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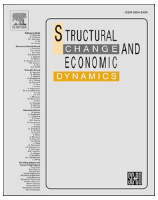

Multi-factor, multi-country testing of the Heckscher-Ohlin theorem without factor price equalization: A critical view☆

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A R T I C L E I N F O

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A B S T R A C T

Several recent empirical studies conclude that there is evidence in favour of a version of the Heckscher-Ohlin theorem that dispenses with the assumption of factor price equalization. However, many of these studies base their conclusions on small data sets, relating to one or two factors and a not very high level of disaggregation by industry. Moreover, the studies do not always take into account international differences in factor efficiency. In the present study, the Heckscher-Ohlin model is tested by considering data available in the World Input-Output Database (2016 release) for 7 factors, 56 industries and 40 countries plus a composite 'country' comprising the rest of the world, and by measuring factor use in efficiency units. Analysing this data sample, it is found that the capital and skill content of trade is only weakly correlated with countries' factor abundance. This correlation is weaker when international differences in factor use are adjusted for relative factor efficiency and when the level of industry disaggregation increases. Paradoxically, this is not the case for the energy and emissions content of trade.

1. Introduction

The Factor Abundance Theory implies the insight that trade in commodities is equivalent to trade in factor services, insofar as the latter are embodied in the former (Mundell, 1957; Vanek, 1968). Based on assumptions relative to production functions, preferences and some equilibrium conditions, this theory has been summarized as the Heckscher-Ohlin theorem: every country is a net exporter of its relatively-abundant factor services and a net importer of its relatively-scarce factor services. This simple prediction has been one of the main test targets in economic research for the past 70 years. The reason for this great prominence is because the Heckscher-Ohlin theorem is a very ambitious prediction of the theory of general equilibrium applied to international trade and that, in addition, it can be tested empirically.[1]

Despite its theoretical consistency, the empirical testing of the Heckscher-Ohlin theorem has frequently provided evidence against it. This has encouraged scholars to reformulate the theorem in a weaker form, under the premise that the source of incoherence between theory and empirical evidence lies in its assumptions. In turn, the predictions of each new version of the theorem have been tested with empirical data and, based on the new evidence obtained, the theorem has been modified again to relax its assumptions.

In its traditional form, the Heckscher-Ohlin model is a statement about the commodity composition of trade, according to which net trade in goods reflects countries' factor abundances when factor prices are equalized internationally (Samuelson, 1948, 1949). This version of the Heckscher-Ohlin theorem was soon abandoned, partly because of theoretical inconsistencies related to the problem of trade indeterminacy in many-factor, many-good, many-country settings (Melvin, 1968; Samuelson, 1953), and partly because empirical evidence was soon found to contradict the predictions of such a simple statement (Leamer and Levinsohn, 1995; Leontief, 1953, 1956).

Inconsistencies in the original form encouraged the reformulation of the theorem in a weaker form, now involving the factor content of trade rather than its commodity composition. This weaker version of the theorem, known as the Heckscher-Ohlin-Vanek (HOV) theorem (Vanek, 1968), retains its 'classical' assumptions –equalization of goods and factor prices, identical and homothetic preferences-, but can be stated for any number of factors, goods, and countries. Moreover, Vanek's version of the theorem allows intermediate inputs to be treated consistently within the framework of the theory, since the emphasis is now on

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[1] According to Davis & Weinstein (2003): 'the study of the factor content of trade is a laboratory for general equilibrium'.

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the net balance of factor services embodied in goods rather than on the net balance of goods.[2] This also implies new forms of empirical testing. Indeed, Vanek's theoretical innovation initially gave rise to optimism regarding the possibility of obtaining empirical evidence in favour of the theorem (Deardorff, 1982; Leamer, 1980). However, the first studies that considered data for several factors, countries and industries found no support for this weaker version of the theorem (Bowen et al., 1987; Maskus, 1985).

This new setback encouraged a further reformulation in which the classic assumption of factor price equalization (FPE) was dispensed with. In this, the weakest version of the theorem, known as the 'HOV theorem without FPE' (Davis and Weinstein, 2003; Dornbusch et al., 1980; Romalis, 2004), countries concentrate its exports among the goods that most intensively employ their abundant resources, so that countries' exports are 'disjoint', as each country specializes in different 'cones of production' according to its factor abundance. This means that goods within the same industry but made in different countries are not perfect substitutes, as earlier formulations of the Heckscher-Ohlin theorem assumed, but rather 'varieties' of goods that differ in their factor intensities.[3]

The 'HOV theorem without FPE' involves new forms of testing, and this started to gain empirical interest once it became possible to gather cross-country data on the structure of production, trade and domestic demand, thanks to projects such as the OECD Input-Output Database (Yamano and Ahmad, 2007) or GTAP (Dimaranan and McDougall, 2006). Indeed, these new data sets showed that the failure of factor price equalization is essential to the data and this led to the expectation of a better fit of the most recent version of the HOV theorem. And so it was. Since Davis & Weinstein (2001) several studies have provided empirical evidence in favour of the 'HOV theorem without FPE' (Artal-Tur et al., 2011; Cassing and Nishioka, 2015; Ito et al., 2017; Nishioka, 2012; Reimer, 2006; Romalis, 2004; Trefler and Zhu, 2000, 2010); this has represented a radical change with respect to the trend of empirical testing since the 1950s.

Thus, the current mainstream consensus is that the Heckscher-Ohlin theorem in its 'classical' formulation, in which factor price equalization is assumed, is not consistent with the data, but a weaker version of it, in which this same assumption is dispensed with, is indeed consistent. In fact, even weaker versions of the theorem have been tested, which consider the existence of trade costs and differences in preferences (Cassing and Nishioka, 2015; Davis and Weinstein, 2001), but the main conclusion is that the great improvement in the adequacy of the theory to the data appears when the assumption of factor price equalization is dispensed with. This change implies that the production of countries is no longer composed of a finite set of goods that all countries produce or can produce, but rather of a large set of varieties of goods that are different from each other due to their factor intensity and that countries produce exclusively. This is a radical change from all previous literature and its rationale coincides with that of international trade models based on monopolistic competition and 'taste of variety' (Helpman, 1999; Helpman and Krugman, 1987). In fact, there are quite a few studies that provide evidence in favour of a certain correlation between the factor intensity of the varieties of exported goods and the factor abundance of countries beyond the framework of the HOV model (e.g.: Chor, 2010; Regolo, 2013; Timmer et al., 2014).

Despite the current optimism, many recent tests of the HOV theorem found in the literature suffer from deficiencies connected to the accounting of the factor content of trade. In fact, almost all recent tests of the HOV theorem base their results on the analysis of input-output tables; however, their input-output accounting is often flawed. Specifically, most of these recent contributions employ relatively small datasets, regarding one or two factors (typically, total labour and capital) and a not-very-high level of disaggregation by industry.[4] Furthermore, in many cases the factor content of trade is estimated from a set of national input-output matrices, from which a world input-output model is constructed in a very approximate manner, normally using standard proportionality techniques (e.g., Cassing and Nishioka, 2015; Davis and Weinstein, 2001; Nishioka, 2012; Trefler and Zhu, 2010). Finally, the factor content of trade is often accounted for inconsistently in the case of trade in intermediates, either due to the theoretical irrelevance of the assumed definition of factor content (e.g., Trefler and Zhu, 2000) or to accounting inconsistencies (e.g., Davis and Weinstein, 2001).

Moreover, many recent tests of the HOV theorem measure the quantity of inputs used worldwide in natural units. This seems particularly inappropriate in a context where FPE is assumed to fail. Indeed, in such a context, factor efficiency is expected to vary across countries. Thus, if a factor is less efficient in some country, all industries in that country will tend to use more of that factor when measured in natural units. Consequently, the country will appear to be a net exporter of the services of its least efficient factor and at the same time appear to be an abundant country in that factor. Thus, a correlation between the factor content of trade and the factor abundance of countries will appear in the data, but this correlation has nothing to do with countries' specialization in different varieties of goods, but rather with international differences in factor-augmenting productivity. Therefore, controlling for international differences in factor efficiency seems a necessary task to adequately test the Heckscher-Ohlin theorem.[5]

All these shortcomings when testing the HOV theorem call into question the generality of the results of many studies found in the literature. Thus, the aim of the present study is to test the HOV theorem in a more consistent way, avoiding the aforementioned deficiencies. To this end, two new features are introduced in this paper.

First, to avoid the poor input-output accounting common to many studies, consideration is made of the World Input-Output Database (Timmer et al., 2015), which includes multi-year information on 7 factors, 56 industries, and 40 countries, plus a composite 'country' comprising the rest of the world. Considering these data, the factor content of trade is measured indirectly, from the factor content of expenditure, in a similar way to the 'footprints' of environmental

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[2] It should be noted that the literature on the Heckscher-Ohlin model anticipated the concept of 'trade in value added' several years earlier (Hummels et al., 2001; Johnson & Noguera, 2012). In fact, trade in value added is nothing more than the factor content of trade when each primary factor is measured by the value of its flow of services (e.g. labour is measured in payrolls rather than in persons engaged).

[3] The introduction of 'varieties' of goods into the Heckscher-Ohlin framework allows Vanek's formulation to be generalized even further. Indeed, instead of focusing on industries with different factor intensities, the new formulation of the theorem assumes that there are activities within each industry that vary in their factor intensities. Countries now specialize not in different industries but in different varieties of goods within each industry, and at the same time consume a proportion of the varieties of goods produced by each country. Intra-industry trade is thus introduced into the Heckscher-Ohlin framework, and with it the new formulation comes closer to the 'New Trade Theory' approach (Fadinger, 2011; Helpman & Krugman, 1987; Romalis, 2004).

[4] E.g., Davis & Weinstein (2001) use the OECD Input-Output Database for 10 countries, 34 industries and 2 factors (labour and capital) for the year 1985; Trefler & Zhu (2010) use GTAP (version 5) for 41 countries, 24 industries and 1 factor (labour) for the year 1997; Nishioka (2012) and Cassing & Nishioka (2015) use the OECD Input-Output Database for 29 countries, 30 industries and 2 factors (labour and capital) for the year 2000.

