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Explaining trade in industrialized countries by country-specific human capital endowments

Frank Cörvers*, Andries de Grip

Research Centre for Education and the Labour Market, Faculty of Economics and Business Administration, Maastricht University, P.O. Box 616, 6200 MD Maastricht, Netherlands

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Abstract

This paper simultaneously incorporates, for the first time, three different country-specific human capital endowments to analyse the impact of human capital on trade performance. Within a Heckscher–Ohlin–Vanek model, the factor endowments of intermediate and highly-skilled labour and technological knowledge are distinguished to explain the trade performance of 14 industrialized countries. Contrary to previous empirical studies, the results show that the Heckscher–Ohlin–Vanek model is still of value for explaining international trade flows. The estimation results suggest that an abundance of highly-skilled labour and technological knowledge in a country indicates a comparative advantage for the technology-intensive sectors, and a comparative *dis*advantage for the labour-intensive sectors.

JEL classification: F14; J21

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1. Introduction

This paper focuses on the relevance of country-specific human capital endowments for the trade performance of industrialized countries. There are good

* Corresponding author. Tel.: 31 43 388 36473751; fax: 31 43 321 0999; e-mail: f.corvers@roa.unimaas.nl.

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reasons to assume that human capital endowments are dependent on country-specific circumstances, such as the educational system or the technology policies of the government. The Heckscher–Ohlin–Vanek model (Vanek, 1968; Leamer, 1980; Leamer and Bowen, 1981; and Deardorff, 1982), which is also known as the factor content version of the more familiar Heckscher–Ohlin model, demonstrates that countries with relatively large stocks of a particular factor endowment will export the services of this factor endowment. The Heckscher–Ohlin–Vanek (HOV) model shows that country-specific factor endowments rather than sector-specific factor inputs determine trade (e.g. Leamer and Bowen, 1981; and Leamer, 1992), which is in contrast with the emphasis on sector-specific factor inputs as determinants of international trade flows in many empirical studies (e.g. Baldwin, 1971; Katrak, 1973; Branson and Monoyios, 1977, Stern and Maskus, 1981; and Courakis, 1991).

The present study simultaneously incorporates, for the first time, three different country-specific human capital endowments to analyse the impact of human capital on trade performance. The model used is analogous to the *neo-factor endowments models*, which include not only the traditional production factors of labour and physical capital, as in the studies of Leontief (1953, 1956), but also human capital and technological knowledge (for overviews, see Deardorff, 1984; Hughes, 1986; and Memedovic, 1994). The human capital endowments of this paper are represented by the share of both intermediate-skilled labour and highly-skilled labour in a country's labour force, and the proportion of R & D (research and development) workers in a country's labour force.

With regard to the first two skill groups it is widely accepted that the distinction between the intermediate-skilled 'craft' workers and highly-skilled 'professionals' is very important for explaining productivity differences (e.g. Prais, 1981; Daly, 1986; Campbell and Warner, 1991; and Lindley, 1991). This might also be expected to hold for explaining international trade flows. Therefore this study does not follow previous empirical studies on international trade, which measure human capital from discounted sector-wage differentials (e.g. Branson and Monoyios, 1977; and Stern and Maskus, 1981), especially as these differentials have the disadvantage of being only an indirect measure of labour skills. Nor is human capital measured by occupational categories of workers (e.g. Keesing, 1966, 1968; Baldwin, 1971; Leamer, 1984; and Bowen et al., 1987), since the latter measure is based on the type of work done rather than on the skill level of the workforce.

The third skill group mentioned above, workers participating in R & D activities, embodies an important part of the country's stock of technological knowledge.[1] The country-specificity of technological knowledge is shown by, for example, Daniels (1993), who found evidence for the importance of national differences in technological capabilities as a determinant of the trade performance of technology-intensive sectors. Moreover, R & D workers often have an education in

[1] Lucas (1988) also uses the notion that (technological) knowledge is embodied in human beings and is passed on to younger generations.

natural sciences or engineering, which may imply that, in measuring the stock of technological knowledge, it is not only the level of education that matters, but also the type.

Empirical studies often show poor results if, in accordance with the HOV model, net trade flows at sector level are explained by country-specific factor endowments (e.g. Bowen et al., 1987; and Bowen and Sveikauskas, 1992). This paper will point to some reasons why empirical research may fail to explain trade performance if the HOV model is used. Furthermore, it is often argued that trade models assuming economies of scale and product differentiation are best suited to explain trade flows between industrialized countries. However, these intra-industry trade models explain only the *amount* of trade between countries, whereas the HOV model has the potential to explain the *direction* of net trade flows (see Helpman, 1981). Net trade flows are particularly important, since they determine the surplus or shortage in the trade balance, which is a hot item in the trade negotiations between the Unites States, Japan and the European Union. Furthermore, 40% of total trade in industrialized countries is still inter-industry trade (OECD, 1987).[2]

The paper is organised as follows. Section 2 presents a derivation of the most important implication of the HOV model: that the trade performance of sectors is dependent on country-specific factor endowments rather than on sector-specific factor inputs. Section 3 presents the empirical model, which is based on the preceding theoretical exposition. Section 4 develops hypotheses regarding the impact of the relative factor endowments of labour, physical capital and human capital on the trade performance of four different categories of sectors. Section 5 presents the results of the empirical analysis. In this section the revealed comparative advantages of 14 industrialized countries will be regressed on the relative factor endowments of labour, physical capital and human capital. The regression method used is the ordinary least squares method (OLS). Section 6 summarizes the main conclusions of the paper.

2. The country-specificity of the determinants of trade in the HOV model

One of the theorems following from the HOV model, the Heckscher–Ohlin–Vanek theorem, says that countries tend to export the factor services of their relatively abundant production factors and tend to import the factor services of their relatively scarce production factors.[3] It emphasizes that factor services are exchanged through trade. The traded goods that embody or contain the services of the production factors merely conduct that exchange.

[2] Inter-industry trade can be measured by the industry's absolute value of net exports expressed as a percentage of the industry's total trade (i.e. the sum of exports and imports).

[3] The use of the verb 'tend' indicates that this theorem holds *on average* (see Deardorff, 1982 and Forstner, 1985).

The *assumptions* of the HOV model are (Leamer, 1980):

(a) perfect competition in the goods and factors markets,
(b) zero cost of transport of commodities and no other impediments to trade,
(c) immobility of production factors between countries, but complete mobility of production factors between sectors within a country,
(d) identical input–output (technology) relations in all countries,
(e) production functions showing constant returns to scale,
(f) factor-price equalization across countries,
(g) equal numbers of factors and goods, and
(h) consumers maximize their identical homothetic utility functions.

