Coral reefs are known as one of the most complex and species-rich ecosystems in the world, with vital connections to many other ecosystems and of a global-scale importance. They play a central role in many ecosystem services, such as coastal protection, water chemical balance, CO₂ cycles and marine biomass and biodiversity production (Hicks and Cinner, 2014). However, marine biodiversity is threatened. About 50 per cent of the area covered by coral reefs has been lost in the past 30 years, and an estimated 83 per cent of reefs have lost more than half of their expected fish biomass (WWF, 2015a and MacNeil *et al.*, 2015).

Direct human pressure has been proved to be the major threat on these ecosystems, and this threat is still increasing. It is indeed estimated that more than two billion people and nearly half of the world’s major cities are found within 50 km of coastlines (Brown *et al.*, 2008, and MEA, 2005). On the other hand, at least three billion people are thought to depend on marine and coastal biodiversity for their livelihoods (SCBD, 2009). A key question is then how to reach an equilibrium between coastal development and ecosystem conservation. Development and conservation could be both seen as part of the same basic infrastructure needed to deliver essential services in coastal areas (Emerton, 2014), but a number of more or less hidden trade-offs are to be taken in account in such complex socio-ecosystems (Daw *et al.*, 2015).

Though coral ecosystems are nowadays highly studied, surveyed and monitored, and many consensual scientific recommendations have been proposed (Worm *et al.*, 2009), they are still globally decreasing, and many coral countries have not set up so far proper regulation measures to address this trend (Hughes *et al.*, 2012). Even in developed countries with high environmental awareness such as Australia or the US, the coral cover has dramatically decreased by the end of the twentieth century (De’ath *et al.*, 2012). There are many different threats on coral reefs, and if some of them are partly natural (ecological succession, diseases, predators and cyclones), their effect is strongly increased by human influence.

This human influence consists of many different types of pressures. These pressures can be indirect and diffuse, such as global change, or direct and local, such as pollution (Carpenter *et al.*, 2008). Due to global threats, perturbations like massive bleaching are now observed worldwide. Local threats include most notably pollution, overpopulation, overfishing or even direct reef destruction through construction works, destructive fishing gears or limestone exploitation. It is commonly considered that small-scale threats such as destructive fishing, watershed-based pollution, or direct extractions are more closely linked to developing countries (in particular, in the “Coral Triangle” in South-East Asia or in East Africa), whereas long-term stressors such as shifts in water quality or species assemblage are more linked to rich countries (such as the US, outer sea France and Japan).

¹¹²I would like to thank Steven Durlauf and Grigoris Emvalomatis for insightful thoughts and suggestions as well as data and econometric programs shared at the 2nd Advanced summer school in economics and econometrics at the University of Crete, Rethymno on the 19th-26th of August 2007. I would also like to thank Enrique Moral-Benito for suggestions and data from Moral-Benito (2012) and Steven Poelhekke for data from van der Ploeg and Poelhekke (2010). I am grateful to the participants at the *Séminaire du Centre International de Recherche sur l'Environnement et le Développement* (CIRED) on the 29th January 2017 and at the *Séminaire Développement Durable Environnement et Economie Publique* (DDEEP-EconomiX, Paris Nanterre) on the 31st January 2017 for their comments and suggestions on the methodology.

Other local threats like coastal development, marine pollution or coral bleaching seem to affect both developing and developed countries as soon as coasts get populated (WRI, 2011). Some early agro-industrialized countries have been experiencing coral loss for many tens of years, especially in the Caribbean where the current coral cover is alarming (Mumby *et al.*, 2007), whereas in other parts of the world such as Maldives the coral ecosystems had kept a healthy state until the 1980s, but now suffer from the same large-scale stressors (Andréfouët, 2012). These latter areas have scope to set up adequate policies to protect and benefit from the shrinking but yet important size of coral cover.

A major reasons why marine biodiversity is highly threatened is that their social importance is poorly recognized. In particular, most markets do not capture the non-monetary values of coastal and marine ecosystems services delivered by coral reefs, and so they are rarely considered when resource management decisions are made (Mohammed, 2012). In addition, the need to develop a comprehensive macroeconomic framework and the associated the accounting guidelines is prominent in order to mainstream these ecosystem services amongst economic activities (Jackson, 2009, Victor and Jackson, 2013 and Weber, 2014). There have already been some efforts on marine and coastal valuation that have enabled to raise awareness among the population and policy makers on the weight of marine and coastal ecosystem services in local economic activities such as tourism (Pascal, 2010). The valuation and accounting guidelines remain nevertheless largely behind those developed for terrestrial ecosystem services.

Rather than examining the putative role of marine biodiversity on economic growth which, in any case, should be better addressed through microeconomic analyses, we want to examine the specific determinants of growth in this type of countries.¹¹³ To our knowledge, this is a first attempt to have a better understanding of the determinants of economic growth in countries with relatively high marine biodiversity. Our analysis controls for the existence of multiple growth regimes under a Bayesian Model Averaging (BMA) method that accounts for theory and specification uncertainty. This work aims at motivating the need to further develop appropriate accounting and macroeconomic frameworks to fully integrate marine biodiversity within the basic infrastructure required to sustain economic activity.

In the following section, we describe the previous empirical academic literature on economic growth and its relationship with natural capital and biodiversity in coastal countries and we explain how we attempt to contribute to this literature. In section three, we describe the econometric model and some preliminary analyses to explore whether there are multiple economic growth regimes. We present the data used in our analysis and share both the preliminary results on the presence of economic growth regimes, and the estimations on the determinants of economic growth under uncertainty. In section four, we conclude and share some future avenues of work. The appendix provides a detailed description of the data and the estimations.

5.2. The determinants of economic growth in coastal countries with biodiversity

The impact of natural capital on economic growth is still a controversial topic among researchers. Early standard macroeconometric models uncover a negative relationship between resource dependence and economic growth. Sachs and Warner (1995) find evidence that resources rich countries underperform resources poor countries regarding export-led growth, after controlling for a number of other factors. Most of the analyses in the late 1990s and early 2000s also find evidence of a negative relationship between resource dependence and economic

¹¹³ Besides our data identifying countries with high marine biodiversity, coral reefs (square-km), is in physical units compared to our data on the natural capital determinants in monetary units. Some preliminary regressions on economic growth showed that, in any case, the variable coral reefs had no significant explanatory power on economic growth as one could expect. The effects of marine biodiversity are better captured through microeconomic analyses (see, for instance, McClanahan *et al.*, 2008).

growth (van der Ploeg, 2010). Many of these studies attempt to explain the causes of such a negative relationship although there is no universally accepted theory of the curse of natural resources (Sachs and Warner, 2001 and Torres et al., 2013).

Since about the mid-2000s however, there are a number of analyses that challenge the existence of a resources curse (Dinh and Dinh, 2016). For instance, several papers suggest that the negative relationship between natural resource intensity and economic growth can be reversed if institutional quality is high enough (Boschini et al., 2013). Lederman and Maloney (2002) also argue that the negative correlation between natural resources and economic growth might be contingent on the choice of natural resources indicators and also due to international heterogeneity in the effects of natural resources on economic growth.

Concerning indicators, although natural resource dependence measured by the share of exports of primary products in the gross domestic product and other indicators in relative terms might retard growth, natural resource abundance (per capita values of production and reserves or stocks) may be positively correlated or have no significant impact on economic growth (Ding and Field, 2005, Cerny and Filer, 2007 and Gylfason, 2011). Moreover, the adverse effect of resource dependence on institutional quality and economic growth would be particularly strong for easily appropriable 'point-source' rents with concentrate production and revenues and large rents such as minerals, oil and plantation crops (coffee, sugar, banana, tobacco) compared to agriculture (rice, wheat, animals) whose rents are more dispersed and less easily appropriated by state institutions (van der Ploeg, 2010).

In terms of presence of international heterogeneity when analysing the impact of natural resources on economic growth, the academic literature based on fixed-effects estimations provides evidence that natural resource export dependence variables are not significant determinants of economic growth (Mansano and Rigobon, 2001 and Lederman and Maloney, 2002). However, such fixed-effects methods leave unexplained exactly the long-run cross-country growth variation originally motivating the research (Durlauf and Quah, 1999). To account for international heterogeneity in the effects of the determinants of growth, controlling for mean shifters by including regional dummies can be an alternative to fixed-effects estimations (Lederman and Maloney, 2008).

Despite these developments, little attention has been paid to explore the impact of biodiversity on economic growth and, even less, to the determinants of growth in countries with high biodiversity. As an exception, in the first chapter I analyze separately the renewable and non-renewable components of natural capital, finding that renewable capital has some indirect negative impact on economic growth through health proxies. The bulk of the studies on biodiversity and economic growth have instead focused on the reversed causality, that is, the (negative) impact that economic growth can have on biodiversity (Antoci et al., 2004). Many analyses explore whether the environmental Kuznets curve exists, where a U-shaped relationship between the per capita wealth and the proportion of species conserved is expected (McPherson and Nieswiadomy, 2005, and Mills and Wait, 2009). Biodiversity is often found to be one of the class of environmental problems where economic growth on its own is unlikely to result in a turning point towards a more sustainable and secure environmental future (Dietz and Adger, 2003).

The new economic geography on the role of large agglomerations with increasing returns to scale could also be useful to account for the weight of coastal natural capital in supporting economic activities (Krugman, 1998, Emerton, 2014). If we explore the determinants of economic growth in coastal countries, Smith (1976) already stressed the relationship between the geographical location, international trade and economic growth. The rapid development of civilizations around the Mediterranean basin was helped by the relative ease of sea-based trade in the region (Braudel, 1972, McNeill, 1974, Jones, 1981 and Crosby, 1986).

There are several reasons that explain the higher income in coastal countries compared to landlocked countries. Radelet and Sachs (1998) find, for instance, that the cost of freight and

insurance for landlocked developing countries was on average 50 per cent higher than for coastal economies, which had a negative impact on economic growth. Moreover, countries with a longer coastline are likely to have more ports, a larger share of the population with relatively easy access to the sea, and a greater proportion of economic activity grounded in international trade. Bloom and Sachs (1998), Masters and Sachs (2001) and Bloom et al. (2003) find that coastline length is a positive and significant determinant of economic growth.

Gallup et al. (1998) find that higher coastal population density is associated with faster economic growth. Population density on the coast is likely to be associated with an increased division of labor, with increasing returns to scale in infrastructure, and with falling rates of population growth as incomes per household rise.¹¹⁴ In addition, Gallup et al. (1998) also find that more ocean-accessible regions in the world are more urbanised. According to Radelet and Sachs (1998) almost all fast-growing developing countries have based their rapid growth in the period after 1965 on labour-intensive assembly-type industries.

Almost without exception, large export processing zones are located in coastal economies, near good port facilities, and close to markets in the U.S., Japan or Europe. There are also geographical effects on economic policy choices. A coastal economy, for example, may face a higher elasticity of output response with respect to trade taxes than a landlocked economy (Gallup et al., 1998). The early liberalisers, on the whole, were the coastal economies. In sum, high levels of gross domestic product per capita in coastal countries are associated with low transport costs, economies of agglomeration, liberal economic policy choices and a coastal population.

From an econometric perspective, regression analyses show that a large number of variables are correlated with economic growth but are far from implying the direction of causation. The lack of agreed theoretical bases for empirical work and for a reduced form to apply in empirical analyses, has led researchers to abandon any a priori models and to let the data show which variables are correlated with economic growth through model uncertainty (Capolupo, 2009). In order to estimate accurately the determinants of the so-called new growth theories in determining economic growth, Durlauf et al. (2005, 2008a) and Sala-i-Martin et al. (2004) propose the BMA methodology.¹¹⁵

Starting with Durlauf and Johnson (1995), many researchers have also explored whether there is evidence of multiple growth regimes focusing on different variables in order to divide the sample and using several methodologies.¹¹⁶ That is, they analyse whether there is a common growth regime for the whole sample under conditional convergence or whether there is a growth process with multiple growth regimes in which economies with similar conditions tend to converge to one another. Konte (2013), for instance, allows for multiple growth regimes and finds that democracy helps a given country to belong to the blessed regimes in terms of natural resources while education has no effect.

To our knowledge, we propose a first attempt to have a better understanding of determinants of economic growth in coastal countries with relatively high marine biodiversity. We estimate the augmented Solow model including new growth theories, among which the natural capital theory. We control for the existence of multiple convergence regimes under a BMA method that accounts for uncertainty. Such an analysis enables to compare our results

¹¹⁴ There is a negative and significant relationship between population growth and economic growth (see, for instance, Kormendi and Meguire, 1985).

¹¹⁵ Fernandez *et al.* (2001) show the superiority of BMA over other techniques in selecting regressors to explain cross-country growth.

¹¹⁶ See Owen *et al.* (2007) and Konte (2013) for a summary on how the question of multiple growth regimes has been addressed in numerous papers focusing on different theories such as neoclassical, geography, demography and institutions. There are a number of studies that employ a wide variety of statistical methods in attempting to identify multiple growth regimes (Durlauf *et al.*, 2005).

with those of Durlauf et al. (2008a), where the latter uses a larger sample with coastal and landlocked countries, not specifically concerned with marine biodiversity.

5.3. Empirical analysis

Econometric methodology

In section three, we firstly present the baseline model based on the augmented Solow model and a set of new growth theories. Secondly, we explain how we integrate theory and specification uncertainty through the BMA. Lastly, we explain how we perform our preliminary analysis on the existence of multiple convergence regimes. Lastly, we explain how we perform our preliminary analysis on the existence of multiple convergence regimes.

Economic growth model: Baseline with eight fundamental and proximate theories

Many empirical growth models are estimated using panel data to multiply the number of observations. Since the variation of growth rates at annual frequency rates may give very misleading information about the long-term growth process, we average data over five year periods.¹¹⁷ Based on Durlauf and Quah (1999), we use the following augmented Solow model with a set of new growth theories (Solow, 1956 and Durlauf *et al.*, 2005, 2008a):

$$\log(y_{i,r}) = \gamma_0 \log(y_{i,r-T}) + \gamma_1 \log(s_{i,r}^k) + \gamma_2 \log(s_{i,r}^h) + \gamma_3 \log(n_{i,r} + g + \delta) + z_{i,r} + \alpha_i + \theta_r + \varepsilon_{i,r} \quad [1]$$

$$\gamma_1 = e^{\lambda T} \gamma_2 = (1 - e^{\lambda T}) \frac{\alpha_k}{1 - \alpha_k - \alpha_h} \gamma_3 = (1 - e^{\lambda T}) \frac{\alpha_h}{1 - \alpha_k - \alpha_h} \gamma_4 = -(1 - e^{\lambda T}) \frac{\alpha_k + \alpha_h}{1 - \alpha_k - \alpha_h}$$

where $y_{i,r}$ is the real per capita GDP for country i ($i = [1, \dots, N]$) across a time period $[r, r+T]$, T being 5 years, $s_{i,r}^k$, $s_{i,r}^h$ and $\log(n_{i,r} + g + \delta)$ denote the variables that measure net factor accumulation in the neoclassical growth theory with the saving rates of physical ($s_{i,r}^k$) and human capital accumulation ($s_{i,r}^h$) and population growth rates ($n_{i,r}$) plus the rate of labor augmenting technical progress (g) and the physical capital depreciation rate (δ), $z_{i,r}$ denotes a set of variables proxying eight new growth theories that go beyond the neoclassical model as described in the data section and in the appendix (Tables 5.5 and 5.6), α_i is a country-specific effect, θ_r is a time-specific effect and $\varepsilon_{i,r}$ is the error term.¹¹⁸

Each growth theory can be proxied by several variables. Note that typically $g + \delta = 0.05$ (Mankiw *et al.*, 1992). α_k and α_h are the parameters associated with the Cobb-Douglas production function on physical and human capital input variables, such that $\alpha_k > 0$, $\alpha_h > 0$ and $\alpha_k + \alpha_h < 1$. λ is a parameter that denotes the rate of convergence such that $\lambda < 0$. Saving rates of physical capital accumulation and saving rates of human capital accumulation are referred to hereafter as investment in physical capital and schooling, respectively.

We work with the following set of new eight growth theories including both proximate and fundamental theories: Demography, macroeconomic policy, regional heterogeneity for proximate theories, and religion, natural capital, geography, fractionalisation and institutions for

¹¹⁷ We have replicated the analysis with 10 year periods but the sample size is too small given the nature of our data (presence of heteroskedasticity and serial correlation). Even though averaging over the longest time horizon possible should better deal with eliminating business cycle effects that probably dominate per capita income fluctuations at higher frequencies, it comes at the cost of reducing the sample size (Durlauf *et al.*, 2008b). In turn, when the sample size is too limited and the number of explanatory variables large, estimation methods can be of limited use to distinguish robust from irrelevant variables.

¹¹⁸ We note that in our economic growth regressions we replace the country-specific effect variables by the regional heterogeneity variables included in the new growth theories which enables us to take into account regional heterogeneity while decreasing the number of variables in the regression given the short number of observations typically associated with economic growth estimations.

fundamental theories (see Table 5.1). The determinants derived from a neoclassical growth model are referred to as proximate determinants because they are thought to be the most established drivers of economic growth. The term ‘proximate’ also reflects the ease with which these determinants can be influenced by policy measures. Fundamental determinants depend instead on slow-moving fundamental growth (Durlauf *et al.*, 2008b). Our economic growth regressions include both proximate and fundamental theories.

Table 5.1. Proximate and fundamental growth theories

PROXIMATE THEORIES

Demography	Health may contribute to explain differences in income per capita among countries (Shastri and Weil, 2003 and Weil, 2005)
Macroeconomic policy	Inflation, government consumption and terms of trade can impact economic growth (Barro, 1997)
Regional heterogeneity	Countries in different continents may not represent draws from a common growth model (Brock and Durlauf, 2001)

FUNDAMENTAL THEORIES

Religion	Religion beliefs and adherence may influence growth (Barro and McCleary, 2003, Durlauf <i>et al.</i> , 2012)
Natural capital	Natural capital dependence and abundance may impact economic growth (Sachs and Warner, 1995 and Gylfason, 2011)
Geography	Geographical and ecological conditions (climate zone, disease ecology, distance from the coast) can affect economic growth (Sachs, 2003)
Fractionalisation	Ethnic and linguistic heterogeneity can affect economic growth (Alesina <i>et al.</i> , 2003 and Easterly and Levine, 1997)
Institutions	The regulation of entry of new firms, the procedural formalism in courts can impact economic growth (Djankov <i>et al.</i> , 2002, 2003)

Fundamental theories can have direct and/or indirect effects on economic growth. To analyse this matter, we first develop estimations including both proximate and fundamental theories. If fundamental theories are significant in these estimations, this implies that they have a direct impact on economic growth. It may also be the case that fundamental theories are not significant in these estimations, and yet may have an indirect impact on economic growth.

To test this hypothesis, we develop estimations only including fundamental theories. If some of the fundamental theories in these latter estimations are significant, while they were not significant in the estimations with proximate and fundamental theories, we can infer that such fundamental theories have an indirect impact on economic growth through proximate theories. In fine, we analyse whether fundamental theories exert a direct influence on economic growth, or an indirect influence through their correlation with proximate theories.

Economic growth model: Uncertainty

There is a problem of model uncertainty when performing economic growth estimations that account for new growth theories following the regression model [1] (Brock and Durlauf, 2001, Brock *et al.*, 2003). That is, there is theory uncertainty since the statement that a theory is relevant does not preclude others from being relevant as well. Moreover, there is specification uncertainty since new growth theories do not translate naturally into specific regressors. To deal with model uncertainty, we employ a BMA.

In model averaging models, we treat the growth model as an unobservable variable. In order to account for this variable, each model specification m in the model space M is associated with a posterior model probability $\mu(m|D) \propto \mu(D|m) \mu(m)$, where D is the available data, $\mu(D|m)$ is the likelihood of the data given the model and $\mu(m)$ is the prior model probability. The posterior model probability is the probability that model m is the true model

given the data and hence we can calculate whether a theory is in the true model by computing $\sum \{m \in M\} \mu(m|D, m \in A)$, where A is the event that at least one proxy variable is in the true model. Note that we set the prior probability that a particular theory is in the true model to 0,5 to reflect non-information across theories (Durlauf *et al.*, 2008a).¹¹⁹ The posterior model probability is the probability that model m is the true model given the data and we can hence calculate whether a theory is in the true model by computing $\sum \{m \in M\} \mu(m|D, m \in A)$, where A is the event that at least one proxy variable is in the true model.

Preliminary analysis: Presence of multiple convergence regimes

We apply a preliminary analysis to the augmented Solow model to explore whether there are multiple convergence regimes. The so-called conditional beta-convergence is interpreted as evidence that poorer countries are converging with richer ones after controlling for heterogeneity.¹²⁰ Alternatively, there can be evidence of multiple convergence regimes if there is no single regime model for global convergence (Durlauf and Johnson, 1995). That is, even after controlling for structural heterogeneity there is a role for initial conditions in explaining variation in cross-country growth behaviour.¹²¹

To analyse whether there are multiple convergence regimes we proceed in two steps. Based on Durlauf and Johnson (1995), we use the Classification Analysis and Regression Tree (CART) model applied to Solow variables to identify those that are most likely to provide a more ‘reasonable’ separation of observations. We then perform preliminary estimations for the full sample and for the identified sub-samples, and we test the hypothesis that all the countries in the sample follow the same convergence dynamics through a Chow test. This test enables to derive whether we should perform our economic growth regressions on one sample or whether we should work with several sub-samples.

To perform these preliminary estimations, since the country-specific effect α_i is not distributed independently with respect to $\log(y_{i,r-T})$, we use a fixed-effects method rather than a random effects method. Another alternative is to difference the model to eliminate fixed-effects and then use the Differenced Generalised Method of Moments (DIF-GMM) method developed by Arellano and Bond (1991) to address the contemporaneous correlation between the differenced lagged dependent variable $\log(y_{i,r-T})$ component of $\Delta \log(y_{i,r-T})$ and the $\Delta \varepsilon_{i,r-T}$ component of the new error term:

$$\Delta \log(y_{i,r}) = \gamma_0 \Delta \log(y_{i,r-T}) + \gamma_1 \Delta \log(s_{i,r}^k) + \gamma_2 \Delta \log(s_{i,r}^h) + \gamma_3 \Delta \log(n_{i,r} + g + \delta) + \Delta z_{i,r} + \Delta \theta_r + \Delta \varepsilon_{i,r} \quad [2]$$

We follow the standard approach where lagged values of the potentially endogenous regressors in levels are used as instruments. However, if the explanatory variables are highly persistent, lagged levels can be weak instruments and the estimator can be biased. To check for the consistency of the DIF-GMM results, we propose to compare the estimates of the rate of convergence of the OLS and the within-group models with those of DIF-GMM methods. If the explanatory variables other than lagged output are exogenous then a consistent DIF-GMM

¹¹⁹ Assigning equal prior probability to each possible model can have odd implications for linear regressions with a large number of potential regressors, though. However, the number of variables we are including is not very large compared to other analyses, since we are based on Durlauf *et al.* (2008a) results.

