Factor productivity differences and missing trade problems in a regional HOV model

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Abstract

Empirical tests of the Heckscher-Ohlin-Vanek (HOV) model using international data suggest the need of relaxing its restrictive assumptions in order to reconcile theory and data. This paper focuses on how much factor productivity differences helps to improve the performance of the HOV model in a regional setting. Using a dataset of 17 Spanish regions and three different HOV specifications, we seek for the existence of Hicks-neutral (HN) or factor-augmenting industry-neutral (FAIN) technology differences. Data support the existence of HN technology differences, which contributes for a remarkable improvement of the HOV performance since the so-called missing trade problem largely disappears.

Keywords: Heckscher-Ohlin-Vanek, Factor Regional Trade, Productivity gaps, Missing trade problem. JEL classification: F11, F14.

1. Introduction

The Heckscher-Ohlin (HO) model is a very illustrative example of what a theory should be: simple, rich, ambitious and very insightful. No doubt, this explains its ubiquity in the field of international economics, sometimes used as a framework for studying the location of production, others for discussing the welfare impact of international trade flows (Bernstein and Weinstein, 2002; Davis, 1998). Jaroslav Vanek re-interpreted the model as one of trade in factor services, stating that, under some assumptions1, the model predicts that net export of factor services will be the difference between a region’s endowment and the endowment typical in the world for a region of that size. The importance of

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1 The strict version assumes: (1) identical constant returns to scale (CRS) technology and factor price equalization; (2) perfectly competitive markets in goods and factors; (3) identical and homothetic preferences; (4) factor endowment
his contribution was establishing a testable relationship between factor endowments, factor input requirements and (net) factor trade, the so-called “Vanek equation” (Vanek, 1968).

This contribution obviously stimulated academic curiosity in order to see how the model worked empirically, with early tests showing a poor predictive power of the HOV model using a large number of countries and factors (Maskus, 1985; Bowen et al. 1987). As a response, more recent contributions have followed the path of relaxing some of the strict assumptions of the original model, extending it in a way more consistent with observed data. In the country approach, these contributions have shown the prominent role that the assumptions of international identical technologies, factor price equalization and identical and homothetic preferences play in reconciling theory and evidence (Trefler, 1995; Davis and Weinstein, 2001; Hakura, 2001).

In this context, a regional approach to the HOV model was developed as a good laboratory for testing its performance, given that the regional dimension overcomes some of the problems faced by the international trade literature. A priori, regional tests of the basic HOV model were expected to show a superior performance, because the three key assumptions of the model - identical technologies, factor price equalisation and identical and homothetic demands – are more plausible to hold in a regional (intra-national) setting than for an international one. The pioneer contribution of Davis et al. (1997), using data on the prefectures of Japan, found that relaxing world factor price equalisation assumption, but maintaining it for Japan, was enough to obtain a remarkable improvement of the match between theory and data. In contrast, Artal et al. (2006) and Requena et al. (2008a), using data on 14 Spanish regions, found a quasi-perfect performance of the strict HOV model when predicting the direction of factor trade services (95 per cent of cases), but serious missing trade problems remain when predicting the volume of differences; and (5) free trade in goods but not factors.
factor trade services (that is, the theoretical model predicted much more factor trade than the one
observed in the data).

In this paper we get deeper understanding of the HOV model, paying especial attention to
whether introducing technology differences between trading partners may help to improve the
performance of the HOV model in a regional setting.\textsuperscript{2} Our approach assumes that regions could present
differences in their unit factor requirements, but arraying solely from the existence of differences in their
factor productivities. It allows us still assuming that regions share identical production technologies once
we account for productivity differences, that is, at the productivity-equivalent level. With this aim, we
address two specifications of technological differences: Hicks-neutral technological differences (HN)
and factor-augmenting industry-neutral differences (FAIN). In the HN specification, productivity differs
among regions uniformly for all factors, while in the FAIN case, we also account for productivity
differences in each factor inside every region, but neutral to all industries.

Our analysis will focus on the Spanish interregional trade flows, which accounts for 80\% of total
Spanish trade. Artal et al. (2006) and Requena et al. (2008b) have shown that the assumption of national
factor price equalisation is valid in the interregional HOV framework, so intra-national space becomes a
good setting to investigate the impact of technology differences on the factor trade model.

A first novelty of the paper is to apply three different specifications in testing the performance of
the HOV model: the standard model, the pair-wise model, and the relative model. The first one is the
typical Vanek equation, which evaluates the HOV model based on a region by region comparison for
one specific factor. The second one follows Hakura (2001) and it is based on comparisons between all
pairs of regions for one specific factor. The third one follows Debaere (2003) and it is based on

\textsuperscript{2} Requena et al. (2008a) investigated the importance of Hicks-neutral technological differences across Spanish regions by
simply scaling factor endowments by per capita GDP differences as suggested in Trefler (1993). The results indicated that
such simple adjustment did not improve the performance of the HOV model.
comparisons of factor contents and factor abundances between pairs of regions for each pair of factors. The pair-wise model and the relative model have two advantages respect to the standard model. First, bilateral comparisons increase the number of observations employed in the tests, improving the robustness of the results. Second, although less important in a regional framework, is the fact that comparisons between regions do not require a vector of world or national endowments.³

A second novelty of the paper is the use of a new database of Spanish Input-Output regional tables (C-interreg). This newly constructed data set provides homogeneous information on trade flows, gross production, absorption patterns and technical coefficients for 17 Spanish regions, notably improving the data set characteristics, and allowing us to eliminate common measurement errors (Davis and Weinstein, 2001). The new database expands the scope of previous exercises incorporating information not before available for three Spanish regions (Murcia, Cantabria and La Rioja). Moreover, all data used in the estimation of regional technology parameters in the empirical exercise is now provided by a unique source, the Lawrence-Klein Institute at the Autonoma University of Madrid, who developed an intense statistical effort of data homogenisation when building the whole regional Input-Output Spanish framework.⁴ Gains in quality of data are of salient relevance, given than previous data sets were surveyed separately by 14 different regional statistical agencies (see, Artal et al., 2006).⁵

Our results provide evidence on the importance of accounting for technological differences in a regional HOV framework. Extending the HOV model by copying with such differences clearly improves the model’s performance, first increasing its capacity to predict the direction of factor trade services (sign tests values), and second making the missing trade problem largely disappear (variance ratios). The

³ This property of the bilateral comparisons is more important when using international data due to the difficulty of computing a vector of “world” endowments and the subsequent problems of statistical homogeneity (see Debaere, 2003).