In particular, the assumptions of similar input–output coefficients and factor-price equalization across countries may be crucial for the relevance of the HOV model. Deardorff (1982) shows that if both these assumptions are met, factor intensity reversals cannot occur. However, these assumptions of the HOV model are more valid for a group of industrialized countries than for a mixed group of industrialized and developing countries.[4] Therefore the HOV model might usefully be applied to a group of industrialized countries, as in this study. As for other assumptions of the HOV model, Leamer (1984) concludes that, if the assumptions with regard to trade impediments, international factor mobility, non-traded and intermediate goods, transportation costs, factor market distortions and consumer preference dissimilarities are not fulfilled, outcomes from the HOV model are not seriously affected.[5]

For each country i, the vector AQ_i is the vector of factors required to produce the $n \times 1$ vector of goods Q_i (see, for example, Leamer, 1980), where the matrix A is the $m \times n$ input–output (factor intensity) matrix with input (or factor) requirements a_{kj}. These input requirements indicate the amount of factor k used to produce one unit of good j.[6] Due to assumptions (d), (e) and (f), the matrix A is identical for all countries, AQ_i also represents the factors embodied in the production of Q_i. Equilibrium in the factor markets requires that factor demand AQ_i is equal to factor supply V_i, so $AQ_i = V_i$. The summation of this equation across all countries gives $AQ_w = V_w$ (since $Q_w = \Sigma_i Q_i$ and $V_w = \Sigma_i V_i$). Because of assumption (a), the vector of goods prices is equal across all countries. Equalization of goods prices and assumption (h) imply that each country i will consume a proportion β_i of all world-wide produced goods that is the same for all goods. So for the $n \times 1$ vector of goods consumed in country i it holds that $C_i = \beta_i Q_w$, where β_i is a scalar. The net exports of country i equal the difference between its production and its consumption, $T_i = Q_i - C_i$. The factors embodied in the net exports $AT_i = A(Q_i - C_i) = V_i - A\beta_i Q_w = V_i - \beta_i V_w$. This also implies that $\beta_i V_w$

[4]Generalizations of the HOV theorem, without assuming factor-price equalization, are found in Brecher and Choudhri (1982), Deardorff (1982) and Helpman (1984).
[5]Moreover, the results of the HOV model are less distorted by trade barriers now than they once were, as the barriers are gradually broken down by free trade agreements.
[6]This matrix does not allow intermediate inputs.

indicates the extent to which the world's factor endowments are used by country i's consumption. Therefore formula (1) represents the Heckscher–Ohlin–Vanek theorem:

$$AT_i = V_i - \beta_i V_w \quad (1)$$

Following Bowen and Sveikauskas (1992), formula (1) can be corrected for trade imbalances B_i, where B_i is a scalar which equals $P'T_i$ (vector P is the $n \times 1$ vector of goods prices). Therefore $\beta_i V_w$ has to be written as $(GDP_i - B_i)/GDP_w V_w = (GDP_i/GDP_w)V_w - (B_i/GDP_w)V_w = \alpha_i V_w - (B_i/GDP_w)V_w$, where GDP_i stands for the gross domestic product of country i and α_i is country i's share of world income GDP_w. When $(B_i/GDP_w)V_w$ is subtracted from each side of formula (1) it follows that

$$AT_i - (B_i/GDP_w)V_w = V_i - \alpha_i V_w. \quad (2)$$

The vector AQ_w can be substituted for V_w. If the vector S is defined as the $n \times 1$ vector of world shares of each good, Q_w/GDP_w, then formula (3) results:

$$A(T_i - B_i S) = V_i - \alpha_i V_w. \quad (3)$$

Subtracting $B_i S$ from T_i implies that the excess or deficit for a country's net exports per sector is corrected by $B_i S$. The term $B_i S$ indicates how the trade imbalance is distributed over the various sectors. If a country's consumption level is too high or too low relative to its income level, the difference is assumed to be distributed over the various sectors according to the share of the production (or consumption, because $Q_w = C_w$) of each good (or sector) on the world market. This follows from the assumption of homothetic utility functions (assumption (h)). Moreover, if T_{Bi} is defined as $T_i - B_i S$, this results in

$$AT_{Bi} = V_i - \alpha_i V_w. \quad (4)$$

A definition of factor abundance can be derived from formula (4). The vector V_i represents the factor endowments $(V_{1i}, \ldots, V_{ki}, \ldots, V_{mi})'$ of country i. Similarly, the vector V_w represents the world's factor endowments $(V_{1w}, \ldots, V_{kw}, \ldots, V_{mw})'$. The quotient of V_{ki} and V_{kw} represents the factor endowment of country i in factor k relative to the world's factor endowment. If the right-hand side of formula (1) is positive for factor k, i.e. if country i is abundant in factor k, then it also holds that $V_{ki}/V_{kw} > \alpha_i$. This result can be used to define factor abundance. Following Leamer (1984), country i is abundant in factor k if its share of the world's supply of factor k, V_{ki}/V_{kw}, exceeds its share of the world's income, α_i, i.e. $V_{ki}/V_{kw} > \alpha_i$. It follows that country i is abundant in factor k if

$$(V_{ki}/V_{kw})/(GDP_i/GDP_w) > 1. \quad (5)$$

The larger the left-hand side of (5), the larger the relative factor endowment of country i in factor k.

Finally, formula (4) can be rewritten as

$$T_{Bi} = A^{-1}V_i - A^{-1}\alpha_i V_w. \tag{6}$$

Formula (6) indicates that the net exports of country i are dependent on the vector of factor endowments V_i. The inverse of matrix A only exists if there are equal numbers of factors and goods (assumption (g)).[7] If there are more sectors (goods) than production factors, then it is not possible to determine the net trade flows for each sector on theoretical grounds, because the system of equations for country i is under-determined. The input–output matrix A is not square and therefore it has no inverse. However, Leamer (1984) states that this is not a cause for concern, because in an empirical analysis the number of goods or sectors depends on the level of aggregation, and the observed production factors are just a selection from a larger set of production factors.

A few more steps have to be inserted to derive the final equation of this section.[8] First note that $GDP_i = P'Q_i$, $\alpha_i = GDP_i/GDP_w$ (where α_i, GDP_i and GDP_w are scalars), and $V_w = AQ_w$. From Eq. (6) it follows that $T_{Bi} = A^{-1}V_i - A^{-1}V_w\alpha_i = A^{-1}V_i - A^{-1}AQ_w\alpha_i = A^{-1}V_i - Q_w GDP_i/GDP_w = A^{-1}V_i - Q_w P'Q_i/GDP_w = A^{-1}V_i - Q_w P'A^{-1}V_i/GDP_w = (I - Q_w P'/GDP_w)A^{-1}V_i$, where I represents the identity matrix. As a result, it holds for each sector j of the vector T_{Bi} that

$$T_{Bji} = \sum_{k=1}^{m} b_{jk}V_{ki}. \tag{7}$$

The b_{jk} coefficients of Eq. (7) represent the matrix $(I - Q_w P'/GDP_w)A^{-1}$. It follows that these coefficients are derived from the factor intensities of matrix A, which is equal for all countries.[9] Furthermore, Eq. (7) clearly shows the main point of the HOV theorem, that the net exports of sector j in country i are dependent on country i's vector of factor endowments V_{ki} rather than on the sector-specific factor inputs of sector j. This equation will be used for developing the empirical model of Section 3.

