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"Essays on Trade and Technology"

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Introduction

Why are some countries so rich while others are so poor? Standard wisdom attributes about half of the variation in cross country differences in income per worker to differences in productivity while the remaining half is seen to be due to differences in factor endowments, such as human- and physical capital. The main topic of this thesis is to combine insights from trade theory with those from the growth and development literature to study cross country differences in productivity. In particular, I develop tools that allow me to use the richness of information contained in trade data to estimate productivities both at the aggregate - factor specific - and at the sector level, which enables me to obtain a number of new results on the reasons and the effects of cross country variation in the efficiency of production.

In chapter one I build a quantitative world equilibrium model of trade, that combines the Helpman and Krugman (1985) Heckscher-Ohlin cum intra-industry trade model with factor specific cross country productivity differences. Since this model has predictions both on income differences and the factor content of trade, I simultaneously fit data on income, factor prices and trade to estimate productivity differences and the aggregate elasticity of substitution between human capital and physical capital. The results of my estimations show that human and physical capital are complements at the aggregate level, thus rejecting a Cobb-Douglas production function. I find that the productivity of human capital is much higher in rich countries than in poor ones, while there is no clear relation between the productivity of physical capital and income per worker.

In chapter two[2] I design and apply a method to estimate cross country differences in productivity at the sector level from bilateral trade data. I take and integrated

[2]This chapter is joint work with Pablo Fleiss.

Heckscher-Ohlin-Krugman-Ricardo approach, and estimate differences in sectoral productivity as observed trade that cannot be explained by differences in factor intensities and factor prices nor by differences in trade costs. The advantage of this endeavor is that it helps to overcome data problems that render the application of standard methods for computing sectoral productivities, which require comparable information on inputs and outputs at the sector level, inadequate for most countries. I estimate total factor productivity for 24 manufacturing sectors in more than 60 countries at all stages of development. I find that productivity differences between rich and poor countries are substantial and systematically more pronounced in sectors that are intensive in human capital and research and development. Subsequently, I use these estimates to test theories from the growth and development literature that have implications for the the patterns of productivity differences across sectors, such as the role of human capital for technology adoption, or the effect of financial development.

Chapter 1

Productivity Differences in an Interdependent World

1.1 Introduction

Finding answers to the question why some countries are so much richer than others is one of the fundamental challenges in economics. While according to the consensus view cross country differences in factor endowments and differences in productivity are more or less equally important causes for the cross country variation in income per worker (Caselli (2005)), there is little evidence whether individual economies are actually well described by an aggregate Cobb-Douglas production function and whether differences in productivity across countries are really factor neutral as usually assumed in the quantitative growth literature.

Moreover, even though trade is empirically very important [1] and may also potentially affect the shape of countries' aggregate production possibility frontiers (Ventura (2005)) most research in growth and development still uses closed economy models when estimating cross country differences in productivity. This may not only be too

[1] In the early 1990ies trade already amounted to 38 per cent of world income and by the turn of the millennium it had reached 52 per cent of world output (Trade is measured as exports+imports, data are from the Penn World Tables 6.1.).

restrictive for theoretical reasons but - since these models have by their very nature nothing to say about trade - it also leaves one of the best sources of cross country information - bilateral trade data - completely unexploited.

A second, independent line of investigation in international trade deals with the prediction of the Heckscher-Ohlin-Vanek (HOV) Theorem, that states that capital abundant countries should export capital (through trade in goods), while labor abundant countries should export labor. This research, which uses trade data to evaluate the validity of this theory, finds that cross country differences in productivity greatly help to explain factor flows embodied in trade.

The goal of this paper is to merge these two approaches by using a world equilibrium model - the Helpman-Krugman-Heckscher-Ohlin (1985) model - to estimate factor augmenting productivities, thereby providing a unified framework and exploiting the information contained both in income and in trade data. This model has been the workhorse of trade economists for more than two decades.[2] It combines inter-industry Heckscher-Ohlin trade with intra-industry trade due to increasing returns and love for variety. I augment the model for differences in the efficiencies with which factors are used across countries to introduce a potential role for productivity in generating cross country variation in income per worker.

The model encompasses two very popular views of the world as particular cases. The first one is the neoclassical one sector model with factor deepening that is the standard framework in the quantitative growth literature, while the second one is the Heckscher-Ohlin model with conditional factor price equalization, the canonical model for estimating productivities in the trade literature (Trefler (1993), Trefler (1995)). Cases of intermediate integration are described by a world that separates into multiple cones of diversification, with different sets of countries specializing in

[2]While the original formulation of the model is due to Helpman (1982), Helpman and Krugman (1985) dedicate an entire book to the study of this model.

the production of different sets of goods.

I simultaneously fit data on income, endowments, factor prices and the factor content of trade. This provides me with over-identifying restrictions that enable me to calibrate productivities and at the same time allow me to evaluate the fit of the model and to estimate the values of underlying parameters. More specifically, I test the factor deepening case against cases with multiple cones of diversification and ones where conditional factor price equalization occurs and I estimate the elasticity of substitution between human and physical capital.

My main findings are that the factor deepening model with factor specific productivities and weak complementarity between human and physical capital vastly outperforms the other versions of the model considered in this paper. In particular, the elasticity of substitution between human and physical capital is estimated to be significantly lower than one, so that the Cobb-Douglas model is clearly rejected. Rich countries have far higher productivities of human capital than poor ones, while there is no clear relation between physical capital productivity and income per worker. Moreover, my results imply that the model best supported by the HOV Theorem has no Heckscher-Ohlin motiv for the exchange of goods and all trade is due to increasing returns and love for variety.

In terms of intellectual ancestors, this paper integrates two lines of investigation. The first one is the literature on development accounting, which uses income and endowment data to measure productivity differences. Some of the classical contributions are due to King and Levine (1994), Klenow and Rodriguez-Clare (1999), Prescott (1998) and Hall and Jones (1999). See Caselli (2005) for a survey. A stable result of these studies is that total factor productivity is strongly positively correlated with income per worker and accounts for at least half of the cross country variation of this variable. Caselli (2005) adds factor specific technology differences to this approach and discovers that rich countries have higher productivities of human capital than poor ones, whereas poor countries have higher productivities of physical capital than rich nations.

The second strand of research, that uses trade data to measure productivity differences, is the literature that tests the prediction of the Heckscher-Ohlin-Vanek (HOV) equations. They state that countries' trade structure is such that they are net exporters of the services of those factors, in which they are more abundant than the world average. A seminal contribution by Trefler (1993) shows how the HOV equations can be used to solve for the unknown factor specific productivities of each country that equalize measured and predicted factor flows under the assumption that differences in factor prices across countries are caused exclusively by variation in factor productivities. He finds that rich countries have both higher productivities of labor and physical capital than poor countries.

In another important paper Davis and Weinstein (2001) relax the assumption that differences in factor prices are caused only by differences in productivities. They show that both Hicks-neutral differences in total factor productivity, which they estimate using input-output data, and local factor abundance must be taken into account in order to improve the fit of the HOV equations. However, their sample is limited to ten large OECD countries, so that they have nothing to say about productivity differences between rich and poor countries.

This paper goes beyond the previous contributions because I allow both for factor productivities and local factor abundance to matter for income differences and I match data on income, factor prices and trade at the same time. Also, since I put more structure on the underlying model, I am able to estimate the value of underlying parameters and to test different special cases of the model.

Turning to the evidence on the aggregate elasticity of substitution between capital and labor, a long line of studies, summarized by Hamermesh (1986), have attempted to estimate this parameter at various levels of aggregation and using both cross section and time series data. Despite of this, the evidence on its value remains inconclusive, which may potentially reflect mis-specification because this body of research considers exclusively Hicks neutral technological change. Recently, Antras (2004) discusses the bias that arises from this restriction and estimates the elasticity of substitution between capital and labor for the US economy allowing for factor augmenting productivity differences using time series data. In line with my results, most of his estimates are significantly lower than one.

Finally, Waugh (2007) performs a development accounting exercise in an open economy framework that extends Eaton and Kortum (2002). However, he restricts his analysis to Cobb-Douglas production technology and his main interest is to investigate the role of trade in accounting for cross country income differences.

Summing up, the main contributions of this paper are threefold: Firstly, it integrates development accounting with trade theory and methods. Secondly, the paper proposes to introduce formal over-identification using data from outside the model to evaluate the fit of the productivity calibrations. Thirdly, this buys me a very precise estimate of the elasticity of substitution between human and physical capital, a clear rejection of the aggregate production function being Cobb-Douglas and the possibility to test which model performs best in terms of fitting the HOV equations.

The outline of the paper is as follows: In the next section I develop a theoretical model of the world economy with trade due to factor proportions and love for variety that includes factor specific cross country productivity differentials. In section three I show how factor productivities can be recovered from the model when data on countries' endowments and factor prices are fed in and I discuss how the HOV equations can be used in this framework to evaluate the plausibility of the calibrated productivities and to estimate the values of underlying parameters. In section four I present the results of calibrating productivities in the Helpman-Krugman-Heckscher-Ohlin framework and use the calibrated productivities to perform a development accounting exercise. The last section concludes.

1.2 The Helpman-Krugman-Heckscher-Ohlin Model

1.2.1 Assumptions and Setup

The model presented in this section is a standard model of international trade. There are two reasons for trade in this environment. The first one is due to increasing returns. Consumers value variety and each variety is produced by a monopolist because increasing returns are internal to the firm and new varieties can be invented without cost. Since consumers want to consume all varieties each producer serves the world market for her particular variety, which leads to trade within sectors. The second motive for trade is factor proportions. There exist many sectors each of which uses factor inputs with distinct intensities and countries differ in the ratios of their endowments. This gives rise to Heckscher-Ohlin trade and countries produce on average more varieties in those sectors that use its relatively abundant factor intensively. I also introduce cross country differences in the productivities with which factors are used in production, so that a given amount of human or physical capital leads to a different amount of production, depending on the country where production is performed.

The Heckscher-Ohlin part of the model adds two main effects to the standard model used in the development accounting literature. The first one is structural change, that is the possibility for countries to adapt their production structure to their factor endowments. Countries which are abundant in physical capital will concentrate their production in sectors that are intensive in this factor. This tends to increase the role of variation in factor endowments in explaining cross country income differences because countries can employ their factors more efficiently. The other one is terms of trade. These work exactly in the opposite direction because they depress the income of those countries that produce goods which are intensive in the globally abundant factor, thereby reducing the importance of factor endowments in accounting for income differentials. The monopolistic competition part is introduced mainly to explain trade in the absence of differences in factor proportions, as is the case in the standard model for development accounting, but it has no important impact on countries' aggregate production possibility frontiers.

The flexible benchmark model of the world economy relies on the following main assumptions.

A.1: Countries are open to trade in goods and possess perfectly competitive factor markets.

A.2: Goods markets are monopolistically competitive.

A.3: Factors are immobile between countries and perfectly mobile within countries.[3]

A.4: Each country is endowed with human capital H_c and physical capital K_c.[4]

A.5: Productivity is specific to a factor located in a country.

[3]The immobility of labor is probably not a very controversial assumption. Even though some mobility of people can be observed, there exist very large barriers to migration from poor to rich countries. Starting at least with Lucas (1990) a large literature in International Economics has been dealing with the question why capital does not flow from rich to poor countries. Caselli and Feyrer (2006) make the interesting point that capital may actually be distributed quite efficiently across countries, so that there is no reason to observe large capital flows from rich to poor nations.

[4]Following the growth literature the factor "human capital" is measured as labor endowments in efficiency units, which is different from the convention used in the trade literature, where human capital is usually the amount of skilled labor. Because the model has only two factors this seems to be the adequate way to measure labor endowments.

A.6: Each country has access to technologies to produce in I sectors, that vary in their capital intensities.

A.7: Consumers in all countries have identical, homothetic preferences with fixed expenditure shares. [5]

The model is then easily described by Assumptions A.1-A.7 and the specification of demand and supply.

1.2.2 Demand

Consider a world economy with countries indexed by $c \in C$ and sectors indexed by $i \in I$.[6] Assuming that trade is balanced, aggregate expenditure of country c equals its aggregate income.

$$E_c = P_c Y_c = \sum_{i=1}^{I} E_{ic} = \sum_{i=1}^{I} \beta_i E_c, \tag{1.1}$$

where $P_c Y_c$ is GDP of country c in dollars, and Y_c is GDP in purchasing power parities and is measured in aggregate consumption units. Aggregate spending is split across I sectors with fixed expenditure shares β_i.[7]

The ideal aggregate price index is Cobb-Douglas. It measures the minimum expenditure to buy one unit of the aggregate bundle of goods.

$$P_c = \prod_{i=1}^{I} \left(\frac{P_i}{\beta_i} \right)^{\beta_i}, \tag{1.2}$$

where P_i are the sectoral price indices.

[5] This together with **A.1** implies that the optimal price index of Gross Domestic Product has the same form in all countries.

[6] I slightly abuse notation by denoting with C and I both the sets of countries and goods and their cardinalities.

[7] A possible interpretation for this setup is that each country has an aggregate Cobb-Douglas production function that produces a final good which can be used for consumption and investment.

Sectoral price indices are constant elasticity of substitution composites of the prices of sector specific varieties.

$$P_i = \left(\int_0^{N_i} p_i(n)^{1-\sigma} dn \right)^{\frac{1}{1-\sigma}}, \tag{1.3}$$

where $\sigma > 1$ is the elasticity of substitution between any two varieties and $N_i = \sum_{c=1}^{C} N_{ic}$ is the total number of varieties produced in sector i.

The form of the sectoral price indices implies that there is love for variety and aggregate consumption is increasing in the number of varieties available in each sector.

The demand function of country c for variety n produced in country c' in sector i implied by the price indices can be found from the sectoral price index by using Roy's law.

$$x_{icc'}(n) = \frac{p_i(n)^{-\sigma}}{P_i^{1-\sigma}} \beta_i E_c \tag{1.4}$$

1.2.3 Behavior of Firms and Technology

Final goods are freely traded and are produced by monopolistically competitive firms.