[5] E.g., Cassing & Nishioka (2015), Nishioka (2012), and Trefler & Zhu (2010) test the HOV model without assuming FPE; however, they measure the factor content of trade in natural units. On the other hand, Reimer (2011) estimates the factor content of trade in efficiency units, but does not test the HOV model. Finally, Ito et al. (2017) test the HOV theorem by measuring factor use by the value of their service flow (i.e., by value added). This amounts to assuming that factor price equalization holds after controlling for productivity differences, which is far from obvious (Bernard et al., 2013; Repetto & Ventura, 1997).

economics (Bohn et al., 2022; Gómez-Paredes et al., 2015). In this manner, it is possible to estimate the factor content of trade in a consistent way both in relation to the principles of input-output accounting and in relation to the HOV model.

Second, to avoid spurious correlations between the factor content of trade and countries' factor abundance due to international differences in factor efficiency, factor use in this study is measured in efficiency units. To do so, factor-augmenting technical differences are identified econometrically and the estimated parameters are used as conversion factors to convert factor use from natural units to efficiency units.

In relation to these novelties, this study finds that, when the factor content of trade is measured in efficiency units and in a more disaggregated framework, the capital and skill content of trade do not seem to be highly correlated with countries' capital and skill abundance. In contrast, the energy (here used as a proxy for machine work) and emissions content of trade do seem to be correlated with countries' energy and emissions abundance. This heterogeneous behaviour is related to the fact that differences in capital and skill intensity across varieties of traded goods are much smaller compared to differences in capital and skill intensity across non-traded goods. Therefore, the HOV model fits the data better the lower the level of industry disaggregation and, therefore, the more capital and skilled labour employed in non-traded goods are wrongly imputed to the factor content of trade.

To show the grounds for these conclusions, the paper is organized as follows. First (Section 2), it is shown that defining the factor content of trade based on the factor content of expenditure is consistent with the HOV theorem and an easy way to measure the factor content of trade from World Input-Output Tables. Subsequently, the data sample used in the present study is explained (Section 3), the results of the measurement of the factor content according to the definition set out above are presented (Section 4), as well as the results of the main tests with which the adequacy of the HOV theorem to the empirical data is checked (Section 5). Furthermore, these results are discussed, particularly in relation to the role that the units in which the factors are measured and the level of aggregation by industry can play in the HOV tests (Section 6). Finally (Section 7), the main conclusions of the present study are summarized and some of their implications are discussed.

2. Defining factor content in a consistent way

The main prediction of the HOV model can be deduced starting from the identity expressing full-employment equilibrium in an open economy. According to that identity, the factor content of trade of a country i can be expressed as the difference between its factor-endowments and the factor content of its expenditure:

$$\mathbf{f}_i = \mathbf{e}_i - \mathbf{A}_i\mathbf{c}_i \tag{1}$$

where $\mathbf{f}_i$ is a vector reflecting country-i's net factor trade, $\mathbf{e}_i$ is the vector of country-i's factor-endowments, and $\mathbf{c}_i$ is the vector of country-i's final expenditure. $\mathbf{A}_i$ is a matrix which maps a vector of goods into a vector reflecting the primary inputs necessary for its production.

From identity (1) an empirically testable prediction can be obtained assuming further statements. Thus, assuming that preferences are identical and homothetic and that product prices are equalized worldwide, it is possible to express country-i's expenditure vector as proportional to the world expenditure vector:

$$\mathbf{c}_i = s_i\mathbf{c}_w \tag{2}$$

where s_i is country-i's share on world income. The term $\mathbf{c}_w$ is the world expenditure vector and also the world net-output vector, given that the world economy is, by definition, a closed economy. Substituting (2) into (1), the following expression is obtained:

$$\mathbf{f}_i = \mathbf{e}_i - s_i\mathbf{A}_i\mathbf{c}_w \tag{3}$$

So, if technologies are everywhere identical:

$$\mathbf{A}_i = \mathbf{A} \tag{4}$$

it turns out that:

$$\mathbf{A}\mathbf{c}_w = \mathbf{e}_w \tag{5}$$

where $\mathbf{e}_w$ is a vector reflecting world factor-endowments. Substituting this last expression into (3), an exact relationship results between the factor content of trade and the factor-endowments:

$$\mathbf{f}_i = \mathbf{e}_i - s_i\mathbf{e}_w \tag{6}$$

This is the main prediction of the HOV theorem. Then, it is shown that, by defining the factor content of trade as (1), and considering the typical assumptions of the theory, the same identity that Vanek (1968) deduced and that is usually considered in the main empirical studies since then can be obtained.

The problem then arises of how to define $\mathbf{A}$ in such a way that it is consistent with assumption (4). This is the point in which the 'classical' HOV theorem differs from the HOV theorem 'without FPE'.

In the 'classical' HOV model, the products of each industry made in different countries are considered to be perfect substitutes. Then, $\mathbf{c}_i$ is a vector of N elements, being N the number of products (or industries), so $\mathbf{A}_i$ is an $F \times N$ matrix, where F is the number of factors. Thus, assumption (4) is equivalent to considering that the factor usage of each industry is the same in all countries. However, since factor prices are not equalized worldwide, production techniques vary by country, so (4) does not hold. Then, it is not surprising that when testing the 'classical' HOV theorem one finds no empirical evidence in its favour; this is a necessary consequence of the factor price equalization breakdown.

In the HOV theorem 'without FPE', on the other hand, the possibility is allowed that the factor prices are not equalized worldwide; this apparently contradicts assumption (4). In order to avoid this contradiction, it is assumed that the products of each industry in different countries are distinct 'varieties' that cannot be perfectly substituted. Then, there are CN different products, being C the number of countries, so that $\mathbf{c}_i$ becomes a vector of CN elements and $\mathbf{A}$ becomes an $F \times CN$ multiregional input-output matrix. In this case, (5) holds trivially, so (6) will hold whenever the assumptions regarding preferences are fulfilled.[6]

To show that (5) is trivially satisfied when it is assumed that the products of each industry in different countries are different products, one only has to pay attention to how $\mathbf{A}$ is constructed from data available in world input-output tables. Often, the following data-set is available from input-output tables and underlying data, for $p, q = 1, \ldots, N$ industries, $i, j = 1, \ldots, C$ countries, and $r, s = 1, \ldots, F$ factors.

A $C \times C$ matrix $\mathbf{Z}$, made up of $N \times N$ matrices $\mathbf{Z}_{ij}$, and whose elements $\left[Z_{pi,qj}\right]$ represent the value of interindustry sales by sector p of country i to sector q of country j:

$$\mathbf{Z} = \begin{pmatrix} \mathbf{Z}_{11} & \cdots & \mathbf{Z}_{1C} \\ \vdots & \ddots & \vdots \\ \mathbf{Z}_{C1} & \cdots & \mathbf{Z}_{CC} \end{pmatrix}$$

A $C \times C$ matrix $\mathbf{C}$, made up of $N \times\ 1$ column vectors $\mathbf{c}_{ij}$, and whose

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[6] In this way, it is shown that the incorporation of trade in intermediate inputs into the HOV model framework not only does not alter the main prediction of theorem (6) as Davis & Weinstein (2003) believed, but is a necessary ingredient for this prediction to be fulfilled in a context where intermediates are frequently used in production. In this sense, the new formulation of the HOV model includes not only intra-industry trade but also 'commodity chains' and 'production sharing' (Feenstra, 1998; Gereffi & Korzeniewicz, 1993). In fact, recalling the main idea of the HOV theorem, it is not difficult to understand how this is so: to the extent that trade in goods is equivalent to trade in factor services, the import of intermediate goods is equivalent to the import of the services of certain (scarce) factors of production. This brings the HOV model closer to the 'trade-in-tasks' approach to international trade (Grossman & Rossi-Hansberg, 2008; Timmer et al., 2019).

elements $[c_{pi,j}]$ represent the value of total final demand of country *i* for product *p* of country *j*:

$$\mathbf{C} = \begin{pmatrix} \mathbf{c}_{11} & \cdots & \mathbf{c}_{1C} \\ \vdots & \ddots & \vdots \\ \mathbf{c}_{C1} & \cdots & \mathbf{c}_{CC} \end{pmatrix}$$

Sometimes it is useful to look at the **C** matrix as made up of $NC \times 1$ vectors $\mathbf{c}_{\bullet i}$, each of which represents country-*i*'s spending on products made in the different countries:

$$\mathbf{C} = \begin{pmatrix} \mathbf{c}_{\bullet 1} & \ldots & \mathbf{c}_{\bullet C} \end{pmatrix}$$

Finally, an $F \times C$ matrix **E**, made up of $1 \times N$ vectors $\mathbf{e}_{ri}$, and whose elements $[e_{pri}]$ represent the amount of factor *r* employed in sector *p* of country *i*.

$$\mathbf{E} = \begin{pmatrix} \mathbf{e}_{11}^T & \cdots & \mathbf{e}_{1C}^T \\ \vdots & \ddots & \vdots \\ \mathbf{e}_{K1}^T & \cdots & \mathbf{e}_{KC}^T \end{pmatrix}$$

It is also useful to look at the **E** matrix as made up of $F \times N$ matrices $\mathbf{E}_{\bullet i}$, each of which represents the factors employed by industries of country *i*:

$$\mathbf{E} = \begin{pmatrix} \mathbf{E}_{\bullet 1} & \ldots & \mathbf{E}_{\bullet C} \end{pmatrix}$$

So, under an assumption of full employment, country-*i*'s factor-endowments can be defined as the sum by columns of country-*i*'s factor employment matrix:

$$\mathbf{e}_i = \mathbf{E}_{\bullet i}\mathbf{i}$$

where **i** is a $N \times 1$ unitary column vector, so that $[i_i] = 1$. The world factor-endowments vector results from the sum of each country's factor-endowment vectors:

$$\mathbf{e}_w = \sum_i \mathbf{e}_i$$

Also, from this primary data-set, it is possible to define a *Cx1* column vector **x**, made up of *Nx*1 column vectors $\mathbf{x}_i$, and whose elements $[x_{pi}]$ represent the value of gross output of sector *p* of country *i*:

$$\mathbf{x} = \begin{pmatrix} \mathbf{x}_1 \\ \vdots \\ \mathbf{x}_C \end{pmatrix} = \mathbf{Zi} + \mathbf{Ci}$$