3. The HOV model with country-specific human capital endowments

From the theoretical exposition in Section 2 it follows that differences in country-specific factor endowments have implications for the pattern of net trade flows. In order to allow for the different impact of the supply of intermediate skilled 'craft' workers and highly-skilled 'professionals', three levels of education can be distinguished by measuring the shares of low-skilled, intermediate-skilled

[7] Furthermore, notice that each row and column of the inverse matrix has to contain both positive and negative elements, since the matrix A contains only positive elements.

[8] See Leamer (1984) for the two-dimensional case.

[9] Moreover, it follows that these coefficients can be positive as well as negative.

and highly-skilled workers in the total workforce of a country (see also Welch, 1970, and Pencavel, 1991).

We would also like to use the proportion of a country's workforce who are engaged in research and development (R & D) as a measure of the country's stock of technological knowledge. However, comparable data on these employment shares and not available for all countries. Nevertheless, the proportion of a country's labour force that is employed in R & D activities can be approximated by the R & D intensity of a country (R & D expenditures divided by GDP), since R & D expenditures consist largely of wage costs for R & D workers.[10] The technological knowledge that countries buy from abroad, which is expressed by the technological balance of payments, is also taken into account to construct a reliable proxy of the level of technological knowledge in a country (see Appendix B).

To test the relevance of the various human capital endowments with regard to the level of education for the pattern of net trade flows, two equations will be considered. Both equations follow directly from Eq. (7), although the first equation does not distinguish between the various levels of education, whereas the second equation distinguishes the three skill categories discussed above:

$$RCA_{ji} = b_{j0} + b_{j1}LAB_i + b_{j5}TEC_i + b_{j6}CAP_i + b_{j7}RCA_i + \mu, \qquad (8a)$$

$$RCA_{ji} = b_{j0} + b_{j2}LSW_i + b_{j3}ISW_i + b_{j4}HSW_i + b_{j5}TEC_i + b_{j6}CAP_i + b_{j7}RCA_i + \mu, \qquad (8b)$$

where

RCA_{ji} = the revealed comparative advantage of sector j in country i;
LAB_i = the relative factor endowment of labour in country i;
LSW_i = the relative factor endowment of low-skilled workers in country i;
ISW_i = the relative factor endowment of intermediate-skilled workers in country i;
HSW_i = the relative factor endowment of highly-skilled workers in country i;
TEC_i = the relative factor endowment of technological knowledge in country i;
CAP_i = the relative factor endowment of physical capital stock in country i;
RCA_i = the revealed comparative advantage of all sectors of country i (excluding those belonging to the same factor-intensity category as sector j);[11]
b_{jk} = estimated coefficients;[12]
μ = disturbance term.

[10] The wage costs of R & D workers comprise between 80% and 90% of total R & D expenditures in most industrialized countries (see Appendix B for data sources on technological knowledge).

[11] In fact, the trade balance variable represents the total of ISIC sectors listed in Appendix A. When calculating the total revealed comparative advantage measure (RCA_i) the category of economic sectors to which a particular sector belongs is excluded. For example, when calculating the total revealed comparative advantage RCA_i of the textile sector (tex), labour-intensive sectors are excluded.

Eqs. (8a) and (8b) are estimated sector by sector. Due to assumptions (d) and (e) of Section 2, each sector has the same regression coefficient, for a particular relative factor endowment, in all 14 industrialized countries. The HOV theorem states that countries tend to export the services of their abundant factors. By estimating Eqs. (8a) and (8b) it will be possible to identify which sectors are mainly responsible for the export of those factor services. In other words, the estimates of Eqs. (8a) and (8b) show which factor endowments contribute to the success of the export performance of a particular sector.

Moreover, it is important to scale both the countries' factor endowments and net exports per sector in Eq. (7). Otherwise the results might be influenced by variations in industry and country size.[13] The factor endowments are scaled by means of the factor abundance definition from Eq. (5). Using this equation and the data sources listed in Appendix B, the *relative* factor endowments are calculated. The factor endowments of country i are in fact *double scaled*, i.e. first with regard to the total amount of the factor endowment k in the world, and second with regard to the share of country i in the total GDP of the world. The total factor endowment of the world, and total world income, are both approximated by the sum of the factor endowments of the 14 countries in the sample and the sum of their GDPs respectively. The values of the relative factor endowments are presented in Appendix C.[14]

The dependent variable, net exports per sector, is double scaled, as proposed by Minne (1988). This implies that the net exports of sector j are first standardized with regard to total trade by country i,[15] and that this ratio is then standardized again according to the proportion of total world trade in all sectors which takes place in sector j. Again, world trade is approximated by the sum of trade of the 14 countries in the sample. The revealed comparative advantage of sector j in country i is shown in the following equation:

$$RCA_{ji} = (T_{ji}/U_{ji})/(U_{jw}/U_w), \tag{9}$$

where

T_{ji} = net exports of sector j in country i;
U_{ji} = half of the sum of exports and imports of sector j in country i, to indicate the total trade of the sector if there are no trade imbalances;
U_{jw} = half of the sum of world exports and world imports of sector j;
U_w = half of the sum of total world exports and total world imports.

Eq. (9) implies that if exports equal imports for a particular industry, so that

[12]The constant term b_{j0} is added to correct for net trade flows between our sample of 14 countries and the rest of the world.
[13]On this topic see, for example, Stern (1976) and Memedovic (1994). The latter also gives an overview of the various ways to scale net exports, which result in indicators for revealed comparative advantage.
[14]Scaling the human capital endowments according to Eq. (7) means that the relative factor endowment of labour, LAB_i, is a linear combination of the three relative factor endowments of human capital, i.e. LSW_i, ISW_i, and HSW_i. The weights of the linear combination are equal to the labour supply of workers with the relevant level of education, in the sample, divided by the total labour supply of all workers in the sample.
[15]Total trade is approximated by the mean of exports and imports.

intra-industry trade is 100%, then the RCA of the industry is zero.[16]

Finally, Section 2 suggests that net exports have to be corrected for trade imbalances. However, it is hard to find appropriate data to correct for trade imbalances (see Appendix B). For this reason the value of a country's trade balance (B_i) is added to the factor endowment variables on the right-hand side of Eq. (7) and double scaled according to Eq. (9). Therefore, after double scaling, the uncorrected net exports can be used as the dependent variable, as in Eqs. (8a) and (8b).[17]

4. Hypotheses on factor endowments and trade performance

This section develops hypotheses with regard to the consequences of countries' different relative factor endowments for their revealed comparative advantages in four categories of economic sectors with different factor intensities: the labour-intensive, capital-intensive low/medium-tech, capital-intensive high-tech and technology-intensive sectors.[18] This classification is based on OECD (1986, 1987) and Verspagen (1995). The resulting classification scheme is shown in Appendix A.