In each sector firms choose a variety and an optimal pricing decision taking as given the decisions of the other firms in the industry.[8] The output of an industry consists of a number of varieties that are imperfect substitutes for each other. Production of each variety is monopolistic because of economies of scale. In the model the invention of a new variety is costless, so firms always prefer to invent a new differentiated variety instead of entering in price competition with an existing firm.

In each country firms are homogeneous within a sector. Firms' technologies differ across sectors by the capital intensity of production for given wages, w_c, and rental rates, r_c. Varieties of final goods are produced using both human capital $H_{ic}(n)$ and physical capital $K_{ic}(n)$ with constant marginal cost and a fixed cost, f. Production

[8] In what follows I will use the terms industry and sector interchangeably.

technology, represented by the homothetic total cost function TC (1.5), is CES in each sector[9] and varies across countries because of differences in factor productivities. Productivities are specific to factors located in country c, so that a country's productivity is described by the duple $\{A_{Kc}, A_{Hc}\}$, which are the productivity of physical capital and human capital in country c.

$$TC(q_{ic}) = \left[\alpha_i^{\epsilon}\left(\frac{r_c}{A_{Kc}}\right)^{1-\epsilon} + (1-\alpha_i)^{\epsilon}\left(\frac{w_c}{A_{Hc}}\right)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}(f + q_{ic}), \tag{1.5}$$

where $\alpha_i \in [0,1]$ is the physical capital intensity of sector i and $\epsilon \in [0,\infty)$ is the elasticity of substitution between human capital and capital.

Monopolistic producers in sector i of country c maximize profits subject to the demand function

$$x_{ic'} = \frac{p_i^{-\sigma}}{P_i^{1-\sigma}}\beta_i \sum_{c=1}^{C} E_c. \tag{1.6}$$

Optimality implies that marginal revenue equals marginal cost. Note that given this constant elasticity demand function the solution to the firms' profit maximization problem implies that the price charged by a firm in sector i in country c is a constant markup over its marginal cost as long as firms are active in that sector in country c.

$$p_i = \frac{\sigma}{\sigma - 1}\left[\alpha_i^{\epsilon}\left(\frac{r_c}{A_{Kc}}\right)^{1-\epsilon} + (1-\alpha_i)^{\epsilon}\left(\frac{w_c}{A_{Hc}}\right)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}} \tag{1.7}$$

If a sector is located in a country, free entry of firms drives profits to zero, so that firms price at their average cost. This determines the number of firms in each sector endogenously.

$$[\alpha_i^{\epsilon}\hat{r}_c^{1-\epsilon} + (1-\alpha_i)^{\epsilon}\hat{w}_c^{1-\epsilon}]^{\frac{1}{1-\epsilon}}\left(\frac{f}{q_{ic}} + 1\right) \geq p_i \tag{1.8}$$

The combination of the pricing rule, the free entry condition and the form of the fixed cost imply that firms' optimal output is the same in all sectors and countries

[9]The assumption that elasticities of substitution are the same across sectors rules out factor intensity reversals - the possibility that a sector i is more intensive in physical capital than sector i' for some combination of factor prices and more intensive in human capital for some other one.

(as long as it is positive).

$$q^* = (\sigma - 1)f \tag{1.9}$$

1.2.4 Equilibrium

It turns out to be useful to rewrite the model in terms of variables in efficiency units. Following Trefler (1993), let me define $\hat{H}_c \equiv A_{Hc}H_c$, $\hat{K}_c \equiv A_{Kc}K_c$, $\hat{w}_c \equiv \frac{w_c}{A_{Hc}}$ and $\hat{r}_c \equiv \frac{r_c}{A_{Kc}}$.

These are factor endowments in efficiency units and efficiency adjusted factor prices. So, for example, one unit of efficient physical capital is equivalent to A_{Kc} units of plain physical capital, and one unit of efficient physical capital, which is measured in common units across countries, costs $\frac{1}{A_{K,c}}$ as much as one unit of plain physical capital, that may differ in efficiency across countries. Hence, capital prices in country c may be higher than in country c' because buying one unit of capital in country c provides ownership of more efficient units of capital or because capital is scarcer in country c.

With this redefinition of variables I am able to describe the world economy as an ordinary Helpman-Krugman-Heckscher-Ohlin (1985) model without productivity differences in which factor endowments in each country are measured in efficiency units, while leaving the structure of the model formally equivalent to the one described by the production possibilities and demand structure listed above. The advantage of this formulation is that the extensive theory available on the factor proportions theory and its monopolistic competition hybrid, as discussed in Helpman and Krugman (1985), can be directly applied to this model.

In general, it may not be profitable to produce varieties in all sectors in every country because production in sectors that use the locally scarce factors intensively may be unprofitable. In this case, countries will be located in different cones of diversification. A cone of diversification is a set of countries that produce at least in two common sectors. Those countries have common efficient factor prices, and when the number sectors active in the cone is larger than the number of factors, individual countries' production of varieties is undetermined and only the aggregate number of varieties produced in each sector in the cone is unique. Consequently, let d be a set of countries with common efficient factor prices. Given this, one can define an equilibrium of the Helpman-Krugman-Heckscher-Ohlin model.

Definition 1: An **Equilibrium** is a collection of goods prices $\{p_i\}$, efficiency adjusted wages $\{\hat{w}_d\}$, efficiency adjusted rental rates $\{\hat{r}_d\}$, and numbers of sectoral varieties $\{N_{id}\}$ such that firms maximize profits, expenditure is minimized, factors are fully employed and goods markets clear in every set of countries d.

Since the general model is rather complex, let us instead take a look at some representative examples to learn something about the forces that determine countries' relative incomes in this world. The intuition gained in these specific cases will carry over to the general model.

Example 1: Factor Deepening

A.8 All sectors have identical factor intensities ($\alpha_i = \alpha$ for all $i \in I$).

This assumption eliminates both the role of structural change and terms of trade effects. From the pricing conditions (2.6) we have that goods in all sectors have the same price $p_i = p_{i'} = p$ and countries produce some varieties in all sectors. Taking this into account, it is not difficult to solve for the aggregate production function implicit in this model[10]

$$Y_c = p\left(\frac{\sigma}{\sigma-1}\right)[\alpha(A_{Kc}K_c)^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha)(A_{Hc}H_c)^{\frac{\epsilon-1}{\epsilon}}]^{\frac{\epsilon}{\epsilon-1}}, \tag{1.10}$$

where

$$p = (\prod_{i=1}^{I}(\frac{N_i}{\beta_i})^{\beta_i})^{\frac{1}{\sigma-1}}. \tag{1.11}$$

It can be seen from (1.10) that countries' aggregate production function is CES with an elasticity of substitution between physical and human capital equal to ϵ. This is the world with factor specific productivities described by Caselli (2005) in the Handbook of Economic Growth. The main features of this world are that countries experience decreasing returns to factor accumulation and that terms of trade do not matter for aggregate income because all relative goods prices are one. There is an aggregate scale effect due to love for variety, but it is irrelevant for relative incomes because all varieties are available in all countries.

In this world all trade is due to love for variety, as producers export their variety to all other countries. Imports by country c' of variety n produced in sector i in country c are a fraction of production that is proportional to the size of the importing country.[11]

$$x_{cc'i}(n) = \frac{p_i^{-\sigma}}{P_i^{1-\sigma}}\sigma_i E_c = \frac{Y_c}{\sum_{c=1}^{C} Y_c} q_{ci}(n) \tag{1.12}$$

Even though differences in factor endowments across countries do not constitute a reason for trade in this world, goods trade embodies factors, since countries that are abundant in efficient physical capital produce varieties much more capital intensively than efficient human capital abundant ones and therefore are net exporters of this factor.

[10]To get this note that all prices are the same, and divide the factor market clearing conditions, which - by Shephard's Lemma - can be obtained by partially differentiating (1.5) with respect to factor prices, to solve for the wage/rental, $\frac{\hat{w}_c}{\hat{r}_c} = (\frac{1-\alpha}{\alpha})(\frac{A_{Kc}K_c}{A_{Hc}H_c})^{\frac{1}{\epsilon}}$. Use this together with the pricing condition (2.6) to solve for factor prices and substitute in the definition of aggregate income.

[11]This follows from the definition of the sectoral price index and the fact that $\sum_{c=1}^{C} p_i N_{ic} q_{ic} = \beta_i \sum_{c=1}^{C} Y_c$

An additional assumption leads us back to the Cobb-Douglas world, that has been the focus of the analysis in most of the development accounting literature.[12]

A.9: $\epsilon = 1$

Then the aggregate production function is Cobb-Douglas.

$$Y_c = p\left(\frac{\sigma}{\sigma-1}\right) A_{Kc}^{\alpha} A_{Hc}^{1-\alpha} K_c^{\alpha} H_c^{1-\alpha} = p\left(\frac{\sigma}{\sigma-1}\right) A_c K_c^{\alpha} H_c^{1-\alpha}, \tag{1.13}$$

where I have defined $A_c \equiv A_{Kc}^{\alpha} A_{Hc}^{1-\alpha}$. This view point of the world economy is similar to Caselli's, just that with a unit elasticity of substitution, only total factor productivity is identified. Countries experience decreasing returns and terms of trade effects are absent.

Example 2: Conditional Factor Price Equalization (CFPE)

A completely different picture of the world arises if we drop assumptions **A.8** and **A.9**, and instead maximize the role of structural change. We do this by assuming that trade integration is so strong, that trade in goods is able to make up for the immobility of efficient factors.

A.10: Conditional on measuring endowments in efficiency units factor prices are equalized in the world economy.

In this extreme case the equilibrium of the world economy is akin to the one of a hypothetical world, in which all impediments to movements of factors measured in efficiency units have been abolished. Call this equilibrium the integrated equilibrium. The Factor Price Equalization Set is the set of distributions of efficient factor endowments across countries, such that the world economy is able to replicate the integrated equilibrium.[13] This implies that the world economy has the allocations

[12]See for example N. Gregory Mankiw and Weil (1991), Klenow and Rodriguez-Clare (1999) and Hall and Jones (1999).

[13]For a thorough discussion of these concepts see, for example, Helpman and Krugman (1985).

of the integrated equilibrium if every country can fully employ its resources when using the same capital to human capital ratios in each sector as in the integrated equilibrium given its endowments of efficient human and physical capital. The size of this set is larger if different sectors use very different capital to human capital ratios for given factor prices (α_i varies a lot across sectors) because even countries with extremely unbalanced factor endowments will be able to find production patterns such that they can employ their factors using the integrated equilibrium techniques. Still, in this world, marginal products of physical units of capital and human capital are not equalized across countries because of differences in factor productivities. Consequently, disparities in factor prices stem only from differences in factor productivities and not from variation in the abundance of human capital and physical capital across countries.

Assume that sectoral input ratios are sufficiently extreme and expenditure on sectors with extreme factor proportions is large enough in order for conditional factor price equalization to hold for the world economy, i.e. $\hat{w}_c = \hat{w}_{c'} = \hat{w}$ and $\hat{r}_c = \hat{r}_{c'} = \hat{r}$ for all c $\in C$. Then - as discussed - it is sufficient to analyze the equilibrium of the integrated economy. For analytical tractability let $\epsilon \to 1$ so that sectoral production functions are Cobb-Douglas. In this case one can show that the aggregate production function of the world economy is also Cobb-Douglas.[14]

$$Q_w = B\hat{K}_w^{\sum_{i\in I}\alpha_i\beta_i}\hat{H}_w^{(1-\sum_{i\in I}\alpha_i\beta_i)}, \tag{1.14}$$

where

[14]To obtain this, solve for sectoral factor shares and total factor shares and divide these equations to obtain sectoral factor use in terms of aggregate factor endowments. Then use the market clearing conditions to solve for goods prices and substitute them in the definition of the price indices to get the implicit aggregate production function of the world economy. Finally, use the definition of sectoral production functions, define $Q_{ic} = N_{ic}q_{ic}$ and substitute the sectoral factor use in terms of aggregate endowments to get equation (1.14).

$$B \equiv (\prod_{i=1}^{I} \left(\frac{N_i}{\beta_i}\right)^{\beta_i}\Big)^{\frac{\sigma}{\sigma-1}} \prod_{i=1}^{I} \left[\frac{(1-\alpha_i)\beta_i}{\sum_{i=1}^{I}(1-\alpha_i)\beta_i}\right]^{(1-\alpha_i\beta_i)} \left[\frac{\alpha_i\beta_i}{\sum_{i=1}^{I}\alpha_i\beta_i}\right]^{\alpha_i\beta_i}$$

and

$$\hat{H}_w = \sum_{c=1}^{C} \hat{H}_c, \qquad \hat{K}_w = \sum_{c=1}^{C} \hat{K}_c.$$

There are decreasing returns to factor accumulation in efficiency units at the world level. World factor prices are given by

$$\hat{w} = (1 - \sum_{i \in I} \alpha_i\beta_i) B \left(\frac{\hat{K}_w}{\hat{H}_w}\right)^{\sum_{i \in I}\alpha_i\beta_i}$$

and

$$\hat{r} = (\sum_{i \in I} \alpha_i\beta_i) B \left(\frac{\hat{H}_w}{\hat{K}_w}\right)^{(1-\sum_{i \in I}\alpha_i\beta_i)} .$$

Consequently, factor prices are determined at the world level and not at the country level. Income of country c is given by

$$Y_c = A_{Hc}H_c\hat{w} + A_{Kc}K_c\hat{r}. \tag{1.15}$$

To the extent that factor prices are given for individual countries, countries' aggregate production functions are linear and countries experience constant returns to factor accumulation. The infinite elasticity of substitution between factors reflects structural change. Countries absorb additional units of factor endowments by changing their production structure while holding constant sectoral production techniques, instead of using factor deepening like in Example 1 or in the closed economy.