Where **i** is a unitary column vector of appropriate dimension ($CN \times 1$ and, $C \times 1$ respectively). Besides, it is possible to define two significant coefficient matrices. First, from **Z** and **x**, the world matrix of input-output coefficients can be defined as:

$$\mathbf{B} = \mathbf{Z}\hat{\mathbf{x}}^{-1} \tag{7}$$

where its elements $b_{pi,qj}$ reflect the amount of sector-*p*'s output from country *i* used as input per unit of sector-*q*'s output in country *j*. Second, from **E** and **x**, the world matrix of direct factor input coefficients can be defined as:

$$\mathbf{D} = \mathbf{E}\hat{\mathbf{x}}^{-1} \tag{8}$$

where its elements $[d_{pr,i}]$ reflect the amount of factor *r* employed per unit of sector-*p*'s output in country *i*. Sometimes, it is useful to look at matrix **D** as made up of $F \times N$ matrices $\mathbf{D}_i$, each of which represents the direct factor input coefficients matrix of each country *i*:

$$\mathbf{D} = \begin{pmatrix} \mathbf{D}_1 & \ldots & \mathbf{D}_C \end{pmatrix}$$

From these data-sets, **A** can be constructed as a matrix that maps a vector of products to a vector of factor content – that is, a vector reflecting the factors embodied in the production of a good wherever the production of that good or its inputs took place. Thus, from the input-output and factor-input matrices, one can immediately obtain the matrix that maps an arbitrary product vector to a vector reflecting the factors embodied worldwide in its production:

$$\mathbf{A} = \mathbf{D}(\mathbf{I} - \mathbf{B})^{-1} \tag{9}$$

A is a $F \times CN$ matrix whose elements $[a_{r,pi}]$ represent factor-*r*'s direct plus indirect employment in sector *p* of country *j*. Thus defined, matrix **A** satisfies condition (5) in a trivial way since, under an assumption of full employment, the factor content of world net output equals the world factor-endowments:

$$\mathbf{A}\mathbf{c}_w = \mathbf{e}_w$$

where:

$$\mathbf{c}_w = \sum_i \mathbf{c}_{\bullet i}$$

with $\mathbf{c}_w$ being a $CN \times 1$ vector whose elements $[c_{pj}]$ represent country-*j*'s net output of product *p*.

It thus follows that assuming that product *p* of country *i* and product *p* of country *j* are different products (or 'varieties' of the same good), assumption (5) is always satisfied and the factor content of trade can be measured from (1) to test whether it is equal to (6), as assumed by the HOV theorem 'without FPE'.

The strategy followed up to this point to define the factor content of trade, which is consistent with both input-output accounting and the HOV model, as has been shown, has not been the strategy followed by the main studies that have tested the empirical adequacy of the HOV theorem. In fact, these studies have considered definitions of the factor content of trade alternative to (1).

Thus, Davis & Weinstein (2001) considered a definition of factor content in which the factor content of a country's trade is defined as the difference between the factor content of domestic production and the factor content of imports. As shown by Reimer (2006) and Trefler & Zhu (2010), this definition would be accounting consistent only when there is no trade in intermediate inputs. But this is not the case in today's world economy, where 'commodity chains' and 'global production sharing' are ubiquitous.

Other researchers, aware of the accounting problem involved in measuring the factor content of trade when there is trade in inputs, have developed alternative algorithms to calculate the factor content of trade in an accounting-consistent manner (e.g., Antweiler and Trefler, 2002; Stehrer, 2012; Trefler and Zhu, 2000, 2010; Zhang, 2015). However, none of these alternatives, with the exception of that of Trefler & Zhu (2010), seems consistent with the HOV theorem, in the sense that the proposed definitions do not seem to be able to be manipulated to obtain the main prediction of the HOV theorem (6) when the assumptions of the theorem are met - or, at least, the proponents of such algorithms do not provide an adequate proof of this.

3. Building a data sample from the World Input-Output Database (2016 release)

In order to test the prediction of the HOV theorem 'without FPE', which is the only version of the theorem that can be expected to hold, the calculations presented in Section 2 were carried out taking as data those provided by the 2016 Release of the World Input-Output Database (WIOD) (Timmer et al., 2015, 2016). This database is, to date, one of the most complete in relation to the number of industries, countries, and factors. WIOD Release 2016 (and the underlying data) covers 56 sectors (classified according to ISIC Rev. 4) and 43 countries for the period 2000–2014. The underlying data of this Release – included within the 'Socio Economic Accounts' – provide information on the use of labour (in thousands of persons engaged) as well as the use of capital (in current USD). Elsewhere, the Joint Research Centre of the European

Commission has published data for 2000–2016 on net energy use (in tera-joules) and carbon-dioxide emissions (in tonnes) by industry and by country, fully consistent with the 2016 Release of the WIOD.

Data on emissions and net energy use can be considered proxies to measure, respectively, the use of clean air and machines as production factors. Indeed, as long as pollutants are by-products of consuming natural resources, there is little difference between quantifying the consumption of natural resources or the emission of pollutants. In this way, recording the emission of pollutants is roughly the same as accounting for the use of clean air as a productive factor (Ten Raa, 2006). Furthermore, taking into account the first law of thermodynamics (i.e. the law of conservation of energy), data on net energy use by industry can be considered as a proxy to measure machine work, i.e. the work performed by machines used in production.[7] Consequently, recording net energy use is equivalent to accounting for the use of machines as a productive factor.

Moreover, the underlying data of the earlier 2013 Release of the WIOD also provided information on the use of three skill types of labour based on workers' educational level (in percentages of persons engaged) for the period 1995–2009, covering 35 sectors classified according to ISIC Rev. 3. As regards the equivalence between the sectors in ISIC Rev. 3 and ISIC Rev. 4., the data available in the 2013 Release can be used when all 56 sectors are considered. This means that the proportions of the three skill types of labour in the total number of persons engaged can be assumed to be the same in those industries in the 2016 Release that must be added together to obtain the sectors in the 2013 Release.[8]

Data on energy use and emissions provide information on either 40 as well as on the rest of the world. This is not true for labour and capital. To bridge this gap, it is possible to use data available from the Penn World Table version 10.0, assuming that all sectors in the rest-of-the-world composite 'country' employ the same amount of labour and capital per unit of income.[9] Furthermore, it is possible to construct plausible figures for the shares of the three skill types of labour in total persons engaged from a weighted average of the countries in the sample whose GDP per capita is similar to that of the rest of the world.[10] As regards the approximate nature of the factor usage by the Rest of the World, the estimates of factor content corresponding to this composite 'country' cannot be considered as evidence for or against the HOV theorem predictions. However, it is of great importance to take this approximation into account in order to estimate with plausibility the factor abundance of each country. Indeed, failure to consider the factors of the rest of the world would introduce a bias that would be difficult to control, even though this omission is quite common in the literature (*e.g.*, Trefler and Zhu, 2010; among many others).

In this way, the present study regards a world economy made up of 41 countries (the 40 countries of the WIOD 2013 Release plus one composite 'country') that exchange final and intermediate goods produced by any of the 56 industries specified by the WIOD 2016 Release. Analysis considers the employment of seven resources: total labour, capital stock, net energy use, CO_2 emissions, high-skilled workers, medium-skilled workers and low-skilled workers.

Once the data sample is ready, the next step is to adjust the data on factor use to take into account differences in efficiency across countries in the sample. Indeed, one of the lessons of the so-called Leontief paradox is that, when calculating the factor content of trade, it is advisable not to use country-level factor intensities without converting them to internationally comparable units (Davis and Weinstein, 2001; Leontief, 1956; Reimer, 2011; Trefler, 1993). This is especially important in the current context, where factor price equalization is assumed not to hold, and factor use is therefore expected to differ across countries in a systematic way when measured in natural units. In the present study, the way of adjusting factor data for factor efficiency is similar to that followed in Davis & Weinstein (2001) and Reimer (2011) and is based on the assumption that current factor-output coefficients (8) can be expressed as:

$$d_{rpi} = \frac{\delta_{rp}\eta_{rpi}}{\lambda_{ri}} \tag{10}$$

where δ_{rp} is a common factor input requirement for factor r in industry p, λ_{ri} is a country-specific shift term representing the factor-r-augmenting technical progress in country i and η_{rpi} is a country- and industry-specific random term. The components of the factor employment matrix **E** can therefore be expressed in efficiency units when rescaled as:

$$e'_{pri} = \lambda_{ri} e_{pri}$$

Once factor employment is expressed in this way, the coefficient matrix **A** (9) must be recalculated.

The value of the shift terms λ_{ri} can be estimated from the data presented above, no additional information is needed. In the present case, this involves performing, for each year of the sample, seven log-log regressions (one for each factor) with $7 \times (56+41)$ dummy variables. Table 1 shows the time average of the estimated values for the shift terms when the normalization condition $\lambda_{rUSA} = 1$ is chosen. In addition, Table 2 shows the main statistics of the performed regressions. From this, some observations follow.

Table 1 shows that factor efficiency varies by up to an order of magnitude for capital stock, energy use, and CO_2 emissions, and by up to two orders of magnitude for labour (both total and skill-disaggregated). Moreover, factor efficiency does not always bear a simple relationship to countries' GDP per capita. For example, capital efficiency appears to be higher in China than in the United States. Also, low-skilled labour in the United States is 33 times more productive than in China, but high-skilled labour is only twice as productive. These differences in apparent factor efficiency cause countries' current factor endowments to change in non-trivial ways. Thus, when measured in natural units, high-skilled and low-skilled workers in the United States account for 13 percent and 1 percent of the world total, respectively; when measured in efficiency units, they account for 24 percent and 22 percent of the world total. This means that the United States does not have as large a shortage of unskilled labour as the raw data might suggest, something that Leontief already suspected (Leontief, 1956).