⁴ For further details on the database, see Llano-Verduras (2004) and CEPREDE (www.c-interreg.es/index.asp).

⁵ In addition, we use a new measure of the stock of physical capital provided by Fundación BBVA (2006).
Hicks-Neutral (HN) approach seems to work slightly better in the regional HOV case, although the factor-augmenting industry-neutral approach (FAIN) follows very closely these results.

In general terms, we observe that extending the model to its productivity-adjusted specifications has an important impact in reducing the missing trade problems and improving the slope tests values for the three versions of the model employed in the research: the Vanek equation, the pair-wise model and the relative one. However, these extensions have a more moderate impact in improving the model’s ability to predict the direction of trade for the case of the pair-wise and the relative versions, showing a bigger impact in the sign test value for the Vanek equation type model.

After this introduction, the remainder of the paper is organised as follows. Section 2 defines three different methods employed in testing the extended version of the model. Section 3 describes the econometric specification in order to estimate productivity differences among the Spanish regions. Section 4 includes the data set and discusses the results of the research, while section 5 states the conclusions of the paper.

2. Three HOV specifications coping with productivity differences

The main focus of the research consists in extending the HOV model by introducing productivity differences for the regions of a country. Our model builds on three different approaches to the HOV equation: the standard, the pair-wise and the relative versions. In this section, we begin by presenting the basic specification of every version, and then extend it to its productivity-adjusted specification, which will be further employed in testing the modified model’s performance.

2.1 The standard HOV model

Let $r$, $i$, and $f$ index regions, industries, and factors, respectively, with country $S$ having $R$ regions, $I$ industries, and $F$ primary factors. Let $V^r_i$ and $V^S_f$ be the endowment of factor $f$ in region $r$ and country
S, respectively, let $T_r$ be the net interregional trade vector for region $r$, and $A_s(I - B_s)^{-1}$ be country’s S technology matrix that transforms good flows into their total (direct and indirect) embodied factor services. Let the term $Y_r$ be the gross national product (GNP) of region $r$, $Y_s$ be country’s S GNP, and $B_r$ be the trade balance of region $r$, so that $s_r = (Y_r - B_r)/Y_s$ captures the final consumption share of region $r$ in the national space. In this framework, the standard regional HOV model shows that, under standard assumptions, the measured factor content of trade ($F_r^f$) for factor $f$ in region $r$ can be predicted by this region’s factor endowments ($V_r^f$) and final consumption share ($s_r$), and by national endowments ($V_s^f$), through the following equation (Vanek, 1968):

$$F_r^f = s_r \sum_{r=1}^{R} V_r^f,$$

for $f = 1 \ldots F$, $r = 1 \ldots R$ (1)

Departing from the standard model by introducing regional factor-productivity differences requires the use of a technology parameter, $\pi_r^f$, such that if $V_r^f$ is the factor endowment of $f$ in region $r$, then $V_r^{*f} = \pi_r^f V_r^f$ would be the corresponding factor endowment measured in productivity-equivalent units. We assume identical technologies at the productivity-equivalent level and normalize factor productivity of country $S$ to be equal to one: $\pi_r^f A_r(I - B_r)^{-1} = A_s(I - B_s)^{-1}$, $r = 1 \ldots R$, with $\pi_r^f$ being the productivity of region $r$ relative to country $S$ for factor $f$. Then equation (2) provides a specification

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6 Our exercise analyses HOV for interregional trade flows, given that this allows us to depart from a universal FPE framework and testing the model assuming just national-FPE, a framework very well suited to isolate remaining questions causing missing trade problems in a regional approach (Davis et al., 1997; Requena et al., 2008b). Additionally, there must be noted that interregional trade flows account for more than 80% of total regional trade of Spanish regions (C-Interregio database).

7 We assume that all differences in technology across regions arise in the form of factor-augmenting productivity differences (HN or FAIN), following Trefler (1993)’s insight.

8 We normalize respect to the country technology by convenience, but one could have normalized respect to a region of reference as it is usual in the country approaches (see, for example, Trefler, 1993, 1995).
for the productivity-adjusted standard HOV model, with the right hand side of the expression capturing the excess of region’s \( r \) endowments supply in efficiency terms:

\[
F_r^f = \pi_r^f V_r - s_r \sum_{r=1}^{R} \pi_r^f V_r^f, \quad f = 1 \ldots F, \ r = 1 \ldots R
\]

with \( F_r^f = A_r(I - B_r)^{-1}T_r \).