In this world there is both intra-industry trade (because of love for variety and monopolistic competition) and inter-industry trade (because of differences in factor endowments across countries). Countries that are more abundant in an efficient factor than the average of the world economy are net exporters of this factor. Even though all countries produce in all sectors, it is not necessarily true that countries produce more in those sectors that use their abundant factor intensively because individual countries' production patterns are undetermined, when the number of sectors is larger than the number of factors,.

We have now seen two very diverse views of how countries' aggregate production possibilities may look like. In general, however, the world is likely to be somewhere between the two extremes of the Factor Deepening world and Conditional Factor Price Equalization and will combine features of both. If differences in efficient factor endowments are too large, efficient factor prices cannot be equalized in the whole world. Instead, there will be multiple cones of diversification. Between those cones, there will generically exist countries that specialize in the production of varieties in a single sector.

Example 3: Multiple Cones

Assume there are only two sectors, $i \in \{H, K\}$ with $\alpha_K > \alpha_H$. Since it is not possible to solve this model analytically, let us take goods prices as parameters. With only two sectors, sectoral production patterns are determined in each country. Countries with extremely high efficient physical to human capital ratios specialize in producing varieties in the K-sector. Countries with intermediate factor endowment ratios have diversified production structures and produce varieties in both sectors, while countries with very low efficient physical to human capital ratios specialize in the H-sector.

It is easy to show that for countries outside the cone of diversification the aggregate production function has the form of the sectoral production function of the sector in which they specialize. [15]

[15] Divide the factor market clearing conditions to get the wage/rental and use this equation together with the pricing equation to solve for factor prices. Then substitute them in the definition of aggregate income.

$$Y_c = p_i \frac{\sigma}{\sigma - 1} [\alpha_i (A_{Kc} K_c)^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha_i)(A_{Hc} H_c)^{\frac{\epsilon-1}{\epsilon}}]^{\frac{\epsilon}{\epsilon-1}} \tag{1.16}$$

In this case countries experience decreasing returns and the elasticity of substitution is ϵ because additional units of factors are absorbed by factor deepening. Terms of trade effects push up the income of countries that specialize in the sector which has a high relative price. Countries that lie in the cone of diversification, on the other hand, have linear production technologies, reflecting again the fact that they are capable of absorbing additional units of factors through structural transformation.

$$Y_c = \hat{w}_d A_{Hc} H_c + \hat{r}_d A_{Kc} K_c \tag{1.17}$$

where

$$\hat{w}_d = \left(\frac{\sigma}{\sigma - 1}\right) \left[\frac{\alpha_H^\epsilon p_K^{1-\epsilon} - \alpha_K^\epsilon p_H^{1-\epsilon}}{\alpha_H^\epsilon (1-\alpha_K)^\epsilon - \alpha_K^\epsilon (1-\alpha_H)^\epsilon}\right]^{\frac{1}{1-\epsilon}} \tag{1.18}$$

$$\hat{r}_d = \left(\frac{\sigma}{\sigma - 1}\right) \left[\frac{(1-\alpha_H)^\epsilon p_K^{1-\epsilon} - (1-\alpha_K)^\epsilon p_H^{1-\epsilon}}{\alpha_K^\epsilon (1-\alpha_H)^\epsilon - \alpha_H^\epsilon (1-\alpha_K)^\epsilon}\right]^{\frac{1}{1-\epsilon}} \tag{1.19}$$

Factor prices are functions of goods prices only and consequently depend on the endowments of the world economy.[16] From the formulas (1.18) and (1.19) one can see that an increase in the price of a sector's output leads to a more than proportionate rise in the price of the factor that is used intensively in that sector. This is the Stolper-Samuelson effect. The intuition is that an increase in an industry's price shifts production towards that sector and thereby increases relative demand for the intensively used factor. Whether an increase in a sectoral price decreases or increases aggregate income depends on how much a country is producing in each sector (which in turn depends on its endowments).

[16] To derive this use the pricing conditions for the relevant goods and solve for factor prices in terms of goods prices. These equations can be inverted if and only if the number of factors equals the number of sectors.

This example provides all the mechanism present in the general model. The world sorts into cones of diversification between which lie countries that specialize in specific sectors. As a consequence the mapping between endowments, factor prices, income and productivity changes its shape depending on whether a country is located in a cone or specialized. Having discussed the properties of the model, let us now turn to calibrating productivities in this world.

1.3 A Method for Productivity Calibration

Given measures of factor productivities for every country I could test if the models described in the previous section are a reasonable representation of the real world. Unfortunately, I lack exactly these measures of productivities. Instead, in a first step I will follow the convention of the development accounting approach to assume that the model is specified correctly, and back out productivities from the model given some additional information about other endogenous variables. Subsequently, I will test the model fit using trade data.

The procedure is to use information on endowments $\{H_c\}$, $\{K_c\}$, wages, $\{w_c\}$, and rental rates, $\{r_c\}$, in order to back out the $2C$ unknowns $\{A_{Kc}\}$, $\{A_{Hc}\}$ from the equilibrium conditions of the model. This allows me to fit perfectly the cross section of income $\{Y_c\}$ and labor and capital income shares, $\{s_{Hc}\}$ and $\{s_{Kc}\}$, respectively, taken as given a combination of sectoral factor intensities $\{\alpha_i\}$, expenditure shares $\{\beta_i\}$ and an elasticity of substitution ϵ.

This method for calibrating productivities is analogous to the usual calibration exercise performed in the development accounting literature. The main complication is that productivities have to be determined simultaneously with the unknown specialization patterns, equilibrium prices and production levels in each country, because the relationship between a countries' inputs and outputs generally depends on endowments and the demand structure of the whole world economy. More formally, a **Productivity Calibration Problem** is defined as follows.

Definition 2: A **Productivity Calibration Problem** (**PCP**) is a collection of goods prices $\{p_i\}$, efficiency adjusted wages $\{\hat{w}_d\}$, efficiency adjusted rental rates $\{\hat{r}_d\}$, numbers of sectoral varieties $\{N_{id}\}$ and factor productivities $\{A_{Hc}\}$, $\{A_{Kc}\}$ such that given a cross section of human capital endowments $\{H_c\}$, physical capital endowments $\{K_c\}$, wages $\{w_c\}$, rentals $\{r_c\}$ and parameters $\{\alpha_i\}$, $\{\beta_i\}$, ϵ, σ and f, firms maximize profits, expenditure is minimized, factors are fully employed and goods markets clear for all d[17].

One can show that a solution to **PCP** is also an **Equilibrium** given efficient factor endowments, and that for given efficient factor endowments an **Equilibrium** also solves the **PCP** and measured productivity differences are zero, which is obviously necessary for the concept of **PCP** to make sense.

Solving the **PCP** requires the use of numerical methods. There are three main challenges. First, the large number of countries in the sample (96), which I use to have a representative picture of the world economy. Second, the fact that one cannot apply standard methods for computing equilibria because parameters and variables have been exchanged (since $\{A_{Hc}\}, \{A_{Kc}\}$ are unknown). Third, that I allow countries to specialize into multiple cones, which makes computation much more complex because corner solutions might occur.

I compute a solution to the **PCP** by imposing a specialization pattern, solving the resulting nonlinear system of equations and checking if the solution satisfies the non-negativity restrictions imposed on the variables. If it does, I accept the solution, otherwise I guess another specialization pattern until a solution is found. For reasons

[17] An exact mathematical definition of the **PCP** can be found in the appendix.

of computational tractability I restrict my attention to models with two sectors.[18]

As a next step I would like to find reasonable parameter values for production and demand $\{\alpha_i\}$, $\{\beta_i\}$ ϵ, for which to solve the model because results will be sensitive to the choice of these parameters[19]. In addition, I would like to test if certain restrictions imposed on the parameters by standard models, like $\alpha_i = \alpha$ or $\epsilon = 1$ or $A_{HC} = A_{KC}$ are realistic.

1.3.1 Using Trade Data to Evaluate the Model

To estimate these parameters I use the model's prediction on trade. The testable hypothesis of the Heckscher-Ohlin-Vanek (HOV) equations is that a country should export (through trade in goods) the services of those (efficient) factors with which it is abundantly endowed relative to the world average and import its relatively scarce factors. The predictions on factor trade provide over-identifying restrictions that enable me to find the combination of parameter values that best match moments of the data and at the same time allow me to test, if certain constraints on parameters are valid.

The HOV-equations hold for a class of trade models that satisfy a consumption similarity condition (see Trefler and Zhu (2005)) and perfect competition in factor markets. In particular, they apply to the Helpman-Krugman-Heckscher-Ohlin model, and all its versions considered in this paper.[20]

Because the HOV-equations are a statement about factor flows embodied in trade and not directly about trade in goods, one needs to define the factor content of trade.

[18] As discussed in the appendix, the solution to **PCP**is unique under some restrictions.

[19] In the simulations I set $\sigma f = 1$ and define $\tilde{p}_i \equiv \frac{\sigma-1}{\sigma} p_i$ for convenience, since the productivities generated by the **PCP** do not depend on the values of these parameters.

[20] Interestingly, they apply to the Heckscher-Ohlin model with perfect competition only in special cases. One is (conditional) factor price equalization, and the other one is complete specialization of all countries, a borderline case. The fact that many models imply the HOV equations means also that one cannot use them to test a particular trade model against an alternative, unless one has an underlying structural model that generates testable data.

Let $f \in \{H, K\}$ denote factors, V_{fc} denote endowments of factor f in country c, $i = 1, ..., I$ denote goods and let D_c be the $F \times I$ factor use matrix in country c, with elements b_{fic} denoting the use of factor f in the production of one unit of good i in country c and rows D_{fc}, that state the use of factor f per unit of output in each sector. Let B_c be country c's input-output matrix and denote factor prices by π_c $= (w_c, r_c)$. Then, for example, the direct use of human capital measured in efficiency units in the production of one unit of good i in country c in the above models is

$$d_{Hic} = \frac{\sigma}{\sigma - 1} p_i^{\epsilon} w_c^{-\epsilon} (1 - \alpha_i)^{\epsilon} A_{Hc}^{\epsilon}. \tag{1.20}$$

In addition, the fth row of the direct factor use matrix of the United States in efficiency units is

$$D_{fUS} = \pi_{US}^{-\epsilon} A_{fUS}^{\epsilon} D_f, \tag{1.21}$$

where D_f is common to all countries because of free and costless trade and the absence of industry specific (Ricardian) technology differences across countries. The factor use matrix measured in efficiency units of every country c can be expressed as a function of the one of the US,

$$D_{fc} = \pi_c^{-\epsilon} D_f A_{fc}^{\epsilon} = \left(\frac{\pi_{US}}{\pi_c}\right)^{\epsilon} \left(\frac{A_{fc}}{A_{fUS}}\right)^{\epsilon} D_{fUS}. \tag{1.22}$$

Following Trefler and Zhu (2005), in the presence of trade in intermediate goods, the measured factor content of trade in efficient factor f by country c is defined as

$$F_{fc}^{*} = E_{fc} X_c - \sum_{c' \neq c} E_{fc'} M_{cc'}, \tag{1.23}$$

where E_{fc} is an $1 \times I$ vector that converts trade in goods into trade in factors measured in efficiency units, X_c is an $I \times 1$ vector of country c's exports and $M_{cc'}$ are $I \times 1$ vectors of bilateral imports of goods by country c from country c'. The total net efficient factor content of country c's trade is computed as the amount of efficient factor f embodied in country c's exports, $E_{fc}X_c$, minus the quantity of efficient factor f that country c imports from other countries, $\sum_{c' \neq c} E_{fc'} M_{cc'}$. Here, E_{fc} is the c'th column of $E_f = \tilde{D}_f (I - B)^{-1}$, which is a complicated function of the efficient factor use matrices D_{fc}, and the input-output matrices B_c of all countries in the world. [21]

The reason why one needs to consider the input-output relations of the whole world to compute the factor content of a single country's trade is trade in intermediate goods. For example, if the US imports cars from Germany that have been produced using Chinese steel, the factors embodied in the Chinese steel must be evaluated using the Chinese factor use matrix, and not the German one.

To obtain the HOV equations in efficiency units, one needs to make the assumption that each country c consumes a fraction of the world's total consumption of all goods produced in a country c' which is proportional to the importing country's size.

A.11: $C_{cc'} = s_c \sum_{c' \in C} C_{c'}$

This condition is met by the class of models considered in this paper, since - because of love for variety and monopolistic competition - each country imports a fraction of every good produced in each country and the entire production of every good is consumed.

As Trefler and Zhu (2005) show **A.11** is sufficient (and in general also necessary) for the HOV-equations to hold in efficiency units. Hence, we have that

$$F^*_{fc} = A_{fc} V_{fc} - s_c \sum_{c \in C} A_{fc} V_{fc} = \hat{V}_{fc} - s_c \hat{V}_{fw}. \tag{1.24}$$

Equation (1.24) states that F^*_{fc}, the measured efficient factor content of trade, equals the difference between a country's endowments of factor f in efficiency units, $\hat{V}_{fc}$ and the world endowments of this factor in efficiency units, $\hat{V}_{fw}$, multiplied by

[21] For the exact definitions of $\tilde{D}$ and B I refer the interested reader to Trefler and Zhu (2005).

country c's share in world GDP. The right hand side of (1.24) is usually called the predicted factor content of trade.

Consequently, a country exports an efficient factor f in net terms (i.e. $F^*_{fc} > 0$) whenever $\hat{V}_{fc} > s_c \hat{V}_{fw}$ because it consumes a fraction of the world efficient endowments that is proportional to its size.