¹²⁰ There is evidence against unconditional beta-convergence, where the latter implies that countries that are poorer and have higher marginal productivity of capital should grow faster in the transition to the long-run steady state, independently of structural heterogeneity. In conditional convergence, countries will tend to different levels of income in the long run. There is evidence of unconditional convergence among manufacturing industries rather than entire economies suggesting that the lack of convergence is due to the factors that influence the speed of reallocation from non-convergence to convergence activities (Rodrik, 2012).

¹²¹ Note that multiple regimes may represent evidence of multiple steady-states as well as evidence of non-linearity in the growth process.

parameter estimate should lie between OLS and within-group estimates which are biased in opposite directions (Caselli *et al.*, 1996).

Besides, lagged variables in levels can also be inappropriate instruments if there is serial correlation in the error terms of the growth equation before differencing. For instance, education variables can influence output with a considerable delay. Due to these drawbacks associated with the DIF-GMM method, we estimate as well equation [2] through the system GMM (SYS-GMM) method derived by Arellano and Bover (1995). This estimator uses, in addition to the moment conditions used in DIF-GMM, instruments in first differences for the equation in levels and offers higher robustness.

Data

The unbalanced panel data set covers 80 countries and geographical locations with coral reefs for 10 five-year periods from 1960 to 2009 (see appendix for more details). The choice of the eight growth theories and the associated variables is largely inspired by the work of Durlauf *et al.* (2008a).¹²² Besides the eight growth theories, we include a category named ‘other’ to account for some instruments and for time dummy variables. We also include the variables on natural capital dependence and abundance suggested by Gylfasson (2011), that is, natural capital in wealth and natural capital per capita, respectively (World Bank, 2006).¹²³

There are some differences in the choice of variables when comparing our work with the study of Durlauf *et al.* (2008a). In particular, we use the average growth rate of real per capita GDP instead of the average growth rate of real per worker GDP since the dataset from Caselli (2005) does not cover our period of study. For the geography theory, we use some variables suggested by Durlauf *et al.* (2005) since those used by Durlauf *et al.* (2008a) were often not available for our sample of countries. For the institutions theory, we use some proxies for individual and minority rights and public sector corruption, instead of expropriation risks since the latter was not available for our period of study. The detailed definition of the variables, their designation and the data sources are given in Tables 5.5-5.6 in the appendix.

Preliminary results

In this section, we summarise the preliminary analysis results discussed in the appendix (see Tables 5.7-5.14). We perform some preliminary tests which have revealed that the data shows heteroskedasticity and serial correlation which needs to be taken into account in our analyses. Moreover, we find some evidence of the existence of multiple convergence regimes among our panel of countries based on the CART model. Given this result, we develop the regressions on economic growth determinants for the whole sample and for the two sub-samples defined by the cut-off point in the near-median level of schooling.

Furthermore, we present the summary statistics and the correlation matrix between proximate and fundamental theories for the full sample and for the two sub-samples according to the cut-off point in the near-median level of schooling. The correlation matrix conveys some useful information on the explanatory power of fundamental theories in the economic growth regression. It may be the case that the influence of some of the fundamental theories (religion, fractionalisation and institutions) on economic growth is exerted through proximate theories, and that these fundamental theories may have no direct impact on economic growth.

¹²²The analysis of Durlauf *et al.* (2008a) is robust since they built their work over an exhaustive survey of the empirical growth literature which identifies 43 growth theories and 145 regressors. Each of these theories is found to be statistically significant in at least one study (Durlauf *et al.*, 2005). Besides

¹²³We acknowledge that this data is subject to certain limitations as described by van der Ploeg and Poelhekke (2010). For instance, the data use the same discount rate of four per cent per annum regardless of the rate of economic growth, and the same remaining lifetime of 20 years and the same elasticity of the cost of extraction independently of the type of resource, country and date. van der Ploeg (2010) also argues that there is a caveat in using World Bank data on resource stocks as a measure of abundance since it is based on rents.

Economic growth regression results

In the following lines, we present our findings for the augmented Solow model and eight new growth theories based on equation [1].¹²⁴ The results for natural capital can be found in Table 5.15 for the full sample and in Tables 5.16 and 5.17 for the two sub-samples defined by the cut-off point in the near-median level of schooling. Tables 5.15-5.17 show results for the case where we include both proximate and fundamental determinants in the model space (columns 1-3) as well as the case where only fundamental growth determinants are in the model space (columns 4-6). Columns 1 and 4 of Tables 5.15-5.17 provide the posterior probability that each theory is in the ‘true’ model under BMA. In Tables 5.2 and 5.3 below, we share the summary findings for the BMA posterior inclusion probability results and for the BMA posterior mean results for the full set of eight theories.

Given the prior probability of a theory being in the true model space is set at 0,5, the robustness of a theory will depend on how the data updates this prior through the posterior probability of inclusion of the theory in the true model. In Tables 5.2 and 5.15, we can appreciate that the robust new growth theories for the full sample include demography, macroeconomic policy, natural capital, fractionalisation and institutions. In terms of the fundamental theories, the posterior probability of inclusion is close to one, both for the estimation with proximate and fundamental theories and for fundamental theories alone.

With regards to demography variables, in Tables 5.3 and 5.15, we can see that the effect of *fertility* is detrimental to economic growth and significant as in Barro (1991, 1996 and 1997) and Barro and Lee (1994). With respect to macroeconomic policy, *gov_cons* is negatively and significantly correlated with economic growth, in line with previous findings (Barro, 1991, 1996 and 1997 and Sachs and Warner, 1995). Concerning the natural capital theory, the posterior probability of inclusion is higher than the prior of 0,5 at 1,0, both for the estimation with proximate and fundamental theories and for fundamental theories alone. This indicates that natural capital measured through our proxies is a robust determinant of economic growth for countries with marine biodiversity while it is not for larger sample of countries (see chapter 2). In terms of the fractionalisation theory, the associated variable *matter* for economic growth in the sense that the posterior probability of inclusion is close to one. These results confirm previous work in the empirical literature suggesting an important role for fractionalisation in growth (Easterly and Levine, 1997 and Alesina *et al.*, 2003).

Our results for institutions point out that executive constraints have a negative and significant impact on economic growth in contrast with the result of Acemoglu *et al.* (2002) where institutions are positively correlated with economic growth. These results may suggest that greater checks and balances may depress growth (Barro, 1994). They may also suggest that to the extent that our measure of executive constraints correlates with political instability, there is significant evidence in the empirical literature of a negative relationship with respect to economic growth.¹²⁵

¹²⁴ The ratio of observations to independent variables should not fall below five (Bartlett *et al.*, 2001). As in Durlauf *et al.* (2005), we therefore exclude from the BMA regressions the variables which have weaker explanatory power in our regressions with respect to those presented in Table 5.7 (some religion variables: buddhism, catholic, jew and orthodox). We check for multicollinearity whereby additional variables are also excluded from the BMA regressions (some regional heterogeneity variables: East Asia and the Pacific and some institutional variables: liberal democracy, public sector corruption, legal formalism: Check (1), legal formalism: Check (2) and complex).

¹²⁵ Our executive constraints variable reflects the outcomes of most recent elections as a ‘political institution’ variable (Glaeser *et al.*, 2004). Some authors suggest that this variable cannot be therefore interpreted as reflecting durable rules, procedures or norms. Given such view, Cox and Weingast (2015) find that in terms of moderating succession-related downturns and thereby promoting steadier economic growth, the quality of legislatures measured by the executive’s horizontal accountability is more

In terms of the religion theory, the associated variables do not appear to matter for economic growth in the sense that the posterior probability of inclusion is lower than the prior of 0,5 at 0,08. These results appear to contradict previous work in the empirical literature suggesting an important role for religion in growth (Barro and McCleary, 2003). If we drop proximate growth theories from the model space and retain only fundamental growth theories, the posterior probability of inclusion for religion as a theory is very high at 1,00 for $school \geq 3,50$ as the eastern religion variable is important by our t-statistic rule of thumb as in Durlauf *et al.* (2008a).

One interpretation of these results is that religion affects economic growth indirectly through its influence on proximate variables. In exercises where we included the demography variables in the fundamentals only model space, the religion variables that were found to be robust determinants in column 4 of Table 5.2 become non-robust with a posterior probability of 0,0448.¹²⁶ This is consistent with our preliminary results where, among fundamental theories, religion is correlated with proximate theories' variables (Table 5.13). As in Durlauf *et al.* (2008a), our results indicate that previous findings on the direct importance of religion to economic growth are fragile.

Table 5.2. Economic growth determinants: BMA posterior inclusion probability results

	Proximate and fundamental theories			Fundamental theories		
	Full sample	$school \geq 3,50$	$school < 3,50$	Full sample	$school \geq 3,50$	$school < 3,50$
DEMOGRAPHY	1,000	1,000	0,995			
MACROEC. POLICY	1,000	0,276	1,000			
REGIONAL HETERO.	0,046	0,048	0,063			
RELIGION	0,085	0,523	0,025	0,997	1,000	0,019
NATURAL CAPITAL	1,000	1,000	1,000	1,000	1,000	1,000
GEOGRAPHY	0,110	0,071	0,181	0,046	0,064	0,060
FRACTIONALISATION	0,999	0,059	0,994	0,990	0,085	0,996
INSTITUTIONS	1,000	1,000	0,997	1,000	1,000	0,999

Note: This table provides the summary results for the eight growth theories for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. Results are given for the full sample, and for the sub-samples defined by the median cut-off point in schooling.

In terms of the neoclassical growth variables, our findings are overall consistent with those in the conditional convergence literature as well as previous studies that have used BMA methods. In Table 5.3, we can see that we find robust evidence of conditional convergence with a negative and significant coefficient on initial income as many previous studies (see, for instance, Barro, 1991, Sachs and Warner, 1995, Barro, 1997 and Easterly and Levine, 1997).

There is no evidence however that investment in physical capital is positively and significantly correlated to economic growth in contrast with previous findings (see, for example, Barro, 1991, Barro and Lee, 1994, Sachs and Warner, 1995, Barro, 1996, Caselli *et al.*, 1996 and Barro, 1997). The effect of schooling is not significant, but this result remains largely consistent with the literature (Durlauf *et al.*, 2008a). In exercises where we drop demography from the model space, we find that population growth rates are negatively and significantly

important than the existence of free and fair elections. In addition, to the extent that elections may correlate with political instability, there is significant evidence of negative relationship with respect to economic growth (see, for instance, Barro, 1991, Barro and Lee, 1994, Sachs and Warner, 1995, Alesina *et al.*, 1996 and Castelli *et al.*, 1996).

¹²⁶ Results are available upon request.

related to growth (Mankiw *et al.*, 1992, Kelley and Schmidt, 1995 and Blooms and Sachs, 1998).¹²⁷

Table 5.3. Economic growth determinants: BMA posterior mean results

	Proximate and fundamental theories			Fundamental theories		
	Full sample	<i>school</i> ≥ 3,50	<i>school</i> < 3,50	Full sample	<i>school</i> ≥ 3,50	<i>school</i> < 3,50
NEOCLASSICAL						
<i>income_ini</i>	-	-	-	-	-	NS
DEMOGRAPHY						
<i>fertility</i>	-	-	-	NA	NA	NA
MACROEC. POLICY						
<i>gov_consu</i>	NS	NS	-	NA	NA	NA
RELIGION						
<i>eastern</i>	NS	NS	NS	+	+	NS
FRACTIONALISATION						
<i>ethnic</i>	NS	NS	+	NS	NS	NS
INSTITUTIONS						
<i>exe_constr</i>	-	NS	-	NS	NS	NS

Note: This table provides the summary results for the eight growth theories for the growth regression exercise in equation (1) of the text that have variables that are significant. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. Results are given for the full sample, and for the sub-samples defined by the median cut-off point in schooling. ‘+’ stands for a positive and significant impact on average growth rates of pc GDP, ‘-’ stands for a negative and significant impact, ‘NS’ stands for a non-significant impact and ‘NA’ stands for non-applicable.

If we compare the two sub-samples according to the near-median level of schooling in Tables 5.2 and 5.17-5.18 with the results for the full sample, we can appreciate two main differences concerning the new growth theories. Firstly, macroeconomic policy is a robust determinant of economic growth only in the sub-sample with schooling values below the near-median cut-off point. In particular, in Table 5.3 we can appreciate that government consumption is negatively and significantly correlated with economic growth which is consistent with the empirical literature (Barro, 1991, 1996 and 1997 and Sachs and Warner, 1995).

Secondly, the fractionalisation theory is only a robust theory in the sub-sample with schooling values below the near-median cut-off point, with the *ethnic* variable being significant in Table 5.3 in line with previous analyses (Easterly and Levine, 1997 and Alesina *et al.*, 2003). This is consistent with our preliminary analysis where the *ethnic* variable has a higher value in the sub-sample with schooling values below the near-median cut-off point. In Table 5.3, we find that *ethnic* is positively and significantly correlated with economic growth. More diversity can lead to more conflict and less communication, but controlling for the latter it also leads to higher productivity (Alesina and La Ferrara, 2005).

To conclude, we find that according to the BMA method the robust new growth theories include demography, macroeconomic policy, natural capital, fractionalisation and institutions. When dividing the sample according to the cut-off point in near-median level of schooling, the rate of convergence is higher for those countries with higher rates of schooling and lower for the countries with lower rates of schooling. We find that the robust new growth theories include demography, natural capital and institutions for the sub-sample with schooling values above the

¹²⁷ Results are available upon request.

near-median cut-off point and, in addition, macroeconomic policy and fractionalisation for the sub-sample with schooling values below the near-median cut-off point.

5.4. Conclusion

In this analysis, we aim at bringing some light on the economic growth determinants of countries with marine biodiversity under model and specification uncertainty and testing for the presence of multiple economic growth regimes. We find that the neoclassical (initial income), demography, macroeconomic policy, natural capital, fractionalisation and institutions theories are robust determinants of economic growth. These results hold true for all countries with high levels marine biodiversity independently of the size of this sector (see Table 5.17 in the appendix). These results suggest that a country's capacity to deal with marine biodiversity is associated with factors that impact economic growth.

The role of demography is particularly relevant in the current context, since many of the world's coasts are becoming increasingly urban, with strong increases in coastal population, which in turn damages coastal ecosystems. Many studies show a clear and direct antagonism between demography and natural capital, as an increasing population increases the anthropogenic pressure on ecosystems (Cinner *et al.*, 2009a and Bond Estes *et al.*, 2012), through direct exploitation (implying effects such as 'malthusian overfishing', McClanahan *et al.*, 2008) as well as indirect effects such as uncontrolled sewage or farming runoffs. Hence, in countries with high natural capital, high demographic growth and low institutions (such as some regions of Tanzania), natural capital can be wasted for short-term gain rather than used in a more sustainable way for long-term benefit (Larrère and Larrère, 1997), jeopardizing the expected growth. In terms of policies, short-term gain is still often preferred to ecosystem services management (MEA, 2005).

Stable and legitimate institutions have been proven to improve the state of coral ecosystems (Babcock *et al.*, 2010), especially in the case of well-respected fishing norms and Marine Protected Areas (McClanahan *et al.*, 2007). Many studies suggest that the most efficient institutions may not be authoritarian, top-down norms but rather bottom-up measures and especially community-based co-management (Cinner *et al.*, 2009b and Cinner *et al.*, 2012), especially in poor countries or in presence of high levels of corruption (Sundström, 2012). The improvement in reef state entailed by such successful institutions have even shown direct effect on local population income and livelihood (McClanahan, 2010). In turn, regarding institutions and economic growth, one of the main determinants of differences in prosperity across countries are differences in economic institutions. Fostering economic development through better institutions is challenging though, since it entails reforming these institutions which are collective choices that are the outcome of a political process (Acemoglu and Robinson, 2010).

There is a long stream of literature on the relationship between ethnic diversity and environmental conservation (Serra Maggi, 2013). On the one hand, lower ethnic fractionalisation may result on better environmental performance because of greater cohesion and better communication (Das and DiRienzo, 2010). The (negative) interplay between ethnic and religious identities, resource competition and poverty is characteristic of politics, particularly in Africa (Cilliers, 2009). While oversight of the social and cultural way of organising, the interests and history of local communities has often resulted on the failure of marine conservation projects (Serra Maggi, 2013), ethnic plurality can also lead to higher productivity as our results suggest (Alesina and La Ferrara, 2005). Ethnic minority groups may depend more on information sharing within their communities which may decrease externalities and improve resource management by helping establishing social norms (Gutierrez *et al.*, 2011). Besides, their different knowledge and experiences may positively impact overall ability to adapt to environmental changes (Barnes-Mauthe *et al.*, 2013).

When we compare our results with those of Durlauf *et al.* (2008a) and chapter 2, we find different results in terms of the robust determinants of economic growth while using the same methodology which suggests that the evidence is contingent on the time frame and

country sample.¹²⁸ Regarding the large sample on 83 coastal and landlocked countries for the period 1960-2009 in chapter 2 using the same methodology as in this chapter, the robust determinants of economic growth are neoclassical (initial income), demography, institutions, fractionalisation and religion theories, instead. Hence, compared to a data set including a larger sample of coastal and landlocked countries, macroeconomic policies and natural capital are additional robust determinants of economic growth in countries with high marine biodiversity. There is strong historical evidence on the role of macroeconomic policies and non-renewable natural resources in trade flows and economic growth in coastal countries. Both factors highlight the pressures that coastal areas can be subject to such as construction and public works, population growth and urbanisation.

Natural capital can have two components: On the one hand, its living component (biomass, biodiversity, dynamics) and, on the other hand, its non-renewable component, including the biophysical ability of a particular place to accommodate important 'living' natural capital (both included in our natural capital variable). Hence, marine substrate complexity can buffer anthropogenic effect on reef systems (Cinner *et al.*, 2009a), and hence allow a better transition to economic development while preserving reef resilience, allowing potential virtuous circles. Maldives, The Bahamas and some archipelagos in the Pacific may be examples of such nature-rich sustainably developing areas. In contrast, in Florida, in the Antilles and in certain African coastal countries since coral reefs are more fragile and hence less resilient to external pressures, economic development induces a loss in natural capital. These elements contribute to explain the complex relationship between economic growth and coral reef health, often described as U-shaped (Cinner *et al.*, 2009a). While resilient marine natural capital can hence allow a better transition to economic development, we find that a strong dependence on natural capital wealth can hinder economic growth in countries that are less developed as commonly highlighted in the empirical literature (van der Ploeg, 2010 and Ross, 2015). In particular, a strong dependence on the export of non-renewable natural resources can hinder economic growth.

Growth-oriented macroeconomic policies can exert great pressure on marine resources as it was the case, for instance, in Indonesia (Dahuri and Dutton, 2000). In fact, policies with inflationary impacts such as increases in money supply and government expenditures, and decreases in taxes, cause the aggregate demand to grow. Despite higher prices of consumer goods and higher demand for labour in the formal sector, wages need not increase when there is labour surplus. Hence, expansionary policies may place more pressure on the marine resource and lead to faster depletion and degradation (Francisco and Sajise, 1992). In addition, greater government consumption can lead to lower economic growth because resources are diverted from more productive investments. There is also strong historical evidence on the role of these policies in trade flows and economic growth in coastal countries.

In our analysis, we find that education plays an important role in countries with high marine biodiversity. According to our results, the rate of economic convergence in these countries increases with the level of education. In addition, education and investment in physical capital have a significant and positive impact on economic growth in countries with very high levels of marine biodiversity.¹²⁹ It is well-known that proper management of marine resources requires investments both in education and infrastructure (White *et al.*, 2000 and Pandolfi *et al.*, 2005). Our results suggest that diversifying away from natural capital wealth by

¹²⁸In Durlauf *et al.* (2008a) with a sample on 57 coastal and landlocked countries for the period 1965-1994, only the neoclassical (initial income and investment in physical capital) and macroeconomic policy theories are robust determinants of economic growth.

¹²⁹Detailed results beyond those shared in Table 5.19 in the appendix, are available upon request. We can appreciate that the weight of renewable natural capital is much stronger, about two times higher, in the sub-sample with higher levels of marine biodiversity than in the sub-sample with lower levels of biodiversity, both the terms of renewable natural capital in wealth and in per capita renewable natural capital (see Table 5.20 in the appendix).

investing in education and, more generally, in intangible capital can enhance economic growth, particularly in countries with very high levels of marine biodiversity.

5.5. Appendix

Data

The data set constructed for this study contains observations for the period 1965-2009 on the following countries listed in Table 5.4 for which we have sufficient data on neoclassical variables.¹³⁰ We have data on 74 countries with coral reefs. Reef areas have been rounded to the nearest 10 sq km, while for those countries with small areas of coral reefs, the terms <100, <50 and <10 sq km have been used.

Table 5.4. Countries and geographical locations with coral reefs

Country and geographical locations	Reef Area (sq km)	Percentage of world total
Indonesia	51.020	17,95
Australia	48.960	17,22
Philippines	25.060	8,81
France including: Clipperton, Mayotte, Réunion, Guadeloupe, Martinique, New Caledonia, French Polynesia, Wallis and Futuna Islands	14.280	5,02
Papua New Guinea	13.840	4,87
Fiji	10.020	3,52
Maldives	8.920	3,14
Saudi Arabia	6.660	2,34
Marshall Islands	6.110	2,15
India	5.790	2,04
Solomon Islands	5.750	2,02
United Kingdom including: British Indian Ocean Territory, Anguilla, Bermuda, Cayman Islands, Pitcairn, Turks and Caicos Islands, British Virgin Islands	5.510	1,94
Vanuatu, Republic of	4.110	1,45
Egypt	3.800	1,34
United States of America including: Florida and Gulf of Mexico, Hawaii, United States Minor Outlying Islands, American Samoa, Puerto Rico, US Virgin Islands, Guam	3.770	1,33
Malaysia	3.600	1,27
Tanzania	3.580	1,26
Eritrea	3.260	1,15
Bahamas	3.150	1,11
Cuba	3.020	1,06
Kiribati	2.940	1,03
Japan	2.900	1,02

¹³⁰The following 6 countries with coral reefs were excluded from the analysis: Kenya, Micronesia, Myanmar, Nauru, Tuvalu and Spratly Islands.