2.2 The pair-wise HOV model

In order to obtain the pair-wise HOV model (Staiger et al., 1987; Hakura, 2001), we adopt a two-region version of the strict Vanek equation (1) for two given regions 1 and 2, and factor \( f \):

\[
F_1^f - \alpha F_2^f = V_1^f - \alpha V_2^f
\]

where \( \alpha = s_1 / s_2 \), \( F_1^f - \alpha F_2^f \) is the measured pair-wise factor content of trade \( F_1 = A_1(I - B_1)^{-1}T_1 \) and \( F_2 = A_2(I - B_2)^{-1}T_2 \), and \( V_1^f - \alpha V_2^f \) is the predicted pair-wise factor content of trade.\(^9\)

This version requires all assumptions of the basic HOV model to hold. Further, we can relax the assumption of identical regional technology, with \( A_r(I - B_r)^{-1} \neq A_r(I - B_r)^{-1} \neq A_s(I - B_s)^{-1}, \forall r \neq r' \), obtaining in this way the version popularised by Staiger et al. (1987) and more recently used by Hakura (2001). In order to specify the model in its productivity-equivalent version, we start defining a vector of technology parameters of the form \( \pi_{rr}' \), that captures the productivity ratio by pairs of regions in country

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\(^9\) Defining \( F_1^f = V_1^f - s_1 \sum_{r=1}^{R} V_r^f \), \( F_2^f = V_2^f - s_2 \sum_{r=1}^{R} V_r^f \), \( \alpha = s_1 / s_2 \), cancelling \( s \sum_{r=1}^{R} V_r^f \) and reordering terms, we obtain equation (3).

\(^{10}\) Note that in the strict pair-wise regional version we assume identical technologies at the national level, with \( A_r(I - B_r)^{-1} = A_s(I - B_s)^{-1}, \forall r \).
S. Given that productivity differences are the unique technology differences allowed for in the model, regions will share the same technology matrix at the productivity-equivalent level for every factor $f$, that is, $A_r(I - B_r)^{-1} = \pi_{r,f}(I - B_r)^{-1}A_r$, with FPE holding at a national level (Trefler, 1993, 1995).

Introducing productivity differences for two given regions 1 and 2, leads to the following specification of the model:\[\text{(4)}\]

The relative HOV model

The relative version of the Vanek equation was proposed by Debaere (2003) as an extension of the basic HOV model, and it is based on comparisons of endowments and observed factor trade services by pairs of factors and regions. In order to obtain the simple version of the relative HOV model, we start with the strict Vanek equation for a region $r$ and a factor $f$, under standard assumptions, as displayed in (1). Dividing both sides of equation (1) by the regional consumption share ($s_r$), and defining $f_{r,f} = F_{r,f}/s_r$ and $v_{r,f} = V_{r,f}/s_r$ yields, $f_{r,f} = v_{r,f} - \sum_{r=1}^{R} V_{r,f}$. Extending this expression for two given regions $r$ and $r'$, taking the difference between them, and dividing both sides of the resulting equation by

\[\text{Derivation of the pair-wise HOV model with factor-productivity adjustments assumes that } A_r(I - B_r)^{-1} = \pi_{12,r}A_r(I - B_r)^{-1}.\]

Applying it for region 1 and factor $f$, we have two equations: (1) $\pi_{12}A_2(I - B_2)^{-1}T_1 = V_1 - \pi_{12}A_2(I - B_2)^{-1}C_1$ and (2) $A_2(I - B_2)^{-1}T_2 = V_2 - A_2(I - B_2)^{-1}C_2$. Pre-multiplying (1) with $\pi_{12}^2 = \pi_{21} = A_2(I - B_2)^{-1}/A(I - B_2)^{-1}$ and (2) with $\alpha$, taking the difference between the two equations, and noting that in the pair-wise version $C_1 = \alpha C_2$ (Staiger et al., 1987; Brecher and Choudri, 1988), we obtain equation (4).
the sum of both region’s normalised endowments, \( v_r^f + v_r^f \), we obtain
\[
(f_r^f - f_r^f)(v_r^f + v_r^f) = (v_r^f - v_r^f)(v_r^f + v_r^f).
\]

Now, if we compute this expression for a supplementary factor \( f^* \) and again take differences, we obtain the basic version of the relative HOV equation. Debaere’s proposal provides a testable modified version of the standard HOV model that compares standardized relative factor contents of trade and endowments by pairs of factors between regions:
\[
\frac{f_r^f - f_r^f}{v_r^f + v_r^f} - \frac{f_r^f - f_r^f}{v_r^f + v_r^f} = \frac{v_r^f - v_r^f}{v_r^f + v_r^f} - \frac{v_r^f - v_r^f}{v_r^f + v_r^f}
\]

Introducing regional productivity differences in the relative HOV model requires premultiplying every region’s factor endowment by its productivity measure \( \pi_r^f \) in equation (5). In order to make it simpler, we again normalize factor productivity of country S to unity \((\pi_r^f, A_r(I - B_r)^{-1} = A_S(I - B_S)^{-1}, r = 1 - R)\), with \( \pi_r^f \) being the productivity of region \( r \) relative to country \( S \), for factor \( f \). Then, we define factor endowments at the productivity-equivalent level as \( V_r^f = V_r^f / s_r = \pi_r^f V_r^f / s_r = \pi_r^f v_r^f \), with the productivity-adjusted relative model yielding:
\[
\frac{f_r^f - f_r^f}{v_r^f + v_r^f} - \frac{f_r^f - f_r^f}{v_r^f + v_r^f} = \frac{v_r^f - v_r^f}{v_r^f + v_r^f} - \frac{v_r^f - v_r^f}{v_r^f + v_r^f}
\]

and \( f_r^f = \pi_r^f A_r(I - A_r)^{-1} T_r / s_r = A_S(I - B_S)^{-1} T_r / s_r \) for factor \( f \).

3. Estimating regional factor productivity differences

We have just defined the theoretical framework of the investigation, both in the basic specification and in the productivity-adjusted extension. In this section, we estimate the factor-
augmenting parameters of the three versions of the HOV model, further incorporating them in the extended models in order to see how these new specifications affect the performance of the model, with a primary focus on missing trade questions.

