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Abstract

This working paper analyzes the connection between country specialization across goods and country specialization within goods along the quality dimension. It builds a model that introduces quality differentiation and firm heterogeneity into the Dornbusch, Fischer and Samuelson (1977) framework. Country market shares across goods are continuous and decreasing in comparative costs. Within each industry, 1) the highest quality is produced by the country with the absolute advantage in the industry; 2) the lowest quality is produced by the country with the lowest wages; 3) each country's average quality is decreasing in its comparative costs in the industry and increasing in its wage level. The model is consistent with previously documented facts and with the specific empirical motivation being provided: it is shown for some illustrative goods that exporter *revealed comparative advantage*, conditional on exporter income per capita, is positively correlated with the unit value of exports (unit value being interpreted as a proxy for quality).

Key words

Vertical differentiation, quality margin, extensive margin, North-South trade.

Resumen

En este documento de trabajo se analiza la conexión entre la especialización horizontal (a lo largo del conjunto de bienes) de los países y la especialización vertical (a lo largo de los distintos niveles de calidad de cada bien). Con este fin, se construye un modelo con diferenciación en la calidad y heterogeneidad empresarial en el marco teórico del modelo de Dornbusch, Fischer y Samuelson (1977). Se obtiene que las cuotas de mercado de los países en los distintos bienes son una función continua y decreciente de sus costes comparativos. Para cada bien, 1) el país con mayor ventaja absoluta (eficiencia) en el bien produce la calidad más alta; 2) el país con los salarios más bajos produce la calidad más baja; 3) la calidad media que produce cada país es creciente en su nivel salarial y decreciente en sus costes comparativos en el bien. El modelo es coherente con la evidencia empírica previa y con la motivación específica que se proporciona: se muestra para dos bienes ilustrativos que la *ventaja comparativa revelada* del país exportador, condicional a su renta per cápita, está positivamente correlacionada con el valor unitario de las exportaciones (interpretándose el valor unitario como una *proxy* de calidad).

Palabras clave

Diferenciación vertical, margen de calidad, margen extensivo, comercio Norte-Sur.

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CONTENTS

1. Introduction

RECENT empirical research has documented the importance of country specialization across both the horizontal and the vertical (quality) dimensions of goods to characterize the current patterns of trade. Existing models tend to concentrate on only one of these two dimensions and neglect their possible connections. However, there is evidence suggesting that these connections may be important. This paper provides a simple integrated model where both the horizontal and the vertical dimensions of trade are present and their interactions are investigated. The paper shows that the factors that create absolute and comparative advantages across goods also play an important role in the vertical specialization within goods.

Schott (2004), Hummels and Klenow (2005) and Khandelwal (2007), among others, have shown strong evidence of the significance of the quality dimension in characterizing current international trade. Horizontal specialization (specialization across goods) seems to be fading, while vertical specialization (specialization within goods along the quality dimension) is becoming increasingly important [1]. Still, the importance of the horizontal dimension of specialization cannot be underestimated. For example, Hummels and Klenow (2005) show that the horizontal dimension plays a key role in the expansion of exports as countries become richer. They found that a 10% increase in per capita income brings about, on average, an 8.5% increase in the range of goods being exported (the extensive margin of exports) and a 0.9% increase in the unit price of exports (the quality margin, with unit price interpreted as a proxy for quality). Along the same lines, Kehoe and Ruhl (2002) showed that the extensive margin accounts for the bulk of trade growth after trade liberalizations. Ideally, trade models should be able to incorporate both the horizontal and the vertical dimensions of specialization.

There are several general equilibrium models analyzing the patterns of country specialization across the quality dimension (Flam and Helpman, 1987; Falvey and Kierzkowski, 1987; Grossman and Helpman, 1991;

1. For example, Schott (2004) has shown that 62% of industrial goods imported by the U.S. in 1994 were sourced from both low- and high-wage countries, and that this figure had risen steadily from 30% in 1972.

Stokey, 1991; Murphy and Shleifer, 1997, among others). They predict that richer countries specialize in producing higher quality, which conforms to the general evidence in Schott (2004) and Hummels and Klenow (2005). The main underlying argument is that richer countries have a larger endowment in human or physical capital which provides a comparative advantage in producing higher quality. A limitation of these models is that they assume either only one vertically differentiated good in the economy (together with some non-differentiated goods) or only one quality level per good at each point of time. As a consequence, they cannot account for the simultaneous existence of the extensive and the quality margins of exports, and the possible interactions between horizontal and vertical specialization. Moreover, some evidence suggests that richer countries do not always produce higher quality than poorer countries. For example, the highest quality varieties of tropical and semi-tropical crops like tobacco or coffee do not originate from the richest producers. Schott (2004) found that about 50% of the industrial goods exported by low-wage as well as high-wage countries showed a significant (at the 10% level) positive correlation between unit values and exporter per capita GDP. However, this leaves the other 50% of selected industrial goods without a significant correlation between income and the proxy for quality. This evidence calls for digging deeper into the determinants of the relative quality of exports across countries.

Likely candidates to contribute to producing higher quality of a given good are absolute and comparative advantage in that good. Going back to the example of tropical crops, a country may produce the best cigars because its soil and climate are the best to grow tobacco. It is then likely that the country also has a horizontal specialization in the production of cigars. The quality of exports of a given good and the absolute or the comparative advantage in that good are likely to be related. As a consequence, less developed countries may export higher quality than richer countries in goods where they have an absolute or a comparative advantage. Section 2 provides two examples. We use coffee as a primary good that may have significant quality differences across producers, and men's cotton shirts as an industrial good that has a wide set of low- as well as high-income exporters. It is shown for these goods that exporter *revealed comparative advantage* is positively and significantly correlated with the unit value of exports. Moreover, the significance of revealed comparative advantage increases when income per capita is also included in the regression. Thus, these illustrative examples show that, at least for some goods, specialization across goods is related to vertical specialization within each good and that this relationship is independent of a potential link through income per capita.

A second limitation of available trade models on country specialization along the vertical dimension is that they assume homogeneous producers within each country. However, heterogeneity of firms' efficiency is a prominent phenomenon whose consideration has proven to be very fruitful in capturing important features of international trade [2]. It is shown in this paper that accounting for this heterogeneity is also important for describing the patterns of vertical specialization. Moreover, firm heterogeneity helps explain why each country's range of exported goods, as well as exported qualities within each good, often overlaps with other countries' ranges (even if wages and efficiency across industries differ) [3].

This paper builds a simple two-country Ricardian model with a continuum of goods that can be produced along a continuum of quality levels. Furthermore, each good can be produced by a set of firms that are heterogeneous in terms of their efficiencies. Thus, the model introduces the quality dimension as well as firm heterogeneity into the Dornbusch, Fischer and Samuelson (1977) model (DFS). This model provides the basis to investigate the interactions between horizontal specialization across goods and vertical specialization within goods.

The paper focuses on the implications for international trade of technological differences across countries, industries, and firms in markets with many vertically differentiated goods. In contrast with the more complex supply side, it greatly simplifies the demand side. In particular, it assumes the same homothetic demand across goods and quality varieties in both countries. To be sure, non-homotheticities are important in shaping the patterns of trade along the quality dimension (see Hallak, 2006; Choi, Hummels and Xiang, 2006; Fieler, 2008). However, homotheticity may prove to be a useful simplification enabling the derivation of sharp predictions that are consistent with the empirical evidence. Moreover, there is no reason to

2. See Bernard and Jensen (1995) for pioneering empirical work; Bernard et al. (2003) and Melitz (2003) for path breaking general equilibrium trade models; and Eaton, Kortum and Kramarz (2005) for how the heterogeneous-firm framework coupled with Cournot equilibrium fits regularities on the distribution of firms and market shares across output destinations. Tybout (2003) and Bernard et al. (2007) review the literature. Bernard, Redding and Schott (2007) analyze firm heterogeneity and comparative advantage in a two-country two-factor two-industry model with no quality differentiation.

3. The intuitive argument is that firms' choices on output quality are likely to be correlated with their efficiency. As a consequence, the distribution of firm efficiency within each industry, in each country, is likely to be an important determinant of the distribution of output qualities. Then, overlapping distributions of firm efficiencies across countries will imply overlapping distributions of output qualities.

expect that the predictions in this paper would be reversed by introducing non-homotheticities.

In the model's equilibrium, more efficient firms produce higher quality [4]. Therefore firm heterogeneity implies that each good is produced in every country in many different qualities. The spectrum of qualities produced by each country in each industry (good) is likely to overlap with the other country's spectrum. This gives rise to non-trivial patterns of country market shares across quality varieties where the richer country does not necessarily produce the highest quality. The main implications of the model are as follows. Country market shares across goods are a continuous decreasing function of comparative costs. Richer countries export a wider set of goods (the extensive margin). Within each industry, 1) the highest quality is produced by the country with the absolute advantage in the industry; 2) the lowest quality is produced by the country with the lowest wages; 3) country average quality is decreasing in comparative costs and increasing in the wage level. Thus, the model integrates the analysis of horizontal specialization across goods with the analysis of quality specialization within each good. In so doing, it reveals important connections between these two dimensions. Results are consistent with the empirical literature cited above and with the empirical motivation provided in the paper.

The working paper is organized as follows. Section 2 provides some empirical evidence on the relationship between export unit values and exporter revealed comparative advantage. Section 3 lays out the model. Section 4 analyzes specialization across goods. Section 5 analyzes quality specialization within goods. Section 6 concludes.

4. See Alcalá and Hernández (2006), Baldwin and Harrigan (2007), Johnson (2007), Verhoogen (2008) and Kugler and Verhoogen (2008) for other models with this feature analyzing different empirical implications.

2. Quality and Comparative Advantage Across Goods: Some Empirical Evidence

THIS section provides illustrative evidence that exporter comparative advantage (jointly with exporter income per capita) is positively correlated with export unit value (used as a proxy for average quality). We consider two cases: a primary good (coffee) and an industrial good (men's cotton shirts). These products were selected since previous studies showed that they are exported by a wide array of countries with different income levels and that their unit values may widely differ across producers.

As the basic observable measure of comparative advantage we use the index of *revealed comparative advantage (RCA)* (Balassa, 1965). This index is a measure of relative export performance (or specialization) by industry and country. The index for country i and good j can be defined as $RCA_i(j) = 100^*(EXP_i(j) / EXP_i) / (EXP_W(j) / EXP_W)$; where $EXP_i(j)$ is country i's exports of good j to the world, EXP_i is its total exports, $EXP_W(j)$ is total international trade of good j, and EXP_W is total world trade (all variables in value terms). We also consider a *quantity variation* of this concept which may be labeled as *quantity revealed comparative advantage (QRCA).* This measure has the same definition as $RCA_i(j)$ except that $EXP_i(j)$ is replaced by the number of units of good j exported by country i. Hence $QRCA_i(j) =$ $= RCA_i(j) / \text{ } unit\ value_i(j)$. Although the empirical measure that is directly connected to the theoretical model below is *RCA*, using the *QRCA* measure serves as a robustness check for the empirical relationship.