Sudan	2.720	0,96
Madagascar	2.230	0,78
Thailand	2.130	0,75
Mozambique	1.860	0,65
Mexico	1.780	0,63
Seychelles	1.690	0,59
China	1.510	0,53
Tonga	1.500	0,53
Belize	1.330	0,47
New Zealand including: Cook Islands, Niue, Tokelau	1.310	0,46
Viet Nam	1.270	0,45
Jamaica	1.240	0,44
Brazil	1.200	0,42
United Arab Emirates	1.190	0,42
Palau	1.150	0,40
Costa Rica	970	0,34
Colombia	940	0,33
Taiwan	940	0,33
Mauritius	870	0,31
Honduras	810	0,28
Panama	720	0,25
Nicaragua	710	0,25
Somali Democratic Republic	710	0,25
Iran	700	0,25
Qatar	700	0,25
Yemen	700	0,25
Sri Lanka	680	0,24
Dominican Republic	610	0,21
Bahrain	570	0,20
Oman	530	0,19
Independent State of Western Samoa	490	0,17
Venezuela	480	0,17
Netherlands including: Aruba, Netherlands Antilles	470	0,17
Djibouti	450	0,16
Haiti	450	0,16
Comoros	430	0,15
Antigua and Barbuda	240	0,08
Brunei Darussalam	210	0,07
Saint Kitts and Nevis	180	0,06
Saint Lucia	160	0,06
Grenade	150	0,05
Saint Vincent and the Grenadines	140	0,05

Kuwait	110	0,04
Barbados	<100	
Singapore	<100	
Trinidad and Tobago	<100	
Bangladesh	<50	
Cambodia	<50	
Ecuador	<50	
Jordan	<50	
Israel	<10	
GLOBAL TOTAL	284,300	

Source: Spalding et al. (2001).

We have collected data on variables regrouped in five categories: neoclassical, natural capital, demography, macroeconomic policy, regional heterogeneity, religion, geography, fractionalisation, institutions and other. The definition of these variables and the data sources are given below.

Table 5.5. Data description

Designation	Source(s)
NEOCLASSICAL	
Growth rates of pc GDP	Average growth rates (constant 2005 USD prices) for the periods 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004, 2005-2009.
Initial income	Logarithm of real GDP per capita (constant 2005 USD prices) at 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000 and 2005. The instruments for the initial income include the values at 1955, 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, and 2000.
Population growth rates	Logarithm of average population growth rates plus 0,05 for the periods 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, 2000-2004, 2005-2009. The instruments for populations growth rates include the average values of 1955-1959, 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, 2000-2004.
Investment in physical capital	Logarithm of average ratios over each period of investment to GDP for the periods 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, 2000-2004, 2005-2009. The instruments for populations growth rates include the average values of 1955-1959, 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, 2000-2004.
Schooling	Logarithm of the ratio of male population enrolled in secondary school to total population in 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000 and 2005.
DEMOGRAPHY	

Life Expectancy	Reciprocals of life expectancy at age 1 in 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000, 2005.
Fertility rate	The log (LN) of the total fertility rate in 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000, 2005.

MACROECONOMIC POLICY

Openess	Average ratios for each period of exports plus imports to GDP in 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004, 2005-2009. The instruments include the average values of 1955-1959, 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, 2000-2004.
Government consumption	Average ratios for each period of government consumption to GDP in 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004, 2005-2009.
Inflation	The consumer price inflation rate for the periods 1960-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2009.

REGIONAL HETEROGENEITY

Latin America and Caribbean	Dummy variable.
Sub-Saharan Africa	Idem.
East Asia and the Pacific	Idem.
South-East Asia	Idem.

RELIGION

Buddhism	Buddhism share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the Buddhism share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Catholic	Catholic share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the catholic share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Eastern Religion	Eastern Religion share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the eastern religion share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Hindu	Hindu share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the Hindu share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Jew	Jew share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the Jew share in 1900 expressed as a fraction of the population who expressed adherence to some religion.

Muslim	Muslim share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the Muslim share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Orthodox	Orthodox share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the orthodox share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
Other	Other religion share in 1970. The instruments include the other religion share in 1990.
Protestant	Protestant share in 1970 expressed as a fraction of the population who expressed adherence to some religion. The instruments include the protestant share in 1900 expressed as a fraction of the population who expressed adherence to some religion.
NATURAL CAPITAL	
Natural capital in wealth	Time-invariant variable measuring the weight of natural capital in total wealth in 2000.
Natural capital per capita	Time-invariant variable measuring natural capital per capita in 2000. The variable is scaled to take values between zero and one.
GEOGRAPHY	
Coastline	Coastline length in km, scaled to take values between zero and one.
FRACTIONALISATION	
Language	Time-invariant measure of linguistic fractionalization that reflects the probability that two randomly selected individuals from a population belong to different groups. The data ranges from zero to one.
Ethnic	Time-invariant measure of ethnic fractionalization that reflects the probability that two randomly selected individuals from the population belong to different groups. The data ranges from zero to one.
INSTITUTIONS	
Liberal democracy	Time variant-index that emphasizes the importance of protecting individual and minority rights against the tyranny of the state and the tyranny of the majority. This is achieved by constitutionally protected civil liberties, strong rule of law, an independent judiciary, and effective checks and balances that, together, limit the exercise of executive power. To make this a measure of liberal democracy, the index also takes the level of electoral democracy into account. This variable is calculated as the average for the periods 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2009. It ranges from zero to one. Higher scores imply a more liberal democracy.
Public sector corruption	Time-variant variables that measures to what extent public sector employees grant favors in exchange for bribes,

	kickbacks, or other material inducements, and how often they steal, embezzle, or misappropriate public funds or other state resources for personal or family use. This variable is calculated as the average for the periods 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2009. It ranges from zero to one. Higher scores imply a more corruption.
Legal formalism: Check (1)	Time-invariant index of the professionals vs. laymen, written vs. oral elements, legal justification, statutory regulation of evidence, control of superior review, and engagement formalities indices, and the normalized number of independent procedural actions for the case of collection of a check. The index ranges from zero to seven, where seven means a higher level of control or intervention in the judicial process.
Legal formalism: Check (2)	Time-invariant index of formality in legal procedures for collecting on a bounced check, rescaled to lie between zero to one for 2003. Lower scores imply a less legal formality.
Complex	Time-invariant index of complexity in collecting a commercial debt valued at 50% of annual GDP per capita, rescaled to lie between zero and one for 2003. Lower scores imply a less complexity.
KKZ96	Time-invariant composite governance index. It is calculated as the average of six variables: voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption in 1996. It ranges from -2 to 2. Higher values imply better governance.
Executive constraints	Time varying variable that measures the extent of institutionalized constraints on the decision making powers of chief executives. This variable is calculated as the average for the periods 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2009. This variable ranges from zero to seven where higher values equal a greater extent of institutionalized constraints on the power of chief executives.
OTHER	
Time dummy variables	Dummy variables for 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2009
Colonial (Spain or Portugal)	Binary variable where one indicates that country was colonized by Spain or Portugal.
English legal origin	Binary variable where one indicates that country was colonized by The United Kingdom, and English legal code was transferred.
French legal origin	Binary variable where one indicates that country was colonized by France, Spain, Belgium, Portugal or Germany and French legal code was transferred.
Latitude	Djankov <i>et al.</i> (2003)

Mineral stocks	Norman (2009) and van der Ploeg and Poelhekke (2010)
System	Beck <i>et al.</i> (2001)

Table 5.6. Data sources

Designation	Source(s)
NEOCLASSICAL	
Growth rates of pc GDP	Penn World Tables 7.1
Initial income	Idem
Population growth rates	Idem
Investment in physical capital	Idem
Schooling	Barro and Lee (2014)
NATURAL CAPITAL	
Natural capital in wealth	World Bank
Natural capital per capita	Idem
DEMOGRAPHY	
Life Expectancy	World Bank
Fertility rate	Idem
MACROECONOMIC POLICY	
Openness	Penn World Tables 7.1
Government consumption	Idem
Inflation	World Bank
REGIONAL HETEROGENEITY	
Latin America and Caribbean	World Bank country classification
Sub-Saharan Africa	Idem
East Asia and the Pacific	Idem
RELIGION	
Buddhism	World Christian Encyclopedia (2001)
Catholic	Idem
Eastern Religion	Idem
Hindu	Idem
Jew	Idem
Muslim	Idem
Orthodox	Idem
Other	Idem
Protestant	Idem
GEOGRAPHY	
Latitude	Djankov <i>et al.</i> (2003)
Coastline	UNEP (2015)
FRACTIONALISATION	
Language	Alesina <i>et al.</i> (2003)
Ethnic	Idem
INSTITUTIONS	
Liberal democracy	The QOG Standard Dataset
Public sector corruption	Idem
Legal formalism: Check (1)	Djankov <i>et al.</i> (2003)
Legal formalism: Check (2)	Doing Business, World Bank
Complex	Idem
KKZ96	Kaufmann <i>et al.</i> (2005)
Executive constraints	Polity IV Project, 1946-2013

OTHER

Time dummy variables	Own construction
Colonial (Spain or Portugal)	Barro and Lee (1994)
English legal origin	Easterly (2001)
French legal origin	La Porta <i>et al.</i> (1999), and Djankov <i>et al.</i> (2003)

Descriptive statistics

We share the preliminary analysis results in Tables 5.7-5.14. Firstly, we present the summary statistics and the correlation matrix between the variables that proxy proximate and fundamental economic growth theories. This correlation matrix conveys some information on whether fundamental theories may have some explanatory power in the economic growth regression, beyond the influence exerted through proximate theories.

Secondly, we perform some preliminary tests to prepare the data for the analyses. Thirdly, we test on our dataset whether there is evidence of multiple convergence regimes among our panel of countries through the CART model. We verify the robustness of these results through the OLS, the fixed-effects and the DIF-GMM and SYS-GMM methods. Finally, we present the summary statistics and the correlation matrix according to the results of the CART model.

In this appendix, we can see some descriptive statistics. In Table 5.7, we share the summary statistics for all the variables that we used in our estimations. In Table 5.8, we present the correlation matrix between the proximate theories' variables and the variables associated with the fundamental theories, whenever the level of correlation is above or equal to 0,40. The variables associated with some fundamental theories (religion, fractionalization and institutions) present some degree of correlation with proximate theories' variables. Building on these results, we analyse whether the fundamental theories just mentioned have some explanatory power in the economic growth regression, beyond the influence exerted through proximate theories' variables.

Before proceeding with the CART model and the economic growth regressions, we perform a series of preliminary tests. We find that our dependent variable is stationary in levels, that panel data is preferred to pool data and that there is presence of heteroskedasticity and serial correlation, and we treat our data accordingly.¹³¹ We then perform the CART analysis to search for the presence of convergence regimes. The CART analysis identifies subgroups of countries that obey a common linear growth model based on neoclassical variables.

We identify four subgroups according to three different cut-off points by order of relevance: 3,61 for schooling, -2,40 for population growth rates and 10,08 for initial income. The subgroups are: *school* < 3,61 and *population* < -2,41 with 318 observations, *school* < 3,61 and *population* ≥ -2,41 with 33 observations, *school* ≥ 3,61 and *income_ini* < 10,08 with 53 observations and *school* ≥ 3,61 and *income_ini* ≥ 10,08 with 135 observations. To test the

¹³¹ Firstly, through the Fisher unit root test, we find that the dependent variable is stationary in levels. Secondly, we verify whether it is preferable to pool or not the data by testing the appropriateness of random and fixed-effects panel data compared to the pool analysis through the goodness-of-fit results. Panel data is preferred to pool data which implies that the parameters of the equation vary from one period to the other over the ten periods of available data. Thirdly, our data shows heteroskedasticity across panels through the Erilat LM-test and serial correlation through the Baltagi LM-test. The OLS and fixed-effects methods have adjusted standard errors for intra-group correlation which should hence be robust to heteroskedasticity and serial correlation. The GMM method also controls for heteroskedasticity and we test the presence of serial correlation of order one and two. This method assumes there is no second-order autocorrelation in the error term in levels. To perform the 2SLS method for the economic growth regressions, we use Driscoll and Kraay's approach which guarantees that the covariance matrix estimator is consistent, independently of the cross-sectional dimension, in contrast to Parks-Kmenta and the Panel-Corrected Standard Errors (PCSE) approaches, which typically become inappropriate when the cross-sectional dimension of a microeconomic panel gets large (Driscoll and Kraay, 1998).

robustness of these results, we separate the data according to the subgroups, and we test the hypothesis that all the countries in the sample follow the same convergence dynamics.

Unfortunately, we are unable to compare subgroups according to the CART cut-off points since the number of observations is insufficient in three of the four sub-samples.¹³² To overcome this problem, for the most relevant variable in the CART procedure, *school*, we select a cut-off point, 3,50, closer to the median value of 3,36.¹³³ This choice enables us to have over 250 observations in each of the two sub-samples which are sufficient to verify the presence of convergence regimes. We can see in Table 5.9 that there are no large differences in neoclassical variables when separating the sample according to the CART point and to the value closer to the median point.¹³⁴ In Table 5.10, we therefore explore whether we find evidence of the presence of two convergence regimes after accounting for variation in structural characteristics.

In addition to showing the convergence rate, λ , associated with the explanatory variables estimates of equation [2], Table 5.10 includes the number of observations actually used, *Observations*, the F and the Wald statistics, *F* and *Wald*, to test the joint significance of the coefficients associated with the dependent and the explanatory variables, the Hansen statistic with the p-value in parentheses, *Hansen*, to test the validity of instruments, the first- and second-order autocorrelation coefficients of the residuals in first differences, *m1* and *m2* and the chow test, *Chow*, which tests the hypothesis that the coefficients of the two sub-samples are the same.¹³⁵

The results of the chow test reveal that we can find evidence of the presence of two convergence regimes according to the OLS and fixed-effects methods. This is consistent with the main findings in the empirical literature (Durlauf *et al.*, 2005). Our global convergence rates are close to those typically estimated in the academic literature and which generally lie between two and three per cent (Barro and Sala-i-Martin, 1992). We can also appreciate in Table 5.10 that OLS and fixed-effects estimates are biased in opposite directions as expected. Moreover, when dividing the sample according to the cut-off point in schooling, we find that the rate of convergence is higher for those countries with higher rates of schooling and lower for the countries with lower rates of schooling.

In Table 5.10, we can appreciate that the estimates of the convergence rate for the DIF-GMM method do not stand between OLS and fixed-effects estimates. As in the case of Castelli *et al.* (1996), this large sample prediction is not valid raising the question about the validity of the DIF-GMM method. The SYS-GMM method is likely to be more robust in the presence of highly persistence series. Indeed, the estimates of the convergence rate for the SYS-GMM method stand between OLS and fixed-effects estimates. Besides, we can see in Table 5.10 that there is overall compliance with the SYS-GMM assumptions. There is no second order serial autocorrelation except for $school \geq 3,50$. In addition, the Hansen test accepts the validity of the instruments in the system GMM model.

¹³²With fewer than 5 cases per group and fewer than 50 groups, standard errors for fixed effects will be too small (increased Type I errors), and random effects (variances) and their standard errors may be underestimated (Hox, 2002, 2010).

¹³³ The fact that, given the opportunity to split the sample according to different neoclassical variables, the regression tree shows a preference for schooling splits suggests that schooling dominates the other variables in identifying multiple regimes in the data.

¹³⁴As the cut-off point for schooling gets closer from the median 3,36 to the CART value 3,61, there are larger differences between the rates of convergence in the sub-sample below the cut-off point and in the sub-sample above the cut-off point. We choose the near-median cut-off point 3,50 which enables to have more balanced sub-samples the the CART cut-off point and still finds some evidence of the presence of convergence clubs.

¹³⁵ If DIF-GMM and SYS-GMM generate instruments that grow according a quadratic law with T which can bias the estimates when the number of instruments is too large with respect to the number of observations. The weakness of specification tests is a particular concern for the SYS-GMM whose instruments are only valid under non-trivial assumptions. We should hence take a conservative p-value of the Hansen test (Roodman, 2009).

In Table 5.11, we present countries with schooling values above and below the near-median cut-off point 3,50. In Table 5.12, we share the summary statistics above and below the near-median cut-off point in schooling for the variables that we use in our economic growth regressions. The most significant differences between the sub-samples with the schooling values above and below the near-median cut-off point are those associated with the macroeconomic policy (*open*, *inflation*), natural capital (*natural_w*), fractionalisation (*ethnic*) and institutional endowments (*corruption*, *KZ96*, *exe_const*) variables.

In Tables 5.13 and 5.14, we present the correlation matrix between the proximate theories' variables and the variables associated with the fundamental theories, whenever the level of correlation of above or equal to 0,40 for the sub-samples above and below the near-median cut-off point in schooling. The variables associated with three fundamental theories, religion, fractionalisation and institutions, are strongly correlated with variables most proximate theories in the sub-samples both above and below the near-median cut-off point in schooling. Building on these results, we analyse whether these fundamental theories have some explanatory power in the economic growth regression, beyond the influence exerted through proximate theories' variables.

Table 5.7. Summary statistics

Designation	Variable	Obs.	Mean	Median	Std. Dev.	Min.	Max.
NEOCLASSICAL							
Growth rates of pc GDP	<i>growth_pc</i>	658	0,02	0,02	0,03	-0,08	0,13
Initial income	<i>income_in</i>	653	8,46	8,47	1,22	5,71	11,37
Population growth rates	<i>population</i>	740	-2,69	-2,71	0,20	-3,18	-1,56
Investment in physical cap.	<i>invest</i>	653	3,04	3,11	0,55	0,26	4,53
Schooling	<i>school</i>	539	3,13	3,36	0,94	-3,21	4,47
DEMOGRAPHY							
Life Expectancy	<i>life_exp</i>	685	0,02	0,01	0,09	0,01	2,54
Fertility rate	<i>fertility</i>	686	1,41	1,50	0,47	0,01	2,21
MACROECONOMIC POLICY							
Openness	<i>open</i>	654	0,75	0,68	0,49	0,01	4,20
Government consumption	<i>gov_consu</i>	689	0,14	0,11	0,09	0,00	0,65
Inflation	<i>inflation</i>	516	0,14	0,06	0,79	-0,01	16,67
REGIONAL HETEROGENEITY							
Latin America and Caribbean	<i>lac</i>	740	0,31	0,00	0,46	0,00	1,00
Sub-Saharan Africa	<i>ssa</i>	740	0,13	0,00	0,34	0,00	1,00
East Asia and the Pacific	<i>eac</i>	740	0,28	0,00	0,45	0,00	1,00
South-East Asia	<i>sea</i>	740	0,05	0,00	0,22	0,00	1,00
RELIGION							
Buddhism	<i>buddhism</i>	730	0,05	0,00	0,18	0,00	0,92
Catholic	<i>catholic</i>	730	0,28	0,15	0,34	0,00	0,94
Eastern Religion	<i>eastern</i>	730	0,03	0,00	0,10	0,00	0,56
Hindu	<i>hindu</i>	730	0,03	0,00	0,11	0,00	0,76
Jew	<i>jew</i>	730	0,01	0,00	0,09	0,00	0,85
Muslim	<i>muslim</i>	730	0,23	0,00	0,37	0,00	0,99
Orthodox	<i>orthodox</i>	730	0,01	0,00	0,05	0,00	0,45
Other	<i>other</i>	730	0,03	0,00	0,10	-0,16	0,57
Protestant	<i>protestant</i>	730	0,17	0,00	0,23	0,00	0,78
NATURAL CAPITAL							
Natural capital in wealth	<i>natural_w</i>	560	0,24	0,18	0,21	0,00	0,88

Natural capital per capita	<i>natural_pc</i>	560	0,12	0,05	0,19	0,00	1,00
GEOGRAPHY							
Coastline	<i>coastal</i>	710	0,03	0,01	0,07	0,00	0,50
FRACTIONALISATION							
Language	<i>language</i>	680	0,30	0,24	0,25	0,00	0,89
Ethnic tensions	<i>Ethnic</i>	720	0,38	0,40	0,23	0,00	0,87
INSTITUTIONS							
Liberal democracy	<i>Democracy</i>	499	0,37	0,31	0,27	0,02	0,95
Public sector corruption	<i>Corruption</i>	499	0,45	0,44	0,28	0,01	0,97
Legal formalism: Check (1)	<i>check(1)</i>	410	3,46	3,30	1,11	1,41	6,00
Legal formalism: Check (2)	<i>check(2)</i>	300	0,41	0,38	0,17	0,09	0,83
Complex	<i>Complex</i>	440	0,57	0,54	0,14	0,29	0,86
KKZ96	<i>KKZ96</i>	720	0,14	0,05	0,73	-1,68	1,92
Executive constraints	<i>exe_constr</i>	523	4,22	4,00	2,23	0,00	7,00
OTHER							
Time dummy variables	<i>year_dummy</i>						
Colonial (Spain or Portugal)	<i>colonial</i>	580	0,17	0,00	0,37	0,00	1,00
English legal origin	<i>english</i>	690	0,53	1,00	0,49	0,00	1,00
French legal origin	<i>french</i>	580	0,06	0,00	0,25	0,00	1,00
Latitude	<i>latitude</i>	720	0,20	0,17	0,12	0,01	0,60
Mineral stocks	<i>minerals</i>	510	-6,47	-6,27	3,38	-14,51	0,26
System	<i>system</i>	640	0,92	0,77	0,87	0,00	2,00

Table 5.8. Correlation matrix between proximate and fundamental theories

Fundamen. theories	Proximate theories										
	<i>popu</i>	<i>inves</i>	<i>scho.</i>	<i>life.</i>	<i>fert.</i>	<i>open</i>	<i>gov_.</i>	<i>infl.</i>	<i>lac</i>	<i>sea</i>	<i>ssa</i>

	<i>t</i>										
RELIGION											
<i>catholic</i>	0,06	-0,17	-0,14	0,08	0,15	-0,10	-0,22	0,11	0,68	-0,25	-0,07
<i>hindu</i>	0,05	-0,01	-0,07	-0,01	0,14	-0,15	0,11	-0,03	-0,18	0,82	-0,04
<i>muslim</i>	0,52	0,03	-0,08	-0,02	0,31	0,42	0,10	-0,02	0,32	-0,04	-0,00
<i>other</i>	0,02	-0,12	-0,37	-0,05	-0,15	0,01	0,07	-0,02	0,00	0,02	0,87
FRACTIONALISATION											
<i>ethnic</i>	0,38	0,04	-0,37	-0,08	0,47	0,23	-0,07	0,10	0,39	0,01	0,20
INSTITUTIONS											
<i>democracy</i>	-0,49	-0,05	0,47	0,08	-0,67	-0,34	-0,07	0,02	-0,24	0,02	-0,12
<i>corruption</i>	0,36	-0,05	-0,50	-0,06	0,52	0,20	0,00	0,07	0,31	-0,05	0,12
<i>check(1)</i>	0,34	-0,08	-0,28	-0,01	0,43	0,22	0,07	-0,02	0,47	0,10	0,14
<i>check(2)</i>	0,34	-0,09	-0,31	-0,01	0,45	0,24	0,05	-0,00	0,46	0,01	0,14
<i>KKZ96</i>	-0,42	0,01	0,47	0,07	-0,61	-0,17	-0,03	-0,08	-0,44	-0,25	-0,20
<i>exe_constr</i>	-0,43	-0,08	0,45	0,02	-0,52	-0,27	-0,06	-0,00	-0,08	0,18	0,13

Note: Values are only reported for those variables with a correlation above or equal to 0,40. The correlation matrix with all variables is available upon request to authors.