4. Measuring the factor content of trade

Once the dataset is ready, it is possible to test the main prediction of the HOV theorem (6). However, the theorem assumes no intertemporal trade and, therefore, a null trade balance for all countries; but this is not the case in the actual world. In order to overcome this difficulty, it is convenient to adjust the amount of factor content under a null-trade-balance assumption. To do this, it must be taken into account that

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[7] Strictly speaking, energy use in production equals the work done by machines (i.e., mechanical work, induced changes in electromagnetic variables, etc.) plus heat. Heat, in turn, may be a desirable outcome (e.g., in a heating system) or an undesirable outcome (e.g., due to limited thermal efficiency).

[8] It should be noted that assuming that the share of skill types in the number of persons engaged is the same across a set of sectors does not imply assuming that the use of skill types per unit of output is the same across that set of sectors. This is because the number of persons engaged per unit of output varies, in general, across sectors, as we have these data in the more disaggregated form of the 2016 WIOD publication. Therefore, the assumption used in the present study to match the data from the 2013 and 2016 WIOD releases is not equivalent to assuming 35 sectors for some factors and 56 for others.

[9] Since income per output is different in the different sectors, and we know this data from the World Input-Output Tables, the assumption made does not imply that the use of capital and labour per unit of output in the rest of the world is the same for all sectors.

[10] Specifically, the share of the three types of workers' skills in the total number of persons engaged in the rest of the world was assumed to be the same as the weighted average for Bulgaria, Brazil, China, Hungary, Indonesia, India, Mexico, Poland, Romania, Russia, Turkey and Taiwan.

Table 1
Estimated factor efficiency relative to that of the United States.

Country	Labour	Capital	En. Use	CO₂ Em.	High Sk.	Med. Sk.	Low Sk.
AUS	0.92	1.14	1.59	1.74	1.68	1.41	0.17
AUT	0.88	0.83	2.31	3.97	1.44	0.81	0.45
BEL	1.15	0.95	1.57	1.75	1.95	1.22	0.41
BGR	0.13	1.08	0.71	1.09	0.42	0.45	0.02
BRA	0.19	0.98	0.93	1.26	0.39	0.28	0.04
CAN	0.79	2.27	0.8	0.87	1.06	0.65	3.33
CHN	0.11	1.22	0.73	0.61	0.49	0.16	0.03
CYP	0.45	0.88	1.12	1.73	0.44	0.68	0.16
CZE	0.36	0.76	0.83	1.51	0.79	0.28	0.55
DEU	0.79	1.15	2.68	1.61	0.89	0.79	0.45
DNK	1.03	0.86	2.46	2.7	1.08	1.31	0.38
ESP	0.72	1.02	1.59	2.26	0.61	1.96	0.15
EST	0.3	1.24	0.86	1.12	0.25	0.32	0.28
FIN	0.88	1.29	1.36	3.42	0.72	1.14	0.4
FRA	0.98	1.47	1.45	1.92	0.97	1.3	0.32
GBR	0.92	1.12	1.69	2.15	0.86	1.2	0.33
GRC	0.5	1.5	1.46	4.07	0.74	0.75	0.15
HUN	0.26	0.66	0.91	0.85	0.44	0.24	0.17
IDN	0.07	0.94	0.64	0.61	0.29	0.15	0.01
IND	0.04	0.66	0.51	0.58	0.07	0.07	0.01
IRL	1.04	1.63	1.59	2.8	0.87	1.61	0.38
ITA	0.88	1.06	1.81	3.28	2.29	1.16	0.2
JPN	0.97	0.67	1.51	1.74	0.96	0.81	1.02
KOR	0.55	0.84	0.76	0.76	0.35	0.75	0.42
LTU	0.22	0.81	0.76	1.46	0.2	0.22	0.3
LUX	1.19	1.35	2.37	3.08	1.65	1.67	0.36
LVA	0.23	0.83	0.86	1.14	0.28	0.23	0.17
MEX	0.32	1.47	1.02	0.91	0.64	0.4	0.11
MLT	0.46	0.81	3.82	4.25	1.53	1.58	0.06
NLD	1.03	1.03	1.48	1.86	1.17	1.42	0.3
POL	0.28	1.44	1.05	0.95	0.44	0.24	0.36
PRT	0.51	0.92	1.69	2.07	1.77	1.84	0.07
ROU	0.17	0.8	0.74	0.79	0.53	0.58	0.02
RUS	0.13	0.78	0.35	0.59	0.35	0.1	0.17
SVK	0.31	0.65	1	1.22	0.65	0.24	0.71
SVN	0.41	0.66	1.28	2.13	0.6	0.39	0.29
SWE	0.99	0.98	1.58	2.83	1.29	1.03	0.46
TUR	0.3	1.07	1.07	1.88	0.69	0.69	0.05
TWN	0.23	0.86	0.97	1.25	0.23	0.44	0.09
USA	1	1	1	1	1	1	1
ROW	0.09	0.73	0.64	0.66	0.23	0.15	0.01

Note: Differences in factor efficiency across sample countries λ_{ri} were identified econometrically by estimating: $\log d_{pri} = \log \delta_{pr} - \log \lambda_{ri} + \epsilon_{pri}$, where d_{pri} are factor-output coefficients measured in natural units, δ_{pr} are industry-specific factor-output requirements, λ_{ri} are country-specific shift terms representing the efficiency of factor r in country i and ϵ_{pri} are the error terms. Estimates were made for each of the sample years, so the numbers in Table 1 are time averages for the sample period. In addition, time averages of the main statistics from this multiple linear regression can be seen in Table 2.

Table 2
Key statistics of multiple linear regression for estimating country-specific factor efficiency.

Statistic	Labour	Capital	En. Use	CO₂ Em.	High Sk.	Med. Sk.	Low Sk.
R^2	0.83	0.52	0.72	0.72	0.8	0.81	0.86
F	106.13	23.08	55.97	54.65	88.02	93.72	131.8
p-value	0	0	0	0	0	0	0
Error Var.	0.28	0.49	0.74	1.02	0.34	0.3	0.43

Note: Numbers are time averages for the sample period; see note to Table 1.

country-i's share on world expenditure s_i can be expressed as:

$$s_i = \frac{y_i - b_i}{y_w} \tag{11}$$

where y_i is country-i's GDP, b_i is country-i's trade balance, and y_w is world GDP. Therefore, the assumption on preferences (3) can be expressed as:

$$\mathbf{c}_i + \frac{b_i}{y_w}\mathbf{c}_w = \frac{y_i}{y_w}\mathbf{c}_w \tag{12}$$

where the left side of the equation denotes the consumption of country i in the case of its trade balance being null. So, the adjusted factor content of trade can be calculated as:

$$\mathbf{f}_i^A = \mathbf{e}_i - \mathbf{A}\left(\mathbf{c}_i + \frac{b_i}{y_w}\mathbf{c}_w\right) \tag{13}$$

And, according to the prediction of the HOV theorem, (13) is expected to be equal to:

$$\mathbf{f}_i^A = \mathbf{e}_i - \frac{y_i}{y_w}\mathbf{e}_w \tag{14}$$

Then, (13) reflects the factor content as revealed by the data while (14) reflects the predicted factor content of trade as results from revealed factor abundance. The adjusted factor content of trade can be calculated from (13), considering a single 2296 × 2296 **A** matrix and 41 2296 × 1 $\mathbf{c}_i$ vectors. The time average of the ratio of factor content

Table 3
Ratio of net factor exports to domestic factor endowment, as revealed by trade data (%).

Country	Labour	Capital	En. Use	CO₂ Em.	High Sk.	Med. Sk.	Low Sk.
AUS	−4.1	5.7	4.3	7.4	−2.2	−4.1	−8.5
AUT	−2.4	−1	−1.7	23	−3.8	−1.8	−3.3
BEL	0.3	−4	−1.6	−15.7	4.6	1	−3.8
BGR	9.5	4.9	−7.8	11.1	8.7	7.7	9.3
BRA	3.1	1	4.3	1.4	−0.9	0.9	7.5
CAN	−2.9	7.9	13.1	−4.4	−1.5	−1.6	4.7
CHN	7.4	3.6	7.6	10.3	5.9	6.3	10.9
CYP	−8	1.2	−75.8	−24.5	3.3	−6.7	−13.3
CZE	3.6	−0.7	−6.3	16	0.8	5.6	5.8
DEU	−5	0.8	9.1	−7.7	−5.8	−3.9	−8.4
DNK	−5.8	−0.8	40.1	44.7	−7.1	−4.5	−7.3
ESP	0.8	−0.3	−2.4	8.9	0.6	1.7	0.6
EST	4	5.2	2.9	14.3	2.9	5.8	4.7
FIN	−5	1.9	22	21.8	−6.6	−3.4	−8.3
FRA	0.4	1.7	−18.2	−20.5	1.7	0.7	−2.5
GBR	−0.9	−2.8	−15.6	−3.5	0.5	−0.5	−5
GRC	−0.9	5.8	19.7	13.9	1.2	−0.2	1.1
HUN	−3	−3.2	−14.8	−41.3	−4.5	−1.4	0.6
IDN	0.5	−6.1	−9.6	−12.8	−4.9	−4.9	2.9
IND	2.5	−3.6	−9.4	−1.8	−2.1	1.4	5.2
IRL	−18.5	−2.8	−60	−8.8	−20.2	−16.1	−19.3
ITA	1.1	0.2	−8.4	7.9	2.6	1.6	1.4
JPN	−0.4	−2.8	4.7	3.4	−0.1	−0.6	−3.1
KOR	−3.3	2.1	7.3	−6	−2.9	0.3	−11.3
LTU	−3.9	−6	−31.6	−18.6	−3.2	−0.4	−2.5
LUX	−20.3	−10.1	6.5	21.9	−6.8	−17.3	−29.3
LVA	1.6	4.7	−33.2	−25.3	3.5	2.2	−0.1
MEX	−0.5	2.1	−13.9	−10.8	−6.8	−2.2	4.4
MLT	2	3.5	32.8	31.6	12	12.3	−1.9
NLD	−2.1	−4.3	62.3	5.2	0.2	−1.3	−6.5
POL	3.8	−3.1	−3.1	2.7	0	6.2	9.7
PRT	3.7	1.2	4.6	−0.9	4.3	3.7	3.7
ROU	5.4	−2.1	−14.5	−5.3	2.1	3.2	5.1
RUS	−18.3	−5.4	8.1	20.7	−12.8	−14.7	−24.2
SVK	0	3.7	12.4	10.1	0.3	1.6	0
SVN	−1.5	−5.8	−31	4.5	−1.8	0.6	5.1
SWE	−4.1	−0.8	6.7	−8.4	−2.7	−3.3	−8
TUR	3.9	0.5	−9.1	9.2	−2.7	1.5	6.1
TWN	−11	−6.6	24.3	25.3	−11.3	−5.6	2.1
USA	−1.2	−0.8	−12.6	−10.7	0.7	−0.9	−2.8
ROW	0.2	−3.2	−13	−12.2	−2	0.5	−7

Note: Factor usage is measured in efficiency units. Numbers are time averages for the sample period.

estimates to national factor-endowments $\left[\frac{f^A_{ki}}{e_{ki}}\right]$ can be seen in Table 3. In addition, the time average of the ratio of factor abundance (12) to national factor-endowments $\left[1-\frac{y_i/y_w}{e_{ki}/e_{kw}}\right]$ can be seen in Table 4.