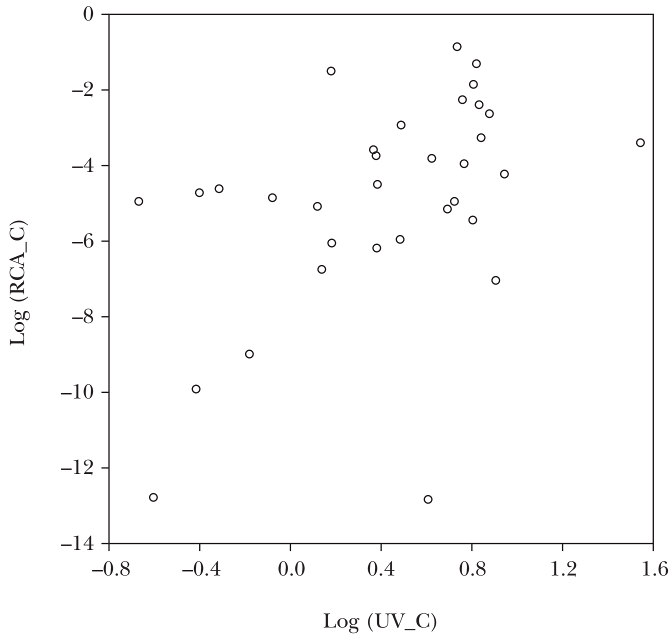
The basic relationship to be estimated is:

$$\text{Log } unit\ value_i(j) = a_0 + a_1 \text{ Log } PCGDP_i + a_2 \text{ Log } RCA_i(j) + u_i, \qquad (2.1)$$

where $unit\ value_i(j)$ is the ratio of the value of country i's exports of good j over the quantity exported (in kilograms or in number of items, depending on the commodity), $PCGDP_i$ is country *i*'s PPP per capita GDP, and u_i is the error term. Data used to estimate this equation are from United Nations Commodity Trade Statistics Database (SITC, rev.3, available online at http://comtrade.un.org/) except for *PCGDP* which is from the World Development Indicators, World Bank, 2007. All data correspond to 2005.

Graphs 2.1-2.3 summarize the main point in this section. Graph 2.1 depicts the scatter plot of the log of revealed comparative advantage against the log of unit value of exports for the case of coffee exports to the world market [5]. Graph 2.2 depicts a partial scatter plot drawn using the results from estimating equation (2.1) for men's cotton shirts exports to the U.S. The vertical axis measures Log $unit\ value_i(j) - (\hat{a}_0 + \hat{a}_1 \text{ Log } PCGDP_i)$ using the coefficient estimates $\hat{a}_0$ and $\hat{a}_1$, whereas the horizontal axis measures Log $RCA_i(j)$.

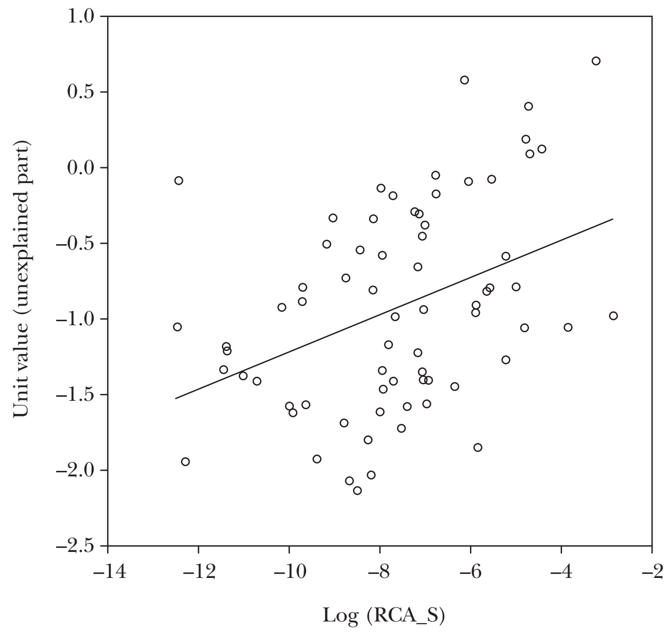
GRAPH 2.1: Scatter plot: revealed comparative advantage-unit value. Coffee



Note: The horizontal axis measures the log of exporter revealed comparative advantage in coffee. The vertical axis measures the log of unit value of coffee exports (units are kilograms).

5. Since the UN *comtrade* statistics for coffee exports reflect re-exports by many non-producers, the sample was restricted to countries included in the International Coffee Organization list of main exporters of coffee (see http://www.ico.org/about_statistics.asp. The problem remains after using the UN *comtrade* data on re-exports). Also note the outlier with a log *(unit value)* about 0.5 and log*(RCA)* about –13 which corresponds to Philippines. This country has a surprising high unit value for 2005 in comparison to unit values in 2004 and 2006. Results would significantly improve if this outlier were dropped.

GRAPH 2.2: Partial scatter plot: revealed comparative advantage' unit value. Men's cotton shirts



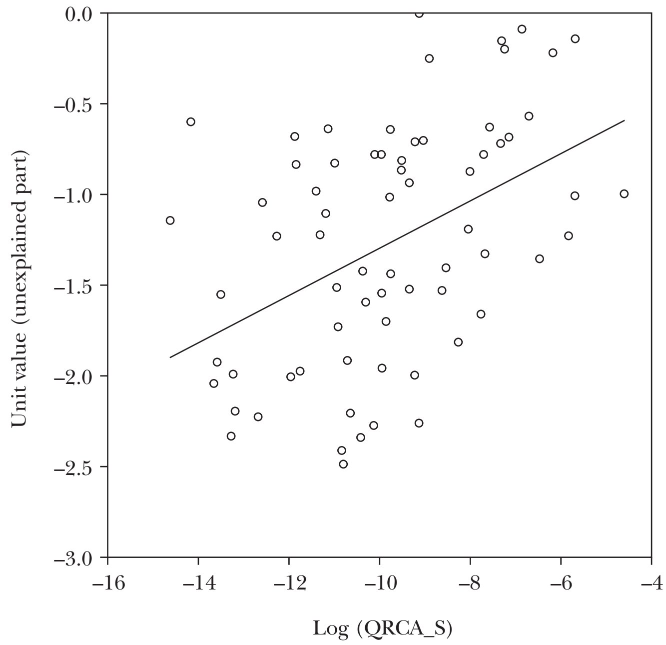
Note: The vertical axis measures Log *unit value of men's cotton shirts (U.S. market)* – *($\hat{a}_0$ + $\hat{a}_1$* Log *PCGDP)* with the coefficient estimates $\hat{a}_0$ and $\hat{a}_1$ taken from column (3) in table 2.2a. The horizontal axis measures the log of exporter revealed comparative advantage in men's cotton shirts.

Graph 2.3 does the same using Log $QRCA_i(j)$ instead of Log $RCA_i(j)$. In all cases, a positive relationship between comparative advantage and export unit values becomes apparent.

The details of regressions are shown in tables 2.1-2.2b. Table 2.1 shows OLS estimates of equation (2.1) for coffee exports to the world market. Per capita GDP is not significant by itself, whereas comparative advantage is positive and significant by itself at 5% level. When both variables are included in the regression, both coefficients and significances increase. Columns 4 and 5 repeat the regressions using *QRCA*. The size of the coefficient for *QRCA* is somewhat reduced but is still significant at the 5% level in the joint regression with *PCGDP*.

Tables 2.2a and 2.2b show that these results are not exclusive to primary goods but may also hold for industrial goods. As already noted, we consider men's cotton shirts exports to the U.S. (comparative advantage is computed using world exports). The sample includes all the countries exporting at least 500 items to the U.S. in 2005, as reported by the U.S. All columns

GRAPH 2.3: Partial scatter plot: quantity revealed comparative advantage' unit value. Men's cotton shirts



Note: The vertical axis measures Log *unit value of men's cotton shirts* – *(*$\hat{a}_0$ + $\hat{a}_1$ Log *PCGDP* + $\hat{a}_2$ Log *quantity exported)* with the coefficient estimates $\hat{a}_0$, $\hat{a}_1$ and $\hat{a}_2$ taken from column (4) in table 2.2b. The horizontal axis measures the log of quantity exporter revealed comparative advantage in men's cotton shirts.

TABLE 2.1: Unit values and exporter characteristics. Coffee

	Dependent variable is log unit value				
	(1)	(2)	(3)	(4)	(5)
PCGDP	0.042		0.059*		0.059*
	(0.029)		(0.024)		(0.028)
Log RCA		0.085*	0.095**		
		(0.032)	(0.032)		
Log QRCA				0.060	0.075*
				(0.037)	(0.037)
Number of observations	34	34	34	34	34
Adj. R^2	0.05	0.20	0.28	0.08	0.14

Note: This table reports OLS results of regressing the log of unit values of coffee exports to the world market on exporter PPP per capita income *(PCGDP)* and the log of exporter revealed comparative advantage *(RCA)* or the log of exporter quantity revealed comparative advantage *(QRCA)*. All regressions include a constant. The sample of exporters was restricted to countries included in the International Coffee Organization list of the main exporters of coffee. Heteroskedasticity-consistent standard errors in parenthesis. ** means significant at 1% and * 5%.
Source: United Nations Commodity Trade Statistics Database, except *PCGDP* which is from World Development Indicators (WDI), World Bank. Data correspond to 2005.

TABLE 2.2a: Unit values and exporter characteristics. Men's cotton shirts

	Dependent variable is log unit value				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Log PCGDP	0.553**		0.620**	0.560**	0.560**
	(0.080)		(0.082)	(0.076)	(0.083)
Log RCA		0.054	0.122**	0.162**	0.163**
		(0.047)	(0.038)	(0.039)	(0.040)
Log quantity exported				–0.090**	–0.090*
				(0.021)	(0.035)
Number of observations	70	70	70	70	70
Adj. R^2	0.38	0.01	0.47	0.56	0.58

Note: Results of regressing unit values of men's cotton shirts exports to the U.S. on exporter PPP per capita income *(PCGDP),* exporter revealed comparative advantage *(RCA)* and number of units exported to the U.S. *(quantity exported).* Columns 1-4 use OLS. Column 5 uses two-stage least squares using exporter population and openness as instruments for quantity exported. The sample includes all countries exporting at least 500 items to the U.S. market. All variables are in logs and all regressions include a constant. Heteroskedasticity-consistent standard errors in parenthesis. ** means significant at 1% and * 5%.
Source: Data correspond to 2005 and are from United Nations Commodity Trade Statistics Database, except PCGDP and population which are from WDI World Bank.

TABLE 2.2b: Unit values and exporter characteristics. Men's cotton shirts

	Dependent variable is log unit value				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Log PCGDP	0.553**		0.620**	0.576**	0.573**
	(0.080)		(0.086)	(0.081)	(0.086)
Log QRCA		–0.008	0.084*	0.130**	0.133**
		(0.045)	(0.036)	(0.039)	(0.043)
Log quantity exported				–0.089**	–0.094*
				(0.024)	(0.041)
Number of observations	70	70	70	70	70
Adj. R^2	0.38	–0.01	0.42	0.50	0.52

Note: Results of regressing unit values of men's cotton shirts exports to the U.S. on exporter PPP per capita income *(PCGDP),* exporter quantity revealed comparative advantage *(QRCA)* and number of units exported to the U.S. *(quantity exported).* Columns 1-4 use OLS. Column 5 uses two-stage least squares using exporter population and openness as instruments for quantity exported. The sample includes all countries exporting at least 500 items to the U.S. market. All variables are in logs and all regressions include a constant. Heteroskedasticity-consistent standard errors in parenthesis. ** means significant at 1% and * 5%.
Source: Data correspond to 2005 and are from United Nations Commodity Trade Statistics Database, except PCGDP and population which are from WDI World Bank.

report OLS regressions except column 5 of each of these two tables which report 2SLS regressions. Table 2.2a uses the *RCA* measure of comparative advantage. *RCA* is not significant by itself but is positive and significant at the 1% level when *PCDGP* is included in the regression (column 3). Graph 2.2 was drawn using these last results.