In the basic versions of every HOV model, standard, pair-wise or relative, we assume the existence of identical technologies in a national-FPE framework, with all regions of country $S$ having the same technology matrix $(A_S(I - B_S)^{-1} = A_S(I - B_S)^{-1})$, and consequently every regional industry $i$ presenting the same unit total (direct and indirect) factor requirement for every factor $f$ $(a_{if}^S = a_{if}^r, \forall r)$. Within the new framework, once we allow for regional technological differences in the form of productivity or factor efficiency gaps, regions will continue to share identical production technologies but now at the productivity-equivalent level, observing the equality of adjusted total unit factor requirements: $a_{if}^S = a_{if}^r$, with $a_{if}^r = \pi_r^f a_{if}^r$ and $\pi_r^f$ representing productivity of region $r$ and factor $f$ relative to country $S$.

Following this approach, we estimate two types of factor-augmenting technological differences by regressing unit total factor requirements of country $S$ (Spain) against those of region $r$. In the first specification we allow for factor-augmenting productivities common to every factor $f$ in region $r$ and industry $i$, that is, in a Hicks-neutral fashion ($\pi_r^f = \pi_r, \forall f$):

$$a_{if}^S = \pi_r a_{if}^r + \varepsilon_{ir}$$  \hspace{1cm} (7)

In the second specification of the technological parameters, we allow for the existence of regional productivity differences specific to every factor, in a factor-augmenting industry-neutral specification ($\pi_r^f \neq \pi_r, \forall f$), and estimate the following equation:

$$a_{if}^S = \pi_r^f a_{if}^r + \varepsilon_{ir}$$  \hspace{1cm} (8)
Equations (7) and (8) allows for regional technological differences arising in the form of productivity differences. Both equations are estimated using data that vary across 20 industries for each of the 17 regions through seemingly unrelated equations regressions (SURE), what ensures estimation of productivity parameters that are independent of the equation system of the HOV model. This procedure is used for the standard and relative versions of the HOV model. In estimating productivity parameters in the pair-wise version of the model, we apply the next specification for every regional pair:

\[ a_{i2} = \pi_{21} a_{i1} + \varepsilon_{i} \]  
(9)

\[ a_{2i} = \pi_{21} a_{1i} + \varepsilon_{1i} \]  
(10)

where \( \pi_{21} \) is the productivity of country 2 in terms of country 1, uniform for all factors in equation (9) or factor-specific in equation (10). Both equations allows us estimating interregional productivity differences, now for all binary combination of regions rather than simply for each region relative to Spain, the country of reference. In all cases, we assume that factor requirements are generated by a process obeying to the HN or FAIN assumptions, with measurement errors randomly distributed around zero and embodied in the residual terms.\(^{12}\)

Further, we incorporate productivity estimates in the extended versions of the HOV model, equations (2), (4) and (6), and then explore how it affects the performance of the model through the standard tests of sign, variance ratios and slope of the regressions of actual versus predicted factor contents of trade for the Spanish regions.\(^{13}\)

\(^{12}\) This procedure permits the model staying at the productivity-equivalent framework, avoiding at the same time the criticism by Gabairx (1997) to the original Trefler’s (1993) approach, which was previously implemented in Requena et al (2008a).

\(^{13}\) The tests employed in the paper are standards in the HOV literature. We describe them in more detail in the following subsection.
4. Data and results

4.1 Data

The research is based primarily on information coming from the *Spanish C-Interregio database*, a set of homogeneous input-output (IO) tables for 17 Spanish regions developed by the Lawrence-Klein Institute at the Autonoma University of Madrid (INTERTIO project). The importance of this newly constructed data set is that it provides comparable data on trade flows, gross production, absorption patterns and technical coefficients for all of the Spanish regions in the year 1995, significantly improving available information to date, which only could be obtained by the compilation of information provided by 14 different regional statistical offices in Spain, with all the heterogeneity it introduces in the model. This new data set allows us as well to incorporate three new Spanish regions to the study, La Rioja, Murcia and Cantabria, regions for whom there were not available information to date. The regional data set is equally compatible with the country or national statistical framework, with aggregated regional information coherently reproducing the national accounting system, what markedly improves previous data set characteristics, and it is important in terms of efficiently capturing the production and absorption (consumption plus investment) patterns present in the HOV framework. The homogeneity of regional IO data, also allows us to compute comparable technical coefficients for every Spanish region, what then will be used to estimate our productivity parameters.

Additionally, we will use the input-output table of Spain in 1995 when computing the factor content of trade for the strict and extended versions of the regional HOV model, and, through the use of its technical coefficients, it will provide the technology of reference when estimating our regional specific productivity estimates. Direct input requirements are constructed as factor endowments divided by gross output, while total input requirements imply multiplying direct requirement vectors by corresponding Leontief inverse tables. Trade flows come from the IO tables, which allow us to
breakdown the trade vectors of every Spanish region in their interregional (80% of total trade) and international flows.

Endowment data is taken from Encuesta de Población Activa and from National Accounts (INE-National Statistics Institute; www.ine.es) for the labour force, which breakdowns the labour force regional vectors in terms of education levels, with high educated individuals defined as those with secondary and above levels of enrolment and low educated ones as those that have not finished the secondary studies or have a lower level of education. Data on physical capital stock comes from the new database launched by Fundación BBVA, which applies a methodological revision to its precedent work in El stock y los servicios del capital en España y su distribución territorial (1964-2005). Nueva metodología, defining new concepts of gross, net and productive capital stocks and following new methodological recommendations of the OECD (see, www.fbbva.es, for further details).

Our database then compiles a new data set of 20-industries, including primary, secondary and tertiary activities, for 17 Spanish regions plus the country as a whole, and for three production factors (K, H and L). More details on the data composition can be found in the Appendix.