Looking at the data in Tables 1 and 2, some notable features of the factor content of trade emerge, as in the cases of the U.S. and China. According to the data on factor content (Table 3), the U.S. appears to import all types of resources except high-skilled labour. In particular, U. S. trade reveals that the United States is especially short of machine work (measured by energy use) and emissions. Moreover, it can be seen that, when factor use is measured in efficiency units, the amount of labour services imported by the United States is relatively small compared to the U.S. labour endowments: 1.2 % and 2.8 % of the total and low-skilled labour, respectively. The case of China is different: it appears to export all types of resources. Moreover, China's trade reveals that China is especially abundant in emissions and low-skilled labour, exporting, respectively, 10.3 % and 10.9 % of its domestic endowments, after adjusting for efficiency.

Next, when the figures in Table 3 are compared with the factor abundance data predicted by the HOV theorem (Table 4), it appears that the U.S. should import all types of factors except capital. In particular, according to the HOV algebra, the U.S. is especially short of energy, emissions, and low-skilled labour. Note also that according to the factor abundance data, the U.S. appears to be short of highly skilled labour. The reason for this is that while American high-skilled workers account for about 24 % of the world total when measured in efficiency units (12.9 % in natural units), the U.S. share of world income is even higher: 26.9 % on average over the sample period. Meanwhile, the HOV algebra indicates that China is especially abundant in low-skilled labour and emissions. High-skilled labour is also abundant in China: Chinese high-skilled workers account for 14.1 % of the world total when measured in efficiency units (15.2 % in natural units), while China's share of world income in the sample period is about 7.5 %.

From comparisons between the data on the factor content of trade (Table 3) and the data on factor abundance (Table 4), some patterns can be observed. Thus, it is easy to see that the sign of the factor content of trade agrees in many cases with that predicted by the HOV theorem. However, when the data are analysed country by country, it is not difficult to find Leontief-like 'paradoxes': for example, trade reveals that the United States is abundant in high-skilled labour (Table 3), but the data on factor abundance say the opposite (Table 4). On the other hand, it can be seen that the factor content of trade predicted by the HOV theorem is often an order of magnitude higher than the actual factor content of trade. For example, low-skilled labour services imported by the United States amount to 2.8 percent of its domestic endowment; However, according to the factor abundance data, the United States should import low-skilled labour services equivalent to 22.1 percent of its domestic endowment. Thus, the expected amount of factor trade is found to be much smaller than the observed amount, resulting in a huge amount of 'missing trade'.

Table 4

Ratio of net factor exports to domestic factor endowment, as predicted by the Heckscher-Ohlin-Vanek theorem (%).

Country	Labour	Capital	En. Use	CO₂ Em.	High Sk.	Med. Sk.	Low Sk.
AUS	−11.2	20.5	7.4	33	9.6	−9.7	−45
AUT	−11.2	12.4	8.3	27.6	−8.5	−7.5	−24.3
BEL	0.7	−4.9	12.4	−32.8	10.1	7.8	−23.6
BGR	8.2	19.3	31.8	65	26.3	11.5	2
BRA	10.7	3.2	9.8	−33.5	4.1	1.1	15.8
CAN	−15.1	33.8	−6.4	−60	−2.2	−11.4	−8
CHN	43.2	12.1	46.6	53.1	46.8	34.2	60.3
CYP	−42.6	−9.9	−88	11.6	−26	−34.6	−46.7
CZE	−3.4	14.3	5.2	44.9	11.3	2.3	−14.2
DEU	−11.8	24.3	26.5	−20.3	−12.6	−8.9	−28.7
DNK	−9.4	2.9	27.5	37.8	−1.3	−6.9	−31.5
ESP	−3.4	7	−18.6	1.2	−10.3	5.7	−14.9
EST	−4.5	19.2	23.8	59.7	−3	−2.2	−19.1
FIN	−15.7	30.4	26.7	39.8	−17.2	−10	−43.8
FRA	−3.3	38.4	−50.8	−103	0.2	−1.3	−23.9
GBR	−4.5	−9.1	−45.9	−19.8	−2.7	−0.8	−29.9
GRC	−25.3	25.5	6.8	60.1	−2.2	−20	−16.6
HUN	−15.7	−0.1	−3	−44.6	1.4	−10.9	−26.2
IDN	27.5	−7	6.2	−4.8	26.2	4.8	35.2
IND	34.6	−67.1	11.2	26.2	−36.4	22	61.8
IRL	−22.2	27.1	−94.8	−7	−24.5	−15.1	−35
ITA	−3.2	15.7	−19.5	19.1	24.6	0.8	−13.1
JPN	3	−44.5	−22.7	−23.4	−11.9	−0.6	−20.6
KOR	4.1	7.6	7.1	−7.9	7	4	−25.5
LTU	−22.4	−13.1	−1.5	14.1	−19.3	−15.8	−18.6
LUX	−26.2	4.1	22.1	11.8	−3.7	−18.2	−45.3
LVA	−10	−29.2	−13	−12.2	−4.3	−3.8	−24.8
MEX	0.8	25.2	−24.1	−38.9	−28.5	−11.4	37
MLT	−10.9	−19.4	64	75.2	34.7	14.1	−35.5
NLD	2.8	9.2	63	−21.4	15.2	7.4	−24.2
POL	−0.9	−23.7	20.1	36.3	10.6	1.7	19
PRT	6.8	−7.6	15.3	9.3	34.5	16.3	−3.2
ROU	5.1	−15.4	2.7	12.2	−7.4	−15.6	6.9
RUS	−20.7	−36.8	17.6	46.2	−0.6	−15	−24.3
SVK	−13.1	11.6	33.8	27.8	9.7	−8.3	−13.2
SVN	−16.6	−25.6	−12.4	31.3	−4.1	−12.2	−10.4
SWE	−10.7	0.9	−2.2	−38.8	14.4	−13.8	−43.4
TUR	9.8	−26.6	3.3	40.8	6.9	−5.4	15.1
TWN	−15.4	−39.2	26.7	42.1	−1.5	−6.3	4.1
USA	−14.7	0.6	−48.4	−51.4	−12.9	−8.4	−22.1
ROW	−14.3	−53.6	7.2	4.9	−33.2	−7.9	−38.3

Note: Factor usage is measured in efficiency units. Numbers are time averages for the sample period.

5. Testing the HOV theorem

To test the prediction of the HOV theorem, the k-th element of (14) can be written as[11]:

$$\frac{f^A_{ki}/e_{kw}}{y_i/y_w}=\frac{e_{ki}/e_{kw}}{y_i/y_w}-1 \tag{15}$$

Thus, testing the HOV theorem is the same as testing the conformity of the adjusted net factor export data $\left[\frac{f^A_{ki}/e_{kw}}{y_i/y_w}\right]$ with the factor abundance data $\left[\frac{e_{ki}/e_{kw}}{y_i/y_w}-1\right]$. This conformity is usually tested according to four criteria.

First, testing the proposition that factor content of trade is equal in amount to that predicted by factor abundance data. This can be done through a slope test, regressing factor content on factor abundance data without an intercept.

Second, testing the statement that the amount of the observed factor content of trade is of the same order as the predicted one. This can be checked through a variance test, computing the variance of factor content over the variance of factor abundance.

Third, testing the proposition of conformity in sign between factor content of trade and factor abundance. For this, a sign test can be conducted, obtaining the proportion of sign matches between the observed and predicted factor content.

Fourth, testing the proposition of the conformity between the factor content of trade and relative factor abundance through a rank test. This test can be performed either by computing rank correlation (typically Kendall's) between the factor content and factor abundance ratios, or by computing the proportion of correct rankings when compared pairwise.

Each of these tests can be carried out factor-by-factor or country-by-country, as it is assumed in expression (15) that k remains constant while

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[11] Writing the HOV prediction in this way allows for controlling for country size, as country income shares are used to scale the observations.

i varies, or vice versa.[12] Tables 4 and 5 show the results of all these tests. Both represent time averages in the case where the null hypothesis is evaluated factor-by-factor (Table 5) and in the case where the null hypothesis is evaluated country-by-country (Table 6). In addition, Figs. 1 and 2 plot factor export data against factor abundance data, both factor by factor and country by country (the latter only for the eight largest countries in the sample).

As shown in Table 5, the proposition that the amount of factor content is equal to that predicted receives uneven support when tested for each factor. The estimated slope is close to '1′ only for one of the seven factors (energy use, as a proxy for machine work) and the fit is acceptable for several factors, but not for capital and high-skilled labour. Moreover, the variance of the observed factor content of trade is of the same order for one factor (energy use), is one order of magnitude lower for two factors (emissions, medium-skilled labour) and is two orders lower for all other resources. Thus, a large amount of 'missing trade' is observed, especially for capital, high-skilled labour and low-skilled labour. Indeed, taking the slope test and variance test together, one cannot reject the hypothesis that the capital and high-skilled labour content of trade is not as predicted by the capital and high-skilled labour abundance data.