The number of units of *j* exported by a country *i*, $n_i(j)$, may also have some impact on the unit value of its exports [6]. We therefore consider $n_i(j)$ as an additional control in the regressions (column 4). The coefficient on *RCA* increases when *quantity exported* is included. The coefficient of *quantity exported* is also significant and has the expected negative sign. Since endogeneity may be a problem with $n_i(j)$ (recall that it is used to compute unit values of exports) we instrument it using the logs of country i's population and openness (exports + imports of goods and services over GDP) [7]. Results are in column 5. Comparison of columns 4 and 5 reveals that coefficients are amost identical in the OLS and the 2SLS estimations. Table 2.2b performs exactly the same empirical analysis using the *QRCA* measure instead of *RCA*. All the results are qualitatively the same with both measures, even if the estimated coefficients for *QRCA* are somewhat lower than those for *RCA*. Graph 2.3 was drawn using the results in column 4 of this table.

In sum, country per capita income and comparative advantage show positive and jointly significant correlations with export unit values. Furthermore, either *PCGDP* or *RCA* may not be significant when including only one of them in the regression [8]. In the following sections we build a trade model of horizontal and vertical specialization that predicts these conditional correlations. The model is also able to predict other previously documented facts already cited such as the richer-country extensive margin of exports.

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6. For example, if two countries have the same per capita GDP and the same *RCA* but different sizes, the larger country will tend to export a larger quantity of the good. Then, if there is some horizontal differentiation related to each specific exporting country (the Armington hypothesis) besides vertical differentiation, we should expect a negative relationship between $n_i(j)$ and *unit* $value_i(j)$.

7. Table 2.3 reports the first stage regressions for this instrument.

8. This may be more likely to happen for products where per capita income and comparative advantage are negatively correlated. In the sample used, correlation between (the logs of) these two variables are –0.24 in the case of coffee and –0.25 in the case of men's cotton shirts.

TABLE 2.3: First stage regressions. Men's cotton shirts

	Dependent variable is Log of quantity exported	
	(1)	(2)
Log PCGDP	–0.681+	–0.536
	(0.361)	(0.405)
Log RCA	0.385+	
	(0.206)	
Log QRCA		0.437*
		(0.213)
Log Population	1.26**	1.21**
	(0.258)	(0.257)
Log Openness	1.85**	1.68*
	(0.686)	(0.701)
Number of observations	70	70
F statistic	9.52	10.21
Adj. R^2	0.37	0.39

Note: This table reports OLS results of regressing the log of the number of men's cotton shirts exported to the U.S. *(quantity exported)* on the log of exporter PPP per capita income *(PCGDP),* the log of exporter revealed comparative advantage *(RCA)* (or the log of exporter quantity revealed comparative advantage, *QRCA,* in column 2), the log of exporter population, and the log of exporter openness (exports + imports of goods and services over GDP). This last two variables are used as instruments for *quantity exported* in the 2SLS regressions reported in columns 5 of tables 2.2a and 2.2b. The sample includes all countries exporting at least 500 items to the U.S. market. All regressions include a constant. Heteroskedasticity-consistent standard errors in parenthesis.
** means significant at 1%, * 5% and + 10%.
Source: United Nations Commodity Trade Statistics Database, except *PCGDP,* population, and openness which are from WDI World Bank. Data correspond to 2005.

3. The Model

CONSIDER a two-country economy. Home and foreign countries are denoted by H and F, respectively. Subscript W indicates world aggregates. There is a measure-one continuum of goods indexed by j. Each good defines an *industry*. Every good can be produced along a continuum of qualities. For each good, there is an infinite set of efficiency-heterogeneous potential producers in each country. In equilibrium, only a finite measure of firms will be active. Each firm produces only one good and chooses which quality and how many units to produce taking as given other firms' quality and quantity choices (Cournot equilibrium). Firm k from country i in industry j produces $x_{ki}(j)$ units of good j with quality $q_{ki}(j)$. Firms choosing zero output are said to be inactive. There are no transportation costs so that the production of firm $k_i(j)$ has the same price $P_{ki}(j)$ in both countries.

3.1. Demand

Denote by $c^h_{ki}(j)$ country-h representative agent's consumption of firm $k_i(j)$'s output. Consumers from both countries maximize the same utility function:

$$\int_0^1 \ln \left(\sum_{i=H,F} \sum_k q_{ki}(j)\, c^h_{ki}(j) \right) dj, \tag{3.1}$$

with respect to $c^h_{ki}(j)$ for every $k_i(j)$, subject to $Y_h = \int_0^1 \left[\sum_{i=H,F} \sum_k P_{ki}(j)\, c^h_{ki}(j) \right] dj$; where Y_h is country-h representative consumer's income. $\sum_{i=H,F} \sum_k q_{ki}(j)\, c^h_{ki}(j)$ may be referred to as the number of *quality units* of good j consumed by h. The first-order equilibrium conditions of maximizing (3.1) are straightforward:

$$\frac{P_{ki}(j)}{P_{k'l}(j)} = \frac{q_{ki}(j)}{P_{k'l}(j)};\ \ i,\ l = H, F. \tag{3.2}$$

$$\sum_{i=H,F} \sum_k P_{ki}(j)\, c^h_{ki}(j) = Y_h. \tag{3.3}$$

Condition (3.2) states that the relative price between any two varieties $k_i(j)$ and $k'_l(j)$ of the same good j is given by their relative quality (e.g., the products of two firms producing the same quality variety of the same good are perfect substitutes, and the marginal rate of substitution between any two quality varieties of the same good is constant). Condition (3.3) states that expenditure is the same across all goods, as with any symmetric Cobb-Douglas utility function. Denote by $P(j)$ the price of a unit of good j with quality equal to 1. Then, from expression (3.2) we have:

$$P_{ki}(j) = P(j) \cdot q_{ki}(j).$$

We will refer to $P(j)$ as the *price level in industry j*. Using this expression to substitute in (3.3) and assuming market clearing for each firm's output, $x_{ki}(j) = \sum_{h=H,F} c^h_{ki}(j)$, yields the price level in industry j as a function of firms' output and quality choices:

$$P(j) = \frac{Y_H + Y_F}{\sum_{i=H,F} \sum_k q_{ki}(j)\, x_{ki}(j)}. \tag{3.4}$$

This is the *inverse demand function* to be used in solving for the Cournot equilibrium of each industry.

The general equilibrium of the economy with this demand setting yields a determinate composition for each firm's output in terms of both quantity and quality, and therefore a determinate composition of world consumption. However, if no further considerations are made, each representative consumer is indifferent in this equilibrium between consuming any quality variety of each good, as long as relative prices between the quality varieties satisfy (3.2). In other words, the composition of each individual's consumption basket in terms of quality varieties within each good is indeterminate even if the composition of aggregate world consumption is fully determinate. Since a characterization of exports requires a determinate composition of each country representative agent's consumption basket, we will informally consider a slight modification of utility function (3.1) that renders this composition fully determinate. We will assume an infinitesimal preference for variety over all the varieties produced by the set of firms. As a result, each individual's consumption basket is a scaled down version of the world's consumption basket. Moreover, the composition of each country's exports is exactly the same as the composition of its production. Formally, if υ_i is country i's share in world income $(\upsilon_H = Y_H / (Y_H + Y_F) = 1 - \upsilon_F)$, then country i consumes a portion υ_i of every firm's output, and exports a portion $1 - \upsilon_i$ of every domestic firm's output. Under this assumption, the vertical and horizontal characterization of each country's output in sections 4 and 5 should also be interpreted as a characterization of its exports.

3.2. Technology

Labor is the only production factor. Increasing output quality comes at the cost of lower output per worker. Efficiency of firm *k* from country *i* in industry *j* is given by the product of three positive parameters: T_i, $a_i(j)$, and z_k; where T_i is a country-specific aggregate efficiency parameter, $a_i(j)$ is a country-industry-specific efficiency parameter, and z_k is a firm-specific efficiency parameter. Firm $k_i(j)$'s production function is given by:

$$x_{ki}(j) = [\, T_i \, a_i(j) \, z_k]^{1-\sigma} \frac{l_{ki}(j)}{e^{q_{ki}(j) / [T_i \, a_i(j) \, z_k]^{\sigma}}}, \; 0 < \sigma \leq 1, \tag{3.5}$$

where $l_{ki}(j)$ is its input of labor. The parameter σ measures the extent to which more-efficient firms have a relative advantage in producing higher quality goods ($\sigma = 0$ would imply that higher efficiency is neutral with respect to quality). The parameter T_i captures differences across countries in general sources of productivity (e.g., generic human capital, good institutions, and public infrastructures). Parameter $a_i(j)$ captures country-industry-specific asymmetries, which may be due to differences in specialized knowledge, skills, and natural resource endowments. z_k captures firm-specific components such as entrepreneur's skills and the myriad of physical and procedural elements that characterize a firm and cannot be easily imitated.

Units of goods are normalized so that $T_F = a_F(j) = 1$ for all *j*. Thus, we can drop subscripts for home technology parameters, i.e., $T_H = T$ and $a_H(j) = a(j)$. The function $a(j) : [0, 1] \rightarrow \mathrm{R}_{++}$ is assumed to be continuous, differentiable, and strictly decreasing. There are an infinite number of potential firms in each country and sector, indexed by $k = 0, ..., \infty$, which are ordered inversely with respect to efficiency. Hence firm 0 is the most efficient one. Its efficiency is normalized $z_0 = 1$. In equilibrium, only a finite measure of firms will be active. The distribution of firm efficiencies z_k is the same in all industries and countries [9].

9. The assumption that the distribution of firm-specific parameters z_k is the same in every industry and country is not necessary for the results in the paper but it greatly simplifies the exposition. The same results can be obtained by assuming the following first-order stochastic dominance of firm productivities across countries: if $T_i a_i(j) > T_h a_h(j)$ then $T_i a_i(j) z_{ki}(j) > T_h a_h(j) z_{kh}(j)$; where $z_{ki}(j)$ and $z_{kh}(j)$ are efficiency of the k^{th} most efficient firm in industry *j* in countries *i* and *h*, respectively.

Country i's wage is denoted by w_i. The foreign wage is used as the *numeraire:* $w_F = 1$. Let $c_{ki}(q, j)$ be the (constant) marginal cost of firm k from country i producing good j with quality q:

$$c_{ki}(q, j) = \frac{w_i}{[T_i\, a_i(j)\, z_k]^{1-\sigma}}\; e^{q\,/\,[T_i\, a_i(j)\, z_k]^{\sigma}}\,. \tag{3.6}$$

The use of the terms absolute and comparative advantage may lead to some confusion when both horizontal and vertical specialization are considered and become intertwined. We reserve these terms for comparison of advantage across goods and avoid their use in the analysis of trade along the quality dimension. Country H (respectively, F) is said to have an *absolute advantage* over country F (resp. H) in industry j if $Ta(j) > 1$ (resp. $Ta(j) < 1$). This implies that for each k, efficiency of firm k from country H, $Ta(j)\, z_k$, is higher than efficiency of firm k from country F. At any rate, even if the home country has an absolute advantage, some foreign firms may be more efficient than some home-country firms in the industry. Additionally, we will refer to $[w_i \,/\, T_i\, a_i(j)] \,/\, [w_h \,/\, T_h\, a_h(j)]$ as country i's *comparative cost* with respect to country h in industry j. Note that due to normalizations $w_F \,/\, T_F\, a_F(j) = 1$, so that home country's comparative cost is simply $w \,/\, Ta(j)$. Country H (respectively, F) is said to have a *cost advantage* over country F (resp. H) in industry j if $w \,/\, Ta(j) < 1$ (resp. $w \,/\, Ta(j) > 1$).