Let us now turn back to the question how to determine the parameter values of the **PCP**. As we noted, the HOV-equations provide restrictions on the factor productivities computed from the model for given parameter values $\theta = (\{\alpha_i\}, \{\beta_i\}, \epsilon)$. Let $F^*_{fc}(\theta)$ be the factor content of trade constructed using the factor use matrices that have been generated by the model, $D_{fc}(\theta)$. Dividing (1.24) by the equation for the US and normalizing A_{fUS} to one, we obtain the following relation.

$$A_{fc}(\theta) = \frac{Y_c}{Y_{US}} \frac{V_{fUS}}{V_{fc}} + \frac{F^*_{fc}(\theta)}{V_{fc}} - \frac{Y_c}{Y_{US}} \frac{F^*_{fUS}(\theta)}{V_{fUS}} + u_{fc}, \tag{1.25}$$

where I have augmented the equation for an i.i.d error term, u_{fc}. Hence, a country has a high factor productivity relative to the US if its relative factor-output-ratio is low and if it exports more of a factor relative to its endowments compared to the US controlling for its relative size. If $\{A_{fc}(\theta)\}$ are good estimates of factor productivities, equation (1.25) should hold roughly with equality.

This test requires - in addition to calibrated values of $A_{fc}(\theta)$ - information on countries' input-output matrices, on bilateral trade at the sector level and on the factor use matrix of the US (or any other reference country).

To make this more formal, I use a GMM estimation procedure to choose the vector of parameters θ.

I use the following L=4 orthogonality conditions to estimate θ: $E(u_{fc}) = 0$ and $E(u_{fc}\frac{Y_c}{Y_{US}}) = 0$ for $f \in \{H, K\}$. These conditions exactly identify θ in the two sector multiple cone case and over-identify it in the factor deepening and the CFPE case.

Let $Z = [1, \frac{Y}{Y_{US}}]$ be the matrix of instruments, let $g_c(\theta) = Z_c' u_c(\theta)$ and let $g(\theta) = 1/C \sum_{c=1}^{C} g_c(\theta)$ be the L vector stacking the orthogonality conditions. Then I choose θ to minimize the quadratic form

$$\min_{\theta} J = \min_{\theta} g(\theta)' W_i g(\theta), \tag{1.26}$$

where $\theta = (\{\alpha_i\}, \{\beta_i\}, \epsilon)$ is the vector of parameters to be estimated and W^i is a weighting matrix.

The procedure is to

1) choose $W_0 = I$,

2) solve **PCP** for a given θ_n,

3) evaluate (1.26) at θ_n and update using an optimization routine to get θ_{n+1} and

4) repeat steps 2) and 3) until $||\theta_{n+1} - \theta_n||$ is small enough and obtain the preliminary estimate θ_i

5) update $W_i = C[\sum_{c=1}^{C} g_c(\theta(i)) g_c(\theta(i))']^{-1}$

6) iterate on 2) - 5) until $||W_{i+1} - W_i||$ is small.

The GMM estimator $\hat{\theta}$ has an asymptotic normal distribution with $E(\hat{\theta}) = \theta$ and variance covariance matrix $\Sigma = 1/C[(1/C \sum_{c=1}^{C} \nabla g_c(\theta))' W_i^{-1} (1/C \sum_{c=1}^{C} \nabla g_c(\theta))]^{-1}$.

The data set used for implementing this approach consists of a cross section of endowments, income and factor prices in PPPs for 96 countries in 2001. Data on human capital, $\{H_c\}$, measured as efficient labor, are constructed following Caselli (2005) using data from Barro and Lee (2001) and the Penn World Table (PWT) version 6.2. Data on income in PPPs are also taken from the PWT and capital stocks are constructed from PWT investment data using the perpetual inventory method. Finally, factor prices in PPPs, $\{w_c\}$ and $\{r_c\}$, are computed using the previous data and information on labor income shares $\{s_{Hc}\}$, from Bernanke and Gürkaynak (2002) and my own calculations, by making use of the fact that $w_c = s_{Hc}Y_c/H_c$ and $r_c = (1 - s_{Hc})Y_c/K_c$. The required data on factor use matrices, input-output matrices and bilateral trade at the sector level for 53 countries are from the Global Trade Analysis Project (GTAP) Version 6.[22]

1.4 Results

In this section I provide the results of calibrating productivities and estimating parameters within the Helpman-Krugman-Heckscher-Ohlin model. I start by discussing the examples considered in section two and then compare the fit of the different models in terms of the HOV equations.

Example 1: Factor Deepening

As a starting point assume that all sectors have identical factor intensities (**A.8**). In this case it is straightforward to derive analytical solutions for the **PCP**, because the possibility of structural change has been eliminated and terms of trade effects are absent. Hence, a country's aggregate income is independent of foreign variables. [23]

$$A_{fc} = \left(\frac{\sigma}{\sigma - 1}\right)\frac{1}{p}\left(\frac{1}{1-\alpha}\frac{\pi_c V_{fc}}{Y_c}\right)^{\frac{\epsilon}{\epsilon-1}}\frac{Y_c}{V_{fc}} \tag{1.27}$$

Consequently, relative factor productivities are given by the following expression,

$$\frac{A_{fc}}{A_{fUS}} = \left(\frac{s_{fc}}{s_{fUS}}\right)^{\frac{\epsilon}{\epsilon-1}}\frac{\left(\frac{Y_c}{V_{fc}}\right)}{\left(\frac{Y_{US}}{V_{fUS}}\right)}. \tag{1.28}$$

[22]Even though I compute productivities for 96 countries, because of data availability on input-output matrices only a subset of 53 countries can be used in evaluating the model fit. For a detailed description of the data and their construction see the data appendix.

[23]To derive this divide the factor market clearing conditions and solve for factor prices using the pricing condition.

This is Caselli (2005)'s formula for calibrating productivities with factor augmenting productivity differences. If factors are substitutes ($\epsilon > 1$), relative factor productivities are increasing in relative factor shares. The intuition is that when inputs are good substitutes, factor demand shifts towards the productive factor, raising its income share. When factors are complements ($\epsilon < 1$) the opposite is true. Since the unproductive factor is required in production, a high income share is a sign of inefficiency.

Moreover, relative factor productivities are linearly decreasing in relative factor-output ratios. Holding constant factor income shares, and the technology parameter, α, a high output per unit of factor implies that the factor must be productive.

To estimate ϵ, the only parameter of interest in this specification, combine (1.28) with the HOV-equations. The efficient factor use relative to the US can then be written as $D_{fc} = \left(\frac{s_{fc}}{s_{fUS}}\right)^{\frac{1}{\epsilon-1}} D_{fUS}$, while the HOV-equations relative to the US become

$$\left(\frac{s_{fc}}{s_{fUS'}}\right)^{\frac{\epsilon}{\epsilon-1}} \frac{Y_c}{Y_{US}} \frac{V_{fUS}}{V_{fc}} = \frac{Y_c}{Y_{US}} \frac{V_{fUS}}{V_{fc}} + \frac{F^*_{fc}(\epsilon)}{V_{fc}} - \frac{Y_c}{Y_{US}} \frac{F^*_{fUS}(\epsilon)}{V_{fUS}} + u_{fc}. \tag{1.29}$$

The first rows of table 1.1 present the estimation results for the factor deepening case. The first specification uses all four orthogonality conditions. The estimate of the elasticity of substitution between factors, $\hat{\epsilon}$, is 0.836 and extremely precise. The J-statistic implies that the imposed orthogonality conditions are valid. In addition, the null that $\epsilon = 1$ is rejected at the one percent level. To check whether these estimates are robust, I re-estimate ϵ using first only the first two orthogonality conditions (zero mean of the error term). This alternative estimate is 0.833, again estimated very precisely, and extremely close to the first estimate. Subsequently, I redo the estimation using only one factor content of trade at a time. Again, the estimates remain very stable and precise and are surprisingly similar independently whether the human or physical capital content of trade is used.

Table 1.1: Model fit 1 - Parameters. GMM estimates of the elasticity of substitution between human and physical capital (ϵ) (the capital income share (α) in the Cobb-Douglas case) using different sets of moment conditions from the HOV equations (1.25). The last column is the P-value for the validity of the overidentifying restrictions.

Case	Moment Cond.	ϵ	Std(ϵ)	t-statistic	J-statistic	P-value
Factor	all	0.8363	0.009	-18.29	0.234	0.972
Deepening	$E(u) = 0$	0.8342	0.012	-13.23	0.179	0.672
	F_H	0.8158	0.046	-3.99	0.006	0.9392
	F_K	0.8373	0.009	-17.75	0.028	0.868
Cobb-	all	0.5407	0.035	6.08	16.123	0.001
Douglas (α)	$E(u) = 0$	0.6868	0.04	8.79	2.617	0.106
	F_H	0.2311	0.064	-1.53	0.098	0.755
	F_K	1	0	-	356.067	0
Multi Cone	all	0.5	-	-	-	-

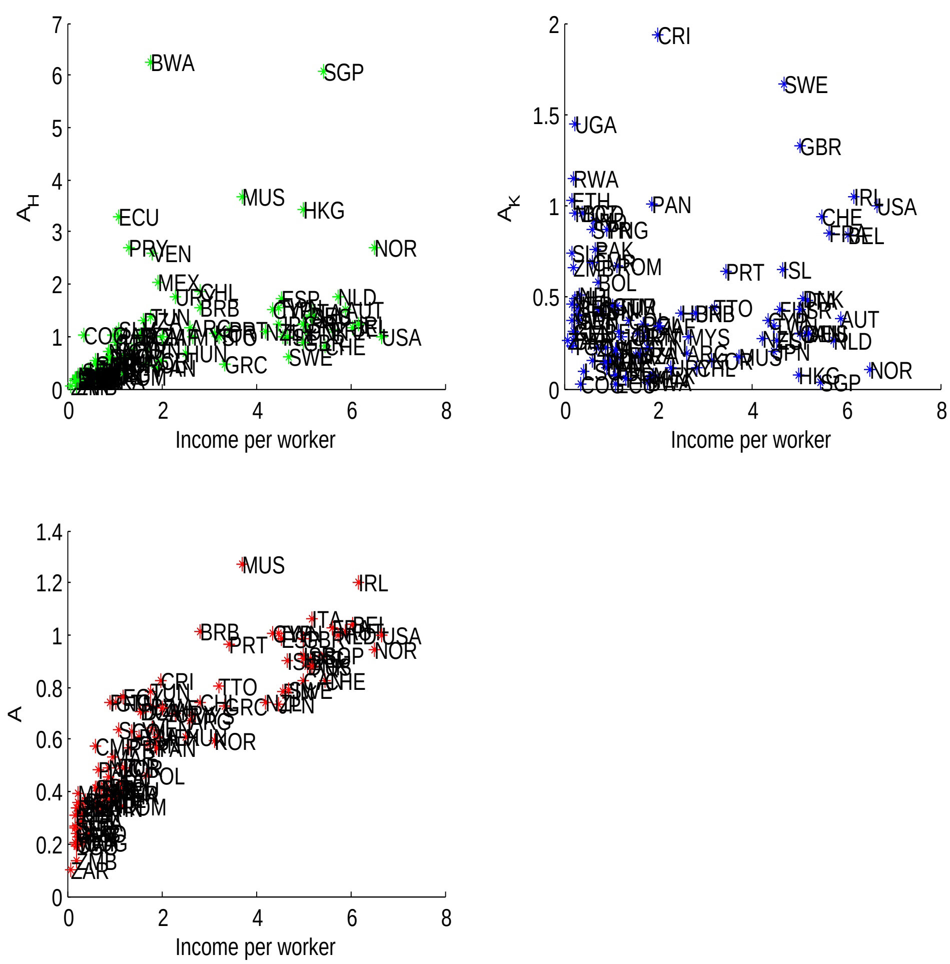
Consequently, if the factor deepening case is assumed to be the true model, the HOV-equations imply that physical and human capital are weak complements, with point estimates of the elasticity of substitution lying in the interval [0.816,0.837].

The upper left panel of figure 1.1 plots the productivity of human capital against income per worker for $\epsilon = 0.836$. There is a strong positive correlation between the productivity of human capital and income per worker, which is easily explained by the fact that empirically there is no clear correlation between the income share of labor and income per worker and a positive relation between output per unit of human capital and income per worker. On the other hand, there is no obvious relation between the productivity of physical capital and income per worker (see right panel of figure 1.1).

If in addition to assuming that factor intensities are identical across sectors we presuppose that productivities are not factor augmenting but Hicks neutral and that the elasticity of substitution is one[24], we obtain the standard model for development

[24] The assumption of a unit elasticity of substitution is necessary if productivity is Hicks neutral, if one wants to match the fact that there is no correlation between factor income shares and income

Figure 1.1: Factor deepening case. The upper panels plot factor augmenting productivities against income per worker for the factor deepening case ($\epsilon = 0.836$). The lower panel plots TFP against income per worker in the Cobb-Douglas case ($\epsilon = 1$).



accounting that has been used by Klenow and Rodriguez-Clare (1999), Hall and Jones (1999) and many others.

$$A_c = \frac{Y_c}{p\left(\frac{\sigma}{\sigma-1}\right) K_c^{\alpha} H_c^{1-\alpha}} \tag{1.30}$$

$$\frac{A_c}{A_{US}} = \left(\frac{Y_c}{Y_{US}}\right)\left(\frac{K_{US}}{K_c}\right)^{\alpha}\left(\frac{H_{US}}{H_c}\right)^{1-\alpha} \tag{1.31}$$

In this case one data point per country is sufficient to determine A_c, so I follow the tradition to take aggregate income, Y_c, as given. Hall and Jones (and others using this approach) find that cross country differences in A_c are large and strongly positively correlated with income per worker. This can be seen clearly from the lower panel of figure 1.1, which plots countries' calibrated productivities against their incomes per worker for $\alpha = 0.33$, the average capital income share in my sample.[25]

Since the Cobb-Douglas case is not directly a limiting case of the general factor deepening model[26], I estimate α using the HOV-equations to check if a plausible value for this parameter can be obtained.