4.2 Results

Table 1 presents the results of estimating productivity parameters for the regions of Spain. We include two types of results: in the first data column of the table we report the productivity estimates ($\pi_r$) of Spanish regions relative to those of Spain for every factor in the Hicks-neutral (HN) specification (equation 7). The following three columns of the table include the same information for the factor-augmenting industry-neutral (FAIN) specification ($\pi_f^I$) (equation 8). We do not report the
estimated pair-wise productivity parameters because of the great number of results it supposes, with 272 (17*16) regional pairs for every specification of the technology assumption (HN and FAIN).\textsuperscript{14}

Productivity estimates of the regions of Spain in the HN assumption show that Madrid is the most productive region; the value of 1.29 means that Madrid uses 29 percent less of each factor to produce one final unit of output in all industries than Spain as a whole does. It is followed by Canary Islands (1.10), Catalonia (1.03) and Basque country (1.00). The least productive regions in Spain appear to be Extremadura (0.60), Castille-La Mancha (0.69) and Andalusia (0.78). The degree of dispersion in the value of coefficients ranging from 0.60 to 1.29 reveals the existence of substantial regional productivity differences, and therefore, of efficiency-based factor endowments differences across regions. In addition the degree of adjustment shows a remarkable achievement of the estimation by SURE procedure. All regions exhibits a $R^2$ statistic equal to or greater than 0.9 except for Extremadura (0.68) and Asturias (0.89).

In terms of individual factors, now under the FAIN assumption, we observe clear differences with respect to the HN estimates in all three factors of production. For example, in the case of Madrid, efficiency gains in terms of capital unit requirements in the FAIN specification coincide in value (1.29) with those obtained for the three factors jointly in the HN specification. However, the FAIN specification reveals that Madrid is less efficient than other regions in the use of high-educated labour (up to 19 percent inferior) while it is highly efficient in the use of low-educated labour across industries (up to 43 percent more than the entire country). In general terms, the coefficients obtained for the physical capital in the FAIN specification appear to be closer to those obtained in the HN specification, while bigger differences seem to emerge for the two types of labour. For example, in the case of low-educated labour factor (L), some regions (Murcia, Valencian Region, Castille-La Mancha, Catalonia and

\textsuperscript{14} As usual, information is available in request to the authors.
Balearic Islands) experience important productivity gains in comparison with their HN estimates and other regions (Navarra, Madrid, La Rioja and Aragon) lose positions in the national ranking.

When we tested whether the FAIN coefficients for the three factor were the same as the one obtained from the HN specification, in all cases the null hypothesis of equality was rejected at conventional significance levels. Therefore, and a priori, the FAIN specification is preferred to the HN specification from an econometric point of view.

After computing regional technological parameters, we apply our productivity estimates to the three versions of the HOV model in order to check how technological assumption affects its performance in a regional setting. We run three commonly used tests in testing the performance of the HOV model: the sign test, the variance ratio and the slope test. The three tests compare both sides of the model’s equation: the actual vs the predicted factor contents of trade. The first one compares the sign or net factor trade direction of both sides of the equation for the Vanek, Debaere or Hakura versions of the model; the second one compares the variance of these both sides, while the third one estimates the coefficient of a regression between both sides of the models’ equation. In this sense, while the first test offers an evaluation on the general performance of the model, the second accounts for the problem of missing trade, while the third one provides a measure of the rank test (analyses the matching between actual and predicted values of factor trade services, for both dimensions, the direction and the volume of trade) (Trefler, 1995; Debaere, 2003).

Table 2 presents the results for the three versions of the HOV model (Vanek, Pair-wise and Relative), with every column containing the results for the basic and extended models (HN and FAIN). The Vanek equation or standard HOV model (first column, first panel), shows a limited predictive capacity in its strict version for pooled factors, with a sign value of 0.57 (0.35 for K, 0.71 for H and 0.65
for L, individually), a variance test value of 0.55 (0.54 for K, 0.81 for H and 0.37 for L) and a slope test of 0.08 (with negative values for K and L), but not statistically significant.

Extending the Vanek equation to accommodate HN technology differences (first column, second panel), clearly improves the performance of the model, reaching values for pooled factors of 0.75 in the sign test (0.65 for K, 0.88 for H and 0.71 for L) and showing a positive value for the three individual coefficients in the slope tests (0.29 for pooled factors), although they remain not statistically significant. Moreover, introducing the HN assumption for the Vanek equation clearly makes the missing trade problem nearly disappearing, pushing the variance ratio to a value of 0.90 for pooled factors (0.87 for K, 0.93 for H and 0.90 for L).

Introducing the FAIN technology assumption in the standard model (first column, third panel) also provides a remarkable improvement of the Vanek equation performance, with pooled factors showing slightly below values in all tests in comparison with the HN extension: 0.71 in the sign test, 0.86 in the variance ratio and 0.20 in the slope test. In this way, it seems that for the Vanek equation version, extending the HOV model through the introduction of measurement of factors in efficiency terms clearly improves its performance, not just pushing up its predictive capacity in terms of direction and volume of trade, but also making the missing trade problem disappearing.

Moving to the results for the pair-wise version of the HOV (second column of Table 2), we observe that the strict Hakura (2001) specification performs again badly in terms of sign, variance ratio and slope test, with respective values of 0.55, 0.55 and 0.07 for pooled factors. Extending the pair-wise HOV model by introducing HN technology adjustments improves the performance of the model particularly in terms of the variance ratio, nearly solving the missing trade problem for physical capital (with a test value of 0.91) and remarkably reducing missing trade for the other two factors, with test values of 0.85 for H and 0.79 for L. Slope test values improve again for K and L, with the pooled factor
value shifting from 0.07 in the basic pair-wise version to 0.27 in the pair-wise HN extended one, with all estimated coefficients now being statistically signifcant. The FAIN extension of the pair-wise HOV model reflects an improvement in the model’s performance of approximately the similar magnitude than that of the HN case, with test values slightly below those of the HN case for the sign, variance ratio and slope tests, both for individual factors (particularly H and L) and for pooled factors.