Table 1, parts (a) and (b), gives an overview of the hypotheses that will be tested with regard to the coefficients of the relative factor endowments of Eqs. (8a) and (8b).[19] With regard to the signs of the estimated coefficients, relative abundances of labour, physical capital and technological knowledge would intuitively be expected to be positively related to revealed comparative advantages in the labour-intensive sectors, the capital-intensive sectors and the technology-intensive sectors, respectively. These expectations are represented by the positive signs of the virtual diagonal running from upper left to lower right of the matrix in Table 1(a). The other elements of this matrix of signs are not clearly positive or negative, excluding the bottom left-hand corner and the top right-hand corner of the matrix. The latter two negative signs indicate that labour-rich countries are assumed to import technology-intensive goods (i.e. net exports are negative), and technology-abundant countries are assumed to import labour-intensive goods.[20]

Table 1(b) gives an overview of the expected signs of the factor endowments of labour skills in the four classes of sectors mentioned above. The expectations with regard to the signs of Table 1(b) are based upon two fundamental hypotheses, i.e. the *capital–skill complementarity* hypotheses (Griliches, 1969; Hamermesh, 1993) and the *technology–skill complementarity* hypothesis (e.g. Bartel and Lichtenberg,

[16] See Minne (1988) for a further discussion of this measure.

[17] See Appendix C for a figure presenting the uncorrected revealed comparative advantages of four categories of sectors of the countries in the sample.

[18] The resource-intensive sectors are not considered, since the trade performance of these sectors is strongly dependent on the abundance of natural resources, which are excluded from the analysis.

[19] Notice that both matrices of signs contain symmetric properties.

[20] There is no negative sign in the column for physical capital, as physical capital is expected to be strongly negatively related to the trade performance of service sectors, which are excluded from the analysis.

Table 1
(a) Hypotheses regarding the coefficients of the relative factor endowments of labour, capital and technological knowledge

Sectors	LAB_i	CAP_i	TEC_i
Labour-intensive	+	0	−
Capital-intensive, low/medium-tech	0/+	+	0/−
Capital-intensive, high-tech	0/−	+	0/+
Technology-intensive	−	0	+

(b) Hypotheses regarding the coefficients of the relative factor endowments of three skill levels

Sectors	LSW_i	ISW_i	HSW_i
Labour-intensive	+	0/−	−
Capital-intensive, low/medium-tech	0/+	0/−	0/−
Capital-intensive, high-tech	0/−	0/+	0/+
Technology-intensive	−	0/+	+

1987).[21] In general it is expected that the higher the capital intensity or the technology intensity of sectors, the higher the level of human capital that is required. For Table 1(b), this implies that the signs in the columns for intermediate- and highly-skilled labour increase from the first to the last row, in contrast to the signs in the column for low-skilled labour. As can be seen from Table 1(b), applying both the capital–skill and the technology–skill complementarity hypotheses results in clear positive or negative expected signs only for the four corner elements of the matrix. This implies that a relative abundance of low-skilled labour is expected to be positively related to revealed comparative advantage of the labour-intensive sectors, and negatively related to revealed comparative advantage of the technology-intensive sectors. Moreover, a relative abundance of highly-skilled labour is expected to be positively related to revealed comparative advantage of technology-intensive sectors and negatively related to revealed comparative advantage of labour-intensive sectors. For the column of intermediate-skilled labour, and for the two rows of capital-intensive sectors, the expected signs are less evident.

5. Explaining trade performance by human capital endowments

One of the attractive features of the HOV model is that the pattern of relative factor endowments in each country determines the pattern of sectoral net exports from that country. For example, countries that are relatively capital abundant should have a surplus of net exports in the capital-intensive sectors. As has been discussed in Section 3, the variables in the model have to be scaled properly,

[21] See also Wood (1994) on the relationship between, on the one hand, human capital and physical capital and, on the other hand, human capital and technological knowledge.

resulting in Eqs. (8a) and (8b). By estimating these equations, we can test to what extent the hypotheses formulated in Section 4 hold. The empirical analysis is applied to 14 industrialized countries: 11 European Union member states, Japan, Canada and the United States (see Appendix C). The reference year is 1985.

Table 2, parts (a) and (b), shows the results of the OLS regression of the revealed comparative advantages per category of sectors[22] on the relative factor endowments per country, according to Eqs. (8a) and (8b), respectively.[23] The results in Table 2(a), in particular the F-statistics, indicate that the estimated Eq. (8a) is significant at the 5% level for these four categories of sectors. Moreover, the signs and the significance of the coefficients of the relative factor endowments generally confirm the hypotheses of Table 1(a). However, the relative factor endowment of labour does not produce a significant result for any category of economic sectors, which may point to the relevance of distinguishing the various levels of human capital. On the other hand, the coefficient of the technological knowledge variables is, in accordance with the hypotheses, negative and significant for both the labour-intensive and the capital-intensive low/medium-tech sectors. The magnitude of the coefficient for the latter category is somewhat smaller, in line with the hypotheses. Furthermore, confirming the hypotheses, the estimated technological knowledge coefficients for the capital-intensive high-tech and the technology-intensive sectors are zero, and significantly positive, respectively. Finally, the estimated coefficients for the physical capital variable are only significantly positive for the capital-intensive sectors of industry, which is again in accordance with the hypotheses of Table 1(a). These results generally confirm the value of the HOV model for explaining net trade flows between industrialized countries.