Table 5.9. Neoclassical variables for CART and near-median cut-off points

	<i>income_ini</i>	<i>population</i>	<i>Invest</i>	<i>school</i>
CART cut-off point				
<i>school</i> ≥ 3,61	8,86	-2,74	3,10	3,92
<i>school</i> < 3,61	8,00	-2,63	2,97	2,71
Near-median cut-off point				
<i>school</i> ≥ 3,50	8,85	-2,74	3,11	3,85
<i>school</i> < 3,50	7,90	-2,62	2,94	2,61

Note: The table reports the mean values of the neoclassical variables (initial income, population growth rates, investment in physical capital and schooling) according to the CART and the median cut-off points in schooling. See Tables 5.5-5.6 for more details on data definitions and sources.

Preliminary results

Table 5.10. Estimation results for the existence of multiple convergence clubs

	OLS	FE	GMM	System GMM
Full sample				
λ	-0,004	-0,015	-0.028	-0,015
<i>Observations</i>	491	491	383	434
<i>F</i>	5,83***	1,62		
<i>Wald</i>			-	5.352***
<i>Hansen</i>				16,42
<i>M1</i>			-4,27***	-3,89***
<i>M2</i>			-1,52	-1,63
Cut-off point in <i>school</i> $\geq 3,50$				
Λ	-0,006	-0,031	-0.044	-0.024
<i>Observations</i>	224	224	199	204
<i>F</i>	8,24***	2,72**		
<i>Wald</i>			-	1.534***
<i>Hansen</i>				24,74
<i>M1</i>			-3,32***	-2,94***
<i>M2</i>			-1,***	-0,72*
Cut-off point in <i>school</i> $< 3,50$				
λ	-0,002	-0,021	-0.043	-0,017
<i>Observations</i>	267	267	184	223
<i>F</i>	1,92	4,25***		
<i>Wald</i>			-	601***
<i>Hansen</i>				6,25
<i>M1</i>			-2,94***	-2,18**
<i>M2</i>			-0,65	-0,66
Chow test	2,22**	11,01***	-	-

Note: The table reports mean values of the convergence rate, λ , according to four estimation methods (OLS, fixed-effects, DIF-GMM and SYS-GMM). We report the F and the Wald statistics, *F* and *Wald*, that test the joint significance of the coefficients associated with the dependent and the explanatory variables, the Hansen statistic with the p-value in parentheses, *Hansen*, that tests the validity of instruments, the first- and second-order autocorrelation coefficients of the residuals in first differences, *m1* and *m2*, and the chow test, *Chow*, that tests the null hypothesis that the coefficients of the two sub-samples are the same and hence that there is only one convergence regime. ***/** stand for significance at the one and five per cent levels. In system GMM, we use *english* in levels as instruments for the equation in first differences.

Table 5.11. Classification of countries according to the near-median cut-off point in schooling

<i>school</i> < 3,50		<i>school</i> ≥ 3,50	
Bangladesh	Nicaragua	Antigua and Barbuda	Marshall Islands
Bahrain	Panama*	Australia	Mauritius*
Belize	Papua New Guinea	Bahamas	The Netherlands
Brazil	Philippines*	Barbados	New Zealand
Cambodia	Qatar	Brunei Darussalam	Oman
Colombia	Saudi Arabia	China	Palau
Costa Rica	Sudan	Comoros	Panama*
Dominican Rep.	Tanzania	Cuba	Philippines*
Ecuador	Thailand	Djibouti	Saint Kitts and Nevis
Egypt	Trinidad and Tobago*	Dominica	Saint Lucia
Fiji*	United Arab Emirates	Eritrea	Saint Vincent and Gre.
France*	Venezuela	Fiji*	Seychelles
Haiti	Viet Nam*	France*	Singapore
Honduras	Yemen	Grenada	Solomon Islands
India		Samoa	Somali Dem. Rep.
Indonesia		Israel	Sri Lanka
Iran		Jamaica*	Taiwan
Jamaica*		Japan	Tonga
Jordan*		Jordan*	Trinidad and Tobago*
Kuwait		Kiribati	United Kingdom
Mauritius*		Madagascar	United States
Mexico		Malaysia	Vanuatu, Republic of
Mozambique		Maldives	Viet Nam*

Note: A country is designated under a classification when half of its sample or more belongs to it. * indicates that half of the country sample is under the classification.

Table 5.12. Summary statistics according to the near-median cut-off point in schooling

Designation	Variable	<i>school</i> ≥ 3,50		<i>school</i> < 3,50	
		Obs.	Mean	Obs.	Mean
NEOCLASSICAL					
Growth rates of pc GDP	<i>growth_pc</i>	386	0,02	272	0,02
Initial income	<i>income_in</i>	386	8,85	276	8,77
Population growth rates	<i>population</i>	427	-2,74	313	-2,62
Investment in physical capital	<i>invest</i>	386	3,11	267	2,94
Schooling	<i>School</i>	226	3,85	313	2,61
DEMOGRAPHY					
Life Expectancy	<i>life_exp</i>	375	0,02	310	0,01
Fertility rate	<i>Fertility</i>	376	1,24	310	1,61
MACROECONOMIC POLICY					
Openness	<i>Open</i>	386	0,85	268	0,60
Government consumption	<i>gov_consu</i>	405	0,16	284	0,11
Inflation	<i>Inflation</i>	295	0,07	221	0,24
REGIONAL HETEROGENEITY					
Latin America and Caribbean	<i>Lac</i>	427	0,26	313	0,37
Sub-Saharan Africa	<i>Ssa</i>	427	0,15	313	0,11
East Asia and The Pacific	<i>eac</i>	427	0,32	313	0,22
South-East Asia	<i>sea</i>	427	0,04	313	0,06
RELIGION					
Buddhism	<i>buddhism</i>	417	0,04	313	0,07
Catholic	<i>catholic</i>	417	0,23	313	0,35
Eastern Religion	<i>eastern</i>	417	0,03	313	0,02
Hindu	<i>hindu</i>	417	0,02	313	0,03
Jew	<i>Jew</i>	417	0,02	313	0,00
Muslim	<i>muslim</i>	417	0,20	313	0,28
Orthodox	<i>orthodox</i>	417	0,01	313	0,00
Other	<i>other</i>	417	0,02	313	0,04
Protestant	<i>protestant</i>	417	0,25	313	0,07
NATURAL CAPITAL					
Natural capital in wealth	<i>natural_w</i>	297	0,19	263	0,30
Natural capital per capita	<i>natural_pc</i>	297	0,12	263	0,11
GEOGRAPHY					
Coastline	<i>coastline</i>	400	0,03	310	0,03
FRACTIONALISATION					
Language	<i>language</i>	386	0,28	294	0,32
Ethnic tensions	<i>ethnic</i>	421	0,33	299	0,44
INSTITUTIONS					
Liberal democracy	<i>democracy</i>	241	0,44	258	0,30
Public sector corruption	<i>corruption</i>	241	0,36	258	0,53
Legal formalism: Check (1)	<i>check(1)</i>	198	3,13	212	3,76
Legal formalism: Check (2)	<i>check(2)</i>	146	0,35	154	0,47
Complex	<i>complex</i>	185	0,51	255	0,62
KKZ96	<i>KKZ96</i>	407	0,35	313	-0,13

Executive constraints	<i>exe_constr</i>	247	4,72	276	3,77
OTHER					
Time dummy variables	<i>year_dummy</i>				
Colonial (Spain or Portugal)	<i>colonial</i>	309	0,04	271	0,07
English legal origin	<i>english</i>	385	0,64	305	0,40
French legal origin	<i>french</i>	309	0,06	305	0,40
Latitude	<i>latitude</i>	407	0,21	313	0,18
Mineral stocks	<i>minerals</i>	239	-6,23	271	-6,68
System	<i>System</i>	327	1,15	313	0,69

Table 5.13. Correlation matrix between proximate and fundamental theories for countries above the near-median cut-off point in schooling

Fundamen. theories	Proximate theories									
	<i>popu.</i>	<i>invest</i>	<i>scho.</i>	<i>life.</i>	<i>fert.</i>	<i>open</i>	<i>gov_.</i>	<i>infl.</i>	<i>lac</i>	<i>sea</i>
RELIGION										
<i>buddhism</i>	-0,38	0,31	0,01	-0,04	-0,19	-0,08	-0,23	-0,06	-0,20	0,49
<i>catholic</i>	-0,02	-0,39	-0,23	0,16	-0,00	0,06	-0,23	-0,06	0,55	-0,21
<i>eastern</i>	-0,28	0,46	-0,01	-0,04	-0,23	-0,00	-0,06	-0,12	-0,20	-0,15
<i>hindu</i>	-0,05	0,07	-0,10	-0,02	0,19	-0,06	0,11	-0,02	-0,11	0,77
<i>jew</i>	0,35	-0,00	-0,13	-0,02	0,16	0,00	0,44	0,49	-0,12	-0,09
<i>muslim</i>	0,64	0,24	-0,03	-0,03	0,51	0,49	-0,04	-0,02	-0,19	-0,04
FRACTIONALISATION										
<i>ethnic</i>	0,49	-0,0	-0,27	-0,09	0,51	0,43	0,04	0,05	0,42	0,15
INSTITUTIONS										
<i>democracy</i>	-0,49	-0,24	0,21	0,09	-0,53	-0,49	-0,17	-0,04	-0,20	-0,16
<i>check(1)</i>	0,25	-0,12	-0,45	0,00	0,31	0,31	0,09	0,04	0,45	0,19
<i>check(2)</i>	0,25	0,13	-0,46	0,00	0,29	0,33	0,08	0,04	0,45	0,13
<i>KKZ96</i>	-0,38	-0,16	0,38	0,06	-0,48	-0,32	-0,12	-0,06	-0,43	-0,41
<i>exe_constr</i>	-0,41	-0,22	0,07	-0,00	-0,35	-0,44	-0,08	0,06	-0,05	-0,01

Note: Values are only reported for those variables with a correlation above or equal to 0,40. The correlation matrix with all variables is available upon request to authors. The variable *ssa* was dropped.

Table 5.14. Correlation matrix between proximate and fundamental theories for countries below the near-median cut-off point in schooling

Fundamen. theories	Proximate theories										
	<i>popu.</i>	<i>invest</i>	<i>scho.</i>	<i>life.</i>	<i>fert.</i>	<i>open</i>	<i>gov_.</i>	<i>infl.</i>	<i>lac</i>	<i>ssa</i>	<i>sea</i>
RELIGION											
<i>catholic</i>	0,02	0,00	0,19	-0,30	0,00	-0,25	-0,21	0,11	0,72	-0,16	-0,29
<i>hindu</i>	0,04	-0,08	-0,07	0,38	0,11	-0,23	0,12	-0,04	-0,26	-0,06	0,91
<i>other</i>	0,03	-0,23	-0,49	0,51	0,17	0,02	0,00	-0,04	-0,11	0,92	0,00
NATURAL CAPITAL											
<i>natural_pc</i>	-0,21	0,11	0,28	-0,43	-0,45	-0,14	-0,15	0,00	0,07	-0,15	-0,17
FRACTIONALISATION											
<i>language</i>	0,00	0,06	-0,19	0,43	0,11	-0,01	-0,01	-0,09	-0,64	0,33	0,34
INSTITUTIONS											
<i>democracy</i>	-0,36	0,01	0,26	-0,40	-0,62	-0,26	-0,03	0,16	-0,05	-0,09	0,26
<i>check(1)</i>	0,34	-0,00	-0,03	0,20	0,42	0,14	0,09	-0,09	0,42	0,15	0,02
<i>check(2)</i>	0,33	-0,00	-0,03	0,21	0,41	0,16	0,08	-0,08	0,37	0,15	-0,11
<i>KKZ96</i>	-0,30	0,12	0,23	-0,52	-0,52	-0,02	-0,00	-0,05	-0,30	-0,26	-0,12

Note: Values are only reported for those variables with a correlation above or equal to 0,40. The correlation matrix with all variables is available upon request to authors.

Results

These tables provide results for the growth regression exercise in equation [1] of the text under BMA regressions with specification and model uncertainty. The dependent variable is the average growth rate of real per capita GDP corresponding to the periods 1960-64, 1965-69, 1970-74, 1975-79, 1980-84, 1985-89, 1990-94, 1995-99, 2000-04 and 2005-2009. Following Durlauf *et al.* (2008a), we instrument for endogenous variables using earlier or initial values if available with the exception of inflation, religion shares and natural capital under the Two-Stage Least Squares (2SLS) regressions (without uncertainty). For inflation we use as instruments the colonial dummy for Spain or Portugal and British and French legal origins and for religion shares we use the corresponding shares in 1900. Following van der Ploeg and Poelhekke (2010) we used a dummy for presidential system and mineral resource stocks as an instrument for natural capital variables. The 2SLS regression results are very similar to the BMA regression results with uncertainty and are available upon request. Please refer to the data appendix for details on the variables used.

Table 5.15. BMA estimation results for average growth rates of pc GDP: Full sample

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probab.(#)	Posterior mean	Posterior standard deviation	Posterior inclusion probab. (#)	Posterior mean	Posterior standard deviation
NEOCLASSICAL						
<i>income_in</i>		-0,058*	0,009		-0,021*	0,009
<i>population</i>		-0,077	0,066			
<i>invest</i>		0,018	0,016			
<i>school</i>		0,003	0,015			
DEMOGRAPHY	1,000					
<i>life_exp</i>		-0,095	0,055			
<i>fertility</i>		-0,202*	0,003			
MACROECONOMIC POLICY	1,000					
<i>open</i>		0,000	0,003			
<i>gov_consu</i>		-0,009	0,050			
<i>inflation</i>		-0,011	0,006			
REGIONAL HETEROGENEITY	0,046					
<i>lac</i>		0,000	0,004			
<i>ssa</i>		0,000	0,005			
<i>sea</i>		-0,000	0,004			
RELIGION	0,085			0,997		
<i>eastern</i>		0,006	0,033		0,352*	0,077
<i>hindu</i>		0,000	0,004		0,007	0,027
<i>muslim</i>		-0,000	0,002		-0,002	0,012
<i>other</i>		0,007	0,039		-0,002	0,021
<i>protestant</i>		-0,002	0,016		-0,002	0,018
NATURAL CAPITAL	1,000			1,000		
<i>natural_w</i>		-0,023	0,038		-0,094	0,053
<i>natural_pc</i>		-0,001	0,036		-0,000	0,023
GEOGRAPHY	0,110			0,046		
<i>coastline</i>		-0,008	0,032		-0,000	0,016
FRACTIONALISATION	0,999			0,990		
<i>language</i>		0,007	0,027		0,037	0,029
<i>ethnic</i>		0,005	0,020		0,000	0,010
INSTITUTIONS	1,000			1,000		
<i>KKZ96</i>		0,000	0,003		0,007	0,016
<i>exe_constr</i>		-0,019*	0,004		-0,002	0,004
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		470			470	

Note: This table provides results for the growth regression exercise in equation [1] of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to the periods 1960-64, 1965-69, 1970-74, 1975-79, 1980-84, 1985-89, 1990-94, 1995-99, 2000-04 and 2005-2009 for 74 countries. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 5.16. BMA estimation results for average growth rates of pc GDP: $school \geq 3,50$

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probab.(#)	Posterior mean	Posterior standard deviation	Posterior inclusion probab. (#)	Posterior mean	Posterior standard deviation
NEOCLASSICAL						
<i>income_in</i>		-0,079*	0,013		-0,051*	0,011
<i>population</i>		0,028	0,092			
<i>invest</i>		-0,007	0,039			
<i>school</i>		-0,033	0,053			
DEMOGRAPHY	1,000					
<i>life_exp</i>		-0,102	0,058			
<i>fertility</i>		-0,250*	0,058			
MACROECONOMIC POLICY	0,276					
<i>open</i>		-0,000	0,003			
<i>gov_consu</i>		0,067	0,181			
<i>inflation</i>		0,007	0,031			
REGIONAL HETEROGENEITY	0,048					
<i>lac</i>		0,000	0,003			
<i>ssa</i>		0,001	0,013			
<i>sea</i>		-0,000	0,006			
RELIGION	0,523			1,000		
<i>eastern</i>		0,150	0,170		0,488*	0,086
<i>hindu</i>		0,002	0,017		0,002	0,020
<i>muslim</i>		0,001	0,011		-0,005	0,021
<i>other</i>		0,015	0,084		0,012	0,069
<i>protestant</i>		-0,011	0,039		-0,001	0,016
NATURAL CAPITAL	1,000			1,000		
<i>natural_w</i>		0,004	0,056		0,019	0,055
<i>natural_pc</i>		0,034	0,059		0,054	0,065
GEOGRAPHY	0,071			0,064		
<i>Coastline</i>		-0,002	0,021		0,000	0,019
FRACTIONALISATION	0,059			0,085		
<i>Language</i>		0,000	0,007		-0,001	0,011
<i>ethnic</i>		0,001	0,011		-0,002	0,014
INSTITUTIONS	1,000			1,000		
<i>KKZ96</i>		0,001	0,010		0,001	0,007
<i>exe_constr</i>		-0,009	0,009		0,010	0,007
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		209			209	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 74 countries. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 5.17. BMA estimation results for average growth rates of pc GDP: *school* < 3,50

Explanatory variable	Proximate and fundamental theories			Fundamental theories		
	Posterior inclusion probab.(#)	Posterior mean	Posterior standard deviation	Posterior inclusion probab. (#)	Posterior mean	Posterior standard deviation
NEOCLASSICAL						
<i>income_in</i>		-0,046*	0,019		0,015	0,016
<i>population</i>		0,016	0,110			
<i>invest</i>		0,004	0,024			
<i>school</i>		-0,027	0,030			
DEMOGRAPHY	0,995					
<i>life_exp</i>		-6,175	9,995			
<i>fertility</i>		-0,178*	0,058			
MACROECONOMIC POLICY	1,000					
<i>open</i>		0,021	0,030			
<i>gov_consu</i>		-0,535*	0,257			
<i>inflation</i>		-0,011	0,007			
REGIONAL HETEROGENEITY	0,063					
<i>lac</i>		0,001	0,010			
<i>ssa</i>		0,000	0,005			
<i>sea</i>		-0,000	0,008			
RELIGION	0,025			0,019		
<i>eastern</i>		0,000	0,009		0,006	0,013
<i>hindu</i>		-0,000	0,005		0,000	0,005
<i>muslim</i>		0,000	0,002		-0,000	0,002
<i>other</i>		0,003	0,029		-0,000	0,009
<i>protestant</i>		0,000	0,006		-0,000	0,011
NATURAL CAPITAL	1,000			1,000		
<i>natural_w</i>		-0,004	0,044		-0,064	0,077
<i>natural_pc</i>		-0,054	0,138		-0,067	0,136
GEOGRAPHY	0,181			0,060		
<i>coastline</i>		-0,034	0,094		-0,000	0,036
FRACTIONALISATION	0,994			0,996		
<i>language</i>		0,017	0,044		0,057	0,054
<i>ethnic</i>		0,058*	0,026		0,075	0,084
INSTITUTIONS	0,997			0,999		
<i>KKZ96</i>		0,000	0,007		0,050	0,034
<i>exe_constr</i>		-0,015*	0,006		-0,011*	0,005
<i>year_dummies</i>		Yes			Yes	
<i>observations</i>		260			260	

Note: This table provides results for the growth regression exercise in equation (1) of the text. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 83 countries. “*” denotes significance. Within BMA, a specific theory is important if the posterior mean of the probability is at least twice the posterior standard deviation (see Brock and Durlauf, 2001). “#” denotes the posterior inclusion probability of each theory (as opposed to each individual variable).

Table 5.18. Classification of countries according to schooling (near-median cut-off point) and income per capita (logarithm of GDP per capita)

<i>school</i> < 3,5 and income per capita < 9	<i>school</i> < 3,5 and income per capita ≥ 9	<i>school</i> ≥ 3,5 and income per capita < 9	<i>school</i> ≥ 3,5 and income per capita ≥ 9
Bangladesh	Bahrain	China	Antigua and Barbuda
Belize	France	Comoros	Australia
Brazil	Kuwait	Cuba*	Bahamas
Cambodia	Mexico*	Djibouti	Barbados
Colombia	Qatar	Dominica	Brunei Darussalam
Costa Rica	Saudi Arabia	Fiji	Cuba*
Dominican Rep.	United Arab Emirates	Grenada*	Eritrea
Ecuador	Venezuela	Jordan	France
Egypt	Trinidad and Tobago	Kiribati	Grenada*
Fiji	Yemen	Madagascar	Israel
Haiti		Malaysia*	Jamaica
Honduras		Maldives	Japan
India		Marshall Islands	Malaysia*
Indonesia		Mauritius	The Netherlands
Iran		Philippines	New Zealand
Jamaica		Saint Kitts and Nevis	Oman
Jordan		Saint Vincent and Gre.	Palau
Mauritius		Samoa	Saint Lucia
Mexico*		Solomon Islands	Seychelles
Mozambique		Somali Dem. Rep.	Singapore
Nicaragua		Sri Lanka	Taiwan
Panama		Tonga	Trinidad and Tobago
Papua New Guinea		Vanuatu, Republic of	United Kingdom
Philippines		Viet Nam	United States
Sudan			
Tanzania			
Thailand			
Viet Nam			

Note: A country is designated under a classification when half of its sample or more belongs to it. (*) indicates that half of the country sample is under the classification. The threshold in the classification according to the income per capita is inspired by the World Bank classification of high-income versus non-high income countries (USD 12 736 for 2016). This threshold stands at about the 50th percentile for the sub-sample *school* ≥ 3,5 and at about the 80th percentile for the sub-sample *school* < 3,5.

**Table 5.19. Determinants of economic growth according to different country typologies:
Posterior exclusion probability**

	Proximate and fundamental theories			Fundamental theories		
	Total	Renewable	Non-renewable	Total	Renewable	Non-renewable
Higher marine biodiversity						
DEMOGRAPHY	0,992	0,995	0,998			
MACROEC. POLICY	0,999	0,999	0,999			
REGIONAL HETERO.	0,901	0,930	0,911			
RELIGION	0,138	0,100	0,133	0,999	0,990	0,999
NATURAL CAPITAL	0,999	0,999	0,999	0,999	0,998	0,999
GEOGRAPHY	0,076	0,073	0,074	0,067	0,066	0,074
FRACTIONALISATION	0,722	0,627	0,759	0,063	0,081	0,095
INSTITUTIONS	0,999	0,999	0,999	1,000	1,000	1,000
Lower marine biodiversity						
DEMOGRAPHY	0,999	0,999	0,999			
MACROEC. POLICY	0,999	0,999	0,999			
REGIONAL HETERO.	0,055	0,075	0,055			
RELIGION	0,038	0,058	0,050	0,169	0,116	0,097
NATURAL CAPITAL	0,999	0,999	0,999	1,000	0,993	0,997
GEOGRAPHY	0,077	0,070	0,101	0,099	0,116	0,097
FRACTIONALISATION	0,962	0,999	0,998	0,991	1,000	1,000
INSTITUTIONS	0,999	0,922	0,987	1,000	1,000	1,000

Note: This table provides the summary results for the growth regression exercise in equation (1) of the text, in particular, the BMA posterior inclusion probability results. The dependent variable is the average growth rate of real per capita GDP corresponding to 10 five year periods, from 1960 to 2009 for 73 countries. Results are given for sub-samples whose threshold is defined by the median in reef area at 1.160.