3.3. Equilibrium

Firms maximize profits $\pi_{ki}(j) = x_{ki}(j)\, [q_{ki}(j)\, P(j) - c_{ki}(q, j)]$ with respect to their output $x_{ki}(j)$ and quality $q_{ki}(j)$, taking as given the inverse demand function (3.4) and other firms' output and quality choices (Cournot equilibrium). From each firm's first order conditions of maximization we have:

$$s_{ki}(j) = \begin{cases} 1 - e\,\dfrac{w_i}{P(j)\, T_i\, a_i(j)\, z_k} & \text{if} \quad 1 - e\,\dfrac{w_i}{P(j)\, T_i\, a_i(j)\, z_k} \geq 0, \\[2ex] 0 & \text{otherwise.} \end{cases} \tag{3.7}$$

$$q_{ki}(j) = [T_i\, a_i(j)\, z_k]^{\sigma}, \tag{3.8}$$

where $s_{ki}(j)$ is firm $k_i(j)$'s market share in value terms, $s_{ki}(j) \equiv q_{ki}\, x_{ki}(j) / \sum_{h=H,F} \sum_g q_{gh}(j)\, x_{gh}(j)$ [10]. The least efficient active firm from i in industry j will be denoted by $\bar{k}_i(j)$. Firm $\bar{k}_i(j)$ satisfies:

$$z_{\bar{k}_i(j)} = \frac{e w_i}{P(j)\, T_i\, a_i(j)}. \tag{3.9}$$

Expressions (3.7) and (3.8) imply that market share and output quality are increasing in the firm's efficiency. The relationship between efficiency and market shares is common to Cournot models with heterogeneous firms. On the other hand, the relationship between efficiency and quality is the consequence of the relative advantage of more efficient firms in producing higher quality (e.g., $\sigma > 0$ in expression [3.5]).

Some discussion of this second link will clarify some differences and similarities between this and other trade models with quality differentiation. The link between efficiency and quality tends to be present in all models of trade with quality-differentiated goods. Notwithstanding, models differ in the level at which this link is established: it may be established at the aggregate level, at the industry level, or at the firm level, depending on the source of efficiency differences. It is useful in this respect to recall the three components of efficiency differences in this paper: a country aggregate component; a country-industry-specific component; and a firm-specific component. The general equilibrium models of international specialization with only one quality differentiated good such as Flam and Helpman (1987) (see the rest of references in the introduction) only consider the first component of efficiency differences. As a consequence, they obtain a positive aggregate-economy link between efficiency and quality: richer countries specialize in producing the higher quality goods. Heterogeneous firm models of international trade with quality differentiation (see references in footnote 4) only consider the third source of efficiency differences. Therefore, the equilibrium is not characterized in terms of country characteristics. The model in this paper considers the industry-country-specific component of firms' efficiency (which may be termed the *Dornbusch-Fischer-Samuelson component),* in addition to the aggregate and the firm specific components. This compo-

10. See appendix. This approach brings about exactly the same result than a Cournot equilibrium where each firm first chooses how many *quality units* of the good to produce (i.e., it chooses the product $x_{ki}(j) \cdot q_{ki}(j)$), given the other firms' production of quality units; and second, it chooses which combination of quantity and quality minimizes the cost of producing this optimal number of quality units. On a different matter, note that for optimal quality choices, firm $k_i(j)$'s cost per unit of quality $c_{ki}\,(q_{ki}(j), j) / q_{ki}(j)$ is equal to $w_i / [T_i\, a_i(j)\, z_k]$. Hence the parameter σ does not play a role when comparing costs across firms and countries in equilibrium.

nent is what brings about a link between the country's absolute advantage in a particular industry and average output quality. A country's absolute advantage in a given industry implies that, on average, its firms will tend to be more efficient relative to the world, and therefore will tend to produce higher quality. Still, the link is not completely straightforward but conditional on other circumstances. If the country also has a low wage, inefficient firms will also be able to stay active in the market. This will tend to reduce average quality of the country's output, even if it has an absolute advantage in the good. These are the issues analyzed in detail in section 5.

Besides the equilibrium conditions at the firm level in expressions (3.7) and (3.8), industry equilibrium also requires that firm market shares add up to 1. Let ψ_{ij} $(P(j))$ be the sum of country-*i* firms' market shares in industry *j:*

$$\psi_{ij} \equiv \sum_{k=0}^{\bar{k}_i(j)} s_{ki}(j).$$

Industry *j* equilibrium condition is:

$$\psi_{Fj}\,(P(j)) + \psi_{Dj}\left(P(j)\frac{Ta(j)}{w}\right) = 1\,. \qquad (3.10)$$

For any wage and technology parameters, which are summarized by the ratio $Ta(j) / w$, there is always an equilibrium industry price level $P(j)^*$ such that (3.10) is satisfied. Intuitively, given technology and wages, all firm market shares would go to zero for a price level sufficiently low (note that even producing output of zero quality is costly). On the other hand, for high enough $P(j)$ we would have $\psi_{Fj}\,(P(j)) + \psi_{Dj}\,\,(P(j)\;Ta(j) / w) > 1$. Continuity of market shares on $P(j)$ ensures the existence of an industry equilibrium price level.

Proposition 3.1. *For any $T > 0$ and $w > 0$, there exists a price level $P_j^* > 0$ such that industry j is in equilibrium (i.e., expression [3.10] is satisfied). Moreover, P_j^* is a continuous and decreasing function of the ratio $Ta(j) / w$, $P_j^* = P^*\,(Ta(j) / w)$.*

Proof. See appendix.

In addition to equilibrium in every industry, the general equilibrium of the model requires that labor demand matches aggregate labor supply in each country. Labor supply is assumed to be equal to one in both countries. Using expressions (3.5), (3.7) and (3.8) we get the following equilibrium condition for the labor market in each country:

$$\int_0^1 l_i(j)\, dj = \frac{1}{w_i} Y_W \int_0^1 \left(\sum_{k=0}^{\infty} s_{ki}(j)\, [1 - s_{ki}(j)] \right) dj = 1;\ i = H, F. \quad (3.11)$$

These two conditions determine the relative wage w and the scale of world income Y_W. The relative wage w may be seen as determining how the sum of market shares is distributed between the two countries in a way that is consistent with their relative labor supplies and productivities. In turn, world income Y_W adjusts to the scale that is consistent with the absolute size of labor supplies [11].

Proposition 3.2. *For any $T > 0$ there exists a wage w^* and a world income Y_W^* satisfying all the equilibrium conditions. Moreover, w^* is continuous and strictly increasing in T.*

Proof. See appendix.

From here, we can then solve for all the variables. Given w^*, the function $P_j^* = P^*\ (Ta(j)\ /\ w)$ determines prices. Then, expression $y_{ij}(P(j)T_i a_i(j)/w_i)$ determines countries' market shares in each industry. Production levels are obtained using these (value) market shares, Y_W^*, and prices.

11. Some intuition on how the equilibrium of the world economy is reached may be as follows. For home wage w low enough, home country market shares would be equal to one in all industries. For w high enough the opposite is true: foreign-country firms would get all the market in all industries. Since industry equilibrium prices and country market shares are continuous in w, there is an intermediate w^* such that the distribution of market shares across countries is consistent with their relative labor supplies.

4. Specialization Across Goods

THIS section characterizes country specialization across industries. Implications of the model are more easily derived by letting the number of firms vary in a continuous way. In what follows we assume that there is a continuous number of potential firms in each country. In every country and industry, the firm-specific efficiency parameters z_k are given by a continuous and differentiable function $g(k)$, $g: [0, \infty) \rightarrow (0, 1]$, such that $g(0) = 1$ and $dg/dk < 0$. The analysis in the previous section carries over exactly the same by substituting sums across the set of firms with integrals. In equilibrium, only a finite measure $\bar{k}_i(j)$ of firms from each country is active in each industry [12].

4.1. Aggregate efficiency, wages and income

In this subsection we obtain some intermediate results that are not interesting by themselves but will prove very useful in the following. An increase in a country's aggregate efficiency lowers its firms' costs and raises their incentives to hire more labor and increase production. This increases wages and lowers the prices in industries where the country is a producer. However, the wage increase and the price reductions do not completely offset the positive impact of efficiency on firms' profits (except in industries where the country is the unique producer). The following proposition summarizes these and other related facts.

12. The use of the continuum in the Cournot setting is not infrequent in the literature (e.g., in the comparative static analysis of the Cournot equilibrium with respect to the number of firms). It is of great mathematical convenience even if somewhat counterintuitive. Note that when each firm takes as given the distribution of competitors' output and qualities, it is irrelevant whether the set of competitors is measured in discrete or in continuous units. Then, given competitors' choices, the firm's optimal output and quality is computed as if it were a *full measure-one firm* (thus, having a non-negligible impact on the industry equilibrium). This implies the same first order conditions as in the model with a discrete number of firms (i.e., expressions [A.1] and [A.2] in the appendix). Finally, each firm's output computed in this way is integrated with the rest of firms' output to make up industry output as in any other model using the convention of a continuum of agents.

Proposition 4.1. *An increase in home aggregate efficiency T brings about: 1) a less than proportional increase in the home wage w; 2) a less than proportional reduction in the price and an increase in the* $P^*(j)T/w$ *ratio in those industries where both countries have positive production; 3) an increase in home-country relative income* υ.

Proof. See appendix.

Results 1) and 3) imply that country aggregate efficiency, wage, and relative income are positively connected. Throughout the rest of the paper we use expressions *richer country, country with higher aggregate efficiency,* and *country with the higher wage* as equivalents [13].

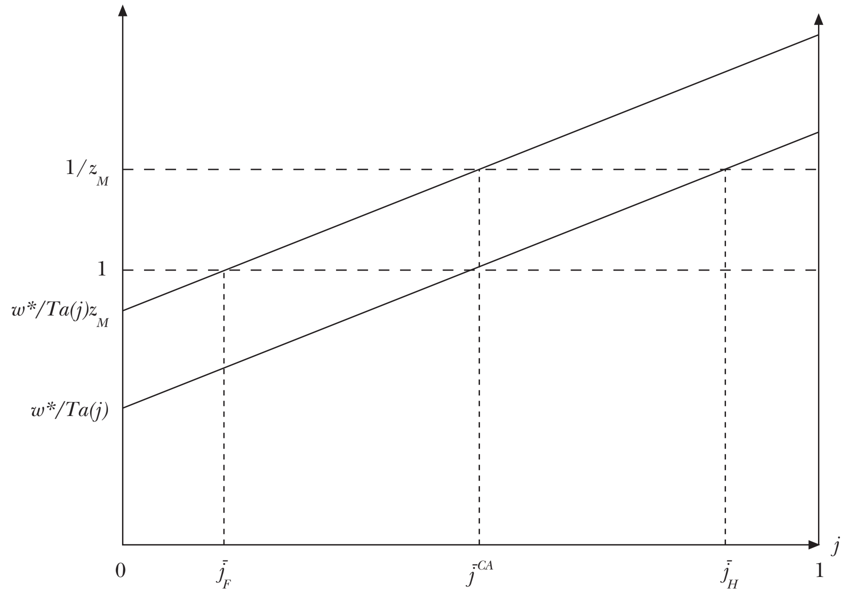
4.2. The extensive margin of exports

How does horizontal specialization relate to income and comparative cost? The model's basic implications on horizontal specialization can be presented graphically. Consider graph 4.1 which is drawn for a given set of technology parameters and the corresponding relative equilibrium wage w^*. Define country *i*'s *marginal firm* in industry *j* as the one that would just be in the margin of being active should firms from the other country have zero share in market *j* (this could be the consequence of country *i* being very competitive in this industry). Subscript *M* denotes marginal firm variables. Graph 4.1 draws firm costs $w_i/T_ia_i(j)z_k$ as a function of the industry [14], for four types of firms: home country's most efficient firms ($k = 0$) and marginal firms ($k = M$); and, similarly, foreign country's most efficient firms and marginal firms. Solid lines correspond to home-country firms whereas dotted lines correspond to foreign-country firms. For each country, the lower line corresponds to the most efficient firms' cost (recall that, due to normalizations, $w_F/T_Fa_F(j)z_0 = 1$). Upper lines correspond to marginal firms' costs. Since $a(j)$ is decreasing, domestic firms become relatively less efficient as we move towards higher *j*.