The slope test also yields mixed results when performed country by country (Table 6). In fact, the estimated slope is close to '1′ only for 6 of the 40 sample countries (Austria, Denmark, Latvia, Netherlands, Russia, and Taiwan). Moreover, the fit is not acceptable for 18 of the 40 sample countries (among them: Brazil, Canada, Spain, Indonesia, and Japan). In fact, for 8 of the sample countries (Belgium, Brazil, Canada, Spain, Indonesia, Italy, Portugal, Sweden), the regression model without intercept appears to be worse than a model with intercept (see note to Table 4), somewhat inconsistent with the HOV theorem.

Moreover, the proposition of sign agreement between factor content and factor abundance data also receives mixed support when tested factor by factor (Table 5) and country by country (Table 6). Indeed, the proportion of sign agreements is 70 % or higher for 6 of the 7 factors (all except high-skilled and medium-skilled labour), and for 27 of the 40 countries in the sample (but not for Canada, Spain, Indonesia, Italy, Japan, Korea, the Netherlands, Turkey, among others). The proposition that factor trade reveals countries' factor abundance also receives mixed support from Kendall's rank tests. Thus, the hypothesis of a zero rank correlation is rejected with 5 % confidence for all factors except high-skilled labour (Table 3), although only for 19 of the 40 countries in the sample. When pairwise comparisons are made, the proportion of correct rankings exceeds 70 % for 6 of the 10 resources (all except capital and high and medium-skilled labour) and for 29 of the 40 countries in the sample. All this means that the factor content of trade often fails to reveal the relative abundance of resources, and this seems to be especially true for capital and skilled labour.

Overall, the results of the tests shown in Tables 4 and 5 offer mixed feelings. On the one hand, there seems to be some agreement between the factor export data and the factor abundance data for at least four of the seven factors in the sample (total labour, energy use, emissions, and low-skilled labour). In fact, the case of energy use, as a proxy for machine work, and emissions, as a proxy for clean air use, is surprising: the tests often give better results for these factors than for the 'classical' factors (labour and capital). This means that countries with abundant machine work or clean air - that is, those whose share of energy use or CO_2 emissions in the world total is greater than their share in income - tend to be net exporters of such factors. And this is so even after adjusting for factor efficiency - that is, it is not true that they export more because they use energy or emissions more inefficiently.

On the other hand, the evidence presented in Tables 5 and 6 does not invite overly optimistic expectations regarding the adequacy of the HOV model to the data. Indeed, for three of the seven factors in the sample (capital, highly skilled labour, medium-skilled labour) the hypothesis that factor abundance is not a good predictor of the factor content of trade cannot be completely rejected. Moreover, the country-by-country tests reveal the occurrence of 'Leontief-type' paradoxes with some frequency - that is, countries are often net exporters of their scarce resources. Naturally, the two aspects are closely related: to the extent that the capital or skilled labour content of trade does not always follow the abundance of capital or skilled labour, it happens that there are countries that seem to export their scarce resources.

The failure of the HOV model to explain the capital and skill content of trade may be due to errors in the measurement of countries' factor use and endowments, or to the inadequacy of the model's assumptions to the actuality of the world economy. One of the assumptions that may not be met is the one related to preferences (2). This assumption implies 'consumption similarity', that is, the existence of identical preferences in all countries so that each country tends to consume a proportion of the varieties of goods produced by all countries. This assumption allows to explain the factor content of trade as a result of the trade specialization of countries in different 'cones of production' depending on their factor intensity. However, when there are non-tradable goods, the similarity of consumption is not met, which affects the conformity of the HOV model with the data. In this respect, Table 7 shows how the slope test changes factor by factor when similarity in consumption is assumed in some of the main non-traded sectors (agriculture, food manufacturing, electricity, construction, real estate services, public administration, education, health). Some observations follow from this.

When consumption similarity is assumed to hold for agricultural and food products, the slope test improves particularly for total labour and low-skilled labour. When consumption similarity is assumed to hold for real estate services, the slope test improves greatly for capital, and when the same is done for public administration, education, or health services, the slope test improves for high-skilled labour. Finally, assuming consumption similarity for utilities and construction, the slope test improves for energy use and emissions, but this time the improvement is substantially smaller. All this means that a good share of low-skilled labour is devoted to producing non-traded foodstuffs, a large share of the capital stock is devoted to providing real estate services, and a significant share of high-skilled labour is devoted to non-traded services that typically depend on the government. In contrast, net energy use and emissions are not as skewed toward non-traded activities.

This large diversion of capital and skilled labour into non-traded activities explains why the HOV model fails to predict the capital and skill content of trade: the differences in the capital and skill intensity of varieties of traded goods are not large enough to compensate for the failure in consumption similarity due to non-traded services. That is, varieties of goods produced in countries with different capital/skill endowments are not so different from each other in terms of capital/skill intensity as to make the factor trade balance statistically significant. This leads to the conclusion that capital and skilled labour play a more important role in explaining the structure of non-traded sectors than in explaining the structure of trade.

6. Discussing the results

The results of the present study differ from those of other well-known recent studies that provide evidence in favour of a greater conformity between the factor content of trade and factor abundance (e.g., Cassing and Nishioka, 2015; Ito et al., 2017; Nishioka, 2012; Trefler and Zhu, 2010). This discrepancy may be due to two reasons.

First, because of the database used. Actually, there are almost no studies that have attempted to test the HOV theorem with actual world input-output tables (Ito et al. (2017) is an exception); most of the previous studies use approximate methods to construct a multi-country

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[12] In the recent literature on HOV testing, country-by-country tests are often overlooked (e.g.: Cassing & Nishioka, (2015), Nishioka (2012), Trefler & Zhu (2010)). However, they are of great importance to control for bias in the selection of countries in the data sample.

Table 5
Slope, variance, sign and rank tests, factor by factor.

Factor	Slope Test			Var. Test	Sign Test	Rank Test		
		Std. Error	R^2			Kendall	p-value	Pairwise
Labour	0.2	0.04	0.41	0.1	0.7	0.5	0	0.75
Capital	0.1	0.03	0.29	0.04	0.71	0.39	0	0.69
En. Use	0.63	0.06	0.71	0.58	0.7	0.53	0	0.76
CO_2 Em.	0.33	0.04	0.62	0.17	0.79	0.57	0	0.79
High Sk.	0.12	0.03	0.25	0.07	0.57	0.24	0.07	0.62
Med. Sk.	0.21	0.05	0.31	0.15	0.69	0.39	0	0.69
Low Sk.	0.15	0.02	0.56	0.04	0.74	0.66	0	0.83

Note: Numbers are time averages for the sample period.

Table 6
Slope, variance, sign and rank tests, country by country.

Country	Slope Test			Var. Test	Sign Test	Rank Test		
		Std. Error	R^2			Kendall	p-value	Pairwise
AUS	0.21	0.03	0.84	0.06	0.83	0.9	0	0.95
AUT	0.45	0.1	0.65	0.31	0.69	0.41	0.39	0.7
BEL	0.08	0.18	−0.18	0.2	0.76	0.33	0.45	0.67
BGR	0.08	0.06	0.1	0.05	0.79	0.03	0.76	0.51
BRA	0.21	0.1	−0.19	0.09	0.74	0.41	0.36	0.7
CAN	0.15	0.13	−0.05	0.1	0.64	0.53	0.19	0.77
CHN	0.17	0.01	0.91	0.04	1	0.86	0.01	0.93
CYP	0.5	0.26	0.06	1.4	0.67	0.42	0.26	0.71
CZE	0.21	0.1	0.23	0.14	0.49	−0.05	0.91	0.48
DEU	0.25	0.05	0.78	0.08	0.94	0.84	0.01	0.92
DNK	1.03	0.13	0.88	1.1	0.79	0.62	0.08	0.81
ESP	0.09	0.14	−1.03	0.11	0.44	0.11	0.77	0.56
EST	0.19	0.05	0.44	0.04	0.57	0.48	0.23	0.74
FIN	0.39	0.1	0.7	0.21	0.97	0.75	0.03	0.88
FRA	0.15	0.05	0.49	0.04	0.73	0.9	0.01	0.95
GBR	0.28	0.04	0.82	0.11	0.9	0.84	0.01	0.92
GRC	0.28	0.07	0.6	0.09	0.7	0.78	0.02	0.89
HUN	0.35	0.35	0.03	1.19	0.57	−0.19	0.69	0.4
IDN	0.02	0.08	−0.48	0.05	0.43	0.56	0.13	0.78
IND	0.07	0.02	0.58	0.01	0.79	0.63	0.07	0.81
IRL	0.37	0.15	−0.66	0.09	0.81	0.69	0.05	0.84
ITA	0.18	0.06	0.52	0.06	0.59	0.55	0.12	0.78
JPN	−0.01	0.06	0	0.04	0.47	−0.03	0.93	0.49
KOR	0.38	0.14	0.49	0.25	0.63	0.6	0.09	0.8
LTU	−0.19	0.65	0.08	5.74	0.59	0.07	0.64	0.53
LUX	0.7	0.18	0.38	0.64	0.74	0.81	0.03	0.9
LVA	0.51	0.54	0.02	6.64	0.47	0.21	0.61	0.6
MEX	0.15	0.05	0.57	0.03	0.93	0.69	0.08	0.84
MLT	0.43	0.03	0.92	0.18	0.64	0.85	0.01	0.92
NLD	0.92	0.07	0.96	0.88	0.39	0.37	0.34	0.69
POL	0.12	0.07	0.15	0.05	0.74	0.3	0.46	0.65
PRT	0.1	0.05	−0.33	0.03	0.64	0.25	0.63	0.62
ROU	0.14	0.19	0.16	0.59	0.46	0.19	0.57	0.6
RUS	0.49	0.09	0.83	0.3	0.9	0.5	0.17	0.75
SVK	0.3	0.06	0.65	0.09	0.6	0.57	0.18	0.79
SVN	0.12	0.31	0	0.93	0.54	0.07	0.71	0.53
SWE	0.15	0.07	−0.42	0.04	0.71	0.48	0.2	0.74
TUR	0.19	0.06	0.52	0.08	0.59	0.55	0.14	0.78
TWN	0.57	0.08	0.88	0.36	0.9	0.51	0.15	0.76
USA	0.21	0.04	0.76	0.09	0.83	0.71	0.05	0.86
ROW	0.01	0.16	−0.77	0.16	0.56	−0.07	0.95	0.47

Note: Numbers are time averages for the sample period.
The R-squared is calculated as:

$$R^2 = 1 - SS_{res} / SS_{tot},$$

where SS_{res} is the residual sum-of-squares from the model, and SS_{tot} is the residual sum-of-squares when subtracting off the mean. Thus, R^2 is negative when the HOV model fits worse than a horizontal line.

table from national input-output tables. Moreover, the data used in previous studies have a higher level of aggregation by industry, so that traded goods are largely mixed with non-traded goods, which affects the estimation.