With a Cobb-Douglas production function the efficient factor use relative to the US is

$D_{fc} = \frac{V_{fc}}{V_{fUS}}\left(\frac{K_{US}}{K_c}\right)^{\alpha}\left(\frac{H_{US}}{H_c}\right)^{1-\alpha} D_{fUS}$ and substituting the expression for productivities, the HOV-equations relative to the US become

$$\frac{Y_c}{Y_{US}}\left(\frac{K_{US}}{K_c}\right)^{\alpha}\left(\frac{H_{US}}{H_c}\right)^{1-\alpha} = \frac{Y_c}{Y_{US}}\frac{V_{fUS}}{V_{fc}} + \frac{F_{fc}^*(\alpha)}{V_{fc}} - \frac{Y_c}{Y_{US}}\frac{F_{fUS}^*(\alpha)}{V_{fUS}} + u_{fc}. \tag{1.32}$$

per worker.

[25]This calibration is Caselli (2005)'s and is an accounting view point of explaining income differences, because some part of differences in capital stocks may actually be due to differences in productivity, since in any neoclassical growth model an increase in A induces capital accumulation. Hall and Jones (1999) control for this by writing output as a function of the capital output ratio which is invariant to total factor productivity in the steady state. Results are not very sensitive to the particular approach taken.

[26]The efficient factor use (1.29)is not well defined if ϵ=1.

Using all 4 orthogonality conditions, $\hat{\alpha} = 0.54$, which is implausibly large (the null that α=0.33 is rejected at the 1 percent level). However, the J-statistic lets me reject the validity of the orthogonality conditions at the one percent level. As a consequence, I reestimate the model using only the first two orthogonality conditions. Now $\hat{\alpha} = 0.69$ (again the null that α=0.33 is rejected at the 1 percent level), which is even more implausible and once more the orthogonality conditions are unlikely to be satisfied. Next, I estimate α using only the moment conditions for the human capital content of trade. Now $\hat{\alpha} = 0.23$, which is somewhat more realistic but still the null that $\alpha = 0.33$ is rejected, while the orthogonality conditions seem to be valid now. Furthermore, using only the moment conditions for the physical capital content of trade, $\hat{\alpha} = 1$, which does not make much sense. Summing up, the Cobb-Douglas model with factor deepening performs poorly in terms of fitting the HOV-equations, especially in the case of physical capital.

Example 2: Conditional Factor Price Equalization (CFPE) & Trefler's Productivities

If one assumes instead that conditional on measuring endowments in efficiency units, factor prices are equalized across countries, relative factor productivities can be directly read off from relative factor prices,

$$\hat{\pi}_c = \hat{\pi}_{US} = \hat{\pi} = \frac{\pi_c}{A_{fc}} = \frac{\pi_{US}}{A_{fUS}}. \tag{1.33}$$

Since $w_c = \frac{s_{Hc} Y_c}{H_c}$ and $r_c = \frac{s_{Kc} Y_c}{K_c}$, I obtain a relationship between factor productivities, factor shares and factor-income ratios that is similar to Example 1.

$$\frac{A_{fc}}{A_{fUS}} = \frac{s_{fc}}{s_{fUS}} \frac{\left(\frac{Y_c}{V_{fc}}\right)}{\left(\frac{Y_{US}}{V_{fUS}}\right)} \tag{1.34}$$

Relative factor productivities are depicted in the upper panels of figure 1.2. Hence, if conditional factor price equalization is assumed to hold, rich countries are again more productive in the use of human capital, while poor countries make more efficient use of physical capital.

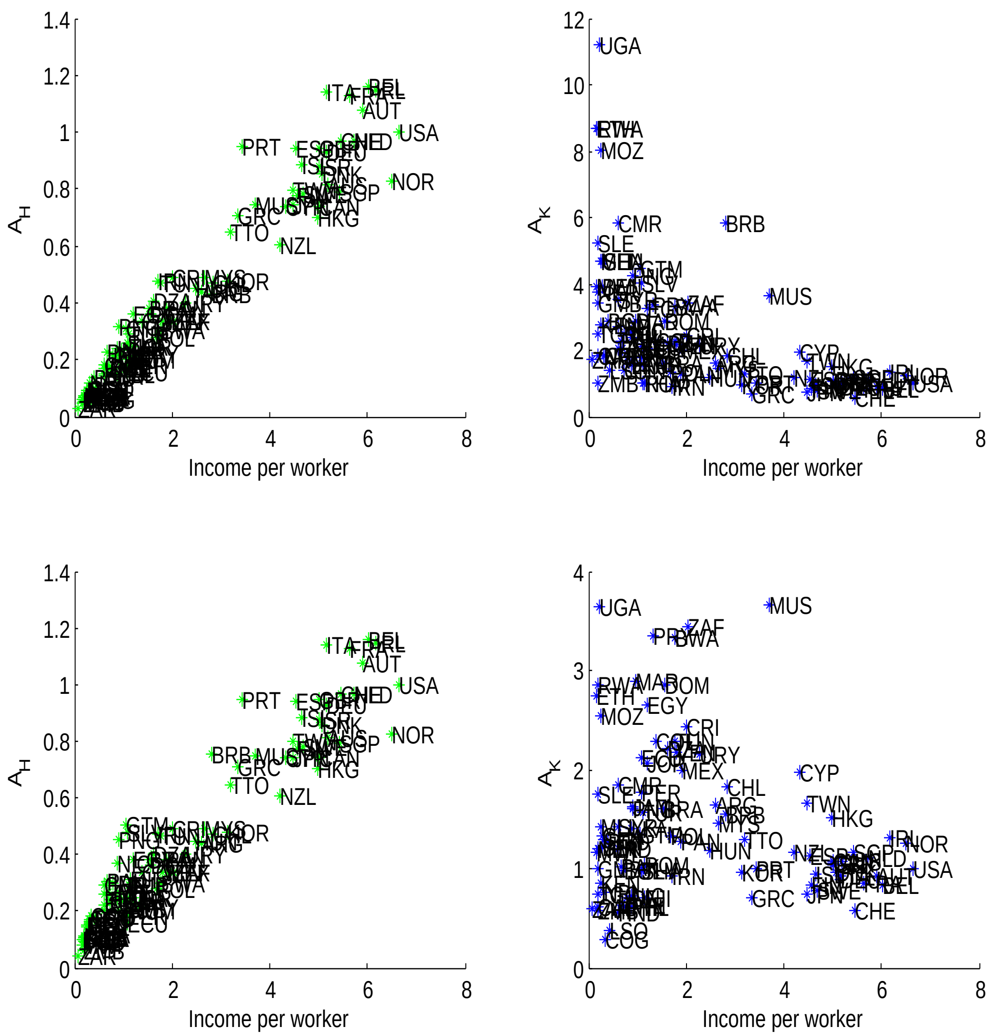
The efficient factor use relative to the US is now $D_{fc} = \left(\frac{s_{fc}}{s_{fUS}}\right) D_{fUS}$ and the HOV-equations relative to the US are $\left(\frac{s_{fc}}{s_{fUS'}}\right) \frac{Y_c}{Y_{US}} \frac{V_{fUS}}{V_{fc}} = \frac{Y_c}{Y_{US}} \frac{V_{fUS}}{V_{fc}} + \frac{F^*_{fc}}{V_{fc}} - \frac{Y_c}{Y_{US}} \frac{F^*_{fUS}}{V_{fUS}} + u_{fc}$, so that they are independent of θ.[27] Note also that as $\epsilon \to \infty$ the HOV equations relative to the US for the factor deepening case (1.29) converge to CFPE. Hence, the hypothesis of the aggregate elasticity of substitution being infinite is strongly rejected by the previous estimates. More evidence against CFPE can be obtained by checking directly the factor use matrices in efficiency units, which by hypothesis should be equal across countries, i.e. $D_{fUS} = \frac{A_{fc}}{A_{fUS}} D_{fc}$. In fact, for both factors there is a significant negative correlation between the average factor use in efficiency units and income per worker, so that poor countries use more efficient factors per unit of output than rich ones.[28]

At this point it seems adequate to relate my procedure to Trefler (1993)'s paper. His approach is to find a set of factor productivities that makes the HOV-equations hold exactly under the assumption of CFPE and then to compare productivity estimates with factor prices. To be more specific, he assumes that there are no Ricardian technology differences and that conditional factor price equalization holds at the world level (**A.10**), so that the factor use matrices of all countries are a simple transformation of the one of the US, $D_{fc} = A^{-1}_{fc} D_{fUS}$ and that all countries have identical

[27] This reflects the fact that the values of θ such that CFPE holds at the world level is not unique. The implicit aggregate elasticity is ∞.

[28] The correlation is -0.26 (P-value 0.06) for human capital and -0.48 (P-value 0.0003) for physical capital.

Figure 1.2: Heckscher-Ohlin case. The upper panels plot factor augmenting productivities against income per worker for the case of conditional factor price equalization. The lower panels show the case of multiple cones ($\epsilon = 0.5$).



input-output matrices, $B_c = B_{US}$. Then one can write the factor content of trade in efficiency units as

$$F^*_{fc} = D_{US}(I - B_{US})^{-1}(X_c - \sum_{c' \neq c} M_{cc'}).$$

Normalizing $A_{fUS} = 1$ and dropping the equation for the US, the HOV equations in efficiency units (1.24) form a system of $C - 1$ independent linear equations in A_{fc}, which can be solved for the unknown factor productivities.

From (1.25) we see that if F^*_{fc} is small, relative productivities equal relative average products. In fact this is the case in the data if the factor content of trade is computed with the US factor use matrix and as a consequence productivities computed with Trefler's method are similar to the ones obtained from (1.34), which also explains why Trefler finds that relative productivities are similar to relative factor prices.[29] Rich countries are measured to have much higher human capital productivities than poor nations, while poor countries tend to have higher productivities of physical capital.[30]

Example 3: Multiple Cones

If there are multiple cones of diversification, the picture is quite different because the mapping between endowments, factor prices and factor productivities changes its shape, depending on whether a country specializes or lies in a cone. Again, let us take goods prices as parameters for now.

For countries that specialize in sector $i \in \{H, K\}$ the mapping from endowments, factor prices and income to factor productivities looks similar to Caselli's.

[29] Productivities are not reported, but very similar to figure 1.2. These results are robust to using the technology matrix of other countries as reference and to using the true input-output tables of each country in computing the factor content of trade.

[30] These results differ from Trefler's. He finds that rich countries tend to use both labor and physical capital more efficiently than poor ones. The main reasons seem to be his small sample and his choice of very high depreciation rates of 15% (instead of 6%, as common in the development accounting literature), which imply capital-output ratios that are higher in rich countries.

$$A_{fc} = \left(\frac{\sigma}{\sigma-1}\right)\frac{1}{p_i}\left(\frac{1}{1-\alpha_i}s_{fc}\right)^{\frac{\epsilon}{\epsilon-1}}\frac{Y_c}{V_{fc}} \tag{1.35}$$

There are, however, some important differences. First of all, terms of trade effects matter. If goods prices in the sector in which a country specializes are higher, a lower factor productivity is sufficient to reach a given income. In addition, if $\epsilon > 1$, factor productivities are decreasing in the weight of capital in production, α_i, which varies across industries, because holding constant factor income shares an increase (decrease) in α_i would increase income per unit of physical capital (human capital). Since it is held constant, factor productivity must decrease. If $\epsilon < 1$, factor productivities are increasing in the weight of factors in production because an increase (decrease) in α_i would cause a decrease in output per unit of factor input for given factor income shares. Holding it constant, factor productivity must increase. Consequently, a high α_K implies that - holding everything else constant - capital abundant countries that specialize in the capital intensive good have high (low) capital productivities if factors are complements (substitutes).

For countries that lie within the cone of diversification the mapping between endowments, income, prices and parameters has another form.

$$A_{Hc} = \left(\frac{\sigma}{\sigma-1}\right)\left[\frac{\alpha_H^{\epsilon}p_K^{1-\epsilon}-\alpha_K^{\epsilon}p_H^{1-\epsilon}}{\alpha_H^{\epsilon}(1-\alpha_K)^{\epsilon}-\alpha_K^{\epsilon}(1-\alpha_H)^{\epsilon}}\right]^{\frac{1}{\epsilon-1}} s_{Hc}\frac{Y_c}{H_c} \tag{1.36}$$

$$A_{Kc} = \left(\frac{\sigma}{\sigma-1}\right)\left[\frac{(1-\alpha_H)^{\epsilon}p_K^{1-\epsilon}-(1-\alpha_K)^{\epsilon}p_H^{1-\epsilon}}{\alpha_K^{\epsilon}(1-\alpha_H)^{\epsilon}-\alpha_H^{\epsilon}(1-\alpha_K)^{\epsilon}}\right]^{\frac{1}{\epsilon-1}} s_{Kc}\frac{Y_c}{K_c} \tag{1.37}$$

Factor productivities are again linear functions of factor-output ratios and also of factor income shares. Terms of trade effects are at work too, but they are more complex than for countries which specialize. Now productivities are decreasing in the price of the sector that uses the factor intensively. The explanation is again the Stolper-Samuelson effect. An increase in the price of an industry shifts production towards that sector, and increases the income share of that factor. If the income share and income per unit of factor are held constant, the factor must have lower productivity.

The lower panels of figure 1.2 plot A_{Hc} and A_{Kc} against income per worker for a model with two sectors and multiple cones, in which goods prices have been solved endogenously for the optimal θ.[31] Again, human and physical capital are estimated to be complements. 39 poor countries specialize in the human capital intensive sector, while the rest of the world lies in a common cone of diversification. The correlation between A_{Hc} and income per worker is again strongly positive and poor countries are still estimated to be more productive in the use of physical capital.

Using the HOV equations to Compare Model Fit

To see which of the different versions of the model performs best I use an economic measure of performance - I evaluate the fit of the HOV-equations in efficiency units at $\hat{\theta}$. I provide the results of the following classical tests. First the "sign test" that reports the fraction of observations for which the left hand side (measured factor content) and the right hand side (predicted factor content) of the HOV-equations (1.24) have the same sign. Second the "weighted sign test" that weights observations by the magnitude of factor flows, third the slope coefficient, β, of a regression of the measured on the predicted factor content, with a theoretical value of one. Fourth, the R-squared from this regression and finally the ratio of the variances of the measured and the predicted factor content, a measure known as the "missing trade" statistic.