13. This is an imprecise equivalence because the share of profits in national income may not be the same in both countries. A sufficient condition for this equivalence to be precise is that the schedule $a(j)$ is symmetric; where symmetry is defined as $a(j) = 1 / a(1-j)$ for every *j*. To see this, consider an economy where this condition holds and assume $T = 1$. It can then be shown that both countries would have the same wage and income (note that equilibrium in this economy involves $P(1-j) = a(j)P(j)$). Now, consider any $T \neq 1$. Recalling that $dw^* / dT > 0$ and $d\upsilon / dT > 0$ we conclude that $w^* > 1$ and $\upsilon > 0.5$ if and only if $T > 1$. Moreover, as long as the difference between countries' aggregate efficiency is large enough, the richer country will also have a higher wage even if the schedule $a(j)$ is not symmetric.

14. The ratio $w_i / T_ia_i(j)z_k$ is firm *k*'s cost *per unit of quality* (or, equivalently, per unit of output value): see footnote 10.

GRAPH 4.1: Specialization across goods



Note: Each line shows costs across *j* for four types of firms: the most efficient firm (firm 0; so that $z_0 = 1$) and the marginal firm (firm *M*) in the home country (solid lines) and the foreign country (dashed lines).

Expression (3.7) implies that two firms $k_H(j)$ and $k_F'(j)$ in a given industry, one from each country, have the same market share if they have the same cost ratio. That is, if $w/Ta_j z(k_H(j)) = z(k_F'(j))$. Now note that for industry $j = \bar{j}_H(T)$, the most efficient home firm has the same cost ratio as the foreign marginal firm. Hence both firms have zero market share since, by definition, marginal firms have zero market share. Thus, for $j > \bar{j}_H(T)$ the most efficient home firm has higher costs than the marginal foreign firm. Hence home-country output for $j \geq \bar{j}_H(T)$ is zero. Symmetrically, for $j \leq \bar{j}_F(T)$ foreign output is zero. Now, any increase in T shifts downwards the domestic schedules since the ensuing increase in the equilibrium wage w^* is less than proportional (proposition 4.1). It therefore moves both cutoffs $\bar{j}_H$ and $\bar{j}_F$ to the right. Therefore,

Proposition 4.2. *An increase in a country's aggregate efficiency expands the range of industries where the country is a producer.*

As long as higher income is linked to aggregate efficiency, this proposition implies that richer countries export a wider set of goods. As pointed out in the introduction, Hummels and Klenow (2005) have shown the large quantitative importance of this extensive margin of exports.

The formal argument for this result is as follows. Denote by $\bar{P}$ the value of $P(j)$ that solves $\psi_{Fj}(P(j)) = 1$ (see the proof of proposition 2.1 for details on $\bar{P}$, which is the same for all j) [15]. This must be the equilibrium price at the cutoff industry $\bar{j}_H$. Moreover, the most efficient domestic firm in industry $\bar{j}_H$ must be exactly on the edge of being active. Hence, $\bar{j}_H(T)$ is the industry satisfying $s_{0H}(\bar{j}_H) = 1 - ew^*(T) / [\bar{P}\,Ta(\bar{j}_H)\,z_0] = 0$. That is,

$$a(\bar{j}_H) = e\,\frac{w^*(T)}{\bar{P}T}. \tag{4.1}$$

Differentiating with respect to T and recalling proposition 4.1 yields the result in proposition 4.2:

$$\frac{d\bar{j}_H}{dT} = \frac{1}{\partial a(\bar{j}_H) / \partial \bar{j}_H}\;\frac{a(\bar{j}_H)}{T}\left[\frac{dw^*}{dT}\,\frac{T}{w^*} - 1\right] > 0.$$

4.3. Comparative costs and country market shares

The cutoff between industries where the home country has a cost advantage and those where the foreign country does corresponds to the crossing of the two upper lines in graph 4.1. This cutoff is denoted by $\bar{j}^{CA}$ and satisfies:

$$Ta(\bar{j}_H^{CA}) / w^*(T) = 1. \tag{4.2}$$

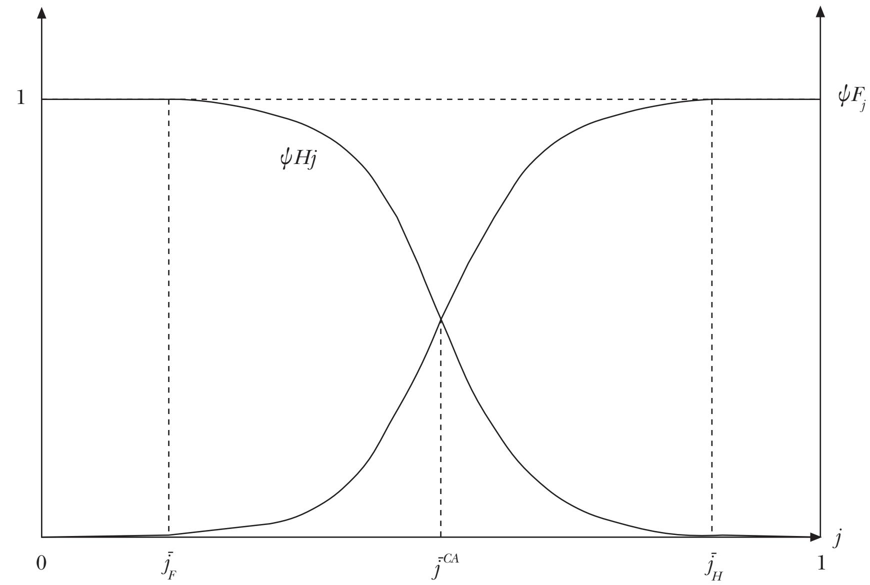
This is the single cutoff in the standard DFS model without transportation costs. In this standard model, country H is the only producer and exporter for $j < \bar{j}^{CA}$, and F is the only producer and exporter for $j > \bar{j}^{CA}$. In this model, continuity of firms' market shares on wages and efficiency parameters leads to the following,

Proposition 4.3. *Home county's market share in industry j is a continuous and decreasing function of its comparative cost w/ Ta(j).*

Graph 4.2 illustrates the pattern of market shares implied by this proposition. It is straightforward to check this proposition recalling that country i's market share is the sum of its firms' markets shares. Expression (3.9)

15. It can also be shown that marginal firms' efficiency is given by $z_M = e / \bar{P}$.

GRAPH 4.2: Country market shares across industries



for $\bar{k}_H(j)$ implies that the set of domestic active firms is decreasing in $w/Ta(j)$. On the other hand, expression (3.7) implies that each domestic firm's market share is decreasing in $w/Ta(j)$. Thus, lower comparative cost implies larger home-country market share both because the number of its active firms is larger and because each firm has larger market share. On the other hand, lower ratio $w/Ta(j)$ also implies a lower equilibrium industry price level $P(j)^*$ (proposition 3.1), which pushes foreign output and market shares down.

5. Countries' Output Quality Within Each Industry

THIS section characterizes countries' specializations within each industry along the quality dimension. Subsection 5.1 investigates which countries produce each specific quality within each industry, and how this relates to wages and absolute advantage. In turn, subsection 5.2 focuses on average quality. Results are then compared at the end of the section with the empirical evidence in section 2.

5.1. Who produces which qualities within each industry?

For obvious reasons, the analysis in this subsection focuses on industries in the interval $(\bar{j}_F, \bar{j}_H)$ where both countries have positive production. Consider an industry in this interval. Active firms from country i span the interval of efficiencies $(T_i\, a_i(j)\, z_{\bar{k}i(j)}, T_i\, a_i(j)]$ which determines the interval of qualities produced by the country. From (3.8) it is clear that the country with the highest value of $T_i\, a_i(j)$ (i.e., the country with the absolute advantage in this industry) produces the highest quality. This expression also implies that the least efficient active firm in each country produces the lowest quality in that country. Now, who does produce the lowest quality in the world market? Consider the least efficient firms from H and F: $\bar{k}_H(j), \bar{k}_F(j)$. From (3.8) and (3.9), we have:

$$1 = \frac{ew_H}{P(j)\,[q_{\bar{k}H}(j)]^{1/\sigma}} = \frac{ew_F}{P(j)\,[q_{\bar{k}F}(j)]^{1/\sigma}}\ .$$

This yields,

$$\frac{q_{\bar{k}H}(j)}{q_{\bar{k}F}(j)} = \left(\frac{w_H}{w_F}\right)^{\sigma}\ . \tag{5.1}$$

Therefore, the lowest quality variety is produced in the country with the lowest wage. The reason is that lower wages allow lower-efficiency firms to be competitive; but lower efficiency implies producing lower quality. Now, consider the range of quality varieties produced by country *i*. The span of this range can be measured by the ratio between the highest and the lowest quality:

$$\frac{q_{0i}(j)}{q_{\bar{k}i}(j)} = \left(\frac{T_i\, a_i(j)}{T_i\, a_i(j)\, z_{\bar{k}i(j)}} \right)^{\sigma} = \frac{1}{(z_{\bar{k}i(j)})^{\sigma}}. \tag{5.2}$$

Since for any $P(j)$, $z_{\bar{k}i(j)}$ will be lower for the country with lower cost $w_i/T_i a_i(j)$ (see expression [3.9]), we conclude that the country with the cost advantage in industry *j* produces a wider spectrum of qualities [17]. Summarizing,

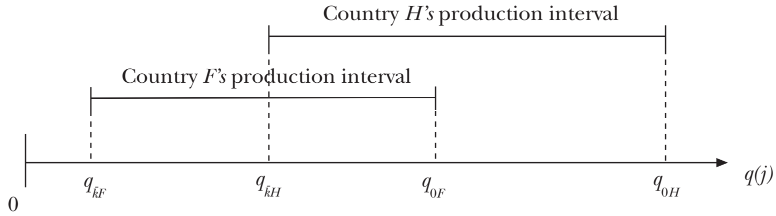
Proposition 5.1. *Consider an industry where both countries have positive market shares: 1) the highest quality is produced in the country with the absolute advantage; 2) the lowest quality is produced in the country with the lowest wage; 3) the country with the cost advantage produces a wider spectrum of qualities.*

Graphs 5.1a and 5.1b illustrate this proposition assuming that the home country has higher wage level. Graph 5.1a considers an industry where the home country has an absolute advantage. Hence it is the unique producer of the highest qualities $q \in (q_{0F}(j), q_{0H}(j)]$. On the other hand, the foreign country is the unique producer of the lowest qualities $q \in (q_{\bar{k}F}(j), q_{\bar{k}H}(j))$ since it has lower wage. Graph 5.1b considers an industry where the foreign country has an absolute advantage. Hence the foreign country is the unique producer of the highest qualities $q \in (q_{0H}(j), q_{0F}(j)]$, as well as the lowest qualities. The richer (home) country only produces some intermediate qualities.