Table 2
(a) Estimation results for four categories of sectors with different factor intensities, excluding skill levels (Eq. 8b)

Category	Constant	LAB_i	TEC_i	CAP_i	RCA_i	$\bar{R}^2$	F-stat.
LI	−0.45	0.36	−1.57	1.27	−0.03	0.47	3.84[b]
	(−0.43)	(0.81)	(−2.49)[b]	(1.51)	(−0.07)		
CILM	−0.34	−0.29	−1.20	1.73	0.69	0.45	3.70[b]
	(−0.37)	(−0.876)	(−2.14)[a]	(2.37)[b]	(1.62)		
CIH	−1.31	−0.34	0.19	1.66	0.41	0.46	3.78[b]
	(−1.50)	(−0.97)	(0.35)	(2.57)[b]	(1.23)		
TI	−1.74	0.21	0.79	0.91	0.25	0.48	4.05[b]
	(−2.72)[b]	(0.77)	(1.93)[a]	(1.73)	(0.87)		

[22] See Appendix C for an impression of the RCAs of the four categories of sectors in the analysis.

[23] As expected, the resource-intensive category of sectors, which is excluded from the analysis for the reason mentioned above, revealed very poor results.

(b) Estimation results for four categories of sectors with different factor intensities, including skill levels (Eq. (8b))

Category	Constant	LSW_i	ISW_i	HSW_i	TEC_i	CAP_i	RCA_i	$\bar{R}^2$	F-stat.
LI	0.64	0.21	−0.24	−0.79	−1.19	0.87	0.30	0.68	5.61[b]
	(0.71)	(1.51)	(−0.54)	(−2.16)[a]	(−2.35)[b]	(1.18)	(0.79)		
CILM	0.03	−0.10	−0.33	−0.36	−1.05	1.67	0.77	0.37	2.27
	(0.025)	(−0.61)	(−0.62)	(−0.81)	(−1.69)	(1.89)[a]	(1.59)		
CIH	−1.49	−0.13	0.44	−0.04	0.11	1.36	0.52	0.42	2.59
	(−1.53)	(−0.88)	(0.84)	(−0.11)	(0.19)	(1.78)	(1.36)		
TI	−2.32	0.06	0.18	0.59	0.57	1.13	0.16	0.65	5.06[b]
	(−4.04)[c]	(0.69)	(0.63)	(2.53)[b]	(1.63)	(2.35)[b]	(0.65)		

Notes:
LI, CILM, CIH and *TI* stand for the labour-intensive, capital-intensive low/medium-tech, capital-intensive high-tech and technology-intensive categories of sectors, respectively.
t-values between parentheses.
[a]Significant at 10%.
[b]Significant at 5%.
[c]Significant at 1%.

Table 2(b) shows the impact of the factor endowments of low-skilled, intermediate-skilled and highly-skilled labour on revealed comparative advantage, by estimating Eq. (8b) instead of Eq. (8a). It is immediately apparent that the adjusted R^2 is higher for the labour-intensive and the technology-intensive categories of sectors. On the other hand, the adjusted R^2 and the significance of the relative factor endowments for the two capital-intensive categories of sectors is lower.

In line with the hypotheses of Table 1(b), the relative factor endowment of highly-skilled workers is significantly negatively, and significantly positively, related to the revealed comparative advantages of the labour-intensive and technology-intensive categories of sectors, respectively. However, the relative factor endowment of low-skilled labour has, in contrast to what was expected, no significant impact on either the labour-intensive or the technology-intensive categories. Moreover, the results for the technology-intensive category of sectors are not exactly as expected, since estimating Eq. (8b) instead of (8a) reduces the effect of the relative factor endowment of technological knowledge to insignificance, and increases the effect of the relative factor endowment of physical capital to a significant level.

The results of Table 2(a) and (b). Indicate that Eq. (8a) is to be preferred for the capital-intensive sectors, whereas Eq. (8b) is to be preferred for both the labour-intensive and technology-intensive sectors of industry. These results will be taken into account below, in testing at a more disaggregated level, by using Eq. (8a) for the capital-intensive sectors and Eq. (8b) for the labour-intensive and technology-intensive sectors. Table 3, parts (a) and (b) presents the results of the respective estimations.[24]

[24]Once again, all resource-intensive sectors revealed very poor results, as expected.

All estimated equations presented in Table 3(a) are significant, except for the machinery sector (mac). The results for the capital-intensive sectors are in accordance with the hypotheses of Table 1(a) as far as the significant coefficients are concerned, although the estimation results of the paper sector (pap) are not adequately explained by the relative factor endowments. For six of the nine capital-intensive sectors, the coefficient of relative factor endowment of physical capital is significantly positive, as expected. Also in accordance with the hypotheses of Table 1(a), the coefficients for the low/medium-tech category are significantly negative for both the plastics (pla) and the non-metallic minerals (nme) sectors, while the coefficients for the high-tech category are significantly positive only for the industrial chemicals (ich) sector. However, the fact that most coefficients cannot be rejected against the null-hypothesis does not contradict the hypotheses of Table 1(a).

The results for the labour-intensive and technology-intensive sectors are presented in Table 3(b). They reveal very strong results only for the textile sector (tex), the other chemicals sector (och) and the optical sector (opt). Interpreting the results of the labour-intensive sectors, it can be concluded that the signs of the significant regression coefficients are in accordance with the hypotheses of Table

Table 3
(a) Estimation results for the capital-intensive sectors, excluding skill levels (Eq. (8a))

Sector	Constant	LAB_i	TEC_i	CAP_i	RCA_i	$\bar{R}^2$	F-stat.
Capital-intensive, low/medium-tech sectors							
pap	1.41	0.36	−1.12	−0.80	2.64	0.50	4.24[b]
	(0.92)	(0.58)	(−1.22)	(−0.66)	(3.75)[c]		
rub	−0.68	−0.61	−0.82)	2.14	0.32	0.36	2.86[a]
	(−0.62)	(−1.37)	(−0.82)	(2.50)[b]	(0.65)		
pla	0.25	−0.58	−1.74	1.67	0.28	0.44	3.52[b]
	(0.27)	(−1.56)	(−3.19)[c]	(2.35)[b]	(0.68)		
nme	0.06	−0.03	−1.72	1.66	−0.34	0.50	4.20[b]
	(0.07)	(−0.08)	(−3.11)[c]	(2.30)[b]	(−0.81)		
bir	−1.99	−0.76	−0.99	3.70	−0.29	0.50	4.29[b]
	(−1.61)	(−1.50)	(−1.33)	(3.79)[c]	(−0.51)		
Capital-intensive, high-tech sectors							
ich	−0.43	−0.21	1.07	−0.02	0.53	0.75	10.61[c]
	(−0.91)	(−1.11)	(3.56)[c]	(−0.04)	(2.94)[b]		
mac	−0.98	−0.22	0.58	0.90)	0.03	0.27	2.21
	(−1.13)	(−0.61)	(1.06)	(1.40)	(0.08)		
ele	−1.47	−0.37	−0.27	2.06	−0.24	0.49	4.11[b]
	(−1.90)[c]	(−1.18)	(−0.54)	(3.60)[c]	(−0.81)		
tra	−2.03	−0.52	−0.51	3.13	0.84	0.45	3.62[b]
	(−1.41)	(−0.88)	(−0.55)	(2.93)[b]	(1.51)		