Second, disagreement may be due to the units in which the use of production factors is measured. Indeed, in the present study, factor use is measured in efficiency units, while most studies measure factor use in natural units. This may be an important source of disagreement since, when factors are measured in natural units, countries that use some factor inefficiently appear to be more abundant in that factor and, at the

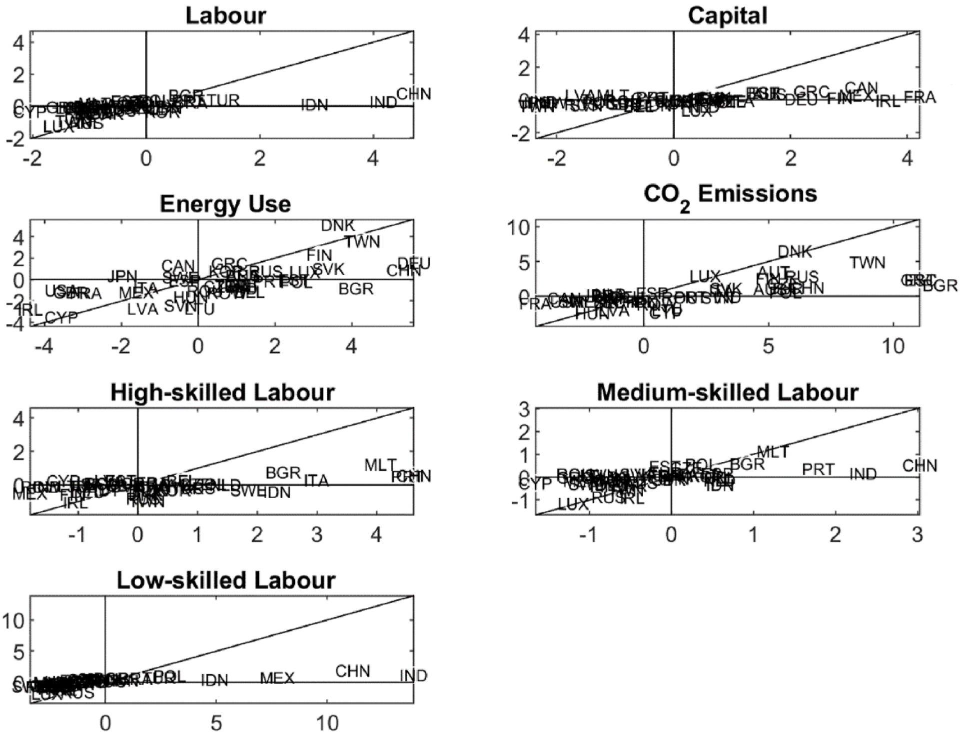

Fig. 1. Slope tests, factor by factor.

Note: The x-axis represents the factor content of trade as predicted by the HOV theorem, while the y-axis represents the factor content of trade as revealed by the trade data. Numbers are time averages for the sample period.

Due to extreme values, observations for energy use and emissions from Malta are not shown, nor are observations for energy use from the Netherlands (see Tables 3 and 4).

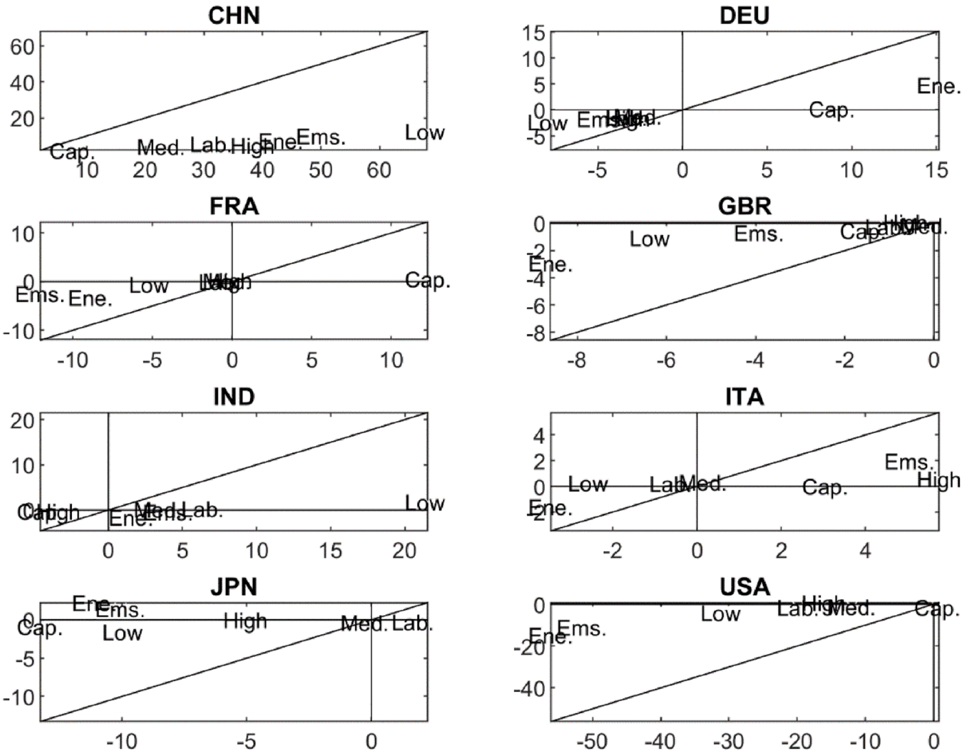

Fig. 2. Slope tests, country by country.

Note: The x-axis represents the factor content of trade as predicted by the HOV theorem, while the y-axis represents the factor content of trade as revealed by the trade data. Numbers are time averages for the sample period.

Table 7
Slope tests assuming consumption similarity in major non-traded sectors, factor by factor.

	Labour	Capital	En. Use	CO_2 Em.	High Sk.	Med. Sk.	Low Sk.
Actual Cons.	0.2	0.1	0.63	0.33	0.12	0.21	0.15
	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.01)
Cons. Sim. in Sector:							
Agr.	0.51	0.1	0.64	0.35	0.13	0.36	0.54
	(0.05)	(0.03)	(0.06)	(0.03)	(0.03)	(0.07)	(0.03)
Food Man.	0.33	0.11	0.65	0.37	0.15	0.25	0.3
	(0.05)	(0.03)	(0.05)	(0.03)	(0.04)	(0.07)	(0.03)
Electr.	0.2	0.11	0.64	0.55	0.13	0.22	0.14
	(0.04)	(0.03)	(0.06)	(0.03)	(0.04)	(0.06)	(0.02)
Constr.	0.4	0.11	0.67	0.38	0.17	0.37	0.28
	(0.04)	(0.04)	(0.05)	(0.03)	(0.04)	(0.06)	(0.02)
Real Est.	0.22	0.64	0.63	0.34	0.13	0.24	0.15
	(0.04)	(0.03)	(0.06)	(0.04)	(0.03)	(0.05)	(0.02)
Publ. Adm.	0.23	0.18	0.62	0.34	0.24	0.31	0.15
	(0.05)	(0.04)	(0.06)	(0.03)	(0.05)	(0.07)	(0.02)
Educ.	0.23	0.13	0.63	0.34	0.53	0.34	0.15
	(0.04)	(0.03)	(0.06)	(0.04)	(0.05)	(0.06)	(0.02)
Health	0.18	0.12	0.63	0.34	0.24	0.23	0.13
	(0.05)	(0.03)	(0.06)	(0.04)	(0.05)	(0.06)	(0.02)

Note: Standard errors are shown in parentheses. Numbers are time averages for the sample period.
'Agriculture' refers to sector 1 of the WIOD input-output tables (2016 release) (i.e., 'crops, animal production, hunting and related service activities'); 'food manufacturing' refers to sector 5 ('manufacture of food products, beverages and tobacco'); 'electricity' to sector 24 ('electricity, gas, steam and air conditioning supply'); 'construction', 'real estate' and 'education' to the homonymous sectors; 'public administration' to sector 51 ('public administration, defence and social security'); 'health' to sector 53 ('human health and social work activities'). These are the sectors whose consumption similarity failure has the greatest influence on the HOV tests.

same time, they appear to export more services of that factor. In this case, measuring factor usage in natural units ensures a better fit between factor export data and factor abundance data. However, this better fit is spurious in nature.

The question then arises as to what role these two aspects - industry aggregation and international differences in factor efficiency - play in testing the HOV theorem. Tables 8 and 9 show comparisons between the factor-by-factor test results obtained in the present study and those that would be obtained under two alternative assumptions: factor usage is measured in natural units rather than efficiency units (Table 8), and there is only one industry in each country rather than fifty-six (Table 9). A number of observations emerge from these comparisons.

Table 8 shows that when factor use is measured in efficiency units, the outcome of factor-by-factor HOV tests worsens in many cases. In particular, for energy use and emissions, measuring factor use in natural or efficiency units does not alter the tests much: in fact, the rank and sign tests get somewhat worse, while the slope and variance tests get better. However, for labour (both total and skill-differentiated) and capital, all tests except the variance ratio get worse when factor use is measured in efficiency units. This means that the better fit that other studies find between the labour/capital content of trade and the labour/capital abundance of countries has to do, to some extent, with the fact that countries where these factors are more inefficient seem to have higher labour/capital endowments and, at the same time, seem to export more labour/capital services.