Table 5.20. Characterisation of countries according to the level of marine biodiversity

	Obs.	Natural capital in wealth			Natural capital per capita		
		Total	Renewable	Non-renewable	Total	Renewable	Non-renewable
Higher marine biodiversity	274	0,37	0,23	0,04	20	12	8
Lower marine biodiversity	210	0,22	0,13	0,09	25	6	19

Note: This table reports mean values of natural capital theory variables. Natural capital per capita is expressed in 2000 K USD\$. The classification of countries is done according to median values in reef area.

6. NATURAL CAPITAL ACCOUNTS AND PUBLIC POLICY DECISIONS: FINDINGS FROM A SURVEY

6.1. Introduction

The concept of natural capital can be described as the components of the natural environment that can be used to generate income, goods or services (Barbier, 2011).¹³⁶ It underlines the role of nature in supporting the economy and human well-being (Pearce et al., 1989). Natural capital can be categorised as geophysical capital (abiotic goods and services) and ecosystem capital (biotic goods and ecosystem services) (Milligan et al., 2014; Petersen and Gocheva, 2015).¹³⁷ Ecosystem services, in particular, can be defined as the outcome of biological, geochemical and physical processes and components that take place within an ecosystem and that are accessible to people (Weber, 2011; Maynard et al., 2015).¹³⁸ According to the Common International Classification of Ecosystem Services (CICES), three broad categories of ecosystem services can be identified, namely: provisioning, regulation and maintenance, and cultural services (MA, 2005; Weber, 2011).¹³⁹

There is no single agreed-upon definition of natural capital or (economic-)environmental accounting (Hetch, 2000; Weber, 2014a). We can nevertheless identify some common elements that usually characterise this concept (Hetch, 2000). Firstly, these accounts provide tools to link environmental and economic data which enables joint analyses. Secondly, they have a comprehensive coverage and can be used for macroeconomic and sectoral policy-making, rather than for decisions at the local level. Third, the accounts have time series data produced on a regular basis which enables analyses of trends over time. In this chapter, we broadly define natural capital accounts as ‘the (economic-)environmental accounts that refer to the statistics that can be integrated with national economic accounts which enable to have joint analyses’.

Since the 1970s with some initiatives in Canada, Denmark, France, the Netherlands, Norway and Spain, we have witnessed substantial efforts to develop natural capital accounting (Laurans et al., 2013; Edens, 2013; Weber, 2014a).¹⁴⁰ In the recent years, the international

¹³⁶ We would like to thank four anonymous reviewers for very useful comments. The work has been accepted under revisions by the Journal of Ecological Economics. This journal has a ranking 1 according to the Centre National de Recherche Scientifique (CNRS) 2016 classification and to the JCR 2016 classification. It has also been published by the French Association of Environmental and Resource Economist (FAERE). We would also like to thank Philippe Puydarrieux and Ophélie Darses from the Ministry of Ecology, Sustainable Development and Energy, and Glenn-Marie Lange and Sofia Ahlroth from the World Bank for their suggestions. A preliminary version of this paper was presented at the weekly ‘inter’ seminar at the Museum National d’Histoire Naturelle in Paris on the 4th December 2014, we thank Anne-Caroline Prevot and Clément Feger for their comments. The paper was also presented at the International Workshop on Opportunities and Obstacles for Natural Capital Accounting organised by the French Ministry of Foreign Affairs and International Development and the WWF in Brussels on the 27th January 2015, we also thank participants for their comments. In particular, we would like to thank Ben Milligan, Günter Mitlacher Jan-Erik Petersen and Robert Smith.

¹³⁷ Some key features of natural capital goods and services are their depletability (or not) and their capacity (or not) to renew or self-maintain. In neoclassical economic theory, goods and services overlap since the value of the good or asset stock is derived from the net present value of expected future benefits (monetary terms) (Weber, 2014a).

¹³⁸ Ecosystem services have not yet been given an exact definition (Weber, 2014b).

¹³⁹ There is no clear-cut boundary between natural capital nor ecosystem services categories (see Milligan et al., 2014 and Petersen and Gocheva, 2005 for more details).

¹⁴⁰ See Edens (2013) and Weber (2015) for a summary of initiatives on natural capital accounting since the 1970s.

natural capital accounting standards have evolved, and many capacity-building partnerships and research programs have been developed.¹⁴¹ Concerning international capital accounting, the United Nations System of Environmental–Economic Accounting Central Framework (SEEA CF) has become in 2012 an international statistical standard that describes stocks and changes in stocks of environmental assets.

The 2012 SEEA Experimental Ecosystem Accounting (EEA) provides the conceptual framework for ecosystem accounting, but does not include an integrated set of accounting tables and provides little guidance on how to implement these accounts (Weber, 2014a). The SEEA EEA defines ecosystem accounting as a coherent and integrated approach to the assessment of the environment through the measurement of ecosystems, and of the flows of services from ecosystems into economic and other human activity. The 2011 EU Framework for Ecosystem Capital Accounting in Europe enables to implement simplified ecosystem capital accounts based on the use of existing data.

The term natural capital accounting is broadly used throughout these initiatives, but not always in an unambiguous way (Weber, 2014a). The usual sense (for instance, its use by the World Bank) relates natural capital both to non-renewable resources of the subsoil and to renewable resources, and to the associated services.¹⁴² While proposing no precise definition of natural capital, the SEEA EEA suggests similar coverage for natural assets and services. In the biodiversity strategy of the European Union (EU), natural capital is equivalent to ecosystem capital only. This is the terminology also used in the UNSD/UNEP/CBD project on Advancing Natural Capital Accounting (ANCA) for ecosystem capital. Natural capital can be also understood as an economic production factor or, in a broader sense, covering non-marketed ecosystem services. Capital can refer implicitly or explicitly to the standard economic theory where capital is equal to the value of discounted future benefits; or capital can be defined as physical systems with capacities and resilience.

The SEEA CF and the SEEA EEA encompass measurement in both physical and monetary terms, and this is also the scope of this chapter.¹⁴³ The monetary valuation in the SEEA CF is limited in scope since generally only goods that have a market price are included (Weber, 2014a; Petersen and Gocheva, 2015). Physical accounts are considered the basis of the framework in the SEEA EEA (Weber, 2011). Because ecosystem accounts are deeply rooted into monitoring databases, implementation presently focuses on physical accounts. Measurement in monetary terms for ecosystem accounting is generally dependent on the availability of information in physical terms since there are few observable market values for ecosystems and their services (Weber, 2014a). According to a review of national ecosystem service assessments across the EU Member States, most provisioning services are, or will be, valued using market prices. Most regulating services using methodologies based on costs, are possible. Cultural ecosystem services, which are mainly valued using stated valuation methods, are subject to methodological challenges and lack of data (Brouwer et al., 2013).

¹⁴¹ Some capacity building programs include the 2008 ‘United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries’ (UN-REDD), the 2010 ‘Partnership for Wealth Accounting and the Valuation of Ecosystem Services’ (WAVES) coordinated by the World Bank and the Convention on Biological Diversity ‘Quick Start Package’ on ‘Ecosystem Natural Capital Accounts’ (ENCA). Some research programs include the 2005 Millennium Ecosystem Assessment, the 2008 Commission on Measuring Economic Performance and Social Progress and the 2010 Economics of Ecosystems and Biodiversity Initiative. See Milligan et al. (2014) and Petersen (2015) for a detailed review of accounting standards, capacity-building partnerships and research programs on natural capital accounting.

¹⁴² The SEEA CF defines environmental assets as the naturally occurring living and non-living components of the Earth that may provide benefits to humanity. The SEEA EEA proposes accounts which describe the supply of ecosystem services as well as asset accounts for ecosystems (Edens, 2013).

¹⁴³ See Petersen and Gocheva (2015) for details on the units of measurement for the different components of the accounts in the SEEA CF and the SEEA EEA.

There are many challenges related to monetary valuation in natural capital accounting. Adding together supporting services and ecosystem services represents a double counting of the contribution of supporting services.¹⁴⁴ To avoid double counting, CICES classification assists in identifying the ‘final outputs’ of ecosystems (Haines-Young and Potschin, 2010). In addition, because there is often lack of resources and time to do monetary valuation studies, the benefit transfer approach extends value estimates for ecosystem services or ecosystem assets to other areas (Pascual et al., 2010). However, the values provided by ecosystem services are often strongly dependent on the local context and on the proximity of other ecosystems (Petersen and Gocheva, 2015). According to the SEEA EEA, the limited data for certain ecosystem services, the variability in methodologies and the lack of common functional variables across studies, limit the use of this approach.

Concerning the monetary valuation of natural capital, the choice of the discount rate, which attributes more relevance to costs and benefits in the present than in the future, is one of the most disputed subjects in economic theory (Russi and ten Brink, 2010). According to the SEEA CF, it is necessary to select marginal, private, market-based discount rates for environmental assets in net present value calculations, to align SEEA values with the system of national accounts. However, lower discount rates are more appropriate to account for intergenerational equity and ethical responsibilities to the world’s poorest that depend directly on natural capital (Gowdy et al., 2009). Although experts agree on the principle of discounting and the formula to be used, they do not agree on the discount rate to be used for the valuation of natural capital (ten Brink et al., 2015).

Another problem related to the monetary valuation of natural capital, is the estimation of exchange values for non-market ecosystem capital, such as many regulation and cultural services.¹⁴⁵ The SEEA CF and SEEA EEA use exchange values, not welfare values, similarly to the system of national accounts.¹⁴⁶ Accordingly, there is a need to value the quantity of ecosystem services at the market prices that would have prevailed if the services had been freely traded and exchanged. Weber (2011) states that in such cases monetary valuation should be carried out on the basis of restoration costs rather than stated or revealed preferences as the latter are based on subjective evaluations, which make up-scaling and aggregation disputable.¹⁴⁷

Besides, in general, the methods based on revealed and stated preferences are based on the measurement of changes in individual welfare, and hence prices should be generated through simulated exchanged value or price function approaches (Day, 2013; ten Brink et al., 2015). In addition, if different methodologies are used for monetary valuation, the values obtained for different ecosystem services are not directly comparable and hence difficult to aggregate (Petersen and Gocheva, 2015). Despite these caveats, the use of monetary valuation is often considered useful for communication purposes (Pascal, 2014).¹⁴⁸

¹⁴⁴ The SEEA EEA argues that peat soils and cultivated biological resources can also be subject to double counting.

¹⁴⁵ It is also difficult to give a market value to biodiversity since it is challenging to evaluate the benefits it provides to humans associated, among other features, with social and cultural, ethical and aesthetic values, as well as unexplored or unknown values (Lavorel, 2014).

¹⁴⁶ In contrast with exchange values, welfare values include the consumer surplus, that is, the difference between the price consumers are willing to pay for a good or service and the market price. Exchange values do not capture the full benefits derived by the agents participating in a transaction. Natural capital accounts using exchange values are not attempting welfare valuation, and do not replace the need for cost-benefit analyses appraisal of policy changes (ten Brink et al., 2015).

¹⁴⁷ Others argue that restoration costs reflect technological ability rather than the value of ecosystem capital (ten Brink et al., 2015).

¹⁴⁸ Accounts in physical units are generally given priority to consider the capacity of ecosystems to deliver services, their resilience and, ultimately, the measurement of ecosystem degradation and enhancement (Weber, 2014a). In current approaches, physical accounts are sitting alongside economic information as a set of satellite accounts (Petersen and Gocheva, 2015).

Regarding the areas covered by natural capital accounts, at least 33 developed (high-income) countries have experiences, out of which 26 regularly compile at least one account (Edens, 2014).¹⁴⁹ The accounts that are most frequently compiled are physical flows in the input and output in production and consumption, namely air emissions, energy and material flow accounts. They also cover quite often environmental transactions in monetary units, mainly taxes and environmental protection expenditure accounts, and natural capital assets in physical and monetary units, mainly energy, timber and land accounts. Ecosystem services are rarely compiled, with exceptions such as non-timber forest resources in physical units.

There are a large number of pilot projects in developed countries concerning environmental protection expenditure, air emissions and non-timber forest resources accounts which suggests that these areas should be covered in the coming years by more countries. In developing (non-high-income) countries, there are fewer natural capital accounting experiences.¹⁵⁰ According to Edens (2014), out of 39 developing countries, 11 have some accounts while 21 have pilot projects. These countries usually develop natural capital asset accounts in physical and monetary units (minerals, energy, fish,...) and, to a lesser extent, physical flows such as water flows. Given these premises, ecosystem services accounts are those with most data gaps both for developed and developing countries. While monitoring databases can enable physical valuation, monetary valuation demands robust primary valuation studies that cover ecosystem services relevant to the decision context which can be very expensive (Hölzinger et al., 2013).

Since setting up natural capital accounts is very demanding in terms of human and financial resources, a relevant question is to which extent and how they are used. Worldwide policy makers were asked, among other things, whether or not they had made use of their natural capital accounts for economic and policy analysis through a survey developed by the UN for the SEEA programme (UN, 2006). Specific components of natural capital accounts were used by some developed countries' line ministries and agencies for planning and policy analysis such as Norway and Sweden (integration of natural capital accounting data with macroeconomic planning tools), Australia (water Act) and the United Kingdom (carbon footprint and sustainable consumption) (Delos Angeles, 2011). The reported uses of natural capital accounting by developing countries are much scarcer.¹⁵¹

There are currently international efforts to support financially and to accompany, from a technical standpoint, some developing countries in the development of natural capital accounts, including ecosystem capital accounts. There is however, no scientific consensus neither on the definition of natural capital, nor on its conceptual relationship with ecosystem services. There are also theoretical and empirical questions about what should be appropriate analytical scales in ecosystem services accounting (EFESE, 2013). The process of creating of ecosystem services accounts has been characterised by tensions between statistics and modelling efforts, and between initiatives that modify the boundaries of the system of national accounts framework and the emergence of multiple systems analyses (Weber, 2015).

Significant progress in the implementation of natural capital accounts is expected given international commitments. In 2010, Parties to the Convention on Biological Diversity (CBD) decided to integrate the values of ecosystem capital in national accounting systems by 2020, under Aichi Target 2 (CBD, 2014). The EU committed to the same goal under the EU Biodiversity Strategy, has given a significant push to natural capital accounting and, in particular, to ecosystem capital accounting (EU, 2011). Under the UN General Assembly 2015 agreement, the Sustainable Development Goals (SDG) target 15.9 requires countries to integrate

¹⁴⁹ Developed countries are those with high-income level according to the World Bank classification.

¹⁵⁰ Developing countries are those with non-high-income level according to the World Bank classification.

¹⁵¹ See Hetch (2000), Edens (2014) and Milligan et al. (2014) for some additional examples in developed and developing countries.

ecosystem capital values into national and local planning, development processes, poverty reduction strategies and accounts by 2020.

These commitments on natural capital accounts are made in a context of accelerated degradation of ecosystem capital (GRET/CIRAD/CDC Biodiversité, 2014). They seek to foster better management decisions, and are often closely linked to defining financing needs and mechanisms (NRC, 2005; TEEB, 2008). In this context, we propose to explore whether or not natural capital accounting has been used so far to inform public policy decisions, and to identify the obstacles that prevent such usage, if any. We explore the specificities of developed and developing countries. We aim at extending UN (2006) survey's sample beyond statistical offices since the latter may not be well informed of policy uses (Smith, 2015b). A survey conducted recently on 21 countries identified the (lack of) political awareness and will, enabling laws, policies and institutions, and technical knowledge and capacity as the challenges to the advancement and implementation of natural capital accounting (Milligan et al., 2014).

The remainder of this chapter is structured as follows. In the second section of the chapter, we describe the existing evidence on the obstacles for the use of natural capital accounts for policy decisions. We find six major obstacles: political, structural, institutional, design, data availability and cooperation. We elaborate a survey that we describe in section 3. In section 4, we provide the data description. In section 5, we describe the results and in section 6 we conclude. The survey, some details about the sample, and the results of the survey can be found in the appendices (Tables 6.7-6.8 and 6.9-6.11, and 6.12-6.19, respectively).

6.2. What do we know about the obstacles in the use of natural capital accounts for policy decisions?

Most of the literature on natural capital accounting and its policy uses comes from practitioners and international organisations aiming at better informing the design of these initiatives. Given this literature, we can define six main obstacles for the use of natural capital accounts for policy decisions: structural, political, institutional, design, data availability and (absence of) cooperation. Regarding structural obstacles, the country's level of development can affect its' capacity to undertake natural capital accounts and to continue them in the long term. In some developing countries fail to develop natural capital accounts in a sustainable manner because of resource constraints and lack sufficient data (Edens, 2013). Because national accounts data is weak they may already devote much of their statistical efforts to improving such accounts at the request of international financial institutions (Hecht, 2007).

Concerning political obstacles, the United States, for instance, developed a natural capital accounting program in the mineral sector in the early 1990s under the Clinton administration. This politically controversial program was abandoned in 1994 following the first publication of natural capital accounts (Edens, 2013). There was strong opposition from the mineral resource industry (Hecht, 1999). Although Nordhaus and Kokkelenberg (1999) concluded at the importance of taking the assets and productive activities related to natural capital into account, little progress has been made. Chile also abandoned one of its natural capital accounting programs for political reasons (Hecht, 2000). In the early 1990s, the Chilean Central Bank started to implement natural capital accounts focusing on forests and minerals. This program concluded that the development strategy of forestry-based countries was not sustainable. This result, contrary to the policy pursued by the government, seems to be at the origin of the significant slowdown in the country's efforts on natural capital accounting (Hecht, 1997).

At the institutional level, there may be lack of sufficient collaboration between conventional natural capital statisticians and natural capital accountants to ensure data compatibility implement accounts. While in developing countries there may be no distinction between statisticians and accountants, in some developed countries this problem can be relevant,

particularly when they work at different institutions.¹⁵² The collaboration is essential to deal with technical problems that may arise to best reflect the interactions between the economy and the environment (Hecht, 2000).¹⁵³ Besides, it is important to choose the appropriate leader in natural capital accounting to promote policy uses by other line ministries (UN, 2005; Edens, 2014). In most cases, the establishment of natural capital accounts is under the responsibility of the national statistical office or the minister of environment. When the country creates natural capital accounts for a particular resource, for instance, forests or water, the project may be entrusted to the ministry that has such competence. Central banks may also be associated with the implementation of natural capital accounts in Latin America (Edens, 2013).

In terms of the design of accounts, a number of international institutions including the UN, the European Commission, the IMF and the World Bank, have worked together to establish a framework for natural capital accounting. The SEEA was created in 1993 and was regularly modified to better fit the needs of countries. However, this framework is not always appropriate in practice. For instance, Japan decided to measure environmental pressures only in physical units (Edens, 2013). Moreover, the development of ecosystem accounts is still at an experimental stage. Besides, countries often lack data and funding to all the accounts recommended by the SEEA CF (Hecht, 2007). A country with established natural capital accounts should also have additional information not to underestimate its' impact on the environment which further increases program costs (Lange, 2003).

The availability and quality of data is a prerequisite for the use of natural capital accounts for public policy decision-making. In most cases, natural capital accounts uses data already collected for other reasons (Hecht, 2000). This secondary data must be treated to match the different concepts in natural capital accounts. Primary data is collected to establish natural capital accounts in very few countries such as Canada (Hecht, 2000). There is low investment in the production natural capital primary data. Developing countries may request external funding to develop natural capital accounts and to collect data. The funding source has an impact on how the work is performed since donors may change their priorities and often work with 3 to 5 year time horizons (Hecht, 2000).

Regular and effective cooperation between countries can contribute to the standardisation of practices. Since the early 1990s, the UNSD, the EU, the OECD, the World Bank, and national statistical offices, among other organisations, are working together to propose a standardised framework to implement natural capital accounts (Lange, 2003). According to the UN (2007), there should be more cooperation and coordination between national statistical offices and the different ministers in charge of natural capital data and information. Data should be shared between and within countries prior to the implementation of frameworks. There are no tools however, to compare the management of resources across similar countries. Cooperation is particularly necessary when environmental problems are trans boundary such as the case of water management in sub-Saharan Africa.

6.3. Survey

The survey was conducted by the French Ministry of Foreign Affairs and International Development in a joint effort with the WAVES program from the World Bank and with technical support from the EEA. The first part of survey deals with the strategies and commitments on natural capital accounting (see Table 6.7 in the appendix). The second part of

¹⁵² For instance, in France statisticians and accountants work at different institutions (the National Institute of Statistics and Economic Studies, INSEE and the Ministry of Ecology, Sustainable Development and Energy, respectively).

¹⁵³ Technically, the key issue is how to integrate data into national accounts, while ensuring compatibility with the data structures used by international groups such as the Intergovernmental Panel on Climate Change. This is adequately addressed in some cases, such as the Norwegian air emissions data, but in general terms there is still much work to be done to effectively link natural capital statistics with natural capital accounting (Edens, 2014).

the survey tackles the policy uses of natural capital accounting (see Table 6.8 in the appendix). In the first part of the survey, there are 4 questions on integration of natural capital accounts in national strategies, and 9 questions on the commitments that the country has made on natural capital accounting. The respondent could answer yes, no or non-applicable. This first part of the survey recalls the potential uses of natural capital accounting, as well as the ongoing international and national processes. This part of the survey was designed with the support of the European Environmental Agency (EEA).

In the second part of the survey, the respondent was asked whether the country compiles or has compiled natural capital accounts. The respondent could answer yes, no or non-applicable. If the answer is positive, the respondent was asked whether or not, to his/her knowledge, natural capital accounts have been used as input for public policy decisions in the country. The respondent could answer to a great extent, somewhat, very little, not at all, very difficult to know or non-applicable. This question relates to the uses of natural capital accounts as input for policy decisions, and does not refer to other potential uses such as ‘derivation of indicators’, ‘input in national accounts’, ‘input in research and modelling’, ‘basis for reporting to international organisations’ (UNCEEA, 2007). Moreover, we understand public policy as ‘an officially expressed intention backed by a sanction, which can be a reward or a punishment’. As a course of action (or inaction), a public policy can take the form of a law, a rule, a statute, an edict, a regulation or an order (Fischer et al., 2007). While it is not the research question of this chapter, we acknowledge the prominent use of natural capital accounts as input for research and modelling (Hoekstra, 2010; Smith, 2015).