(b) Estimation results for the labour-intensive and technology-intensive sectors, including skill levels (Eq. (8b))

Sector	Constant	LSW_i	ISW_i	HSW_i	TEC_i	CAP_i	RCA_i	$\bar{R}^2$	F-stat.
Labour-intensive sectors									
tex	0.74	0.39	−0.43	−0.75	−1.59	0.88	0.17	0.81	10.36[c]
	(0.75)	(2.57)[b]	(−0.90)	(−1.87)[a]	(−2.86)[b]	(1.09)	(0.41)		
pme	0.58	−0.11	0.24	−0.89	−0.58	0.77	0.46	0.37	2.28
	(0.63)	(−0.76)	(0.55)	(−2.39)[b]	(−1.12)	(1.03)	(1.17)		
oma	0.36	0.05	−0.28	−0.78	−0.70	0.97	0.53	0.12	1.29
	(0.28)	(0.27)	(−0.45)	(−1.50)	(−0.98)	(0.93)	(0.96)		
Technology-intensive sectors									
och	−0.50	−0.05	0.03	−0.18	1.09	0.02	0.29	0.74	7.01[c]
	(−1.03)	(−0.63)	(0.18)	(−0.94)	(3.70)[c]	(0.05)	(1.39)		
off	−3.45	0.27	−0.00	1.35	1.23	0.91	0.16	0.35	2.15
	(−2.79)[b]	(1.42)	(−0.00)	(2.67)[b]	(1.63)	(0.88)	(0.30)		
rad	−4.58	0.04	0.52	0.70	−0.53	3.63	0.10	0.50	3.17[a]
	(−3.22)[b]	(0.16)	(0.72)	(1.21)	(−0.62)	(3.06)[b]	(0.16)		
air	1.94	−0.08	−0.47	0.11	0.77	−1.69	0.08	0.43	1.65
	(2.33)[b]	(−0.65)	(−1.12)	(0.32)	(1.51)	(−2.44)[b]	(0.23)		
opt	−2.16	0.07	0.62	0.63	1.12	0.18	0.22	0.78	8.60[c]
	(−3.99)[c]	(0.83)	(2.27)[a]	(2.84)[b]	(3.40)[c]	(0.40)	(0.94)		

Notes:
See Appendix A for the abbreviations of the sectors.
t-values between parentheses.
[a]Significant at 10%.
[b]Significant at 5%.
[c]Significant at 1%.

1(a) and (b). In particular, the regression of the textile sector (tex) performs remarkably well, and in line with the hypotheses for the relative factor endowments of low-skilled labour, highly-skilled and technological knowledge. Moreover, the metal products sector (pme) reveals, as expected, a significant negative coefficient for the relative factor endowment of highly-skilled labour. On the other hand, the sector of other manufacturing industries (oma) shows a poor result, which may be because it is a heterogeneous residual sector.

In accordance with the hypotheses, the technology-intensive sectors reveal the importance of technological knowledge and highly-skilled labour in three out of five cases. The optical sector (opt) is the only economic sector for which an abundance of intermediate-skilled labour seems to matter. The significant results for the relative factor endowment of physical capital in the radio and television sector (rad) and the aircraft sector (air) are not in line with the hypotheses.[25] Moreover, relative abundance of low-skilled labour does not have the expected negative effect on revealed comparative advantage in the technology-intensive sectors.

6. Conclusions

The empirical results generally confirm the value of the HOV model (and the related neo-factor endowments model) for explaining net trade flows between industrialized countries. The empirical results suggest that it is worthwhile to consider country-specific relative factor endowments to explain sector-specific revealed comparative advantages, which are a measure of trade performance. Therefore the HOV model is an adequate framework for testing the relevance of country-specific human capital factors for the trade performance of sectors.

In line with the formulated hypotheses, the human capital endowments of highly-skilled labour and technological knowledge seem to have a significantly positive impact on the revealed comparative advantage of technology-intensive sectors, and a significantly negative impact on the revealed comparative advantage of labour-intensive sectors. Moreover, the factor endowment of highly-skilled labour seems to have at least as great an impact as the factor endowment of technological knowledge on the trade performance of technology-intensive sectors. However, in general the human capital endowment of intermediate-skilled labour has no significant impact on these sectors. For capital-intensive sectors the human capital endowments of intermediate-skilled and highly-skilled labour were not found to have a significant effect, whereas the relative factor endowment of physical capital was found, as expected, to have a significantly positive effect. On the other hand, technological knowledge has a significantly negative effect on the revealed comparative advantage of capital-intensive low/medium-tech sectors, which is according to expectations.

As stated in the introduction, recent empirical research on international trade flows has cast considerable doubt on the explanatory power of the Heckscher–Ohlin–Vanek model. The relatively good empirical results in this paper are, in our opinion, to a large extent due to the correct specification of the model, the method of doubling scaling, and the use of data for industrialized countries, which are probably more equal in their input–output coefficients than a mixed group of industrialized and developing countries.

Three further points should be noted with regard to the specification of the empirical model. First, the specification of the model follows directly from the theoretical exposition of the HOV model of Section 2. Therefore net trade flows between countries should be explained by country-specific factor endowments rather than by sector-specific factor inputs. Secondly, as has been argued in Section

[25] Specialization of countries in these relatively small four-digit sectors may disturb the empirical analysis.

1, the human capital endowments should be measured by the level of education of the workforce rather than by occupational categories. The fact that human capital was measured using occupational categories may account for the relative poor results of human capital endowments in, for example, Leamer (1984). Thirdly, we do not agree with Wood (1994) that the international mobility of financial capital flows means that the factor endowment of physical capital should be excluded from the model. Our empirical analysis shows that both human and physical capital endowments are important for the trade performance of economic sectors.

The suggested country-specificity of skilled labour, technological knowledge and physical capital may be due to differing national educational systems, government technology policies and differing national capital investment climates, respectively. Nevertheless, the results also indicate that country-specific relative factor endowments cannot explain more than about 40%–80% of the variances in revealed comparative advantages at sector level. This may be due to measurement errors or some violations of the assumptions of the model. Moreover, the unexplained variance may plausibly be accounted for by sectoral developments and clusters of economic sectors (as explained by Porter, 1990).