Yet in the relative HOV model case, we observe that the strict version proposed by Debaere (2003) performs slightly better than the Vanek and the Pair-wise basic or strict versions, with test values reaching 0.62, 0.66 and 0.16, respectively, for the sign, the variance ratio and the slope tests. Although being conscious that these test values still reflect a poor performance of the relative HOV model in its strict version, it is interesting to note that the slope test values for factor pairs (K/L, K/H and L/H) depart from more rationale values (0.28 for K/L and 0.17 for K/H) than in the other two basic versions of the model (Vanek equation and Pair-wise), while the missing trade problem is of much less importance in this basic relative HOV specification (0.72 for K/L and 0.71 for L/H), what seems to reflect some of the advantages that the relative model of Debaere presents in comparison with the other two proposals. Once we introduce the HN extension in the relative HOV model, we observe an improvement in the model’s performance in terms of missing trade and slope test values, but not a remarkable improvement in the capacity of the model to predict the factor trade direction, with sign test values remaining relatively stable. The FAIN extension yields a similar result, with variance ratios and slope tests showing a slightly small value than in the HN case.

Our results point out that, in general, it seems that in a regional HOV framework a better measurement of endowments allows for an improvement of the model’s performance, markedly reducing the missing trade problem for the three versions of the model. In terms of predicting the direction of trade, introducing technological differences in the HOV model also improves the predictive capacity of
the Vanek equation model, but not significantly those of the Pair-wise and Relative HOV versions, with slope test values improving for all versions of the model. At this respect, it seems that the performance of the Vanek equation specification of the HOV model is more sensitive to the introduction of endowment measures in efficiency terms.

5. Conclusions

The strict version of HOV model has been repeatedly rejected empirically using international data. Relaxing identical technology and FPE assumptions at a universal level has been mandatory in order to achieve a good performance of the HOV model using country-level data. In this paper we explore whether the introduction of technological differences at a regional level (in a setting where regional FPE holds) may help to improve the performance of the HOV model, particularly investigating its effects on the important missing trade problem found in previous exercises.

With this aim, we estimate factor-productivity parameters from each region’s actual technologies, and address two specifications of technological differences: Hicks-neutral (HN) and factor-augmenting industry-neutral (FAIN). Then, we extend the model allowing for factor productivity-adjusted versions and test how these changes affect the model’s performance for three different HOV specifications: the standard model, the pair-wise model, and the relative model.

Using a new data set for 17 Spanish regions, we find evidence supporting the assumption of HN technological differences, with all test values improving markedly in the Vanek equation case. The pair-wise and the relative versions of the model equally show how the missing trade problem almost disappears once we account for this kind of model extension. In this context, our results indicate that accounting for productivity differences is also an appropriate modification of HOV models at a regional
scale, as it has been shown in the country exercises, although HN is revealed as slightly more adequate in capturing regional technological differences than the FAIN assumption.

The contribution here is to show that a simpler technical modification can establish considerable gains in the predictive performance of the HOV model, nearly solving the missing trade problem, with FPE still holding at a national scale. Therefore, improving the measurement of endowments is showed as a primary way of reducing the missing trade problems in a regional HOV framework, a result that reinforces previous findings of the regional HOV literature.

References


APPENDIX

A) Technical Appendix

As Debaere (2003) demonstrated, equation (5) is directly related to relative factor abundance as showed in equation (A1):

\[
\frac{f_r^f - f_r^f}{v_r^f + v_r^f} - \frac{f_r^f - f_r^f}{v_r^f + v_r^f} = \frac{2v_r^f}{v_r^f + v_r^f} \left( \frac{v_r^f}{v_r^f + v_r^f} \right) - \left( \frac{v_r^f}{v_r^f + v_r^f} \right)
\]  \hspace{1cm} (A1)

For any two factors \( f \) and \( f' \), a region \( r \) is said to be relatively abundant in factor \( f \) compared to region \( r' \) always that \( v_r^f / v_r^{f'} > v_r^f / v_r^{f'} \). Debaere (2003) showed that this statement holds if and only if 

\[
v_r^f / v_r^{f'} > \left( v_r^f + v_r^{f'} \right) \left( v_r^f + v_r^{f'} \right),
\]

which determines the sign of the right-hand side of equation (A1). It establishes a direct relationship between relative factor abundance and the right-hand side of equation (5), what leads this equation to be named as the relative abundance equation.

Rewriting relative factor abundance as:

\[
\frac{v_r^f}{v_r^f} > \frac{v_r^{f'}}{v_r^{f'}} = \frac{v_r^{f'}}{v_r^{f'}} / \pi_r^{f'} > \frac{v_r^{f'}}{v_r^{f'}} / \pi_r^{f'} \iff \frac{v_r^f / \pi_r^f}{v_r^{f'} / \pi_r^{f'}} \iff \frac{v_r^{f'} / \pi_r^{f'}}{v_r^f / \pi_r^f} \iff \frac{v_r^{f'} / \pi_r^{f'}}{v_r^f / \pi_r^f}
\]  \hspace{1cm} (A2)