The second part of the survey then deals with the reasons for not having used natural capital accounts as input for policy decisions, or for not having used them more intensively. Building over the enabling conditions and obstacles highlighted by Edens (2014) and complementing this information with exchanges with experts from the World Bank and the EEA, we have pre-identified a set of indicators that can be aggregated in the six following obstacles previously detailed in the literature review: political, structural, institutional, design, data availability and cooperation (see Table 6.8 in the appendix). For each of the indicators, the respondent could answer not relevant, slightly relevant, very relevant, extremely relevant or non-applicable.¹⁵⁴ The respondent could identify additional indicators beyond the ones included in the question.

The second part of the survey ends with three additional questions to characterise the type of natural capital accounts developed in the country. Firstly, the respondent was requested to share the data of creation of natural capital accounts. Secondly, the respondent was requested to highlight the type of methodology that is used for the development of the accounts: developed by the country, SEEA, the World Bank, other or non-applicable. Thirdly, the respondent was requested to share the level(s) at which the accounts are developed: local, regional, national or non-applicable. Finally, the respondent was invited to share any additional relevant information.

6.4. Data

The survey was sent to about 100 experts from statistical offices and relevant ministries, as well as to some independent experts, between the 24th June and the 15th August 2014 (see Tables 6.9 and 6.10 in the appendix). Experts were identified among the focal points of natural capital initiatives such as the SEEA, WAVES and the EU Mapping and Assessment of Ecosystems and their Services (MAES). There were 42 respondents, of which 16 did not yet have natural capital accounts and 5 completed only some of the answers. There are many countries that have yet to develop natural capital accounts, especially non-high-income countries (UNCEEA, 2015). Besides, some respondents declined the request arguing that policy uses were not under their mandate, or that they did not share the narrow definition of policy

¹⁵⁴ Note there can be interactions between the different obstacles, which may not be independent.

uses described in section 3. 21 surveys could be exploited, a total of 17 countries (see Table 6.1).¹⁵⁵ There were multiple respondents from Austria (2), France (3) and the Netherlands (2). There were 8 respondents from statistical offices and 13 respondents from relevant ministries and also independent experts. There were 9 respondents from high-income countries and 8 from non-high-income countries.

Table 6.1. Respondents

<u>Statistical office experts</u>	<u>Ministry and independent experts</u>
Afghanistan (*)	Afghanistan (*)
Australia (**)	Austria (2)
Bangladesh (*)	Brazil (*)
Bosnia and Herzegovina	Belgium
Central African Republic	Burkina Faso
Denmark (**)	Colombia
Finland	Comores (*)
Guatemala	Côte d'Ivoire (**)
Guinea-Bissau (*)	Estonia
Jamaica (*)	France (3)
Kenya (*)	Ghana (*)
Liberia (**)	Iran, Islamic R. (*)
Mauritania (*)	Korea, Rep.
Mauritius (*)	Republica Dominicana (*)
Mexico (**)	Myanmar (*)
Nepal (*)	Nepal (*)
Netherlands (2)	Sri Lanka
South Africa	Uganda
Sweden	United Kingdom

Note: (*): The country does not have environmental accounts. (**): The survey file is incomplete.

The natural capital intensity of a country's economy could be a confounding factor. The dependence on natural capital measured through variables such as 'natural resource rents as a percentage of the gross domestic product' or 'natural capital as a percentage of total wealth' has often been analysed in the framework of economic growth. According to Gylfason (2001), developed countries have a lower dependence on natural capital as they have diversified their economies by investing in other forms of capital, particularly in intangible capital, while developing countries have a higher dependence on natural capital. In Table 6.11 in the appendix, we can see that we find similar results with our sample of countries. Natural capital as a percentage of total wealth is 2 % for high-income countries, while 41 % for non-high-income countries. We may hence infer that separating our sample in developed and developing countries enables to take into account the natural capital intensity of a country's economy.

6.5. Results

We have analysed the results of the survey for the whole sample, and according to the income level of the country (high-income versus non-high-income), and to the type of respondent (statistical offices versus ministries and independent experts). We present the results

¹⁵⁵ That is, we have attained the desirable sample size for a normal distribution with a 90 % confidence level and 16 % margin of error, given our initial sample size (Krejcie and Morgan, 1970). This confidence interval refers to the sample size and hence to the reliability of the data used in the analysis. When performing a survey, the objectif is to obtain representative data about a number of variables within a certain target group or population, in our case about 100 experts from statistical offices and relevant ministries. It is very important to use a correct sample size, since if it is too small, the results will not be statistically significant and we will not have reliable conclusions.

of the survey in Tables 6.2-6.6 and in Fig. 6.1. Detailed information can be found in Tables 6.12-6.19 in the appendix.

In Table 6.2 and in Tables 6.12-6.14 in the appendix, we can see the results of the first part of the survey. Concerning the strategies and the commitments, the maximum values per respondent are 4 (strategies) and 9 (commitments). There is a fairly high integration of natural capital accounts in country strategies and a relatively high endorsement of commitments, independently of the level of income of the country. Any differences between high-income and non-high-income countries in the second part of the survey should not be related to significant differences in their engagements. If we analyse the samples according to the type of respondent, the differences are neither very strong.

Table 6.2. Strategies and commitments

	<u>Strategies</u>	<u>Commitments</u>	<u>Total</u>
Country mean	2.8	6.1	9.0
High-income country mean	3.0	6.1	9.1
Non-high-income country mean	2.7	6.2	8.9
Statistical office mean	2.3	5.9	8.1
Ministry / independent mean	3.3	6.3	9.7

Note: The values are obtained through a non-weighted sum of questions 1-2 (column 'strategies') and 3-7 (column 'commitments'). The maximum value is 4 for strategies and 9 for commitments. The values in the column 'total' are the sum of the values in the columns 'strategies' and 'commitments'.

In Tables 6.3-6.6 and 6.15-6.19 in the appendix, and in Fig. 6.1, we can see the results of the second part of the survey. We first asked whether or not, according to the respondent, natural capital accounts have been used as input for public policy decisions in the country. In Table 6.3, we can appreciate that respondents consider that natural capital accounts are used between sometimes and very little. 4 respondents signalled that it is very difficult to know whether or not natural capital accounts are used for public policy decisions. If we disaggregate results according to the income level of the country, in high-income countries the accounts have been used sometimes, while in non-high-income countries the accounts are used between very little and not at all. If we disaggregate results according to the type of respondent, there are no major differences between statistical offices, and ministries and experts.

Table 6.3. Uses of natural capital accounts for public policy decisions

	<u>Have natural capital accounts been used as input for public policy decisions in your country?</u>
Mean	1.7
High-income mean	1.3
Non-high-income country mean	2.5
Statistical office mean	1.9
Ministry / independent mean	1.6

Note: For this question, the respondent could select to a great extent (0), somewhat (1), very little (2), not at all (3), very difficult to know (4) or non-applicable (5).

In Table 6.4, we can see the obstacles for the use of natural capital accounts for public policy decisions. The punctuation is generally quite low. Given that in Table 6.3 we can see that accounts are not used very frequently for policy decisions, we explain this low score because of the active involvement of most respondents in the creation, development and/or upgrading of natural capital accounts. Many respondents directly expressed their concerns to us regarding this question, which could eventually undermine the financial and political support to this type of

accounts.¹⁵⁶ Despite the overall low score, we can see in Table 6.4 (first column) that there are two main obstacles: the lack of political support by key people such as politicians or the head of a government agency (political obstacle), and the institutional leadership being unable to promote policy use by other ministries (institutional obstacle). These two obstacles are among the most important, independently of the income level of the country (second and third columns).

Table 6.4. Obstacles in the use of natural accounts for public policy decisions by country income level

	<u>Total</u>	<u>High income</u>	<u>Non-high income</u>
<u>Political</u>			
Strong opposition to a public policy decision from groups of interest	0.62	0.77	0.38
Lack of political support by key people	1.33	1.15	1.63
Concern that natural capital accounts deliver ‘bad news’	0.57	0.54	0.63
Lack of ownership by the country	0.52	0.23	1.00
<u>Structural</u>			
Absence of a serious public good problem and of irreversibility risks	0.43	0.46	0.38
Inadequate stage of development of the country	1.05	0.54	1.88
Exogenous shocks have changed priorities in the country	0.62	0.69	0.50
<u>Institutional</u>			
Insufficiently broad engagement of stakeholders	1.14	0.92	1.50
Lack of a clear lead agency	0.90	0.77	1.13
Institutional leadership unable to promote policy use by other ministries	1.33	1.23	1.50
<u>Design</u>			
Difficulty to draw a link between natural capital accounts and policy decisions	1.05	1.00	1.13
Unclear guidelines	0.86	0.77	1.00
Classifications that are not very relevant to environmental policies	0.43	0.54	0.25
Lack of an ‘umbrella framework’ combining natural c. accounts and statistics	1.05	0.92	1.25
<u>Data availability</u>			
It is too early to use natural capital accounts for a fundamental policy use	0.71	0.69	0.75
Decreasing data availability	0.86	0.46	1.50
Insufficient data because of lack of staff and financial resources	1.00	0.54	1.75
<u>Cooperation</u>			
Lack of strong endorsement and mainstreaming by international agencies	1.10	0.77	1.63
Concerns by developing countries donors might impose ‘conditionalities’	0.62	0.38	1.00
Lack of an international forum for training and exchange	0.90	0.62	1.38

Note: The respondent could select not relevant (0), slightly relevant (1), very relevant (2), extremely relevant (3) or non-applicable (4). The values in the columns ‘total’, ‘high income’ and ‘non high income’ are the average of the total, high income country and non-high income country individual respondent values, respectively.

In addition, the design, data availability and cooperation obstacles are also slightly relevant obstacles for the sample on non-high-income countries. That is, the inadequate stage of

¹⁵⁶ Given the low scores, we do not seem to have strong sample selection or strategic bias. A sample selection bias could occur as a result of using samples from a non-randomly selected data. It could arise if some surveyed individuals are more prone to reply to the survey when the information they convey is relatively positive. The results could be also subject to strategic bias, if the respondents intentionally answer the survey questions in a misleading way. The respondent, for instance, may believe that a higher value would favour future investments on these accounts.

development of the country (structural obstacle), the insufficient broad engagement of stakeholders (institutional obstacle), the difficulty to draw a link between natural capital accounts and policy decisions and the lack of an ‘umbrella framework’ combining natural capital accounts and statistics (design obstacles), the decreasing data availability and insufficient data because of lack of staff and financial resources (data availability obstacle), and the lack of strong endorsement and mainstreaming by international agencies and the lack of an international forum for training and exchange (cooperation obstacles). Being at an inadequate stage of development in the country is the obstacle with the highest score in the sample on non-high-income countries.

We can compare results between statistical offices, and ministries and independent experts. In Table 6.5 (third column), we can see the results for ministries and independent experts where besides the lack of political support by key people (political obstacle) and the institutional leadership being unable to promote policy use by other ministries (institutional obstacle), we find that the design obstacles are also slightly relevant. In particular, the difficulty to draw a link between natural capital accounts and policy decisions and unclear guidelines, for example, guidance is not (yet) available for ecosystem accounting.

Table 6.5. Obstacles in the use of natural capital accounts for public policy decisions by respondent type

	<u>Total</u>	<u>Statistical office</u>	<u>Ministry/indepen.</u>
<u>Political</u>			
Strong opposition to a public policy decision from groups of interest	0.62	0.44	0.75
Lack of political support by key people	1.33	1.33	1.33
Concern that natural capital accounts deliver ‘bad news’	0.57	0.44	0.67
Lack of ownership by the country	0.52	0.78	0.33
<u>Structural</u>			
Absence of a serious public good problem and of irreversibility risks	0.43	0.22	0.58
Inadequate stage of development of the country	1.05	1.11	1.00
Exogenous shocks have changed priorities in the country	0.62	0.67	0.58
<u>Institutional</u>			
Insufficiently broad engagement of stakeholders	1.14	1.33	1.00
Lack of a clear lead agency	0.90	1.22	0.67
Institutional leadership unable to promote policy use by other ministries	1.33	1.11	1.50
<u>Design</u>			
Difficulty to draw a link between natural capital accounts and policy decisions	1.05	0.78	1.25
Unclear guidelines	0.86	0.33	1.25
Classifications that are not very relevant to environmental policies	0.43	0.22	0.58
Lack of an ‘umbrella framework’ combining natural c. accounts and statistics	1.05	1.22	0.92
<u>Data availability</u>			
It is too early to use natural capital accounts for a fundamental policy use	0.71	0.67	0.75
Decreasing data availability	0.86	1.11	0.67
Insufficient data because of lack of staff and financial resources	1.00	1.22	0.83
<u>Cooperation</u>			
Lack of strong endorsement and mainstreaming by international agencies	1.10	1.22	1.00
Concerns by developing countries donors might impose ‘conditionalities’	0.62	0.89	0.42
Lack of an international forum for training and exchange	0.90	1.22	0.67

Note: The respondent could select not relevant (0), slightly relevant (1), very relevant (2), extremely relevant (3) or non-applicable (4). The values in the columns ‘total’, ‘statistical office’ and ‘ministry / independent’ are the average of the total, statistical office and ministry / independent individual respondent values, respectively.

Regarding statistical offices, in Table 6.5 (second column), we can see that the institutional, data availability and cooperation obstacles are slightly relevant. In particular, the insufficient broad engagement of stakeholders and the lack of a clear lead agency (institutional obstacles), the decreasing data availability and the insufficient data because of lack of staff and financial resources (data availability obstacles), and the lack of strong endorsement and mainstreaming by international agencies and the lack of an international forum for training and exchange (cooperation obstacles). In terms of the design obstacles, the lack of an ‘umbrella framework’ that combines natural capital accounts and statistics is relatively important for statistical offices, but not for ministries and independent experts. The differences between results reported by statistical offices, and ministries and independent experts, support the choice have a sample that not only includes statistical offices.

Respondents have signalled other obstacles for the use of natural capital accounts for public policy decisions beyond those in the survey. Lack of awareness has been pointed out by respondents from Finland, France, the Netherlands, and Uganda. In Finland, policy makers only use their traditional sectoral data on forest and energy. In France, there is a need to develop dissemination and communication tools and strategies. In Uganda, there is a lack of clear understanding and appreciation of the importance of natural capital accounting in guiding policy.

In South Africa, the statistical office relies on other government departments to obtain natural capital data. In the United Kingdom, the value-added of accounts compared to existing environmental statistics is not straight forward. Concerning the greenhouse gas emissions accounts, the lack of use by the policy department was mostly because it was seen as a distraction from the Kyoto commitment; in terms of the energy accounts, energy balances have been analysed and used for policy purposes for decades already; in terms of the material flow accounts, the lack of a link to products and to within economy flows has inhibited their use.

Moreover, concerning the environmental protection expenditure accounts, the definition of spending and the lack of information on impact are a problem; in terms of the environmental taxes, the structure of the tax which has more environmental impact than the amounts raised; in terms of oil and gas accounts, some issues related to valuation approaches still need to be resolved; in terms of the water accounts, water balances and other statistics have already developed; idem for the forestry/timber accounts. Most interest may lay in the green economy/resource efficiency policies, but the weakness of material flow accounts significantly limits their use.

In Table 6.6, we aggregate the obstacles for the use of natural capital accounts for public policy decisions. The institutional obstacles are the most relevant, independently of the sub-sample. In addition, in non-high-income countries, the data availability and cooperation are slightly significant obstacles. For ministries and independent experts the design obstacles stand out, while for statistical offices the data availability and cooperation obstacles are slightly relevant. Respondents from non-high-income countries and from statistical offices give relatively high scores to the institutional obstacles.

The second part of the survey provides some additional information. In Fig. 6.1, we can see there is a positive correlation of 0.64 % between the use of natural capital accounts for policy decisions and the date of creation of such accounts. That is, accounts are used for policy decisions with a higher probability, the longer the time elapsed since they were created. This is not always be the case since some accounts that were created decades ago are yet to be exploited and used for policy decisions.

Table 6.6. Obstacles in the use of natural capital accounts for public policy decisions : Aggregated values

	<u>Total</u>	<u>High income</u>	<u>Non-high income</u>	<u>Statistical office</u>	<u>Ministry/ independent</u>
Political	0.76	0.67	0.90	0.75	0.77
Structural	0.70	0.56	0.91	0.66	0.72
Institutional	1.13	0.97	1.38	1.22	1.06
Design	0.85	0.81	0.91	0.64	1.00
Data availability	0.86	0.56	1.33	1.00	0.75
Cooperation	0.87	0.59	1.33	1.11	0.69

Note: The respondent could select not relevant (0), slightly relevant (1), very relevant (2), extremely relevant (3) or non-applicable (4). The values in the columns 'total', 'high income' and 'non high income', 'statistical office' and 'ministry / independent' are the average of the total, high income country and non-high income country, statistical office and ministry / independent individual respondent values, respectively.

Figure 6.1. Correlation between the date of creation of the natural capital accounts and their use for policy decisions

Note. The horizontal-axis represents the answers to the question 8.3 in the survey ('When were natural capital accounts first available in your country?') and the vertical-axis represents the answers to the question 8.1 in the survey ('Have natural capital accounts been used as input for public policy decisions in your country?'). In 8.1, higher scores indicate lower use.

The second part of the survey has two additional questions (see Tables 6.18-6.19 in the appendix). In terms of the methodology used for the development of natural capital accounts, countries are mostly using SEEA (12 respondents) and, to a lesser extent, their own methodology (6 respondents). The accounts are mainly developed at the national level (18 respondents) and, to a lesser extent, at the regional level (6 respondents).

In our sample of developed countries, the accounts that are most frequently compiled are physical flows, mainly air emissions, energy and material flow accounts, and environmental transactions in monetary units, mainly taxes and environmental protection expenditure accounts. Natural capital asset accounts in physical and monetary units, mainly energy, timber and land accounts, are developed much less frequently. Ecosystem services in physical units are rarely compiled. In terms of future developments, there are a large number of pilot projects for subsidies and water emissions accounts. There are also several pilot projects for timber resources and non-timber forest resources accounts.

In terms of uses for policy decisions, in the Netherlands, the water and energy physical flow accounts, and the environmental goods and services sector transactions accounts have been used for specific policies. The National Accounts Matrix including Environmental Accounts (NAMEA) in physical units has been used to set policy targets for the country's environmental performance on climate change, acid rain and eutrophication. In the United Kingdom, natural

capital accounts mainly cover physical flows, natural capital assets in physical and monetary units, and some transactions accounts in monetary units. Accounts are used to feed in resource efficiency and sustainable procurement policies. In Austria, natural capital accounts influence environmental politics in the area of climate policy through the efficient use of resources, and also by driving more investments into the environment.

In Estonia, natural capital accounts are used to set restrictions on economic activities. For example, there is a limitation to preserve 10 % of the forest land from economic activities, and there are also limitations on the use of shale-oil mining to ensure sustainability. In Finland, natural capital accounts are used to estimate environmental taxes. In the Republic of Korea, natural capital accounts are used to decide on the total government environmental budget. Except for Estonia, in developed countries, insufficient data is a major obstacle for the use of natural capital accounts for policy decisions, in contrast with design. For instance, the difficulty to draw a link between natural capital accounts and policy decisions is considered a major constraint in Estonia, France and the United Kingdom.

The developing countries in our sample usually have natural capital asset accounts in physical and monetary units, primarily timber, fisheries and land and, to a lesser extent, energy and minerals. They also have physical flow accounts mainly water flows. Few policy uses have been reported by respondents from developing countries. In Guatemala, natural capital accounts are used for the prioritization of national strategies, and used as input for the attribution of the country's general budget. They were also used for the Law on Vulnerability Reduction and for the legal framework on Adaptation to Climate Change and Mitigation of Greenhouse Gases Emissions. In South Africa, there is lack of ownership, lack of institutional leadership and insufficient data for natural capital accounts to be used for policy decisions. Natural capital accounts are mainly supply-driven and have a low profile (Edens, 2014).

In Burkina Faso, the Central African Republic and Guatemala there is also insufficient data to use natural capital accounts for policy decisions, and in Uganda it is too early for any fundamental policy use. Design is also a major obstacle for the use of natural capital accounts for policy decisions. In Bosnia and Herzegovina, South Africa and Sri Lanka, the design obstacles are mainly due to the lack of an 'umbrella framework' combining natural capital accounts and environmental statistics. In Colombia, the 2010 Natural Capital Strategy was developed with the support of Conservation International to integrate natural capital accounting into decision-making processes (Milligan et al., 2014). There are however, unclear guidelines for the development of accounts, and there is insufficient engagement from the different institutional stakeholders.

6.6. Conclusion

There have been many initiatives and policy commitments in natural capital accounting in the recent years. Based on a survey for statistical offices, ministries and independent experts worldwide, we provide some preliminary evidence on the use of natural capital accounts for public policy decisions. Prior to concluding, we highlight that there is probably no 'best practice' comprehensive approach to integrate natural capital accounts on policy decisions, needing to customise solutions.¹⁵⁷ In addition, further research would be needed to confirm the preliminary evidence reported in this chapter.

We find that, independently of the income level of country, countries are equally engaged in the integration of natural capital accounts in terms of their commitments and strategies. And yet, there is very little use of natural capital accounts for public policy decisions

¹⁵⁷ Milligan et al. (2014) find there is no unique 'best practice' approach for legal and policy reform for natural capital accounting. In several national contexts, there is considerable interest from senior politicians to work towards decision-making informed by natural capital accounting, but a reluctance to take action in absence of clear options for what to do (what legislation should be changed and how, what policies and incentives should be put in place, ...).

and, more so, in developing countries. The most relevant obstacles for the use of accounts in the policy-making process are the lack of political support by key people and the institutional leadership being unable to promote policy use by other ministries.¹⁵⁸ In terms of the political support, there has been a long debate for years between demand-driven and supply-driven natural capital accounts.

Field experience suggests that demand-driven projects are more likely to succeed in influencing public policies. Independently of political support, our respondents suggest that there is still a need to raise awareness on the existence and potential uses of such accounts at the different levels of the administration. Local authorities can remain largely ignorant if there is no targeted strategy to raise awareness (Labarraque and Tardieu, 2014). Raising awareness at the regional level on the potential of natural capital accounts for key EU policy areas such as the water framework and the floods directives, the biodiversity strategy and the cohesion policy, can be helpful to enhance usage (Petersen and Gocheva, 2015).

Regarding the institutional setting, the choice of the leading agency to be in charge of the accounts is key, as this agency should be strong enough to promote the use of accounts by third parties. The ministry of finance may be privileged as leading agency for the coordination of the development of natural capital accounts. In order to ensure the independence of data production and uses, the accounts may be developed in another ministry or in the statistical office. Besides, adapting existing laws or policies concerning natural capital data as in Costa Rica, Japan, Peru and the United Kingdom, is not a sufficient condition for the development and upgrading of natural capital accounts (Milligan et al., 2014).