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Appendix A: classification of ISIC sectors

According to OECD (1987) economic sectors can be divided into five categories with different factor intensities, i.e. resource-intensive, labour-intensive, scale-intensive, differentiated-goods, and science-based sectors. These categories of sectors are assumed to have different factor intensities, so that they can be used to develop hypotheses with regard to the relationship between relative factor endowments and revealed comparative advantages. However, the OECD (1987) admits that it is hard to distinguish the scale-intensive and differentiated-goods sectors. Therefore both kinds of industry are classified in the capital-intensive sector. Moreover, in accordance with the neo-factor endowments theory, it is expected that technological knowledge will also matter. Therefore the OECD (1987) classification is combined with the classification of OECD (1986) and Verspagen (1995), which distinguish between low-tech, medium-tech and high-tech sectors. Since data are available on only one capital-intensive low-tech sector (i.e. paper and paper products, ISIC 3400), the classification will not distinguish between low-tech and medium-tech sectors. Moreover, both the science-based sectors distinguished by the OECD (1987) and the 'core-R & D' sectors distinguished by Verspagen (1995) are here called 'technology-intensive sectors'. The abbreviations and the ISIC codes of the various economic sectors are as follows:

1. Resource-intensive sectors

agr	1000	Agriculture, hunting, forestry and fishing
min	2000	Mining and quarrying
foo	3100	Food, beverages and tobacco
woo	3300	Wood and wood products, including furniture
pet	3530	Petroleum refineries
coa	3540	Miscellaneous products of petroleum and coal
bme	3720	Non-ferrous metal basic industries

2. Labour-intensive sectors

tex	3200	Textile, wearing apparel and leather industries
pme	3810	Fabricated metal products, except machinery and equipment
oma	3900	Other manufacturing industries

3. Capital-intensive, low / medium-tech sectors

pap	3400	Paper and paper products, printing and publishing
rub	3550	Rubber products
pla	3560	Plastic products not classified elsewhere
nme	3600	Non-metallic mineral products, except products of petroleum and coal
bir	3710	Iron and steel basic industries

4. Capital-intensive, high-tech sectors

ich	3510	Industrial chemicals
mac	3820	Machinery except electrical, and excluding sector 3825 (off)
ele	3830	Electrical machinery apparatus, appliances and supplies, excluding sector 3832 (rad)
tra	3840	Transport equipment, excluding sector 3545 (air)

5. Technology-intensive sectors

och	3520	Other chemical products
off	3825	Office, computing and accounting machinery
rad	3832	Radio, television and communication equipment and apparatus
air	3845	Aircraft
opt	3850	Professional, scientific, measuring, controlling equipment not classified elsewhere, photographic and optical goods

Appendix B: Data sources[26]

B.1. Net exports

The data for net exports per sector j of country i (T_{ji}) was drawn from the OECD's

[26] Unless stated otherwise, the reference year for the data used is 1985.

COMTAP database. Data were available for economic sectors at the two-, three- and four-digit levels of the International Standard Industrial Classification (ISIC, revision 2). As it is hard to find appropriate data on volumes of net trade, which is required by the HOV model, values of net trade are regarded as a proxy for the volumes. All net export values are expressed in terms of 1985 dollars (in thousands of dollars). Section 2 indicated the relevance of correcting the net exports per sector to allow for the country's trade imbalance. The share of the production of each good in total world production (compare Q_w/GDP_w of Section 2) would have to be known to correct for trade imbalances in the proper way. As no adequate data were available on this proportion, we have corrected for trade imbalances by adding, after double scaling, an overall trade balance variable to the independent factor endowment variables on the right-hand side of Eq. (7). The country's overall trade balance is the sum of its net sector exports from agriculture (ISIC 1000), mining (ISIC 2000) and manufacturing (ISIC 3000), minus the net exports of the category of sectors which the economic sector being considered belongs to (see Section 3).

B.2. Labour supply

The labour supply variables indicates the amount of labour available in a country. The Eurostat Labour Force Survey (1985) data are used for the various EC countries. These data are supplemented by the data from the *Year Book of Labour Statistics* (various issues) of the International Labour Office (ILO) for Canada, Japan and the United States. There are some minor differences in the definitions used in the two data sources, but these differences are not significant. The indicators for the labour supply available from Eurostat and the ILO are the 'labour force' and the 'economically active population', respectively.

B.3. Educational attainment

The human capital variables are distinguished by the educational attainment or 'educational stock' of the population. A related indicator proposed by the OECD (*Employment Outlook*, 1989) is the distribution of the population over the levels of educational attainment, ranging from A (low) to E (high).[27] This distribution over levels of education is to a certain extent analogous to UNESCO's International Standard Classification for Education (ISCED). In particular, the ISCED levels 0/1 (pre-primary and primary education as highest achieved level) and 2 (lower secondary education as highest achieved level) correspond with the OECD definition of level A. Level A is defined as 'completed less than upper secondary education' (OECD, 1989), which corresponds with 'completed less than ISCED level 3'. This level of education is called low skilled in this paper. The 'highly-skilled' workers in the paper correspond to either level D (higher non-university education) or level E (university education) in the OECD classification. A proxy for the share of intermediate-skilled workers in the labour force is the proportion of the population aged 25 to 64 years who completed an initial education beyond lower secondary education (ISCED level 2), but without achieving level D or E. This implies that workers with vocational education are counted as intermediate-skilled workers. As far as possible, data are drawn from the OECD's (1989) *Employment Outlook*. Additional data sources are the OECD's (1992) *Education at a Glance*, UNESCO's (1992) *Statistical Yearbook* and Eurostat's (1991) *Labour Force Survey*.

[27] Level C is not part of the rank order A to E, it indicates only that a person has vocational skills at some level.

The reference year for the educational data is 1987, except for Belgium (1986), Denmark (1988), France (1989), Ireland (1989), Greece (mean of 1981 and 1991) and the United States (1988). However, we do not expect that these differences between reference years will cause serious problems, since the educational attainment of an entire labour force does not generally change very much in the course of a few years.

B.4. Technological knowledge

The technology variable indicates the stock of technological knowledge embodied by R & D workers of a country, which can be approximated by the research and development (R & D) intensity of a country. The R & D intensity is the R & D expenditures of both the government and the private sector, plus payments for imports of technological knowledge, divided by the gross domestic product. For Portugal the mean of the 1984 and 1986 R & D intensities was used. For Ireland the only figure available for imports of technological knowledge was for 1983. The fact that R & D expenditures instead of R & D stocks are used is, in our opinion, not a serious shortcoming since both R & D intensities and import intensities of technological knowledge are relatively constant over time. See the OECD's *Basic Science and Technology Statistics* and *Main Science and Technology Indicators*, from which the data were drawn.

B.5. Capital stock

The physical capital variable indicates the capital stock of a country. The capital stock measure equals the accumulated, depreciated sum of past gross domestic investments in producer durables, non-residential construction and other construction. This capital stock measure is expressed in 1985 purchasing power parities, in millions of dollars. Data are drawn from Maddison (1991) and the OECD' *Penn World Table*, mark 5. The first source is only used for the Netherlands. Because there are no appropriate data available on the Portuguese capital stock, the Portuguese capital intensity (i.e. capital stock divided by labour supply) has been estimated using the GDP per worker and the R & D intensity.