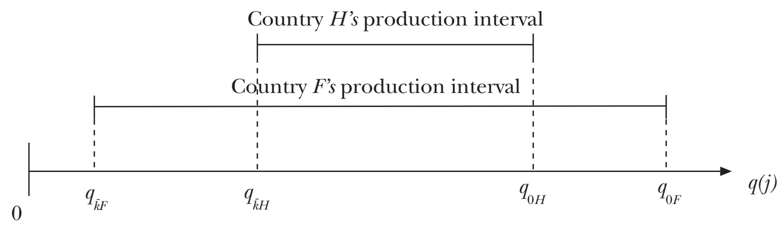
Proposition 5.1 shows some of the connections between vertical and horizontal specializations. Comparative costs $w / Ta(j)$ determine market shares across goods as well as the relative width of the range of qualities produced by each country. Then, each of the two components of this ratio plays a specific role: a high denominator (high absolute advantage) is linked to producing the

17. See Bernard, Redding and Schott (2007) for a similar result in a heterogeneous firm model with no quality differentiation. Also note that this result implies an *extensive margin of exports within the quality dimension:* an increase in a country's income brings about an increase in the range of qualities exported within each industry. The reason is that an increase in a country's aggregate efficiency raises its comparative cost advantage in all industries where it is an exporter (since, according to proposition 4.1, the ensuing wage increase is less than proportional).

GRAPH 5.1a: Interval of quality varieties produced by each country. The case of an industry where the richer country *(H)* has an absolute advantage



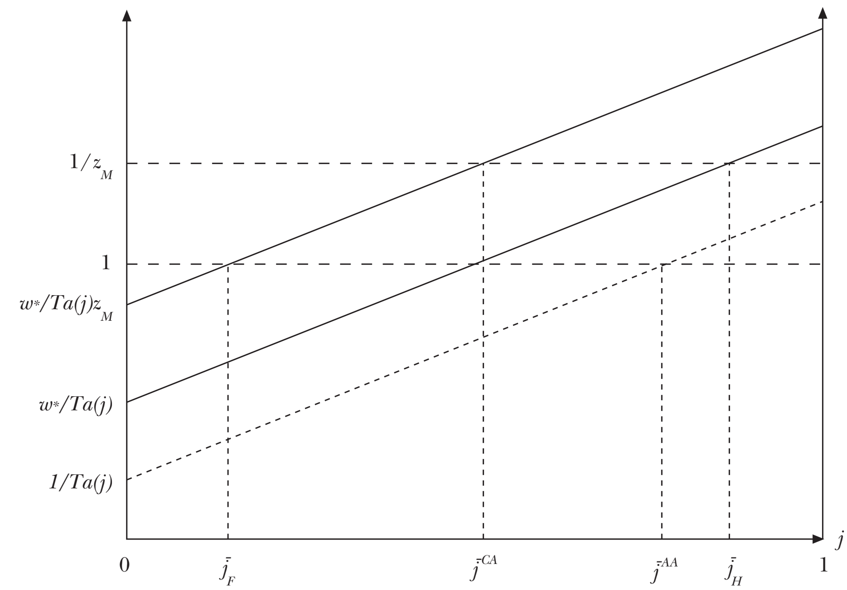
GRAPH 5.1b: Interval of quality varieties produced by each country. The case of an industry where the poorer country *(F)* has an absolute advantage



higher qualities, whereas a low numerator (low wage) is linked to producing the lower qualities.

Graph 5.2 provides an overall picture of countries' horizontal and vertical specializations. In comparison to graph 4.1 it includes a new dotted line that depicts the inverse of country *H*'s efficiency across industries $Ta(j)$. This new line is drawn assuming that country H has a higher wage level than F ($w > 1$) so that it is below the $w/Ta(j)$ line. Industry $\bar{j}^{AA}$ is the cutoff between industries where the home country has an absolute advantage (to the left of $\bar{j}^{AA}$) and industries where the foreign country has it (to the right). According to proposition 5.1, country H produces the highest-quality varieties to the left of $\bar{j}^{AA}$ and country F does so to the right. Moreover, to the left of $\bar{j}^{CA}$ country H has also a cost advantage and produces the widest spectrum of quality varieties (symmetrically for F to the right of this cutoff). As explained in graph 4.1, both countries have positive production for industries between $\bar{j}_F$ and $\bar{j}_H$. Between $\bar{j}^{AA}$ and $\bar{j}_H$, the poorer country is the only producer of the highest quality varieties in spite of the richer country being also a producer of these goods. To the right of $\bar{j}_H$ the poorer country is also the unique producer of the highest qualities but in a trivial sense since the richer country does not produce these goods at all. The lowest qualities of all the goods

GRAPH 5.2: Specialization across goods and quality specialization within goods



Note: The graph adds the inverse of country *H*'s efficiency across industries $1/Ta(j)$ (the dotted line) is added to the lines already in graph 4.1. Country *H* is assumed to have a higher wage level. For goods between $\bar{j}_F$ and $\bar{j}_H$ both countries have positive production. To the left (respectively, right) of $\bar{j}^{AA}$ country *H* (resp. country *F*) has an absolute advantage and produces the highest-quality varieties. To the left (resp. right) of $\bar{j}^{CA}$ it has a cost advantage and produces the widest set of quality varieties. To the right of $\bar{j}_F$ country *F* produces the lowest quality varieties.

are produced in country *F* except to the left of $\bar{j}_F$, which corresponds to the interval of goods not produced in this poorer country.

Note that $\bar{j}^{AA}$ in graph 5.2 could be to the right of $\bar{j}_H$. This would imply that the richer country does not produce some of the goods for which it has an absolute advantage [18]. Another interesting particular case occurs when $Ta\,(1) > 1$ (the richer *H* country has an absolute advantage in all goods) and $Ta\,(1)/w > z_M$ (it produces some variety of every good). Country specialization in this case roughly corresponds to the one described in trade models with only one quality differentiated good: the richter country is the only producer and exporter of the higher qualities of all goods.

18. The country with the absolute advantage in a given industry may gradually abandon it as wages increase. For example, Florida might have the highest absolute advantage for producing oranges, but it would loose market share as its wage level rises (proposition 4.3). The market share reduction will concentrate on the cheapest (lower-quality) varieties which are produced by the least efficient firms. Eventually, for sufficiently high wages, even the most efficient firms would be unable to survive in spite of the absolute advantage.

Proposition 5.1 points out that the production of the highest qualities is not directly linked to country income but to absolute advantage in each specific industry. Still, it is more likely that richer countries produce the higher qualities for the simple reason that countries are richer just because they have an absolute advantage in more (or more important) industries. Some sources of absolute advantage may have an imperfect, low, or even null correlation with per capita income (e.g., specific natural resources or histories of specialization that created some local knowledge and other positive externalities in particular industries). However, the general sources of absolute advantage tend to be highly correlated with income (e.g., high average education, easy and cheap access to financial resources, good institutions, or public infrastructures). The fact that richer countries tend to produce the highest qualities for a larger set of goods than poorer countries is reflected in the model as follows:

Proposition 5.4: *The richer country produces the highest qualities for a set of industries that is larger than the set of industries for which it has a cost advantage.*

This can be checked using graph 5.2. If H is richer, then $1/Ta(\bar{j}^{AA}) =$ $= 1 = w/Ta(\bar{j}^{CA}) > 1/Ta(\bar{j}^{CA})$. Therefore, since $a(j)$ is decreasing, $\bar{j}^{CA}$ is always to the left of $\bar{j}^{AA}$.

5.2. Average quality

5.2.1. Average quality and income level

Average quality of world's and country i's output in industry j are, respectively:

$$Q_W(j) \equiv \sum_{i=H,F} \int_0^{\bar{k}_i} r_{ki}(j)\, q_{ki}(j)\, dk,$$

$$Q_i(j) \equiv \frac{\int_0^{\bar{k}_i} r_{ki}(j)\, q_{ki}(j)\, dk}{\int_0^{\bar{k}_i} r_{ki}(j)\, dk},$$

where $r_{ki}(j)$ is firm $k_i(j)$'s share in the world market of j, in physical units of output. Since,

$$r_{ki}(j) \equiv \frac{x_{ki}(j)}{\sum_{i=H,F} \int_0^{\bar{k}_i} x_{ki}(j)\, dk} = s_{ki}(j)\, \frac{Q_W(j)}{q_{ki}},$$

we have:

$$Q_i(j) = \frac{\int_0^{\bar{k}_i} s_{ki}(j)\, dk}{\int_0^{\bar{k}_i} s_{ki}(j) / q_{ki}(j)\, dk} = w_i^{\sigma} \left(\frac{T_i\, a_i(j)}{w_i}\right)^{\sigma} \frac{\int_0^{\bar{k}_i} s_{ki}(j)\, dk}{\int_0^{\bar{k}_i} s_{ki}(j) / (z_{ki}(j))^{\sigma}\, dk}. \qquad (5.3)$$

Recall that differences across countries in market shares $s_{ki}(j)$ and in the measure of active firms $\bar{k}_i(j)$ can only arise as a consequence of differences in comparative costs $w_i/T_i a_i(j)$ (see expressions [3.7] and [3.9]). It is then immediate the following.

Proposition 5.2. *Consider an industry where both countries have positive production. Conditional on comparative costs, higher country wage implies higher average quality.*

The intuitive argument for this result is simple. Two countries with the same cost level in a given industry will have the same measure of active firms; and for every k, firm k in one country will have the same market share than the corresponding firm k in the other country. However, if the wage in one of the countries is higher, then it must be the case that this country has higher absolute efficiency in the industry. Thus, for every pair of firms with the same cost and market share, one from each country, the firm from the country with higher wage is more efficient and produces higher quality.

This proposition suggests that regressions between export average quality and country per capita income should be run conditional on some measure of comparative costs. This motivates the approach in section 2, as we discuss at the end of this section. Still, unconditional regressions between average quality of exports and country per capita income have delivered significant positive coefficients for a large set of industrial goods, as well as at the aggregate level (see Schott, 2004 and Hummels and Klenow, 2005). Proposition 5.2 is consistent with these empirical findings as long as, for a large set of industries, cross-country differences in costs are moderate or are not positively correlated with country per capita income (since, as proposition 5.3 states below, larger comparative costs bring about lower quality).

5.2.2. Average quality and comparative advantage

Consider now the average quality consequences of differences in comparative costs conditional on wages. Given wages, differences in comparative costs in an industry imply higher absolute advantage. In an economy with homogeneous firms and the same wages, average output quality would unquestionably be higher in the country with higher absolute advantage in the industry. However, the relationship may be uncertain if firms are heterogeneous. The reason is that higher absolute advantage involves a larger set of active firms in the country and a reallocation of market shares across firms producing different qualities. Market shares of less-efficient firms (which produce lower quality) could increase relative to the market shares of more-efficient firms when the country's efficiency increases. In fact, it is straightforward from (3.7) that this will be the case. For some distribution of firm efficiencies, this could give rise to a negative composition effect such that higher efficiency involves lower average output quality. Nevertheless, reasonable assumptions on the distribution of efficiency across firms may rule out this possibility.