we obtain that in the factor-augmenting case, the relative factor abundance ratio without productivity adjustments (\( v_r^f / v_r^{f'} \) or \( v_r^f / v_r^{f'} \)) is the product of the productivity-equivalent relative factor abundance ratio (\( v_r^{f'} / v_r^{f'} \) or \( v_r^{f'} / v_r^{f'} \)) and the factor-productivity ratio (\( \pi_r^f / \pi_r^{f'} \) or \( \pi_r^{f'} / \pi_r^{f'} \)). In the Hicks-neutral (HN) case, factor-productivity ratios remain the same for every factor \( f \) or \( f' \) and every pair of regions \( r \) and \( r' \) (\( \pi_r^f / \pi_r^{f'} = \pi_r^{f'} / \pi_r^{f'} \)), and consequently both definitions of relative factor abundance are identical.
with or without productivity adjustments (Debaere, 2003, p. 609). Nevertheless, in the factor-augmenting industry-neutral (FAIN) case, where productivities of factors could differ inside a region \((\pi'_f / \pi'_r \neq \pi'_f / \pi'_r)\), the relative factor abundance definition differs from the basic specification:\(^{15}\):

\[
\frac{v_r^f}{v_r^f} > \frac{v_r^f}{v_r^f} \Leftrightarrow \frac{v_r^f \pi_r^f}{v_r^f \pi_r^f} > \frac{v_r^f \pi_r^f}{v_r^f \pi_r^f} \Leftrightarrow \frac{v_r^f \pi_r^f}{v_r^f \pi_r^f} \neq \frac{v_r^f \pi_r^f}{v_r^f \pi_r^f} > \frac{v_r^f \pi_r^f}{v_r^f \pi_r^f}
\]

(A3)

now holding when:

\[
\frac{v_r^f \pi_r^f}{v_r^f \pi_r^f} > \frac{v_r^f \pi_r^f}{v_r^f \pi_r^f} \Leftrightarrow v_r^f \pi_r^f v_r^f \pi_r^f > v_r^f \pi_r^f v_r^f \pi_r^f
\]

\[
\Leftrightarrow v_r^f \pi_r^f v_r^f \pi_r^f + v_r^f \pi_r^f v_r^f \pi_r^f > v_r^f \pi_r^f v_r^f \pi_r^f + v_r^f \pi_r^f v_r^f \pi_r^f
\]

\[
\Leftrightarrow \frac{v_r^f \pi_r^f}{v_r^f \pi_r^f} (v_r^f \pi_r^f + v_r^f \pi_r^f) > 1
\]

\[
\Leftrightarrow \frac{v_r^f \pi_r^f}{v_r^f \pi_r^f} > \frac{v_r^f \pi_r^f + v_r^f \pi_r^f}{v_r^f \pi_r^f + v_r^f \pi_r^f}
\]

(A4)

---

\(^{15}\) The proof is taken from Maskus and Nishioka (2007).
## B) Data Appendix

### Spanish regions

<table>
<thead>
<tr>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPAIN</td>
</tr>
<tr>
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</tr>
<tr>
<td>ARAGON</td>
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<tr>
<td>ASTURIAS</td>
</tr>
<tr>
<td>BALEARIC ISLANDS</td>
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<tr>
<td>BASQUE COUNTRY</td>
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<tr>
<td>CANARY ISLANDS</td>
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<tr>
<td>CANTABRIA</td>
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<td>CASTILLE-LEON</td>
</tr>
<tr>
<td>CASTILLE- LA MANCHA</td>
</tr>
<tr>
<td>CATALONIA</td>
</tr>
<tr>
<td>EXTREMADURA</td>
</tr>
<tr>
<td>GALICIA</td>
</tr>
<tr>
<td>MADRID</td>
</tr>
<tr>
<td>MURCIA</td>
</tr>
<tr>
<td>NAVARRA</td>
</tr>
<tr>
<td>(LA) RIOJA</td>
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<tr>
<td>VALENCIAN REGION</td>
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### Sector categories

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<th>BBVA R-20</th>
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<td>01+02+05</td>
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<tr>
<td>ENERGY AND WATER</td>
<td>10+11+12+23+40+41</td>
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<tr>
<td>FOOD, DRINKS AND TOBACCO</td>
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<td>3</td>
</tr>
<tr>
<td>TEXTILES, APPAREL, FOOTWEAR, LEATHER</td>
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<td>4</td>
</tr>
<tr>
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<td>5</td>
</tr>
<tr>
<td>PAPER, PRINTING, AND PUBLISHING</td>
<td>21+22</td>
<td>6</td>
</tr>
<tr>
<td>CHEMICAL</td>
<td>24</td>
<td>7</td>
</tr>
<tr>
<td>RUBBER AND PLASTIC</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>NONMETALLIC MINERALS AND RELATED MANUFACTURES</td>
<td>14 + 26</td>
<td>9</td>
</tr>
<tr>
<td>METAL MINERALS AND IRON AND STEEL MFG. AND METALLIC PRODUCTS</td>
<td>13 + 27 +28</td>
<td>10</td>
</tr>
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<td>AGRICULTURAL AND INDUSTRIAL MACHINERY</td>
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<td>OFFICE MACHINERY, ELECTRIC AND ELECTRONIC PRODUCTS</td>
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<td>TRANSPORT EQUIPMENT</td>
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<td>BANKING AND INSURANCE SERVICES</td>
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<td>19</td>
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<tr>
<td>NON-MARKET SERVICES</td>
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Table 1. Estimated regional factor productivity differences across regions.