Interestingly, the effect of industry aggregation is very similar to the effect of units of measurement. Indeed, Table 9 shows that when the different use of factors by industry is taken into account, the results of the HOV tests worsen in many cases. In fact, the slope, sign and rank tests worsen for labour (both total and skill-differentiated) and capital. In the case of energy use and emissions, the tests show mixed results: the sign and rank tests worsen somewhat but the slope and variance tests improve. The cases of capital and skilled labour are striking: when a single aggregated sector is considered, the fit of theory and data is excellent; on the contrary, when the differences between the 56 industries are taken into account, it is not possible to rule out the hypothesis that the HOV model should be rejected.

The effect of the level of industry disaggregation on the results of the HOV tests has much to do with the failure of consumption similarity (Table 7). Indeed, when all sectors are aggregated into one, traded and non-traded goods are added together. Then, the factors used to produce non-traded goods are imputed to the factor content of trade and that is why there seems to be a high level of conformity between theory and data. With 56 sectors, a better distinction is made between traded and non-traded activities. However, let us not fool ourselves, with this level of industry disaggregation, traded and non-traded goods continue to mix together. In fact, it cannot be ruled out that, if the level of disaggregation were to increase, the discrepancy between the HOV model and the data would increase even further.

7. Conclusions

The foregoing exercise shows the results of testing the Heckscher-Ohlin-Vanek theorem in a context where factor price equalization fails, as the one described by the World Input-Output Database. The main conclusions of the study are four:

Table 8
Effect of measurement units on HOV tests, factor by factor.

Factor	Units		Slope Test		Var. Ratio	Sign Test		Rank Test	
			Std. Error	R^2			Kendall	p-value	Pairwise
Labour	Nat.	0.18	0.01	0.82	0.04	0.96	0.68	0	0.84
	Eff.	0.2	0.04	0.41	0.1	0.7	0.5	0	0.75
Capital	Nat.	0.3	0.01	0.92	0.1	0.94	0.86	0	0.93
	Eff.	0.1	0.03	0.29	0.04	0.71	0.39	0	0.69
En. Use	Nat.	0.24	0.02	0.78	0.07	0.9	0.71	0	0.85
	Eff.	0.63	0.06	0.71	0.58	0.7	0.53	0	0.76
CO_2 Em.	Nat.	0.23	0.02	0.79	0.07	0.91	0.67	0	0.84
	Eff.	0.33	0.04	0.62	0.17	0.79	0.57	0	0.79
High Sk.	Nat.	0.18	0.01	0.82	0.04	0.98	0.81	0	0.9
	Eff.	0.12	0.03	0.25	0.07	0.57	0.24	0.07	0.62
Med. Sk.	Nat.	0.19	0.02	0.78	0.04	0.91	0.57	0	0.78
	Eff.	0.21	0.05	0.31	0.15	0.69	0.39	0	0.69
Low Sk.	Nat.	0.18	0.01	0.86	0.04	0.97	0.53	0	0.77
	Eff.	0.15	0.02	0.56	0.04	0.74	0.66	0	0.83

Note: Numbers are time averages for the sample period.

Table 9
Effect of industry aggregation on HOV tests, factor by factor.

Factor	No. sectors	Slope Test			Var. Test	Sign Test	Rank Test		
			Std. Error	R^2			Kendall	p-value	Pairwise
Labour	1	0.23	0.02	0.85	0.07	0.86	0.8	0	0.9
	56	0.2	0.04	0.41	0.1	0.7	0.5	0	0.75
Capital	1	0.24	0.02	0.81	0.07	0.92	0.78	0	0.89
	56	0.1	0.03	0.29	0.04	0.71	0.39	0	0.69
En. Use	1	0.33	0.02	0.88	0.13	0.77	0.77	0	0.88
	56	0.63	0.06	0.71	0.58	0.7	0.53	0	0.76
CO_2 Em.	1	0.27	0.02	0.8	0.1	0.92	0.75	0	0.87
	56	0.33	0.04	0.62	0.17	0.79	0.57	0	0.79
High Sk.	1	0.24	0.01	0.88	0.07	0.94	0.84	0	0.92
	56	0.12	0.03	0.25	0.07	0.57	0.24	0.07	0.62
Med. Sk.	1	0.24	0.02	0.84	0.07	0.93	0.82	0	0.91
	56	0.21	0.05	0.31	0.15	0.69	0.39	0	0.69
Low Sk.	1	0.2	0.01	0.89	0.04	0.85	0.8	0	0.9
	56	0.15	0.02	0.56	0.04	0.74	0.66	0	0.83

Note: Numbers are time averages for the sample period.

1. The HOV model does not accurately predict the capital and skilled labour content of trade. This is because capital and skilled labour are largely allocated to non-traded activities and the differences in capital and skill intensity across varieties of traded goods produced by different countries are not large enough to compensate for the lack of similarity in consumption.
2. The HOV model predicts reasonably well the energy use (here used as a proxy for machine work) and emissions content of trade. In fact, the use of these factors is not so biased towards non-traded activities and the differences in energy and emissions intensity between varieties of traded goods appear statistically significant, even when measured in efficiency units.
3. The HOV model fits the data worse when factor use is measured in efficiency units than when it is measured in natural units. This is because, when factor use is measured in natural units, countries in which some factor is less efficient appear to have higher endowments of the inefficient factor and, at the same time, seem to export more services from that factor.
4. The HOV model fits the data worse the higher the level of industry disaggregation. In particular, the fewer industries there are, the more traded and non-traded goods are added together and, apparently, the higher the capital and labour content of trade.

These findings have implications for both policy and future research.

Indeed, let us assume that it is true that differences between countries in the capital and skill intensity of traded goods are not large compared to differences in the capital and skill endowments. This may imply that countries' endowments of capital and skilled labour - when measured in efficiency units - are not very relevant to explaining the basket of goods they export. So, if a country increases its capital or skill endowment, this may have a greater influence on non-traded output than on exports. Therefore, a policy aimed at 'export diversification' or 'export upgrading' that was based solely on increasing the stock of physical and human capital through supply-side policies may not be very successful. Perhaps some of this can be seen in primary-exporting countries when a commodity boom allows an increase in physical and human capital formation, and yet this does not have a major effect on the country's export basket, although it has effects on non-traded output (IMF, 2015; Ismail, 2010).

The case of emissions, on the other hand, seems to be different from that of capital and skilled labour. It seems that in this case purely supply-side policies can have an effect on the export basket, as differences in emissions intensity between varieties of traded goods appear significant compared to differences in emissions abundance, even when both are measured in efficiency units. This means that if a policy aimed at reducing the emissions intensity of production succeeds in increasing the efficiency in the use of emissions (i.e. leads to 'emissions-augmenting' technical change), a country may become more emissions-abundant and therefore the production of emissions-intensive varieties of goods will shift from less efficient countries to that country. This seems to be the case for some northern European countries, such as Denmark or Finland, which are net exporters of emissions when measured in efficiency units, although they are net importers when measured in natural units. On the other hand, if the policy restricts the use of emissions without affecting their efficiency, the country will become less emissions-abundant and the production of emissions-intensive varieties of goods will shift to other countries. In the former case, the total amount of emissions worldwide will be reduced; in the latter case, the total amount of emissions may increase or decrease.

Finally, as regards the implications of this article for future research, several points are worth highlighted.

The main one is that, in view of the ups and downs of HOV testing over the past 60 years, the results of the present study can only be considered provisional. Indeed, although the database used is of remarkable quality and the greatest possible care has been taken in constructing the data sample, it is still a very simplified model of the world economy. Actually, 7 factors, 56 sectors and 40 countries plus the 'rest of the world' seems a big step forward compared to the data samples of other well-known studies on the HOV theorem, but it can really only be considered a caricature of the world economy. Moreover, the selection of countries in the sample is somewhat biased, as it includes mainly highly developed countries, while many large middle- and low-income economies are aggregated within the 'rest of the world'.

The limited scope of the database used in the present study seems especially relevant in view of the conclusions mentioned above. Indeed, since the level of data aggregation seems to greatly influence HOV testing, further research is important as new databases with a higher level of disaggregation by industry and by country are published. Specifically, in light of the results of this study, the following question arises: to what extent will HOV tests worsen as disaggregation by industry and country increases and traded activities become increasingly differentiated from non-traded ones? This is a puzzle that only future research will be able to solve.

Another unanswered question concerns the observed heterogeneity in the behaviour of production factors. On the one hand, we have the 'classical' production factors (labour, capital) for which the HOV tests offer mediocre results and, moreover, are highly influenced by the level of industry aggregation and units of measurement. On the other hand, we have other factors (energy use, emissions) for which the tests often offer robust results. The most curious thing about all this is that some of these production factors are not even commonly considered as such and, in fact, until recently they were not considered in this way.

Here, naturally, all kinds of doubts arise. Is this heterogeneity due to some factors being measured consistently and others roughly? Consider, for example, capital use vs. machine work (measured through net energy use). One is estimated from net investment flows and is measured in constant or current dollars, while the other is measured in joules. Joules seem a better measure of the work done by an ingredient of physical capital (machines) than a stock measured in dollars. Moreover, there may be less error in the former measure than in the latter. It is possible that the same is true of the way we measure labour: hours worked and number of people engaged do not adequately represent the effort expended by workers. However, against this line of reasoning one could argue that this is what conversion factors from natural units to efficiency units are for.

If we consider that the heterogeneity in the behaviour of production factors in the HOV tests is not due to biased measurement errors, then it can only be explained by the fact that the varieties of traded goods are much more different in their energy or emissions content than in their capital or skill content. This could be a hypothetical explanation for the results obtained in the present study, but it is not clear why this is so. Surely, this is another question that only future research will be able to answer. Meanwhile, it seems that the factor abundance theory remains the same old puzzle.

Authorship

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been submitted to or published in any other publication.

CRediT authorship contribution statement

Pablo R. Liboreiro: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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