Let us consider the following distribution pattern of firms' efficiency, which satisfies the general characteristics assumed on $g(k)$ at the beginning of section 4:

$$z_k = e^{-\theta k}, \ \theta > 0, \ k \in [0, \infty]. \tag{5.4}$$

Larger θ involves wider heterogeneity across firms. This distribution is flexible enough to approximate a wide array of possible industry configurations. Using (5.4) to substitute in (5.3) we have:

$$Q_i(j) = \frac{\frac{1}{\theta}\left[\ln b + \frac{1}{b} - 1\right]}{\left(\frac{1}{T_i a_i(j)}\right)^{\sigma} \frac{1}{\theta} \frac{1}{\sigma} \left[\frac{1}{1+\sigma} b^{\sigma} + \frac{\theta}{1+\sigma} \frac{1}{b} - 1\right]}, \tag{5.5}$$

where $b \equiv \dfrac{P(j) T_i a_i(j)}{w_i e}$.

The derivative of the log of $Q_i(j)$ with respect to country's efficiency in industry j, $T_i a_i(j)$, yields:

$$\frac{\partial Q_i(j)}{\partial (T_i a_i(j))} \frac{T_i a_i(j)}{Q_i(j)} = \frac{1}{\theta} \frac{s_{0i}(j)}{\psi_i(j)} \left[1 - \frac{Q_i(j)}{q_{0i}(j)}\right] > 0. \tag{5.6}$$

Thus, higher efficiency in industry j implies higher average quality. Note that differences in $Q_i(j)$ across countries only depend on differences in the wage level and efficiency in the industry. Moreover, conditional on wages, higher efficiency in the industry implies lower comparative cost. Therefore, we have the following

Proposition 5.3. *Consider an industry where both countries have positive production. Conditional on wages, lower country comparative cost implies higher average output quality.*

The empirical exercise in section 2 is directly related to propositions 5.2 and 5.3. Section 2 shows for two illustrative goods that *PCGDP* and *RCA* are jointly and significantly correlated with export unit values (whereas unconditional correlations are not significant in some cases). Still, to make more transparent the connection between the empirical section and the propositions, we now check the relationship between the observable *RCA* index used in the regressions and the comparative cost concept used in the propositions. Let us restate the definition of *RCA* using the notation developed so far (recall that country *i* exports a fraction $(1\text{-}v_i)$ of each good):

$$RCA_i(j) = 100 \cdot \frac{(1 - v_i)\, \psi_{ij}\; Y_W}{(1 - v_i)\; Y_i} \Big/ \frac{\sum_{h=H,F} (1 - v_h)\, \psi_{hj}\; Y_W}{\sum_{h=H,F}\, (1 - v_h)\; Y_h} = \\ = 100 \cdot \frac{\psi_{ij}(T_i a_i(j)/w_i)}{v_i} \cdot \zeta(j), \qquad (5.7)$$

where $\zeta(j) \equiv \sum_{h=H,F} (1 - v_h)\; v_h \,/ \sum_{h=H,F} (1 - v_h)\; \psi_{hj}$. Note that $\zeta(j)$ only depends on the industry and therefore enters the expression for $RCA_i(j)$ in the same way for all countries. Hence, conditional on the country's income share $v_i = Y_i \,/\, Y_W$, there is an increasing one-to-one mapping between the country's *RCA* in a given industry and its comparative cost ratio $T_i\; a_i(j) \,/\, w$. Therefore, we can use *RCA* to test propositions 5.2 and 5.3 by including exporter's *GDP* in the estimating equation, in addition to *RCA* and *PCGDP* (this last variable being used as a proxy for the wage level). When the log of exporter's *GDP* is added to the equations estimated in section 2 it turns out to be not significant, whereas the significance of *PCGDP* and *RCA* stays the same. In sum, the evidence in section 2 is entirely consistent with the model and, in particular, with propositions 5.2 and 5.3.

6. Concluding Remarks

RECENT empirical research has documented the importance of country specialization across both the horizontal and the vertical dimensions of goods to characterize the current patterns of trade. Existing models tend to concentrate on only one of the two dimensions of specialization and neglect their possible connections. However, the evidence provided at the beginning of this paper suggests that these connections may be important. This paper provides an integrated model where both the horizontal and the vertical dimensions of trade are present and their interactions are investigated. The paper shows that the factors that create absolute and comparative advantages across goods also play an important role in the vertical specialization within goods. The model is consistent with the specific empirical motivation in the paper as well as with previously documented facts. Some of the most important simplifications of the model relate to demand. Generalizing this component of the analysis seems an especially interesting direction for further research.

Appendix

Firms' profit maximization first order conditions

Firms maximize profits $\pi_{ki}(j) = x_{ki}(j)\,[q_{ki}(j)\,P(j) - c_{ki}(q, j)]$ with respect to $x_{ki}(j)$ and $q_{ki}(j)$, taking as given industry inverse-demand function (3.4) and other firms' output and quality choices. Thus, from firm $k_i(j)$'s perspective,

$$\frac{\partial P(j)}{\partial x_{ki}(j)} = - \frac{P(j)\, q_{ki}}{\sum_{g=H,F} \sum_h q_{hg}(j)\, x_{hg}(j)} \quad \text{and} \quad \frac{\partial P(j)}{\partial q_{ki}(j)} = - \frac{P(j)\, x_{ki}}{\sum_{g=H,F} \sum_h q_{hg}(j)\, x_{hg}(j)}.$$

Hence profit maximization yields the following FOC:

$$\begin{aligned} \frac{\partial \pi_{ki}(j)}{\partial x_{ki}(j)} &= q_{ki}(j)\, P(j) + x_{ki}(j)\, q_{ki}(j) \frac{\partial P(j)}{\partial x_{ki}(j)} - c_{ki}(q, j) = \\ &= P(j) - s_{ki}(j)\, P(j) - \frac{c_{ki}(q, j)}{q_{ki}(j)} = 0. \end{aligned} \tag{A.1}$$

$$\begin{aligned} \frac{\partial \pi_{ki}(j)}{\partial q_{ki}(j)} &= P(j) + q_{ki}(j) \frac{\partial P(j)}{\partial q_{ki}(j)} - \frac{\partial c_{ki}(q, j)}{\partial q_{ki}(j)} = \\ &= P(j) - s_{ki}(j)\, P(j) - \frac{\partial c_{ki}(q, j)}{\partial q_{ki}(j)} = 0. \end{aligned} \tag{A.2}$$

Then (A.1) and (A.2) yield (3.7) and (3.8) in the main text.

Proof of proposition 3.1

First, let us characterize the functions $\psi_{Fj}(P(j))$ and $\psi_{Hj}(P(j)Ta(j)/w)$. Note that (3.9) implies that the number of active firms $\bar{k}_i(j)$ is increasing in $P(j)$. Moreover, when a firm just becomes active it starts with a zero market share. Then, its share increases continuously as a function of $P(j)$. As a result, we have from expressions (3.7) and (3.9) that ψ_{Fj} is continuous in $P(j)$ and satisfies:

I) If $P(j) \leq e/z_0 = e$, then $\psi_{Fj}(P(j)) = 0$;
II) if $P(j) > e$, then $\psi_{Fj}(P(j)) > 0$ and strictly increasing;
III) since $\lim_{P(j)\to\infty} \psi_{Fj}(P(j)) > 1$, there exists $\bar{P}$, $\bar{P} > e$, such that $\psi_{Fj}(\bar{P}) = 1$.

Note that $\bar{P}$ does not depend on any parameter specific to industry j due to the normalization of foreign industry parameters. Similarly, it is easy to check that ψ_{Hj} is also a continuous and increasing function of the ratio $P(j)\ Ta(j)\ /\ w$. Moreover,

$$\psi_{Hj}(P(j)\ Ta(j)\ /\ w) = \begin{cases} 0 & \text{if and only if} \quad P(j)\ Ta(j)\ /\ w \leq e, \\ 1 & \text{if and only if} \quad P(j)\ Ta(j)\ /\ w = \bar{P}. \end{cases}$$

Now, the following claim completes the proof of proposition 3.1 by showing how the equilibrium price P_j^* is determined as a function of any possible value of the ratio $Ta(j)/w$.

Claim 3.1.A. *For any T, w, and the industry parameter a(j), there is an industry equilibrium price P_j^*. Moreover, P_j^* is a continuous and decreasing function of the ratio Ta(j)/w, the same for all j, satisfying:*

$$P_j^* = P^*(Ta(j)\ /\ w) \begin{cases} = \bar{P} & \text{if } Ta(j)\ /\ w \in (0,\ e/\bar{P}], & \text{impying } \Psi_{Hj} = 0,\ \Psi_{Fj} = 1. \\ \bar{P} > P_j^* > e & \text{if } Ta(j)\ /\ w \in (e/\bar{P},\ \bar{P}/e), & \text{impying } \Psi_{Hj} > 0,\ \Psi_{Fj} > 0. \\ = \bar{P}\dfrac{w}{Ta(j)} \leq e & \text{if } Ta(j)\ /\ w \in [\bar{P}/e,\ \infty), & \text{impying } \Psi_{Hj} = 1,\ \Psi_{Fj} = 0, \end{cases}$$

Moreover, if $Ta(j)\ /\ w \in (e/\bar{P},\ \bar{P}/e)$ then $0 > \dfrac{\Delta P_j^*}{P_j^*} \Big/ \dfrac{\Delta\ (Ta(j)\ /\ w)}{Ta(j)\ /\ w} > -1.$

To prove this claim, fix any value of $T\ /\ w$. Then,

I) For $0 < Ta(j)\ /\ w \leq e/\bar{P}$ we must have $P_j^* = \bar{P}$ since for any ratio $Ta(j)\ /\ w$ in that interval, $P(j) < \bar{P}$ would imply $\psi_{Fj} < 1$ and $\psi_{Hj} = 0$ (and $P(j) > \bar{P}$ implies $\psi_{Fj} > 1$). Hence $\psi_{Hj} = 0$ and $\psi_{Fj} = 1$.
II) Now consider $Ta(j)\ /\ w \geq \bar{P}/e$. We then have $P_j^* = \bar{P} w\ /\ [Ta(j)] \leq e$, since: 1) for a price lower than this expression we would have $\psi_{Hj} < 1$ and $\psi_{Fj} = 0$; 2) for a price higher than this expression we would have $\psi_{Hj} > 1$. Hence $\psi_{Hj} = 1$ and $\psi_{Fj} = 0$. Note that at the initial point of the interval defining this case, $Ta(j)\ /\ w = \bar{P}/e$, this result implies $P_j^* = e$.
III) Consider now intermediate values $Ta(j)\ /\ w \in (e/\bar{P},\ \bar{P}/e)$. Starting from $Ta(j)\ /\ w = e/\bar{P}$ and $P_j^* = \bar{P}$, any increase in $Ta(j)\ /\ w$ raises home-country market share above 0. This must be compensated

by a reduction in P_j^* so that (3.10) can be satisfied by means of a reduction in the foreign market share. Moreover, the relative increase $\Delta\ (Ta(j) / w) / (Ta(j) / w)$ must be larger (in absolute terms) than the relative reduction in the equilibrium price $\Delta P^*(j) / P^*(j)$ (otherwise the home country share would be either unaffected or reduced while the foreign share is reduced). This will be the case until ψ_{Fj} turns out equal to 0 as $Ta(j) / w$ reaches $e/\overline{P}$.