In addition to these results, respondents from statistical institutes and developing countries reported to be particularly concerned firstly, about institutional obstacles and secondly, about data availability (insufficient data because of lack of staff and financial resources) and cooperation (lack of strong endorsement and mainstreaming by international agencies and lack of an international forum for training and exchange). Respondents from ministries and independent experts are particularly concerned about design obstacles such as the difficulty to draw a link between natural capital accounts and policy decisions, and unclear guidelines for the creation of the accounts. These results suggest that it is useful to integrate respondents beyond statistical offices and from countries at different stages of development.

Concerning developing countries, the most important obstacle for the use of natural capital accounts for policy making is the country's stage of development. This obstacle, together with the very little use of accounts in these countries for decision-making, may be relevant information for donors. At the same time, developing countries often rely heavily on natural capital for income and hence, they can benefit the most from the development of natural capital accounts. In such countries, engaging first with the ministries of finance and planning to be sure that accounts are relevant for policy-making may be key prior to the development of accounts. Finally, natural capital accounts are used for policy decisions with a certain lag with respect to their creation and hence, no rapid action may be expected following initial investments on the accounts.

In our sample of developed countries, the accounts that are most frequently compiled are physical flows, mainly air emissions, energy and material flow accounts, and environmental transactions in monetary units, mainly taxes and environmental protection expenditure accounts. In terms of future developments, there are a large number of pilot projects for subsidies and water emissions. There are also several pilot projects for timber resources and non-timber forest resources accounts. The developing countries in our sample usually have natural capital asset accounts in physical and monetary units, primarily timber, fisheries and land and, to a lesser extent, energy and minerals. They have also physical flow accounts, mainly water flows. Both in developed and developing countries, ecosystem services accounts in physical units are rarely

¹⁵⁸ The WAVES program found that once there is political support from key people, support from middle management can still represent a significant obstacle.

compiled. While monitoring databases can enable physical valuation of ecosystem services, monetary valuation demands robust primary valuation studies that cover ecosystem services relevant to the decision context which can be very expensive (Hölzinger et al., 2013).

In developed countries, insufficient data is generally not considered a major obstacle for the use of natural capital accounts for policy decisions, in contrast with design. For instance, the absence of clear guidelines for the development of accounts is a major obstacle in Estonia and France. The difficulty to draw a link between natural capital accounts and policy decisions is a major constraint in Estonia, France and the United Kingdom. In developing countries, there is insufficient data to use natural capital accounts for policy decisions. Design is also an obstacle for the use of natural capital accounts for policy decisions, particularly the lack of an ‘umbrella framework’ combining natural capital accounts and environmental statistics. Not many accounts may be available to be used in the policy-making process due to data gaps, design challenges and the required investment, the problem being much more acute in developing countries.

A key result of the survey is the need to evaluate the value-added of natural capital accounts with respect to statistics, prior to the development of accounts. Some developed countries have already developed a significant amount of environmental statistics, and accounts may not provide substantial additional information. Even in countries with few environmental statistics, the question remains relevant. Local problems might be better addressed through cost-benefit analyses and by investing in statistics. Many environmental problems are local in nature and cannot be easily addressed through natural capital accounts because accounting is mainly applicable at the national and regional levels.

It is interesting to draw a parallel with respect to the development of national income accounts, including the gross domestic product (GDP). There is evidence that the investment in data production may increase in times of crisis, for instance, during the energy crisis in the 1970s. The fast decisions required by the situations of crisis provide incentives to managers to develop the information to improve decision-making (Hecht, 2000). National accounts were created on the 1930s to understand whether or not the economic mobilisation program could be met for the World War II and, if so, at what costs (Marcuss and Kane, 2007). It then took over a decade in some countries to have a national-wide economy indicator that would be regularly revised with obstacles that are very similar to the ones currently associated with the creation of natural capital accounts (Ekins, 2015). It is important for natural capital accounts to be considered as relevant from a policy standpoint to attain maturity both in their development and in their integration within the decision-making process.¹⁵⁹

There are two ways of using the economic and natural capital accounts in the policy process, ex-ante and ex-post, and both are important. In this chapter, we have focused on the ex-ante use of natural capital accounts. When the economic accounts are used ex-ante to shape policy, their use is mainly in economic analyses done by technical experts. That kind of analysis usually occurs early in the policy process and some argue that its influence may be diluted by the time the final decision is made by senior officials and politicians who take much more into consideration than empirical studies. Under such an hypothesis, our results on the limited ex-ante use of natural capital accounts for policy decisions may not be surprising.

If we focus on the ex-post use of economic accounts, there are many examples of policies that target the variables such as economic growth, inflation control and employment measured in the economic accounts. The success of policies is measured by economic accounts, not informed by them. We can make a comparison between the ex-post use of economic and natural capital accounts. Since governments make far fewer policies that relate directly to natural capital than to economic activities, there are far fewer opportunities for the ex-post use of natural capital accounts than there are for economic accounts. The comparison of natural

¹⁵⁹ We recall that, for the time being, Hicksian income is not even reflected in SEEA publications. According to Hicks, income in a given period of time is the maximum amount that can be consumed in that period while keeping real wealth unchanged (Hicks, 1939).

capital accounts with economic accounts in terms of the importance in the policy process may not be fair. Further research could be undertaken to understand the relative importance of ex-ante and ex-post uses of economic accounts for policy decisions and hence, to make inferences about the role of ex-ante and ex-post uses of natural capital accounts in the policy-making process.¹⁶⁰

¹⁶⁰ The authors would like to thank Robert Smith of Midsummer Analytics for this insight.

6.7. Appendix

Survey

The survey constructed for this study contains the following questions reported in Tables 6.1-6.2.

Table 6.7. Natural capital accounts: Strategies and commitments (*)

<u>Strategies</u>
1) Is there a sustainable development strategy in your country?
1.1) If yes, is the use of natural capital accounts being considered to provide input?
2) Is there a sectorial sustainable development strategy in your country?
2.1) If yes for one or several sectors, is the use of natural capital accounts being considered to provide input?
<u>Commitments</u>
3) Has your country signed the Kyoto protocol on climate change and on the reduction of greenhouse gases?
3.1) If yes, is your country reporting to UNFCCC following GIEC/IPCC guidelines?
4) Is your country participating to a REDD+ action on reforestation?
5) Is your country putting in place actions related to the implementation of the Convention on biological diversity? (**)
6) Is your country participating in an action of the World Bank Waves partnership on natural capital accounting?
6.1) If yes, are there projects ongoing or foreseen on ecosystems services accounting (forests or coasts)?
7) Is your country participating in an action of the UNEP or OECD programmes on green economy and green growth?
7.1) If yes, is the SEEA methodology being considered to participate to those programmes?
7.2) If yes, are there projects ongoing or foreseen on ecosystems services accounting?

Note: ()*: The (economic-)environmental accounts refer to the statistics that can be integrated with national economic accounts which enables to have joint analyses, while indicators are usually isolated and are more difficult to interpret. *(**)*: Note that according to the Aichi-Nagoya 2010 objectives biological diversity values should be integrated on national accounts by 2020 (Strategy A, Target 2). For questions 1 to 7, the respondent could select yes (1), no (0), or non-applicable (2). We acknowledge that some questions are not dissociated.

Table 6.8. Natural capital accounts: Their uses for public policies (*)

8) Does your country compile (or has it compiled) natural capital accounts?
8.1) If yes, have natural capital accounts been used as input for public policy decisions in your country?(**)
8.2) If yes, please explain the reasons for not having used natural capital accounts as input public policy decisions in your country or for not having used them more intensively.
<u>Political</u>
Strong opposition to a public policy decision from groups of interest.
Lack of political support by key people (e.g., politicians or head of a governmental agency).
Concern that natural capital accounts deliver 'bad news'.
Lack of ownership by the country in the development and uses of natural capital accounts.
<u>Structural</u>
Absence of a serious public good problem and of irreversibility risks.
Inadequate stage of development of the country (other priorities considered more important).
Exogenous shocks have changed priorities in the country (for instance, 2008 global crisis, 1973 oil crisis).
<u>Institutional</u>
Insufficiently broad engagement of stakeholders.
Lack of a clear lead agency (or clear implementation structure among collaborating agencies).
Institutional leadership unable to promote policy use by other ministries.
<u>Design</u>
Difficulty to draw a link between natural capital accounts and policy decisions.
Unclear guidelines, e.g., guidance is not (yet) available in case of ecosystem accounting.
Classifications(***) that are not very relevant to environmental policies.
Lack of an 'umbrella framework' combining natural capital accounts and environmental statistics.
<u>Data availability</u>
It is too early to use natural capital accounts for a fundamental policy use.
Decreasing data availability (confidentiality of data, weaker administrative burden placed on companies).
Insufficient data to use it for policy decisions because of lack of staff and financial resources.
<u>Cooperation</u>
Lack of strong endorsement and mainstreaming by international agencies in their programs.
Concerns by developing countries that additional 'conditionalities' may be imposed by international organi.
Lack of an international forum for training and the exchange of experiences for policy analysis.
<u>Other</u> (please specify)
8.3) If yes, when were natural capital accounts first available in your country?
8.4) If yes, following which methodology? Developed by your own country, SEEA, World Bank, other, non applicable
8.5) If yes, at which level(s)? Local, regional, national, non-applicable
Do you have any comments you would like to share with us?

Note: (*): The (economic-)environmental accounts refer to the statistics that can be integrated with national economic accounts which enables to have joint analyses, while indicators are usually isolated and are more difficult to interpret. (**): Note that this question does not refer to other uses such as 'derivation of indicators', 'input in national accounts', 'input in research and modelling', 'basis for reporting to international organisations'. We understand public policy as "an officially expressed intention backed by a sanction, which can be a reward or a punishment." As a course of action (or inaction), a public policy can take the form of "a law, a rule, a statute, an edict, a regulation or an order" (Fischer *et al.*, 2007). (***): For instance, see the classification on the production of manufactured goods (PRODCOM) or the classification of individual consumption by purpose (COICOP). For question 8, the respondent could select yes (1), no (0), or non-applicable (2). For question 8.1, the respondent could select to a great extent (0), somewhat (1), very little (2), not at all (3), very difficult to know (4) or non-applicable (5). For question 8.2, the respondent could select not relevant (0), slightly relevant (1), very relevant (2), extremely relevant (3) or non-applicable (4). For questions 8.4-8.5, the respondent could select yes (1), or no (0).

Table 6.9. Respondents : Statistical offices experts

<u>Country</u>	<u>Statistical office</u>	<u>Income level</u>
		(+)
Afghanistan (*)	Central Statistics Organisation	LI
Australia (**)	Australian Bureau of Statistics	HI
Bangladesh (*)	Bangladesh Bureau of Statistics	LI
Bosnia and Herzegovina	Agency for Statistics of Bosnia and Herzegovina	UMI
Central African Republic	Institut Centrafricain de la Statistique et des Etudes Eco. et Sociales	LI
Denmark (**)	Statistics Denmark	HI
Finland	Statistics Finland	HI
Guatemala	Instituto Nacional de Estadística	LMI
Guinea-Bissau (*)	Instituto Nacional de Estatística	LI
Jamaica (*)	Statistical Institute of Jamaica	UMI
Kenya (*)	Kenya National Bureau of Statistics	LI
Liberia (**)	Liberia Institute of Statistics & Geo-Information Services (LISGIS)	LI
Mauritania (*)	Office National de la Statistique	LMI
Mauritius (*)	Statistics Mauritius	UMI
Mexico (**)	Statistics Office of Mexico	UMI
Nepal (*)	Central Bureau of Statistics	LI
Netherlands (2)	Statistics Netherlands	HI
South Africa	Statistics South Africa	UMI
Sweden	Statistics Sweden	HI

Note: (*): The country does not have environmental accounts. (**): The survey file is incomplete. (+): World Bank country income level classification : Low-income (LI), lower-middle-income (LMI), upper-middle-income (UMI), high-income (HI).

Table 6.10. Natural capital in total wealth.

	Intangible capital (% total wealth)	Produced capital (% total wealth)	Natural capital (% total wealth)
Austria	0.80	0.20	0.02
Belgium	0.79	0.18	0.01
Estonia	NA	NA	NA
Finland	0.80	0.19	0.05
France	0.82	0.16	0.02
Korea, Rep.	0.75	0.24	0.01
Netherlands	0.80	0.19	0.03
Sweden	0.83	0.16	0.03
United Kingdom	0.86	0.13	0.01
High-income country mean	0.81	0.18	0.02
Bosnia and Herzegovina	NA	NA	NA
Burkina Faso	0.57	0.12	0.33
Central African Republic	-0.09	0.08	1.04
Colombia	0.71	0.13	0.17
Guatemala	0.56	0.12	0.33
South Africa	0.74	0.15	0.12
Sri Lanka	0.71	0.16	0.16
Uganda	0.24	0.08	0.70
Non-high-income country mean	0.49	0.12	0.41

Note: According to the World Bank data on the wealth of nations (1995-2005 mean value). Natural capital is sum of crop, pasture land, timber, non timber forest, protected areas, oil, natural gas, coal, and minerals. NA: Absence of data.

Table 6.11. Respondents : Ministry and independent experts

<u>Country</u>	<u>Ministry / independent</u>	<u>Income level(+)</u>
Afghanistan (*)	National Environmental Protection Agency	LI
Austria (2)	Austrian Institute of Economic Research Federal Institute for Less Favoured and Mountainous Areas	HI
Brazil (*)	Universidade Estadual de Campinas, IPBES Multidisciplinary Expert Panel (MEP)	UMI
Belgium	Bureau fédéral du Plan	HI
Burkina Faso	Ministère de l'Environnement et du Développement Durable	LI
Colombia	Departamento Nacional de Planeación	UMI
Comores (*)	Direction Générale de l'Environnement et des Forêts	LI
Côte d'Ivoire (**)	Ministère de l'Environnement; de la Salubrité et du Développement Durable	LMI
Estonia	Estonian Environment Agency	HI
France (3)	Ministère de l'écologie, du développement durable, et de l'énergie Le Centre de coopération internationale en recherche agronomique pour le développement Muséum national d'Histoire naturelle	HI
Ghana (*)	University of Ghana, Member, Board of the Millennium Ecosystem Assessment (MA), Chair, Subsidiary Body on Scientific Technical and Technological Advice (SBSTTA) of the UN Convention on Biological Diversity	LMI
Iran, Islamic R. (*)	University of Tehran, expert for the UN Convention on Biological Diversity	UMI
Korea, Rep.	Ministry of Environment	HI
Dominican R. (*)	Ministerio de Medio Ambiente y Recursos Naturales	UMI
Myanmar (*)	Ministry of Envi. Conservation and Forestry Forest, University of forestry	LI
Nepal (*)	Ministry of Science, Technology and Environment	LI
Sri Lanka	Board of Investment of SL	LMI
Uganda	National Environment Management Authority	LI
United Kingdom	Department for Environment, Food and Rural Affairs	HI

Note: (*): The country does not have environmental accounts. (**): The survey file is incomplete. (+): World Bank country income level classification Low-income (LI), lower-middle-income (LMI), upper-middle-income (UMI), high-income (HI).

Table 6.12. Strategies and commitments

	<u>Strategies</u>	<u>Commitments</u>	<u>Total</u>
Austria	2	6	8
Belgium	4	5	9
Bosnia and Herzegovina	3	4	7
Colombia	4	8	12
Central African Republic	4	4	8
Estonia	2	3	5
Finland	4	6	10
France	4	9	13
Guatemala	0	9	9
Korea, Rep.	4	5	9
Netherlands	3	8	11
South Africa	2	2	4
Sri Lanka	2	9	11
Sweden	0	8	8
Uganda	4	7	11
United Kingdom	4	5	9
Country mean	2.8	6.1	9.0

Note: The values are obtained through a non-weighted non-rounded sum of questions 1-2 (column 'strategies') and 3-7 (column 'commitments'). The maximum value is 4 for strategies and 9 for commitments. The values in the column 'total' are the sum of the values in columns 'strategies' and 'commitments'.

Table 6.13. Strategies and commitments by country income levels

	<u>Strategies</u>	<u>Commitments</u>	<u>Total</u>
Austria	2	6	8
Belgium	4	5	9
Estonia	2	3	5
Finland	4	6	10
France	4	9	13
Korea, Rep.	4	5	9
Netherlands	3	8	11
Sweden	0	8	8
United Kingdom	4	5	9
High-income country mean	3.0	6.1	9.1
Bosnia and Herzegovina	3	4	7
Colombia	4	8	12
Central African Republic	4	4	8
Guatemala	0	9	9
South Africa	2	2	4
Sri Lanka	2	9	11
Uganda	4	7	11
Non-high-income country mean	2.7	6.2	8.9

Note: The values are obtained through a non-weighted sum of questions 1-2 (column 'strategies') and 3-7 (column 'commitments'). The maximum value is 4 for strategies and 9 for commitments. The values in the column 'total' are the sum of the values in columns 'strategies' and 'commitments'.

Table 6.14. Strategies and commitments by type of respondent

	<u>Strategies</u>	<u>Commitments</u>	<u>Total</u>
Bosnia and Herzegovina	3	4	7
Central African Republic	4	4	8
Finland	4	6	10
Guatemala	0	9	9
Netherlands	3	8	11
South Africa	2	2	4
Sweden	0	8	8
Statistical office mean	2.3	5.9	8.1
Austria	2	6	8
Belgium	4	5	9
Colombia	4	8	12
Estonia	2	3	5
France	4	9	13
Korea, Rep.	4	5	9
Sri Lanka	2	9	11
Uganda	4	7	11
United Kingdom	4	5	9
Ministry / independent mean	3.3	6.3	9.7

Note: The values are obtained through a non-weighted sum of questions 1-2 (column 'strategies') and 3-7 (column 'commitments'). The maximum value is 4 for strategies and 9 for commitments. The values in the column 'total' are the sum of the values in columns 'strategies' and 'commitments'.

Table 6.15. Use of natural capital accounts for public policy decisions

	Have natural capital accounts been used as input for public policy decisions in your country?
Austria	1
Austria	0
Belgium	2
Bosnia and Herzegovina	3
Burkina Faso	NA (*)
Colombia	2
Central African Republic	NA (*)
Estonia	1
Finland	2
France	3
France	NA (*)
France	NA (*)
Guatemala	2
Korea, Rep.	1
Netherlands	1
Netherlands	1
South Africa	3
Sri Lanka	2
Sweden	1
Uganda	3
United Kingdom	1
Mean	1.7

Note: The respondent could answer to a great extent (0), somewhat (1), very little (2), not at all (3) and difficult to know (NA).

Table 6.16. Use of natural capital accounts for public policy decisions according to country income levels

	Have natural capital accounts been used as input for public policy decisions in your country?
Austria	1
Austria	0
Belgium	2
Estonia	1
Finland	2
France	3
France	NA (*)
France	NA (*)
Korea, Rep.	1
Netherlands	1
Netherlands	1
Sweden	1
United Kingdom	1
High income country mean	1.3
Bosnia and Herzegovina	3
Burkina Faso	NA (*)
Colombia	2
Central African Republic	NA (*)
Guatemala	2
South Africa	3
Sri Lanka	2
Uganda	3
Non-high income country mean	2.5

Note: The respondent could answer to a great extent (0), somewhat (1), very little (2), not at all (3) and difficult to know (NA).

Table 6.17. Use of natural capital accounts for public policy decisions according the respondent type

	Have natural capital accounts been used as input for public policy decisions in your country?
Bosnia and Herzegovina	3
Burkina Faso	NA (*)
Central African Republic	NA (*)
Finland	2
Guatemala	2
Netherlands	1
Netherlands	1
South Africa	3
Sweden	1
Statistical office mean	1.9
Austria	1
Austria	0
Belgium	2
Colombia	2
Estonia	1
France	3
France	NA (*)
France	NA (*)
Korea, Rep.	1
Sri Lanka	2
Uganda	3
United Kingdom	1
Ministry / independent mean	1.6

Note: The respondent could answer to a great extent (0), somewhat (1), very little (2), not at all (3) and difficult to know (NA).

Table 6.18. Methodology used for natural capital accounts

	If natural capital accounts been used as input for public policy decisions in your country, following which methodology?			
	<u>Own methodology</u>	<u>SEEA</u>	<u>World Bank</u>	<u>Other</u>
Austria	0	1	0	0
Belgium	1	1	0	1
Bosnia and Herzegovina	0	1	0	0
Burkina Faso	0	1	0	0
Colombia	0	1	0	0
Finland	0	1	0	0
France	1	0	0	0
Guatemala	0	1	0	0
Korea, Rep.	0	1	0	0
Netherlands	1	1	0	0
South Africa	0	1	0	0
Sweden	1	1	0	0
United Kingdom	0	1	0	0
Mean	4	12	0	1

Table 6.19. Scale used for natural capital accounts

	If natural capital accounts been used as input for public policy decisions in your country, at which level(s)?		
	<u>Local</u>	<u>Regional</u>	<u>National</u>
Austria	0	0	1
Belgium	0	1	1
Bosnia and Herzegovina	0	0	1
Burkina Faso	0	0	1
Colombia	0	0	1
Estonia	0	0	1
Finland	0	0	1
France	0	0	1
Guatemala	0	0	1
Korea, Rep.	0	0	1
Nepal	0	0	1
Netherlands	0	1	1
South Africa	0	0	1
Sweden	0	0	1
United Kingdom	0	0	1
Mean	0	2	15

7. CONCLUSIONS AND FURTHER RESEARCH

In this thesis, we explore macroeconomic and accounting frameworks to motivate the integration of marine and coastal ecosystems within the basic infrastructure required to sustain economic activity. After an introductory chapter, in the second one, we analyse whether renewable and non-renewable natural capital are robust determinants of economic growth. We find some evidence of an indirect negative impact of renewable natural capital on economic growth through fertility. This is particularly the case for countries with higher levels of human development, where fertility rates would be still rising in the second-phase of the demographic transition. These results suggest that we find evidence of the ‘Malthusian trap’ where the resource abundance would encourage population growth, which would eventually bring the per capita supply of resources back to its original level. In contrast, the share of non-renewable natural capital in wealth has a direct positive impact on economic growth in countries with lower income inequality and higher institutional quality. This result reflects the effect of capital accumulation in the domestic economy, as capacity constraints are relaxed.