Table 1.2 reports the results of these tests. It is quite obvious that the factor deepening model with complementary factors ($\epsilon = 0.836$) easily outperforms all its competitors - the Cobb-Douglas model ($\alpha = 0.33$), the CFPE model and also the -

[31] $\alpha_H = 0.06$, $\alpha_K = 0.77$, $\epsilon = 0.5$ and $\beta_H = 0.84$. Meaningful standard errors for these estimates are hard to obtain, since J is not continuously differentiable in θ at $\hat{\theta}$.

Table 1.2: Model fit 2 - HOV-equations. Fit of the HOV equations for the factors human capital H and physical capital K of different specifications. *Sign* is the fraction of observations for which measured and predicted factor content of trade have the same sign, *W. Sign* weights the signs with the magnitude of factor flows, β is the slope coefficient in a regression of the measured on the predicted factor content, R^2 is the R-square from this regression and *Missing Trade* is the ratio of the variances of the measured relative to the predicted factor content of trade.

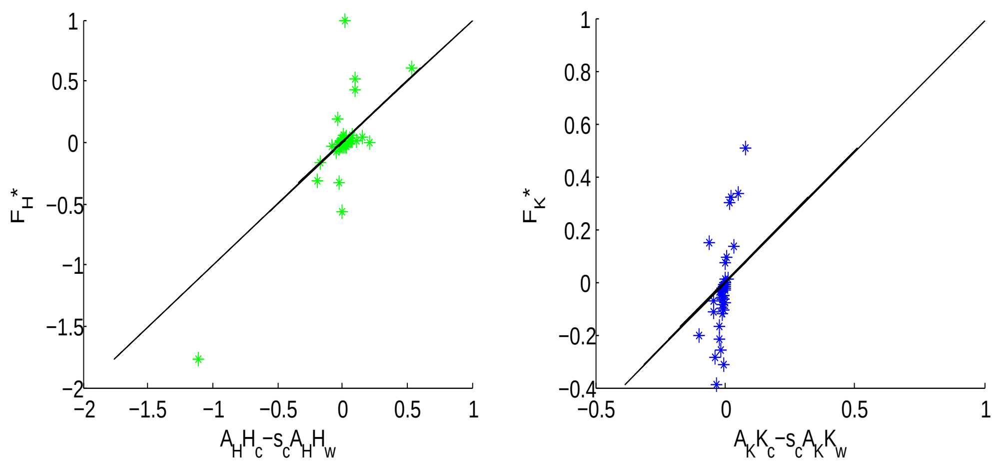
Model	Factor	Sign	W. Sign	β	R^2	Missing Trade
Factor	H	0.698	0.967	1.446	0.656	3.184
Deepening	K	0.925	0.936	3.211	0.693	14.88
Cobb	H	0.34	0.073	-0.341	0.495	0.23
Douglas	K	0.34	0.412	-0.0003	0.121	0
CFPE	H	0.738	0.459	-0.324	0.148	0.7
	K	0.34	0.467	-0.0009	0.096	0
Multi	H	0.623	0.369	-0.077	0.038	0.154
Cone	K	0.509	0.8	-0.0007	0.197	0

admittedly overly simplistic - two sector multiple cone model in virtually all tests. For example, the weighted sign statistic is 0.97 for physical capital and 0.96 for human capital for the factor deepening model, which is by far closer to the theoretical value of one than for any of the other models. It is also the only model that gets βs of the right sign and roughly correct magnitudes and that does not suffer from "missing trade"

Figure 1.3 plots the measured factor content against the predicted factor content of trade for the factor deepening case. The good fit of the model, especially for human capital, is clearly visible, while measured factor trade is somewhat too large for physical capital. Hence, I conclude that the model by far best supported by the HOV-equations is the factor deepening model with factor augmenting productivities and weak complementarity between human and physical capital.

Let me therefore discuss the features of this world in somewhat more detail. Coming back to the upper panels of figure 1.1, we see that rich countries are much more

Figure 1.3: Fit of the HOV equations. The panels show a plot of the measured efficient factor content of trade (vertical axis) against the predicted efficient factor content of trade (horizontal axis) for the factor deepening case with $\epsilon = 0.836$.



productive in the use of human capital than poor ones. The correlation between A_{HC} and income per worker is 0.432 and strongly significant (P-value: 0.000). There are some outliers, like Botswana and Singapore, which have extremely low labor income shares in the data and therefore very high human capital productivities. Since the data quality on labor income shares is not very good, this should be taken with some caution. The ratio of human capital productivity of the 90th to the 10th percentile is 10.72. In the case of physical capital, there is a no clear relation between factor productivity and income per worker. The correlation between A_{Kc} and income per worker is slightly negative (-0.031) but insignificant (P-value: 0.767). The ratio of physical capital productivity of the 90th to the 10th percentile is 10.72. A number of very poor African economies are measured to have very high capital productivities, which is due to their extremely low capital output ratio. When we disregard these countries, there is a positive relation between capital productivity and income per worker, with Sweden, the UK, Ireland, Switzerland, France, Belgium and the US measured to have very high capital productivities. While it is quite intuitive that rich countries are much more efficient in their use of human capital, it is less clear, why a number of very poor African countries should be so productive in the use of physical capital. The fact that some of the poorest countries in the world use so little physical capital in production could well reflect distortions in capital markets, like high tariffs on capital goods and malfunctioning of credit markets instead of high capital productivities. In this world there are incentives for human capital to move to rich countries and for capital to move to poor ones because returns in physical units are not equalized.

A further feature of the factor deepening world is that the physical to human capital ratios in efficiency units are quite similar across countries. This is due to the fact that rich countries, which have large physical to human capital ratios, have very high human capital productivities and that there is no clear relation between capital productivity and income per worker.

Turning to the estimate of the elasticity of substitution, note that my estimates are similar to those of Antras (2004), who estimates the elasticity of substitution between labor and capital for the US aggregate production function from time series data allowing for biased technological change. He finds values in the range of 0.5 to 0.9, so my estimates are consistent with time series evidence for the US.

Another point worth mentioning is the relation of my findings to the extensive literature on the HOV-equations. Even though it is well known that these relations apply to a wide class of models, it seems interesting that the model that actually best fits the HOV-equations (at least in the relatively restrictive class of models considered in this paper) is a one sector economy, in which any Heckscher-Ohlin style trade is absent.

1.4.1 Development Accounting

Having said this, let me now perform the typical development accounting exercise which is to ask why some countries are so much richer than others. The first question I pose is: What would the world income distribution look like if all countries had the same per capita factor endowments given their factor productivities? The experiment is to endow each country at a time with the per worker endowments of human and physical capital of the US and to compute its counterfactual income per worker for given productivities A_{Hc} and A_{Kc}[32].

[32]This experiment differs somewhat from the one performed by Caselli (2005), who asks the question: How much dispersion of the income distribution could we observe if all countries had the same A_K and A_H? He defines 100% success as a model that can generate the actual dispersion of the cross country income distribution without productivity differences. However, with factor augmenting productivities, this statistic is not very meaningful because the effect of productivities and endowments on the variance of income cannot be separated. I ask the question how compressed the income distribution would be if countries had their own productivities but the same endowments, which seems more natural to me because it addresses the question which policy would help to increase

In the factor deepening world, the counterfactual income per worker is given by

$$\tilde{y}_c = [\alpha(A_{Kc}k_{US})^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha)(A_{Hc}h_{US})^{\frac{\epsilon-1}{\epsilon}}]^{\frac{\epsilon}{\epsilon-1}}. \tag{1.38}$$

The upper left panel of figure 1.4 plots predicted income per worker given US per capita endowments against income per worker in the case of factor deepening.[33] The ratio of income per worker of the 90th to the 10th percentile is reduced from 25 to 4.5. The lower left panel plots the output gain (the ratio of predicted to actual income per worker) for this case. Obviously, income gains are largest for poor countries.

Alternatively, I ask the question what the world income distribution would look like if all countries had the US factor productivities but their own factor endowments. In this case, counterfactual income is the following,

$$\tilde{y}_c = [\alpha(A_{KUS}k_c)^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha)(A_{HUS}h_c)^{\frac{\epsilon-1}{\epsilon}}]^{\frac{\epsilon}{\epsilon-1}}. \tag{1.39}$$

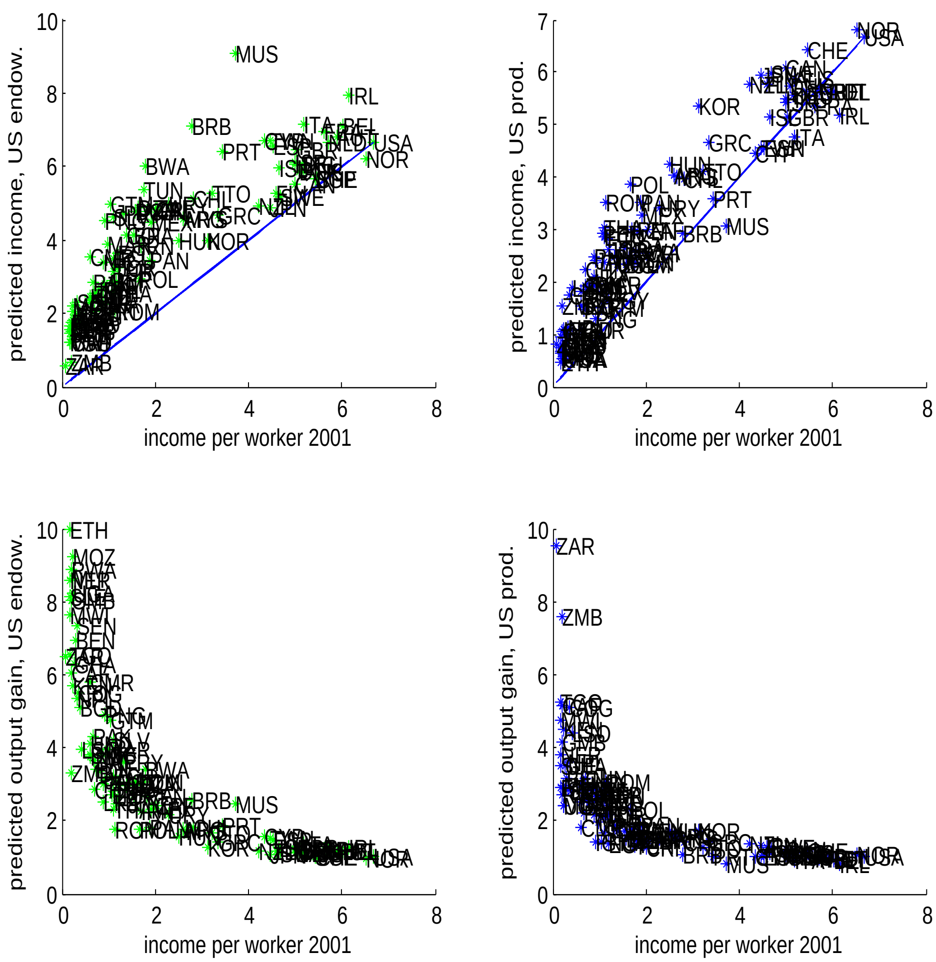
The upper right panel plots predicted against actual income per worker, while the lower right panel plots the predicted output gain. The ratio of income per worker of the 90th to the 10th percentile is reduced from 25 to 6.96, which is a smaller reduction in inequality than in the first case, where all countries have the same endowments per worker. This can also be seen from output gains which are smaller for most countries in the second case. [34] The reason is that the US has some of the largest

the income of poor countries.

[33]For $\epsilon = 0.836$.

[34]Caselli (2005) notes that the factor deepening model is able to replicate the cross country variance in income per capita even if all countries have the same productivities (those of the US) when ϵ is sufficiently low (around 0.5). In that sense the whole cross country variation in income per worker is "explained" by factor endowments. However, this does not imply that factor accumulation would help much in reducing cross country income differences given that we know that productivities differ. In fact, the lower the elasticity of substitution, the less powerful is factor accumulation in reducing income differences.

Figure 1.4: Development Accounting. The upper panels plot the predicted income per worker (vertical axis) against actual income per worker (horizontal axis) for the case in which all countries have the US endowments of factors per worker (left panel) or the US factor productivities (right panel) for the factor deepening world with $\epsilon = 0.836$. The lower panels plot the output gain (vertical axis) against income per worker (horizontal axis) for the same experiments.



per capita human capital and physical capital endowments and a very high human capital productivity, whereas its physical capital productivity is rather low, so that in efficiency units poor countries have higher and more balanced per capita endowment levels when endowed with the US per capita endowments than when given the US factor productivities.

1.5 Conclusion

This paper has developed a quantitative Krugman-Helpman-Heckscher-Ohlin (1985) model of the world economy in order to estimate cross country differences in factor productivities using an approach that integrates the development accounting literature and the research on the Heckscher-Ohlin-Vanek (HOV) Theorem. This has enabled me to simultaneously fit data on income, factor prices, endowments and the factor content of trade to calibrate productivities, which in turn has allowed me to evaluate the fit of the model and to estimate the elasticity of substitution between human and physical capital with great precision.

My main findings can be summarized as follows: The model best supported by the data features an aggregate neoclassical production function with an elasticity of substitution between human and physical capital that is significantly lower than one. This implies that human and physical capital are (weak) complements and productivities are factor augmenting, while the standard Cobb-Douglas model used in the quantitative growth literature is clearly rejected. Rich countries have much higher productivities of human capital than poor ones, while there is no clear relation between the productivity of physical capital and income per worker. My results also show that this one sector economy, where differences in factor prooportions do not constitute a reason for trade, fares far better in terms of explaining cross country flows of efficient factor services (i.e. fits the HOV-equations better) than a simple generalized Heckscher-Ohlin model, where this motive is prominently present.