Appendix C: Data of factor endowments and trade performance

Table C.1 presents the relative factor endowments, which are calculated according to (5). The data sources used to calculate these relative factor endowments are mainly from the OECD and Eurostat, with 1985 as the year of reference.[28]

The relative factor endowment of highly-skilled labour in West Germany is surprisingly low. This can be partly explained by the fact that vocationally skilled workers are considered as intermediate-skilled workers (see Appendix B). Moreover, due to double-scaling, countries with high income levels such as West Germany would have to have proportionally higher absolute factor endowments to reveal equal relative factor endowments as countries with low-income levels. For this reason the relative factor endowments of highly-skilled labour in Greece and Ireland are very high. However, in the case of Ireland, the high relative factor endowments of highly-skilled labour and technological knowledge explain the high RCAs for the capital-intensive high-tech and the technology-intensive sectors (see Fig.

[28] See Appendix B for an extensive list of data sources.

Table C.1
Relative factor endowments per country (1985)

Country	LAB_i	LSW_i	ISW_i	HSW_i	TEC_i	CAP_i
Belgium (BEL)	1.05	1.80	0.56	0.55	1.03	1.34
Canada (CAN)	0.91	0.75	0.78	1.37	0.61	1.06
West Germany (DEU)	1.08	0.87	1.77	0.33	1.15	1.22
Denmark (DNK)	1.23	1.33	1.32	0.90	0.59	1.07
Spain (ESP)	1.41	2.52	0.83	0.43	0.34	1.12
France (FRA)	1.03	1.30	1.00	0.63	0.94	1.17
Great Britain (GBR)	1.24	1.87	0.80	0.86	0.97	0.79
Greece (GRC)	1.88	3.07	1.01	1.22	0.14	0.82
Ireland (IRL)	1.68	2.62	0.95	1.24	1.07	1.22
Italy (ITA)	1.02	1.91	0.58	0.22	0.49	0.97
Japan (JPN)	1.27	1.12	1.53	1.10	1.10	1.67
Netherlands (NLD)	0.99	1.34	0.80	0.68	0.99	1.21
Portugal (PRT)	2.78	6.18	0.60	0.48	0.23	1.00
United States (USA)	0.80	0.46	0.84	1.31	1.14	0.72

Sources: See Appendix B. See Table C.2 for the correlations between the relative factor endowments. The abbreviations of the countries in the sample are used again in Fig. C.1.

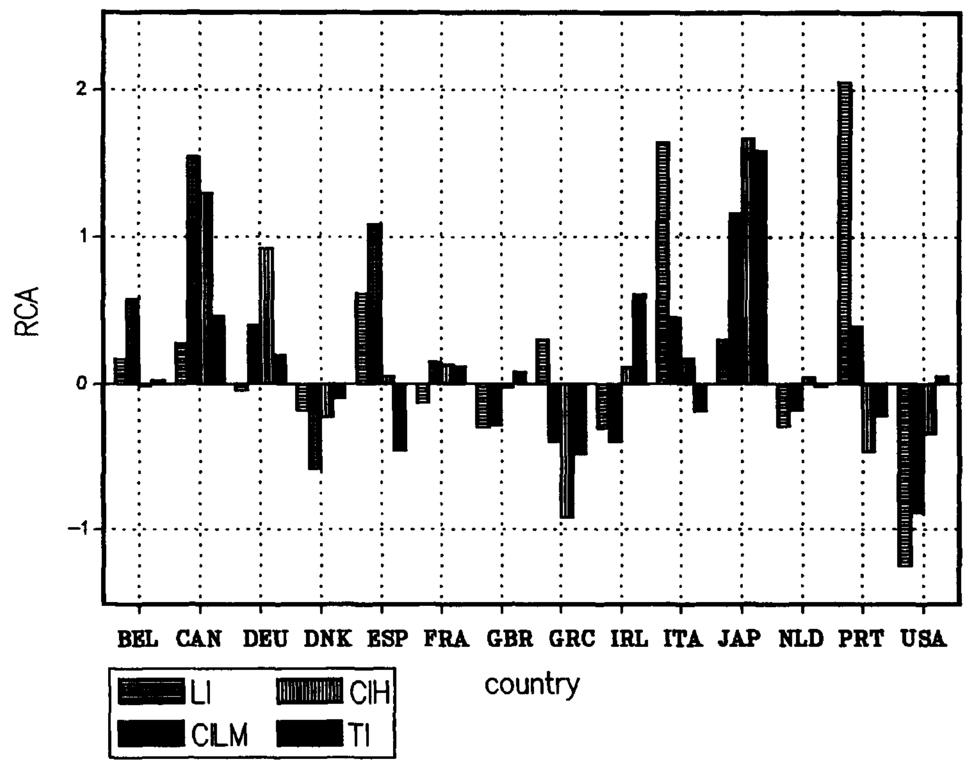

Fig. C.1. Revealed comparative advantages by four categories of economic sectors (1985). Sources: see Appendix B. Note: LI, CILM, CIH, TI stand for the labour-intensive, capital-intensive low/medium-tech, capital-intensive high-tech and technology-intensive categories of economic sectors, respectively. See Table C.1 for the abbreviations of the country names. Note that the RCAs are not corrected for trade imbalances.

Table C.2
Correlations between the relative factor endowments

	LAB_i	LSW_i	ISW_i	HSW_i	TEC_i	CAP_i
LAB_i	1.00	0.96	−0.15	−0.08	−0.59	−0.10
LSW_i		1.00	−0.38	−0.25	−0.64	−0.17
ISW_i			1.00	0.09	0.34	0.42
HSW_i				1.00	0.14	−0.14
TEC_i					1.00	0.39
CAP_i						1.00

Correlation coefficients are significant at 10% if they are larger than 0.46 or smaller than −0.46.

C1). Furthermore, the United States and Great Britain have very low relative factor endowments of physical capital, which is in line with the low capital per worker ratio in the *Penn World Table* relative to the income level in both countries.

Table C.2 presents the correlations between the relative factor endowments of Table C.1. Although the shares of low-skilled, intermediate-skilled and highly-skilled workers are correlated, this correlation is strongly reduced due to the double scaling. From Table C.2 it follows that only the correlations between LAB_i, LSW_i and TEC_i are significant, which may reduce the significance of these variables in the OLS estimation of Section 5.

Fig. C.1 shows the revealed comparative advantages (RCAs) of the four categories of economic sectors for which the HOV model is tested.

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