<table>
<thead>
<tr>
<th>Region</th>
<th>Hicks-Neutral (HN) estimation</th>
<th>Factor Augmenting Industry Neutral (FAIN) estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>π(r)  s.e.  R²</td>
<td>Physical capital (K) s.e.  R²</td>
</tr>
<tr>
<td>Andalucia</td>
<td>0.78  0.03  0.93</td>
<td>0.75  0.02  0.93</td>
</tr>
<tr>
<td>Aragon</td>
<td>0.80  0.02  0.96</td>
<td>0.77  0.01  0.96</td>
</tr>
<tr>
<td>Asturias</td>
<td>0.88  0.04  0.89</td>
<td>0.83  0.02  0.89</td>
</tr>
<tr>
<td>Balearic Islands</td>
<td>0.70  0.03  0.92</td>
<td>0.71  0.01  0.71</td>
</tr>
<tr>
<td>Canary Islands</td>
<td>1.10  0.03  0.95</td>
<td>1.09  0.03  0.95</td>
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<td>Cantabria</td>
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<td>Castille-Leon</td>
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<td>0.77  0.02  0.96</td>
</tr>
<tr>
<td>Castille-La Mancha</td>
<td>0.69  0.03  0.90</td>
<td>0.67  0.01  0.90</td>
</tr>
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<td>1.04  0.01  0.99</td>
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<td>Valencian Region</td>
<td>0.85  0.01  0.97</td>
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<td>Extremadura</td>
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<td>Madrid</td>
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<td>1.29  0.03  0.96</td>
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<tr>
<td>Murcia</td>
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<td>0.85  0.01  0.61</td>
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<td>Navarra</td>
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<td>0.97  0.03  0.96</td>
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<tr>
<td>Basque Country</td>
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<td>Rioja</td>
<td>0.73  0.01  0.98</td>
<td>0.69  0.02  0.98</td>
</tr>
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</table>

Note: The HN estimated coefficients are from equation (7) in the main text, and the FAIN estimated coefficients are from equation (8) in the main text. There are three production factors: physical capital (K), high-educated labour (H) and low-educated labour (L).
Table 2. Results of the HOV model

I. Strict model

<table>
<thead>
<tr>
<th></th>
<th>K</th>
<th>H</th>
<th>L</th>
<th>Pooled</th>
<th>K</th>
<th>H</th>
<th>L</th>
<th>Pooled</th>
<th>K/L</th>
<th>K/H</th>
<th>L/H</th>
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<tbody>
<tr>
<td>Sign test</td>
<td>0.35</td>
<td>0.71</td>
<td>0.65</td>
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<td>0.65</td>
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<td>0.62</td>
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<tr>
<td>Variance test</td>
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<td>0.37</td>
<td>0.55</td>
<td>0.59</td>
<td>0.81</td>
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<td>0.72</td>
<td>0.55</td>
<td>0.71</td>
<td>0.66</td>
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<tr>
<td>Slope test</td>
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<td>0.11</td>
<td>-0.09</td>
<td>0.08</td>
<td>-0.35</td>
<td>0.40</td>
<td>0.02</td>
<td>0.07</td>
<td>0.28</td>
<td>0.17</td>
<td>0.08</td>
<td>0.16</td>
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<td>0.13</td>
<td>0.19</td>
<td>0.04</td>
<td>0.07</td>
<td>0.03</td>
<td>0.02</td>
<td>0.05</td>
<td>0.04</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>R-squared</td>
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<td>0.08</td>
<td>0.03</td>
<td>0.03</td>
<td>0.21</td>
<td>0.11</td>
<td>0.00</td>
<td>0.01</td>
<td>0.11</td>
<td>0.05</td>
<td>0.01</td>
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</table>

II. With Factor Productivity Adjustments - Hicks Neutral (HN)

<table>
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<tr>
<th></th>
<th>K</th>
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<th>K</th>
<th>H</th>
<th>L</th>
<th>Pooled</th>
<th>K/L</th>
<th>K/H</th>
<th>L/H</th>
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<tbody>
<tr>
<td>Sign test</td>
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<td>0.64</td>
<td>0.66</td>
<td>0.62</td>
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</tr>
<tr>
<td>Variance test</td>
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<td>0.79</td>
<td>0.86</td>
<td>0.86</td>
<td>0.67</td>
<td>0.81</td>
<td>0.78</td>
</tr>
<tr>
<td>Slope test</td>
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<td>0.43</td>
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<td>0.11</td>
<td>0.37</td>
<td>0.23</td>
<td>0.27</td>
<td>0.37</td>
<td>0.22</td>
<td>0.17</td>
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</tr>
<tr>
<td>Standard error</td>
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<td>0.24</td>
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<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
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<tr>
<td>R-squared</td>
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<td>0.03</td>
<td>0.09</td>
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III. With Factor Productivity Adjustments - Factor Augmenting Industry Neutral (FAIN)

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<tr>
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<th>H</th>
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<th>Pooled</th>
<th>K</th>
<th>H</th>
<th>L</th>
<th>Pooled</th>
<th>K/L</th>
<th>K/H</th>
<th>L/H</th>
<th>Pooled</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.71</td>
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<td>0.57</td>
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<td>0.63</td>
<td>0.61</td>
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<tr>
<td>Variance test</td>
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<td>0.21</td>
<td>0.33</td>
<td>0.21</td>
<td>0.14</td>
<td>0.22</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.22</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.03</td>
<td>0.05</td>
<td>0.04</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.08</td>
<td>0.14</td>
<td>0.02</td>
<td>0.11</td>
<td>0.01</td>
<td>0.12</td>
<td>0.05</td>
<td>0.00</td>
<td>0.11</td>
<td>0.03</td>
<td>0.00</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Note: The HOV model uses 17 observations per factor and 51 observations in the pooled analysis. The Pair-wise HOV model uses 272 (17x16) observations per factor and 816 observations in the pooled analysis. The Relative HOV model uses 272 (17x16) observations per factor pair and 816 observations in the pooled analysis. The sign test, variance test and slope test are explained in the main text. There are three production factors: physical capital (K), high-educated labour (H) and low-educated labour (L).