Although this paper has taken us a small step further in the estimation of cross country differences in productivity, it has also made evident some of the limits of the Helpman-Krugman-Heckscher-Ohlin model. Specifically, since the model has no trade costs, within the conditional factor price equalization set there is no direct connection between local factor abundance and export shares in sectors that are intensive in abundant factors, while outside this set predicted specialization patterns are too extreme to be realistic. These disproportionate predictions may have potentially lead to a rejection of a Heckscher-Ohlin style world in favor of a one sector economy. An interesting alternative approach has recently been taken by Romalis (2004), who modifies a version of the Heckscher-Ohlin model without productivity differences to get clear predictions on trade in goods instead of trade in factors. This enables him to use very disaggregated trade data and to show the existence of strong Rybczynski effects. Another option is to extend the Eaton and Kortum (2002) model to Heckscher-Ohlin trade, as this model is more tractable in multi-country general equilibrium.

A further restriction of the present work is that I have abstracted from sectoral (Ricardian) productivity differences and income differences due to increasing returns. Ricardian productivity differences shift production towards those sectors in which countries have high productivities, while increasing returns in combination with trade costs tend to increase the income of countries with large markets. Both mechanisms are worth further investigation.

Chapter 2

Trade and Sectoral Productivity

2.1 Introduction

Differences in sectoral total factor productivity (TFP) across countries are at the heart of trade theory and of many theories of growth and development. The Ricardian approach to international trade emphasizes those productivity differences as the main reason for cross-country flows of goods, while the growth literature analyzes factors such as technology spillovers (Klenow and Rodriguez-Clare (2005)), human capital and technology adoption (Nelson and Phelps (1966)), or external financial dependence (Rajan and Zingales (1998)), all of which have clear predictions on the form of sectoral differences in TFP. Moreover, information on sectoral productivity differences across countries is of interest not only to theorists but also to policy makers since it is important for the design of industrial and trade policy. Nevertheless, due to data limitations, very little is known about the form and the size of sectoral productivity differentials across countries outside the industrialized world.

In this paper we try to overcome the data problem faced by the traditional approach to TFP measurement, which requires comparable information on outputs and inputs at the sectoral level. We introduce and apply a new method for estimating sectoral TFP levels that relies on information contained in bilateral trade. To our knowledge we are the first to provide a comparable and, as we will argue, reliable set of sectoral TFPs for twenty-four manufacturing sectors in more than sixty countries at all stages of development.

Our approach extends the Romalis (2004) model - that combines Heckscher-Ohlin trade with trade due to increasing returns and love for variety and trade costs - to sectoral differences in total factor productivity and many asymmetric countries. In this way we are able to back-out sectoral productivity differences as observed trade which cannot be explained by differences in factor intensities and factor prices or by differences in trade barriers across countries.

One main advantage of our approach is that we do not require information on inputs at the sectoral level to compute productivities but just need data on aggregate factor prices. Another point is that our model generates predictions on differences in sectoral prices so that we do not depend on information on sectoral price indices. Finally, we *estimate* sectoral productivities, which allows us to evaluate their reliability.

Our results provide evidence that cross country TFP differences in manufacturing sectors are large, on average of about the same order of magnitude as the substantial variation across countries at the aggregate economy level that has been found in the development accounting literature (for example, Hall and Jones (1999), and Caselli (2005)). In addition, we show that productivity differences between rich and poor countries are systematically larger in skill labor and R&D intensive sectors. Productivity gaps are far more pronounced in sectors such as Scientific Instruments, Electrical- and Non-electrical Machinery, and Printing and Publishing, than in sectors such as Apparel, Textiles, or Furniture.

We perform a series of robustness checks and show that our productivity estimates are neither sensitive to the specific assumptions of our model nor to the estimation method. Aggregate manufacturing TFPs correlate strongly with the productivity estimates found in the development accounting literature, while sectoral TFPs correlate with the productivities constructed as Solow residuals for the few countries and sectors where this method can be applied because of the limited information.

The next section briefly discusses some related literature. Section three introduces the theoretical model and provides some intuition for the economic forces at work. Section four develops a methodology for computing sectoral productivity indices. Section five presents our empirical results on productivities, and section six is dedicated to robustness checks. Section seven discusses some applications of our productivity estimates in testing specific theories of development that have implications for the cross section of productivities within countries. The final section presents our conclusions.

2.2 Related Literature

There is a large body of literature that studies sectoral productivity differences across countries by specifying a production possibility frontier and using data on sectoral inputs and outputs to calculate sectoral productivity indices. Some of the earlier contributions that use sectoral value added as an output measure are Dollar and Wolff (1993) and Maskus (1991). Those studies are limited to a number of OECD economies and do not disentangle sectoral price indices -which are usually unavailable- from output quantities. As a consequence, variation in product prices across countries may wrongly be attributed to differences in TFP. Another line of research that tries to tackle this issue is the work within the International Comparison Project (ICOP) located at the University of Groningen. Its latest project, EU KLEMS, is a high quality growth accounting database for the countries of the European Community.

In the trade literature there is also a large number of contributions that construct productivity indices at various levels of aggregation. Harrigan (1997) computes sectoral TFP indices for eight sectors in ten OECD countries to test the fit of a generalized neoclassical trade model that allows for both Ricardian and Heckscher-Ohlin trade. He finds support for the existence of Rybzcynski effects. Harrigan (1999) carefully constructs sector level price indices for six manufacturing sectors in eight OECD countries and shows that even across this restricted set of economies sectoral prices vary significantly.

Golub and Hsieh (2000) use labor productivities to test a Ricardian model of trade using data from OECD countries, while Eaton and Kortum (2002) develop a multi-country Ricardian model with a probabilistic technology specification that they calibrate to fit trade between OECD countries. Chor (2006) extends their model to Heckscher-Ohlin trade and differences in sectoral characteristics like financial dependence, volatility, etc. This class of models provides an alternative approach to construct sectoral productivity indices from trade data.[1] In parallel work to ours Finicelli, Pagano and Sbracia (2008) apply the baseline Eaton-Kortum model to calibrate aggregate manufacturing TFPs from eighteen OECD economies. They do not include Heckscher-Ohlin motives for trade in their model and compute only aggregate manufacturing productivities, while we estimate productivity differences at a sectoral level and for a sample that includes a large number of developing countries. Their main contribution is to develop a method for evaluating the impact of trade openness on aggregate TFP, which occurs through reallocation of resources towards more efficient firms, a channel that we disregard in the present paper.

Finally, Trefler (1993), Trefler (1995), and Davis and Weinstein (2001) have shown convincingly that differences in total factor productivity at the country -or factor and country- level can help to substantially improve the fit of the Heckscher-Ohlin-Vanek

[1] In our robustness checks we show that the productivity estimates obtained from the capital-augmented Eaton-Kortum model are very similar to the ones estimated with our methodology.

prediction on cross-country trade in factors but those studies do not investigate sector specific productivity differences.

2.3 A Simple Model

In order to use trade data to estimate sectoral TFP differences we need a model in which bilateral trade is determined. A convenient way to achieve this is to follow Krugman (1979) in assuming that consumers have love for variety and that production is monopolistic because of increasing returns.[2] We add three more ingredients to be able to talk about sectoral productivity differences. First, we assume that firms in different sectors use different factor proportions when faced with the same input prices, which gives rise to Heckscher-Ohlin style trade between countries. Second, we add bilateral transport costs. As Romalis (2004) points out in an influential paper, this makes locally abundant factors relatively cheap and strengthens the link between factor abundance and trade. In the Helpman-Krugman-Heckscher-Ohlin model (Helpman and Krugman (1985)), which does not consider transport cost, trade is undetermined as long as the number of factors is smaller than the number of goods and countries are not specialized. On the other hand, in the model we discuss here there is a cost advantage to produce more in those sectors that use the abundant factors intensively. This creates the prediction that countries export more in those sectors. Finally, we add sectoral differences in TFP, which introduces a motive for Ricardian style trade. Countries that have a high productivity in a sector have a cost advantage relative to their foreign competitors and charge lower prices. Because the elasticity of substitution between varieties is larger than one, demand shifts towards

[2] An alternative specification has been developed by Eaton and Kortum (2002). In their Ricardian style model there is perfect competition and every good is sourced from the lowest cost supplier that may differ across destinations because of transport costs. We will briefly turn to this model in the section dedicated to robustness checks.

the varieties of that country and leads to a larger world market share in that sector. Having explained the main features of the model, let us now develop the details.

2.3.1 Demand

Our model generalizes the setup of Romalis (2004). We assume that all consumers in a given country have identical and homothetic preferences. These are described by a two tiered utility function. The first level is assumed to be a Cobb-Douglas aggregator over K sectoral sub-utility functions. This implies that consumers spend a constant fraction of their income, σ_{ik}, which we allow to differ across countries, on goods produced in each sector.[3]

$$U_i = \prod_{k=0}^{K} u_{ik}^{\sigma_{ik}} \tag{2.1}$$

Sectoral sub-utility is a symmetric CES function over sectoral varieties, which means that consumers value each of the available varieties in a sector in the same way.

$$u_{ik} = \left[\sum_{b \in B_{ik}} x_b^{\frac{\epsilon_k - 1}{\epsilon_k}} \right]^{\frac{\epsilon_k}{\epsilon_k - 1}} \tag{2.2}$$

Note that utility is strictly increasing in the number of sectoral varieties available in a country. Sector specific elasticity of substitution between varieties is denoted by ϵ_k, and in this model we assume it to be higher than one, while B_{ik} is the set of varieties in sector k available to consumers in country i.

Goods can be traded across countries at a cost that is specific to the sector and country pair. In order for one unit of good produced by sector k of country j to arrive in destination i, τ_{ijk} units need to be shipped.

[3]For our baseline specification preferences can be generalized to two-tiered CES.

The form of the utility function implies that the demand function of country i consumers for a sector k variety produced in country j has a constant price elasticity, ϵ_k, and is given by the following expression.

$$x_{ijk} = \frac{\hat{p}_{ijk}^{-\epsilon_k} \sigma_{ik} Y_i}{P_{ik}^{1-\epsilon_k}}, \tag{2.3}$$

where $\hat{p}_{ijk} = \tau_{ijk} p_{jk}$ is the market price of a sector k good produced by country j in the importing country i[4] and P_{ik} is the optimal sector k price index in country i, defined as

$$P_{ik} = \left[\sum_{b \in B_{ik}} \hat{p}_b^{1-\epsilon_k} \right]^{\frac{1}{1-\epsilon_k}}. \tag{2.4}$$

2.3.2 Supply

In each country, firms may be active in one of $k = 0, ..., K$ different sectors. Production technology differs across sectors due to differences in factor intensities and differences in sectoral TFP. In each sector firms can freely create varieties and have to pay a fixed cost to operate. Because of the demand structure and the existence of increasing returns, production is monopolistic since it is always more profitable to create a new variety than to compete in prices with another firm that produces the same variety.

Firms in country j combine physical capital, $K_j(n)$, with price r_j[5], unskilled labor, $U_j(n)$ with price w_{uj}, and skilled labor $S_j(n)$ with price w_{sj} to produce.[6] In addition, there is a country and sector specific total factor productivity term, A_{jk}. Firms' production possibilities in sector k of country j are described by the total cost function:

[4]This implies that exporting firms charge the same factory gate price in all markets, so there is no pricing to the market behavior. We discuss the effects of relaxing this assumption in the section on robustness.

[5]For notational ease, we denote r_j alternatively as w_{capj} in the cost function.

[6]The fact that within every country every factor has a single price reflects the assumption that factors can freely move across sectors within a country. For the empirical model we need not make any assumptions on factor mobility across countries.

$$TC(q_{jk}) = (f_{jk} + q_{jk})\frac{1}{A_{jk}}\prod_{f \in F}\left(\frac{w_{fj}}{\alpha_{fk}}\right)^{\alpha_{fk}}, \tag{2.5}$$

where $F = \{u, s, cap\}$. The form of the cost function implies that the underlying sectoral production function of each firm is Cobb-Douglas with sectoral factor intensities $(\alpha_{uk}, \alpha_{sk}, \alpha_{capk})$. To produce, firms need to pay a sector and country specific fixed cost, f_{jk}, that uses the same combination of capital, skilled and unskilled labor as the constant variable cost.

Monopolistic producers maximize profits given (2.3) and (2.5). Their optimal decision is to set prices as a fixed mark-up over their marginal costs,

$$p_k = \frac{\epsilon_k}{\epsilon_k - 1}\frac{1}{A_{jk}}\prod_{f \in F}\left(\frac{w_{fj}}{\alpha_{fk}}\right)^{\alpha_{fk}}. \tag{2.6}$$

The combination of sectors with different factor intensities, and country-sector specific TFP differences gives the model Heckscher-Ohlin as well as Ricardian features. Since the elasticity of substitution across varieties, ϵ_k, is larger than one, consumers spend more on cheaper varieties. This together with the pricing structure implies that lower production costs translate into larger market shares. Low production costs may be either due to the fact that a sector is intensive in locally cheap factors, or due to high productivity in this sector. In the appendix we develop a general equilibrium version of the model and discuss in more detail how comparative advantage is determined.

2.4 Towards Estimating Sectoral Productivities

In this section we derive a method for estimating sectoral productivity levels across countries based on our model of international trade. To make progress, we write the sectoral volume of bilateral trade (measured at destination prices), which is defined as imports of country i from country j in sector k, as

$$M_{ijk} = \hat{p}_{ijk} x_{ijk} N_{jk} = p_{jk} \tau_{ijk} x_{ijk} N_{jk}. \tag{2.7}$$

The measured CIF value of bilateral sectoral trade is the factory gate price charged by country j exporters in sector k multiplied by the transport cost, the quantity demanded for each variety by country i consumers, and by the number of varieties produced in sector k in the exporting country.