In the third chapter, we highlight the potential policy mechanisms through which the ocean and coasts play a key role on climate regulation, and on the reduction of greenhouse gas emissions, with climate change mitigation interventions in coasts having returns in the short-term. We show that climate change mitigation projects in coasts can play a significant role within overall mitigation efforts, and we share a country-taxonomy for mangrove countries according to their climate change mitigation potential and their break-even carbon price to identify priority areas for intervention. Based on these results, in the fourth chapter, we focus on the determinants of economic growth in countries with high exposure to coastal risks and with high coastal climate change mitigation potential, given the potential synergies between nature-based adaptation and mitigation strategies. In the fifth chapter, we examine countries with high marine biodiversity, through the extension of coral reef resources. Compared to a worldwide data set, macroeconomic policies and natural capital are additional determinants of economic growth in these three types of coastal countries. There is strong historical evidence on the role of macroeconomic policies and non-renewable natural resources in trade flows and economic growth in coastal countries. Both factors, together with demography, highlight the pressures that coastal areas are subject to such as construction and public works, population growth and urbanisation. Besides these results, we find that education plays an important role in countries with marine biodiversity. In particular, diversifying away from natural capital wealth by investing in education and, more generally, in intangible capital can enhance economic growth, particularly in countries with very high levels of marine biodiversity.

Finally, in the sixth chapter, based on a survey for statistical offices, ministries and independent experts worldwide, we find that there is very little use of natural capital accounts for public policy decisions and, more so, in developing countries. The most relevant obstacles are the lack of political support by key people and institutional leadership being unable to promote policy use by other ministries. Concerning developing countries, the factor which is considered as the most relevant in preventing the use of natural capital accounts for policy making is the stage of development of the country. A key result of the survey is the need to evaluate the value-added of natural capital accounts with respect to statistics. Most probably, natural capital accounts will only be integrated in national accounts in the aftermath of a major environmental disaster.

7.1. Natural capital and macroeconomic frameworks

Renewable and non-renewable natural capital

In this thesis, we aim at bringing some light on whether natural capital is a robust determinant of economic growth, distinguishing the direct and indirect contributions of renewable and non-renewable natural capital. For this matter, we use a data set on 83 countries for the period 1960-2009 to compare the relevance of proximate and fundamental theories to

explain economic growth when the sample is divided according to investment in physical capital.

Through this first country typology based on investment in physical capital, we find some evidence that renewable natural capital has a rather indirect impact on economic growth. In particular, we find an indirect negative impact through human development and, more precisely, through fertility rates. According to the ‘Malthusian trap’ the resource abundance would encourage population growth, which would eventually bring the per capita supply of resources back to its original level. In contrast, we find neither a direct impact of non-renewable natural capital on economic growth when exploring proximate and fundamental theories together, not an indirect impact when analysing fundamental theories alone.

Is it possible to find some other impact of renewable and non-renewable natural capital on economic growth through methods that take into account model uncertainty? As we can appreciate in Table 2.4, we can separate the sample according to the levels of investment in physical capital, but also divide it according to income per capita, income inequality, human development and institutional quality median values. In Table 2.4, we can see that renewable natural capital has an indirect impact on economic growth in the sub-samples characterised by lower investment in physical capital, as we have already seen, and also in those characterised by higher human development. In particular, the share of renewable natural capital in wealth is positively correlated with fertility in the sub-sample with higher levels of human development and in turn, fertility affects negatively economic growth.¹⁶¹ Hence, in countries with higher human development (higher fertility rates), renewable natural capital has a negative indirect impact on economic growth.

In contrast with previous findings on renewable capital, non-renewable natural capital has a direct impact on economic growth in the sub-samples characterised by lower income inequality and higher institutional quality, given that it affects growth when both proximate and fundamental theories are analysed together. This impact is positive through the non-renewable natural capital in wealth variable in both sub-samples, and significant in the sub-sample characterised by higher institutional quality. This is related to the effect of capital accumulation in the domestic economy, as capacity constraints are relaxed (van der Ploeg and Venables, 2010).¹⁶²

When we compare our results with those of Durlauf *et al.* (2008a) who use a shorter period and a smaller sample of countries, we find different results in terms of the robust determinants of economic growth suggesting that the evidence is contingent on the timeframe and country sample.¹⁶³ Further work based on longer time-series and specific country samples, could enable to provide more evidence on the nature of the effect of natural resources on economic growth in the long-run. Our work and that of Konte (2013) testing whether neoclassical and institutional variables help a given country to belong to a certain economic growth regime with specific implications in terms of natural capital, are some first attempts to

¹⁶¹ Note that it seems that our sample of countries characterised by high levels of HDI would be in the second phase of the demographic transition, that is, life expectancy would be rising but fertility rates would be still high.

¹⁶² Many countries find it indeed hard to absorb windfall of foreign exchange, as it takes time for the non-traded sectors to accumulate capital. In the meantime, it is optimal to park the windfall revenue abroad until there is enough capacity to invest in the domestic economy.

¹⁶³ We can compare our results for the period 1960-2009 with respect to those of Durlauf *et al.* (2008a) for the period 1965-1994. The data set used by Durlauf *et al.* (2008a) consists of 57 countries, of which 54 are also present in our work. In particular, both analyses are based on 11 from Asia and Oceania, 13 from Latin America and Caribbean, 19 countries from North America and Europe and 11 from Middle East and Africa. In addition, we include one country from Europe, 14 from Middle East and Africa, seven from Latin America and Caribbean and seven from Asia and Oceania. While Durlauf *et al.* (2008a) find that among new growth theories, macroeconomic policy is a robust determinant, in our BMA analysis for the full sample demography, religion and institutions are instead the robust determinants suggesting that results are contingent on the time frame and country sample.

develop country typologies. One research question would be then how can countries fall under the classifications that enable to benefit from natural capital.¹⁶⁴ We can also take different country samples, in particular, countries with high coastal climate change adaptation needs and mitigation and potential countries with marine biodiversity, as we do in chapters four and five. Before analysing these samples of countries, we explore whether coastal ecosystems can relevantly contribute to overall efforts to reduce carbon emissions.

Coastal blue carbon: Climate change mitigation potential

In this thesis, we explore whether and how coastal blue carbon mechanisms can be currently developed. We focus on the extent to which these mechanisms are relevant alternative tools for climate change mitigation. This analysis is not about whether coastal blue carbon protection can provide economic incentives strong enough to substantially curtail existing rates of ecosystem loss and contribute to conservation, but whether it has a significant and operational role in the short-term for climate change mitigation in specific countries.

We find that mangroves are the only coastal ecosystem for which we have sufficient scientific knowledge and data to establish priorities for climate change mitigation. This type of coastal blue carbon ecosystem can play a significant role on climate change mitigation since mangroves are carbon-intensive ecosystems that are geographically concentrated and that are among the most threatened ecosystems in the world. We put forward a country-taxonomy according to the climate change mitigation potential and the break-even carbon price for the top 25 mangrove countries, and we identify factors that should be considered to further develop such taxonomy such as co-benefits, but also risks, among other, due to trade-offs between carbon, biodiversity and social objectives.

There are important potential linkages between climate change adaptation and coastal blue carbon. Among the different sectors, coastal zones have the highest adaptation costs and the bulk of the coastal adaptation costs are related to sea dikes. Interestingly, some research points to the role of mangrove forests as an alternative solution to the construction of sea-dikes that can be cost-effective and less damaging for ecosystems. Although the complementarity between adaptation and mitigation strategies can be substantial, attention needs to be paid in the case of the interventions of multilateral development banks. Since large funds are being allocated for resilience and it is easier to measure project inputs than project effectiveness, development banks tend to choose grey instead of green infrastructure.

Coastal countries with climate change mitigation potential and adaptation needs

In this thesis, we aim at bringing some light on the determinants of economic growth in countries with high exposure to coastal risks and with high coastal climate change mitigation potential, given the potential synergies between nature-based adaptation and mitigation strategies. We use a data set on 67 countries for the period 1960-2009, and we take into account theory and specification uncertainty and confirm the presence of multiple growth regimes.

We find evidence that the neoclassical (initial income and investment in physical capital), demography, macroeconomic policy and natural capital are the robust determinants of economic growth both in countries with high exposure to coastal risks and with high coastal climate change mitigation potential. These results suggest that a country's capacity to deal with climate adaptation and mitigation policies relying on nature based-solutions is associated with factors that impact economic growth. There is strong historical evidence on the relationship between demography, macroeconomic policies and non-renewable natural resources, and trade flows and economic growth in coastal countries. These factors highlight the pressures that coastal areas are subject to such as construction and public works, population growth and

¹⁶⁴ There is lengthy literature on natural capital and economic growth seeking to analyse how to attain the characteristics that enable to have a positive relationship between these two variables, particularly applied to institutional endowments (see, for instance, Omgba, 2015).

urbanisation. Our results are particularly relevant for Brazil, Cambodia, Ecuador, Gabon, Indonesia, Madagascar, Malaysia, Myanmar, Philippines, United States and Vietnam, which have both high exposure to coastal risks and high coastal climate change mitigation potential.

Many of the world's coasts are becoming increasingly urban, with strong increases in coastal population, which in turn damages coastal ecosystems. At the same time, most coastal cities' current defences against storm surges and flooding have already high exposure to current climate conditions (Nicholls *et al.*, 2008). Global flood damage for large coastal cities could cost \$1 trillion a year if cities do not take steps to adapt (Hallegatte *et al.*, 2013). Nature-based solutions can serve in this context as climate adaptation and mitigation tools that produce additional co-benefits for societal well-being, thereby being relevant investment options for sustainable urban planning (Kabisch *et al.*, 2016). Ecosystem-based approaches have the potential to be more cost-effective, particularly in the long-run, compared to grey infrastructure solutions.

Higher level of awareness amongst policy makers and the general public are necessary, governments having a guiding role in acting as a motivating actor to foster these actions at the local level (Naumann *et al.*, 2011). Besides, given the little maturity of coastal climate change mitigation mechanisms and the fact that coastal areas have the highest climate change adaptation costs, there is a rationale to pledge for additional funding for climate change adaptation, in favor of both coastal climate change adaptation and mitigation (Ullman *et al.*, 2012).¹⁶⁵

Marine renewable natural capital

In this thesis, we aim at bringing some light on the economic growth determinants of countries with marine biodiversity under model and specification uncertainty and testing for the presence of multiple economic growth regimes. We find that the neoclassical (initial income), demography, macroeconomic policy, natural capital, fractionalisation and institutions theories are robust determinants of economic growth. These results hold true for all countries with high levels marine biodiversity independently of the size of this sector. These results suggest that a country's capacity to deal with marine biodiversity is associated with factors that impact economic growth.

Compared to a data set including a larger sample of coastal and landlocked countries, macroeconomic policies and natural capital are additional robust determinants of economic growth in countries with high marine biodiversity. There is strong historical evidence on the role of macroeconomic policies and non-renewable natural resources in trade flows and economic growth in coastal countries. Both factors highlight the pressures that coastal areas can be subject to such as construction and public works, population growth and urbanisation.

In our analysis, we find that education plays an important role in countries with high marine biodiversity. According to our results, the rate of economic convergence in these countries increases with the level of education. In addition, education and investment in physical capital have a significant and positive impact on economic growth in countries with very high levels of marine biodiversity.¹⁶⁶ It is well-known that proper management of marine

¹⁶⁵ Only for coasts, the global adaptation costs (beach nourishment, port upgrades and capital and maintenance on river and sea dikes) for a scenario of no additional sea-level rise ranges from USD 10.4 billion per year in the 2010s to USD 9.5 billion per year in the 2040s (Nicholls *et al.*, 2010). Two-thirds of the total adaptation cost comes from sea dikes, increasing to over 90 per cent when maintenance costs are considered.

¹⁶⁶ Detailed results beyond those shared in Table 5.19 in the appendix, are available upon request. We can appreciate that the weight of renewable natural capital is much stronger, about two times higher, in the sub-sample with higher levels of marine biodiversity than in the sub-sample with lower levels of biodiversity, both the terms of renewable natural capital in wealth and in per capita renewable natural capital (see Table 5.20 in the appendix).

resources requires investments both in education and infrastructure (White *et al.*, 2000 and Pandolfi *et al.*, 2005). Our results suggest that diversifying away from natural capital wealth by investing in education and, more generally, in intangible capital can enhance economic growth, particularly in countries with very high levels of marine biodiversity.

7.2. Natural capital accounting

There have been many initiatives and policy commitments in natural capital accounting in the recent years. Based on a survey for statistical offices, ministries and independent experts worldwide, we provide some preliminary evidence that there is very little use of natural capital accounts for public policy decisions and, more so, in developing countries. The most relevant obstacles are the lack of political support by key people and institutional leadership unable to promote policy use by other ministries.

Concerning developing countries, the factor which is considered as the most relevant in preventing the use of natural capital accounts for policy making is the stage of development of the country. This factor, together with the very little usage of accounts in these countries for decision-making, could be taken into account by donors. In addition, respondents from statistical institutes and developing countries are firstly, concerned about institutional obstacles and secondly, about data availability and cooperation. Respondents from ministries and independent experts are particularly concerned about design obstacles.

Not many accounts may be available to be used in the policy-making process due to data gaps, design challenges and the required investment, the problem being more acute in developing countries. Developed countries have most frequently physical flow accounts and environmental transactions accounts in monetary units. Developing countries often have natural capital asset accounts in physical and monetary units. Ecosystem services accounts are rarely compiled in developed nor in developing countries. While monitoring databases can enable physical valuation of ecosystem services, monetary valuation demands robust primary valuation studies that cover ecosystem services relevant to the decision context which can be very expensive.

A key result of the survey is the need to evaluate the value-added of natural capital accounts with respect to statistics. Some developed countries have already developed a significant amount of environmental statistics and accounts may not provide substantial additional information. Even in countries with few environmental statistics, the question remains relevant. Indeed, local problems might be better addressed through cost-benefit analyses and by investing in statistics. Many environmental problems are local in nature and cannot be easily addressed by natural capital accounts because accounting is mainly applicable at the national and regional levels. Additional research would be needed to confirm the preliminary evidence reported in this chapter.

7.3. Future avenues of work

There is a growing body of evidence on the financial instruments that policy makers can use for natural capital and ecosystem services conservation (MAEDI, 2014). Building on the academic literature on environmental economics since late 1960s and on ecological economics since late 1980s, the research agenda on the valuation of natural capital and ecosystem services nurtured on the 1990s (Daly and Farley, 2004 and Romero, 2007).

Costanza *et al.* (1997) analysis, though criticised for insufficient rigor, is the first tentative to make a global monetary valuation of natural capital and ecosystem services. In the policy sphere, the concept of valuation in support biodiversity conservation was first used by the programme on payment for environmental services in Costa Rica in 1997. Since then, in the

2000s, we have witnessed a remarkable proliferation of academic and policy contributions to this topic.¹⁶⁷

This proliferation has led to a very intense debate both on the academic and policy arenas on the relevance of emerging market-based instruments versus more traditional public interventions for financing natural capital and ecosystem services (Lapeyre and Picard, 2013). Public funds for the time being cover about 75 per cent of the total financing for biodiversity according to the Little biodiversity finance book (LBFB) of the Global Canopy Programme (Parker *et al.*, 2012).

While market-based instruments have recently gained substantial visibility for financing natural capital and ecosystem services, our understanding of these mechanisms is still poor. There is absence of sound empirical evidence to inform policy decisions and the definition and underpinning theory of these tools are matters yet to be settled. Academic research on market-based instruments for biodiversity is heterogeneous in the use of terminology, in the evaluation criteria, in the methodologies and in the approaches to undertake assessments (Lapeyre *et al.*, 2012).

This context leads to difficulties in drawing lessons from the academic research and in identifying the scope of applicability (Muradian *et al.*, 2010). It also leaves space for the proliferation of substantial ideological biases in the ongoing debate on the risks of using market-based instruments. Besides, while researchers have strongly focused so far on identifying the available instruments for financing natural capital and services, much less attention has been given, among other, to their relative effectiveness and efficiency (see Lederer, 2011 for an exception on the Clean Development Mechanism (CDM) on Reducing Emissions from Deforestation and forest Degradation, REDD+).

In relative terms, marine habitats have received much less attention than terrestrial habitats in the analyses that researchers and policy makers have recently developed on market-based instruments.¹⁶⁸ This situation should nevertheless evolve since there has been a very recent intense proliferation of policy initiatives on marine conservation.¹⁶⁹ In fact, of the set of nine planetary boundaries identified and quantified by a group of 28 internationally renowned scientists, biodiversity loss and nitrogen inputs boundaries have been largely broken which directly affect the oceans (Rockström *et al.*, 2009).

The implementation of market-based instruments has already proved controversial for terrestrial biodiversity, with some unintended negative effects such as the environmental and social impacts of land uses in REDD+. In order to prevent unintended side-effects, and promote the delivery of social and environmental co-benefits from actions to maintain and enhance

¹⁶⁷ For instance, see the MA (2005) called for by the United Nations Secretary-General Kofi Annan in 2000, TEEB (2008) financed by the European Commission and based on the Stern review (Stern, 2007) on the economics of climate change (Gomez-Baggethun *et al.*, 2010), the Convention on Biological Diversity (CBD) proposing since 2008 to explore the potential of new financing mechanisms such as payments for ecosystem services, compensatory and fiscal measures and markets for ecological products, and since 2012 to account for the need of innovative financing mechanisms (Lapeyre *et al.*, 2012) and the declaration on natural capital adopted by the financial sector in 2013 at the Rio+20 conference.

¹⁶⁸ The INVALUABLE project launched by the European Commission is a recent example where marine habitats have been excluded. For some first contributions on marine conservation, see Glavovic and Patterson (2009), Holland *et al.* (2010) and Yassin Mohammed (2014). Note that MA (2005) and TEEB (2008) have developed some recent work on wetlands and, more scarcely, on oceans.

¹⁶⁹ For instance, the Ocean's compact launched by United Nations Secretary General in march 2013, the Global Ocean Commission launched by NGOs among which Pew Environment Group in February 2013, the Global Partnership for Oceans launched by the World Bank in February 2012, the project Oceans 2030 launched by the OECD in October 2013. Together with these worldwide projects, some regional and local initiatives have recently been launched by heads of state concerned by the topic such as the Caribbean Challenge Initiative, the Monaco Blue Initiative and the Western Indian Ocean Coastal Challenge.

natural capital stocks and services, the concept of safeguards is increasingly being used (Eppel *et al.*, 2001).

Since our scientific understanding of marine habitats is much poorer than that of terrestrial habitats, there is a higher risk of generating such unintended effects when failing to anticipate the inadequacy of incentives. Besides, some mechanisms primarily designed for terrestrial habitats are sometimes idly adapted to marine habitats. Binet *et al.* (2014) have argued, for instance, that part of the funds of the European Union -Mauritania fisheries agreement can be understood as a payment for ecosystem services. This statement is largely debatable since the authors fail to comply with the five set of basic principles defined by Wunder (2005) in an attempt to formally define this type of payments and to clarify the concept.

Few market-oriented and incentive schemes have been developed for marine and coastal resources for the time being. Indeed, in many marine and coastal ecosystems, there are fuzzy property rights, difficulties in assessing the scale of service obtained and risks of elite capture (Yassin Mohammed, 2014). Inequitable benefit distribution and difficulties in identifying sustainable financing mechanisms have also hampered the ability to use these mechanisms. Since recently though, there is growing interest on the design of market schemes as means to protect the ocean by generating revenue.

In future research, we seek to explore the effectiveness and efficiency of market-based instruments versus more traditional public interventions in marine and coastal habitats. We would like first to bring some light to the debate between market-based instruments versus more traditional public interventions through the lens of decades of experience on financing mechanisms based on market-mechanisms for the infrastructure sector in Africa (Recuero Virto, 2011).

In particular, we attempt to analyse which are the most appropriate economic instruments to preserve carbon sink and reduce anthropogenic atmospheric pollution related to ocean and coastal activities in the African continent by comparing 'grey' and 'green' infrastructure (Poinsard and Recuero Virto, 2016). In terms of green infrastructure, the complementarity between adaptation and mitigation strategies can be substantial. As we highlight in our policy analysis on mangroves in this thesis, research points to the importance of these forests, for instance, as alternative (green) infrastructure to the construction of expensive (grey) infrastructure sea dikes while preserving ecosystem services, among which carbon storage (Berrenstein, 2012). In turn, local responsiveness to (local) adaptation problems is much higher than that to (global) mitigation concerns.

The goal of this analysis would be therefore to illustrate what lessons can be learned for marine and coastal habitats by revisiting some of the prominent questions surrounding financing grey infrastructure sectors that have been developed in the context of developing economies (Gasmi *et al.*, 2009). More specifically, we seek to review some representative countries' experiences in the definition and implementation of financing policies in grey infrastructure sectors with the purpose of investigating the impact of the structuring of markets and institutions on the performance of these policies and to which extent this wealth of experience can be extrapolated to green infrastructure.

When it comes to developing countries, there is a strong need to amend the past intellectual corpus so as to account for the specific characteristics of their markets and institutions in the context of grey infrastructure goods and services (Laffont, 2005). One of the reflections initiated in this analysis takes its roots in our conviction that this specificity should also apply to green infrastructure coastal goods and services. We aim thus at having a better understanding of the mechanisms that can enable to correct for externalities and to provide a public good or a good affected by the public interest at a socially optimal level, given African specificities (Gasmi and Recuero Virto, 2005 and Squires *et al.*, 2014).

Within future work, we propose as well to explore the effectiveness and efficiency of market-based instruments versus more traditional public interventions through empirical analyses for the case of marine and coastal habitats such as coastal vegetated ecosystems which act as carbon sinks (mangroves, macroalgae, salt-marches and seagrass) (Duarte *et al.*, 2013). These obviously depend on the availability of data. Most of the scientific and economic data that is currently available comes from mangrove projects (Murray *et al.*, 2011).

The methodology to develop these analyses would be based on the Multiple Criteria Decision-Making (MCDM) paradigm (Díaz-Balteiro and Romero, 2007). The management of marine and coastal habitats is becoming an increasingly complex process that requires decision-making involving economic, environmental and social criteria. Indeed, in most marine and coastal management optimisation problems, especially concerning publicly-owned habitats, the decision-maker has a preference structure involving several criteria of very different nature.

Besides, there is an increasing awareness that the complexity associated with the management and protection of a marine and coastal habitat is due not only to the multiplicity of very different criteria involved in the process, but also to the manner in which different segments of society or social groups perceive this criteria. There are several models for addressing group decisions-making problems from a single criterion perspective and within an ecosystem management context (Shields *et al.*, 1999 and Díaz-Balteiro *et al.*, 2009).

MCDM approaches have played a relatively important role in forestry over the last three decades, as shown by the growth rate of works published on forest management with a MCDM perspective. For instance, the USDA Forest Service (1997) already devised a computer tool (SPECTRUM) for the management of public forests from a multiple-criteria perspective. There are areas, like harvests scheduling and biodiversity conservation, where MCDM applications have reached a certain degree of maturity. There are other areas, such as sustainability and group decision-making, where there is potential for future developments.

We would like to apply these approaches developed for forestry for marine and coastal habitats (see, for instance, Romero, 2007 and Díaz-Balteiro and Romero, 2003). The purpose of this work would be to find ‘satisfying’ solutions among different goals and/or to find ‘best compromise’ solutions among conflicting objectives through the goal programming approach. This approach would enable us to compare different management mechanisms with different degrees of public and private intervention contingent on data availability.

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