Proof of proposition 3.2

Consider equation (3.11) in the text:

$$\int_0^1 l_i(j)\, dj = \int_0^1 \sum_{k=0}^{\infty} e \frac{x_{ki}(j)}{[T_i\, a_i(j)\, z_k]^{1-\sigma}} dj =$$

$$= \frac{1}{w_i} \int_0^1 \sum_{k=0}^{\infty} P_j^*\, q_{ki}(j)\, x_{ki}(j)\ e \frac{w_i}{P_j^*\, T_i\, a_i(j)\, z_k} dj =$$

$$= \frac{1}{w_i} Y_W \int_0^1 \sum_{k=0}^{\infty} s_{ki}(j)\, [1 - s_{ki}(j)]\ dj = 1; \quad i = H, F.$$

Recall that market shares $s_{ki}(j)$ are functions of the ratio T / w and prices P_j^*; and that, in turn, prices are also functions of the ratio T / w. We can then define $\Psi_i\,(T / w) \equiv \int_0^1 \sum_{k=0}^{\infty} s_{ki}(j)\, [1 - s_{ki}(j)]\ dj$. Dividing expression (3.11) for $i = F$ by the same expression for $i = H$ yields:

$$w\ \frac{\Psi_F\,(T / w)}{\Psi_H\,(T / w)} = 1. \qquad \text{(A.3)}$$

This condition can be used to substitute for one of the labor-market equilibrium conditions (3.11). Wages satisfying (A.3) guarantee that country shares in production match relative labor supplies, whereas (3.11) for either H or F can be used to insure that world income Y_W adjusts to the scale that is consistent with the absolute size of world labor supply.

Foreign market shares $s_{kF}(j)$ are increasing in P_j^* and therefore decreasing in T / w. To the contrary, domestic shares are increasing in T / w since they positively depend on this ratio and the elasticity of P_j^* with respect to T / w is lower than 1 (see the last statement in claim 3.1.A in the proof of proposition 3.1). Then, recall that $a\ (1) \equiv a_1 = \min(a(j))$ and $a\ (0) \equiv a_0 =$ $= \max\ (a(j))$. Therefore, from claim 3.1.A (in the proof of proposition 3.1) we have that $T / w = e / (\overline{P} a_0)$ implies $\psi_{Hj} = 0$ all j; and $T / w = \overline{P}\ (a_1\ e)$ implies $\psi_{Fj} = 0$ all j. Now, assume the distribution of efficiencies is such that no firm has more than half the market share in any industry, e.g., $s_{0i}(j) < 0.5$, all j (this assumption is not necessary but greatly simplifies the proof). Then, it is easy to check that:

$$\Psi_H (T/w) \equiv \int_0^1 \sum_{k=0}^{\infty} s_{kH}(j)\,[1 - s_{kH}(j)]\; dj : \begin{cases} T/w = e/(\bar{P} a_0) & \Rightarrow \Psi_H (T/w) = 0. \\ e/(\bar{P} a_0) < T/w \leq \bar{P}/(a_1\, e) & \Rightarrow \Psi_H (T/w) > 0 \text{ and increasing.} \end{cases}$$

$$\Psi_F (T/w) \equiv \int_0^1 \sum_{k=0}^{\infty} s_{kF}(j)\,[1 - s_{kF}(j)]\; dj : \begin{cases} e/(\bar{P} a_0) \leq T/w < \bar{P}/(a_1\, e) & \Rightarrow \Psi_F (T/w) > 0 \text{ and decreasing.} \\ T/w = \bar{P}\,(a_1\, e) & \Rightarrow \Psi_F (T/w) = 0. \end{cases}$$

As integrals of continuous functions s_{ij} in T/w, $\Psi_H(T/w)$ and $\Psi_F(T/w)$ are also continuous in T/w. Define the function $\Phi\,(T/w) : (e/(\bar{P} a_0), \bar{P}/(a_1\, e)] \rightarrow [0, \infty)$ as $\Phi\,(T/w) \equiv \Psi_F (T/w) / \Psi_H (T/w)$. This function is characterized as follows:

$$\begin{cases} \lim_{T/w \rightarrow e/(\bar{P} a_0)} \Phi\,(T/w) = \infty. & \\ \Phi\,(T/w) \text{ is strictly decreasing in } T/w & \text{if } e/(\bar{P} a_0) < T/w < \bar{P}/(a_1\, e). \\ \Phi\,(T/w) = 0 & \text{if } T/w = \bar{P}/(a_1\, e). \end{cases}$$

Now, for any given $T \in (0, \infty)$, the product $w \cdot \Phi\,(T/w)$ can be seen as a function of w in the interval $[a_1\, e/\bar{P} T, \bar{P} a_0\, T/e)$, which is again continuous in w and satisfies:

$$w \cdot \Phi\,(T/w) \begin{cases} \lim_{w \rightarrow \bar{P} a_0\, T/e} w \cdot \Phi\,(T/w) = \infty. & \\ \text{strictly increasing in } w & \text{if } \bar{P} a_0\, T/e > w > a_1\, e/\bar{P} T. \\ = 0 & \text{if } w = a_1\, e/\bar{P} T. \end{cases}$$

Therefore for any $T > 0$ there exists w^*, $a_1\, e/\bar{P} T < w^* < \bar{P} a_0\, T/e$, satisfying the general equilibrium condition $w^* \cdot \Phi\,(T/w^*) = 1$. Moreover, since $\Phi\,(T/w)$ is decreasing in T/w, $w^* = w^*(T)$ is increasing in T.

Proof of proposition 4.1

First, consider the following,

Claim 4.1.A. *(Differentiability of country market shares and prices). With a continuous number of firms,* $\psi_{Hj}\,(P(j)\, Ta(j)/w)$ and $\psi_{Fj}\,(P(j))$

are differentiable. Furthermore, $\dfrac{\partial \Psi_H (T/w)}{\partial (T/w)} > 0$ *and* $\dfrac{\partial \Psi_F (T/w)}{\partial (T/w)} < 0.$

To prove this claim, it is useful to define $m \equiv P(j)T_i a_i(j)/w_i$ and consider firm and country market shares as functions of m. Note from expression (3.7) in the main text that each firm's market share $s_{ki}(j)$ is continuous and differentiable at all points $m > 0$, except at the point where the firm switches from being inactive to being active. Specifically, for $k_i = \bar{k}_i(j)$, the firm's market share $s_{\bar{k}i}(j)$ is continuous but not differentiable:

$$\lim_{m_h \to m^-} \frac{\partial}{\partial m} s_{\bar{k}i}(j) = 0 \neq \lim_{m_h \to m^+} \frac{\partial}{\partial m} s_{\bar{k}i}(j) = \frac{1}{m}.$$

However, the country's aggregate market share ψ_{ij} is differentiable at all points, as stated in claim 4.1.A. Specifically:

$$\lim_{m_h \to m^-} \frac{\partial}{\partial m} \psi_{ij} (m_h) = \lim_{m_h \to m^-} \frac{\partial}{\partial m} \int_0^{\bar{k}_{ij}} \left(1 - \frac{e}{m_h\, g(k)}\right) dk =$$

$$= \lim_{m_h \to m^-} \left[\int_0^{\bar{k}_{ij}} \frac{\partial}{\partial m} \left(1 - \frac{e}{mg(k)}\right) dk + \left(1 - \frac{e}{mg(\bar{k}_i(j))}\right) \frac{\partial \bar{k}_i(j)}{\partial m} \right] =$$

$$= \int_0^{\bar{k}_{ij}} \frac{e}{m^2\, g(k)}\, dk = \lim_{m_h \to m^+} \frac{\partial}{\partial m} \psi_{ij} (m_h).$$

Therefore, $\psi_{ij}(m)$ is differentiable with respect to m, for all $m > 0$. Moreover, $\partial \psi_{ij}(m) / \partial m > 0$.

Now, assuming to simplify the proof that the distribution of efficiencies is such that no firm has more than half of the market in any industry ($s_{0i}(j) < 0.5$, all j), we have:

$$\frac{\partial \Psi_F (T/w)}{\partial (T/w)} = \int_0^1 \left(\frac{d \sum_{k=0}^{\infty} s_{kF}(j)\, [1 - s_{kF}(j)]}{d\,(T/w)} \right) dj =$$

$$= \int_0^1 \left(\frac{\partial \sum_{k=0}^{\infty} s_{kF}(j)\, [1 - s_{kF}(j)]}{\partial P_j^*} \frac{dP_j^*}{d\,(T/w)} \right) dj < 0.$$

$$\frac{\partial \Psi_H (T/w)}{\partial (T/w)} = \int_0^1 \left(\frac{d \sum_{k=0}^{\infty} s_{kH}(j) [1 - s_{kH}(j)]}{d (T/w)} \right) dj =$$

$$= \int_0^1 \left(\frac{\partial \sum_{k=0}^{\infty} s_{kH}(j) [1 - s_{kH}(j)]}{\partial (P_j^* T/w)} P_j^* \left[1 + \frac{dP_j^*}{d (T/w)} \frac{T/w}{P_j^*} \right] \right) dj > 0.$$

Where the last inequality takes into account that $0 \geq \frac{\Delta P_j^*}{P_j^*} / \frac{\Delta (T/w)}{(T/w)} \geq -1$ for all j, with strict inequalities for an open interval (see claim 3.1.A). This completes the proof of claim 4.1.A.

Now, to check 1) in proposition 4.1 use claim 4.1.A to differentiate expression (A.3) with respect to T. This yields:

$$0 < \frac{dw^*}{dT} \frac{T}{w^*} = \frac{\varepsilon_\Phi}{\varepsilon_\Phi - 1} < 1, \tag{A.4}$$

where $\varepsilon_\Phi \equiv \frac{\partial [\Psi_F (T/w) / \Psi_H (T/w)]}{\partial (T/w)} \frac{(T/w)}{\Psi_F (T/w) / \Psi_H (T/w)} < 0.$

To check 2), note first that both countries have strictly positive market if $Ta(j) / w \in (e/\bar{P}, \bar{P}/e)$ (see claim 3.1.A). Differentiating $P_j^* (Ta(j)/w)$ with respect to T and using claim 3.1.A and (A.4) yields:

$$-1 < \frac{dP_j^*}{dT} \frac{T}{P_j^*} = \frac{\partial P_j^*}{\partial (T/w)} \frac{T/w}{P_j^*} \left[1 - \frac{dw}{dT} \frac{T}{w} \right] < 0 \text{ for } j \text{ such that } a(j) \in \left(\frac{ew}{\bar{P}T}, \frac{\bar{P}w}{eT} \right). \tag{A.5}$$

For industries where the home country is not a producer or it is the unique producer we have:

$$\begin{cases} \frac{dP_j^*}{dT} \frac{T}{P_j^*} = 0 & \text{for } j \text{ such that } a(j) \in \left(0, \frac{ew}{\bar{P}T} \right]. \\ \frac{dw}{w} - \frac{dP_j^*}{P_j^*} = \frac{dT}{T} & \text{for } j \text{ such that } a(j) \in \left[\frac{\bar{P}w}{eT}, \infty \right). \end{cases}$$

To check 3) consider country i's income:

$$Y_i = \int_0^1 [\int_0^{\bar{k}} P(j)\, q_{ki}(j)\, x_{ki}(j)\, dk]\; dj = Y_W \int_0^1 \psi_{ij}\, dj.$$

Thus, the elasticity of relative income with respect to home aggregate efficiency is given by:

$$\frac{dY_H}{dT}\frac{T}{Y_H} - \frac{dY_F}{dT}\frac{T}{Y_F} = \int_0^1 \left[\frac{d\psi_{Hj}}{dT}\frac{T}{\psi_{Hj}}\right] dj - \int_0^1 \left[\frac{d\psi_{Fj}}{dT}\frac{T}{\psi_{Fj}}\right] dj > 0.$$

The sign follows from the arguments above in this proposition implying $d\psi_{Hj} / dT \geq 0$ and $d\psi_{Fj} / dT \leq 0$; with strict inequalities for industries where both countries have positive production. Thus, country *i*'s share in world income υ_i is increasing in its aggregate efficiency.

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