Substituting the demand function $x_{ijk}(\hat{p}_{ijk})$ from (2.3), we obtain

$$M_{ijk} = \frac{(p_{jk}\tau_{ijk})^{1-\epsilon_k} \sigma_{ik} Y_i}{P_{ik}^{1-\epsilon_k}} N_{jk}. \tag{2.8}$$

Finally, using the fact that exporting firms choose a factory gate price which is a constant mark-up over their marginal cost and substituting the marginal cost function (2.5), we can write bilateral sectoral trade volume as

$$M_{ijk} = \left[\frac{\frac{\epsilon_k}{\epsilon_k - 1} \prod_{f \in F} \left(\frac{w_{fj}}{\alpha_{fk}} \right)^{\alpha_{fk}}}{A_{jk} P_{ik}} \right]^{1-\epsilon_k} \sigma_{ik} Y_i N_{jk}. \tag{2.9}$$

Equation (2.9) makes clear that bilateral trade in sector k measured in dollars depends positively on the importing country consumers' expenditure share on sector k goods, σ_{ik}, and their total income, Y_i. On the other hand, because the elasticity of substitution between varieties is larger than one, the value of trade is falling in the price charged by exporting firms, p_{jk}. This and the pricing rule (2.6) implies that trade is decreasing in the exporters' production costs. If a factor is relatively cheap in a country, this leads to a cost advantage for exporting firms in sectors where this factor is used intensively. The same holds true for sectoral productivities, A_{jk}. If a country has a high productivity in a sector relative to other exporters, it can charge lower prices and has a larger value of exports.

All of the previous statements hold conditional on the number of firms in sector

k in the exporting country. Since we do not consider data on the number of firms active in the exporting countries as very reliable, but we observe the value of sectoral production, we can use the model to solve for the number of firms given total production.[7] The monetary value of total production of sector k in country j, $\tilde{Q}_{jk}$, equals the monetary value of production of each firm times the number of firms.

$$p_{jk}q_{jk}N_{jk} = \tilde{Q}_{jk} \tag{2.10}$$

Assuming that new firms can enter freely, in equilibrium firms make zero profits and price at their average cost. Combining this with (2.6), it is easy to solve for equilibrium firm size, which depends positively on the fixed cost and the elasticity of substitution:

$$q_{jk} = f_{jk}(\epsilon_k - 1) \tag{2.11}$$

Using this result and plugging it into the definition of sectoral output, we get[8]

$$N_{jk} = \frac{\tilde{Q}_{jk}}{p_{jk}(\epsilon_k - 1)f_{jk}}. \tag{2.12}$$

Substituting for N_{jk} in the equation 2.9, we obtain

$$M_{ijk} = \left[\frac{\frac{\epsilon_k}{\epsilon_k - 1} \prod_{f \in F} \left(\frac{w_{fj}}{\alpha_{fk}} \right)^{\alpha_{fk}}}{A_{jk}} \right]^{-\epsilon_k} \left[\frac{\tau_{ijk}}{P_{ik}} \right]^{1-\epsilon_k} \sigma_{ik} Y_i \frac{\tilde{Q}_{jk}}{(\epsilon_k - 1) f_{jk}}. \tag{2.13}$$

This equation can be rearranged to solve for the sector productivity A_{jk}. Because a productivity index needs to be defined relative to some benchmark, we measure productivity relative to a reference country. We choose the US as a benchmark because they export to the greatest number of destinations in most sectors.[9] Another

[7] Using sectoral gross output instead of the number of firms mitigates mis-measurement problems, because these occur mainly for small firms that have a negligible effect on sectoral gross output.

[8] Here we assume, consistently with our model, that firms do not use intermediate goods to produce. We discuss the effect of dropping this assumption in the section on robustness.

[9] We have also tried other benchmark countries like Germany and Japan and our results are robust to these alternative specifications.

advantage of choosing a reference country is that all the terms that are not indexed to the exporting country j (i.e. σ_{ik}, Y_i, P_{ik}) drop from the equation. For each importer i we can express the "raw" productivity of country j in sector k relative to the US.

$$\begin{aligned}\frac{\tilde{A}_{ijk}}{\tilde{A}_{iUSk}} &\equiv \frac{A_{jk}}{A_{USk}}\left(\frac{f_{jk}}{f_{USk}}\right)^{-1/\epsilon_k}\left(\frac{\tau_{ijk}}{\tau_{iUSk}}\right)^{\frac{1-\epsilon_k}{\epsilon_k}} = \\ &= \left(\frac{M_{ijk}}{M_{iUSk}}\frac{\tilde{Q}_{USk}}{\tilde{Q}_{jk}}\right)^{1/\epsilon_k}\prod_{f\in F}\left(\frac{w_{fj}}{w_{fUS}}\right)^{\alpha_{fk}}\end{aligned} \tag{2.14}$$

Our "raw" productivity measure, $\frac{\tilde{A}_{ijk}}{\tilde{A}_{iUSk}}$, is a combination of relative productivities, fixed costs, and transport costs. Intuitively, country j is measured to be more productive than the US in sector k if, controlling for the relative cost of factors, j exports a greater fraction of its production in sector k to country i than the US. Note that we can compute this measure vis a vis every importing country using only data on relative imports and on exporters' relative production and factor prices.

This "raw" measure of relative productivities also contains relative sectoral transport costs and fixed costs of production. While relative transport costs vary by importing country, exporters' relative productivities and fixed costs are invariant to the importing country. Consequently, it is easy to separate the two parts by using regression techniques.

Taking logarithms, and assuming that sectoral fixed costs are equal across countries, i.e. $f_{jk} = f_k$, [10], we get

$$\log\left(\frac{\tilde{A}_{ijk}}{\tilde{A}_{iUSk}}\right) = \log\left(\frac{A_{jk}}{A_{US,k}}\right) + \frac{1-\epsilon_k}{\epsilon_k}\log\left(\frac{\tau_{ijk}}{\tau_{iUSk}}\right). \tag{2.15}$$

We assume that bilateral transport costs, τ_{ijk}, are a log-linear function of a vector of bilateral variables (i.e. distance, common language, common border, tariffs, etc.)

[10] We have experimented with the more general specification without finding much evidence in its favor. An alternative interpretation is to consider productivity as a measure that also contains the fixed cost of production. After all, production is not possible without setting up a plant.

plus a random error term. Hence, $\tau_{ijk}^{\frac{1-\epsilon_k}{\epsilon_k}} = X_{ijk}^{\beta_k} e^{u_{ijk}}$, where X_{ijk} is a vector of bilateral variables and u_{ijk} is noise. Consequently, we obtain a three dimensional panel with observations that vary by industry, exporter, and importer.

$$\begin{aligned} \log\left(\frac{\tilde{A}_{ijk}}{\tilde{A}_{iUSk}}\right) &= \log\left(\frac{A_{jk}}{A_{USk}}\right) + \beta_{1k}(\log Dist_{ij} - \log Dist_{iUS}) + \\ &+\beta_{2k}(\log Tariff_{ijk} - \log Tariff_{iUSk}) + \\ &+\beta_{3k} CommonLang_{ij} + \beta_{4k} CommonLang_{iUS} + ... + u_{ijk} - u_{iUSk} \end{aligned} \tag{2.16}$$

Relative TFP of country j in sector k is captured by a country-sector dummy. The coefficients β_k measure the impact of the log difference in bilateral variables on the sectoral trade cost multiplied by the negative sector specific factor $\frac{1-\epsilon_k}{\epsilon_k}$.

The sector-country dummies are computed as

$$\frac{A_{jk}}{A_{USk}} = exp\left[\log\left(\frac{\bar{\tilde{A}}_{ijk}}{A_{iUSk}}\right) - \beta_k^{FE}\bar{X}_{ijk}\right], \tag{2.17}$$

where the bars indicate means across importing countries i and $\hat{\beta}_k^{FE}$ is the fixed effect panel estimator for the vector β_k. Consequently, the estimated productivity of country j in sector k relative to the US is the mean of $\left(\frac{\tilde{A}_{ijk}}{\tilde{A}_{iUSk}}\right)$ across importing countries controlling for the average effect of relative sectoral transport costs. This is a consistent estimator for relative productivities as long as there are no omitted variables with a nonzero mean across importers.

Our measure of relative TFP is transitive. This implies that productivities are comparable across countries *within* sectors in the sense that $\frac{A_{jk}}{A_{j'k}} = \frac{A_{jk}}{A_{USk}}\left(\frac{A_{j'k}}{A_{USk}}\right)^{-1}$. However, one cannot compare TFP in any country *between* sectors k and k' because this would mean to compare productivities across different goods.

Our productivity indices could alternatively be interpreted as differences in sectoral product quality across countries. In this case there would not exist any cost differences arising from TFP differentials across countries but consumers would be willing to spend more on goods of higher quality. Differences in M_{ijk} across countries would not arise because of differences in quantities shipped due to cost differentials but because of differences in quality. Since we look only at the value of trade, the two interpretations are equivalent.[11]

Before presenting the results of our estimations, we briefly describe all the inputs needed to construct our measures of sectoral productivity. A more detailed description of the data can be found in the appendix. We compute sectoral productivities for twenty-four (ISIC Rev. 2) manufacturing sectors in sixty-four countries at all stages of development for three time periods: the mid-eighties, the mid-nineties, and the beginning of this century. In order to do so, we use data on bilateral trade at the sector level, information on sectoral production, factor prices, sectoral factor intensities, elasticities of substitution, and sectoral bilateral trade barriers. We obtain information on bilateral trade at the sectoral level and on sectoral gross output from the World Bank's trade, production and protection database (Nicita and Olarreaga (2007)). We construct factor prices for skilled and unskilled labor and capital following methods proposed by Caselli (2005) and Caselli and Feyrer (2006) . Sectoral

[11] An isomorphic model to the one presented in the main text is the following one. Replace sectoral subutility with the expression $u_{ik} = \left[\sum_{b \in B_{ik}} (\lambda_b x_b)^{\frac{\epsilon_k - 1}{\epsilon_k}}\right]^{\frac{\epsilon_k}{\epsilon_k - 1}}$, where $\lambda_b > 0$ is a utility shifter that measures product quality and let the cost functions be identical across countries for a given sector, such that $TC(q_{jk}) = (f_k + q_{jk}) \prod_{f \in F} \left(\frac{w_{fj}}{\alpha_{fk}}\right)^{\alpha_{fk}}$. Assuming that all firms within a sector of the exporting country produce varieties of the same quality, demand of country i consumers for sector k varieties produced in j is $x_{ijk} = \frac{\hat{p}_{ijk}^{-\epsilon_k} \lambda_{jk}^{\epsilon_k - 1} \sigma_{ik} Y_i}{\tilde{P}_{ik}^{1-\epsilon_k}}$, where $\tilde{P}_{ik} = \left[\sum_{b \in B_{ik}} (\frac{\hat{p}_b}{\lambda_b})^{1-\epsilon_k}\right]^{\frac{1}{1-\epsilon_k}}$ is the optimal quality adjusted price index. In this case the value of bilateral trade is $M_{ijk} = \frac{(p_{jk}\tau_{ijk})^{1-\epsilon_k} \lambda_{jk}^{\epsilon_k - 1} \sigma_{ik} Y_i}{\tilde{P}_{ik}^{1-\epsilon_k}} N_{jk}$. Comparing this expression with the one in the main text, (2.8), it becomes clear that productivity differences are indistinguishable from differences in product quality, because the value of bilateral trade is identical in both cases.

factor income shares are computed from US data, while information on sectoral elasticities of substitution come from Broda and Weinstein (2006). Data on distance and other bilateral variables such as information on a common border between exporter and importer and between the US and the importing country, and whether a trading partner was a colony of the exporter or importer are taken from Mayer and Zignago (2005) and Rose (2004). Finally, we use information on bilateral sectoral tariffs from the UNCTAD TRAINS database.[12]

Table 1.1 provides some descriptive industry statistics. Skill intensity, measured as the share of non-production workers in sectoral employment, varies from 0.15 (Textiles and Footwear) to 0.49 (Beverages) with a mean of 0.27. Capital intensity, measured as one minus labor compensation in value added, varies from 0.56 (Fabricated Metals) to 0.85 (Beverages) with a mean of 0.66. Finally, the elasticity of substitution varies between 1.90 (Pottery) and 12.68 (Non-Ferrous Metals) with an average of 4.36.

2.5 Results

In this section we report the results of computing productivities using our baseline specification (2.16). We use a simple stepwise linear panel estimation[13] with sector-country specific fixed effects. We limit the sample to exporter-sector pairs for which we observe exports to at least five destinations but ignore zeros in bilateral trade flows and issues of sample selection at this stage of our analysis. This leaves us with a sample of around 42000 observations for a given year.

Table 2.2 shows the regression results for our baseline model using data for the

[12] We have also experimented with including other gravity type variables, such as GATT/WTO membership, being part of a free trade or currency area and others but given that we control for bilateral tariff levels they were mostly not significant.

[13] The stepwise procedure starts with the full model that includes all right hand side variables and one by one discards variables that are not significant at the ten percent level of significance using robust standard errors, while taking care of the fact that a discarded variable might become significant once another variable has been dropped.

Table 2.1: Industry Statistics

Isic Rev. 2	Sector Name	Skill Intensity	Capital Intensity	Elasticity of Substitution
311	Food	0.24	0.77	5.34
313	Beverages	0.49	0.85	3.94
321	Textiles	0.15	0.59	3.88
322	Apparel	0.16	0.6	3.3
323	Leather	0.17	0.63	2.24
324	Footwear	0.15	0.6	4.13
331	Wood	0.17	0.59	9.04
332	Furniture	0.19	0.55	2.07
341	Paper	0.23	0.72	5.72
342	Printing	0.47	0.64	2.58
351	Chemicals	0.41	0.82	5.62
352	Other Chemicals	0.45	0.82	4.73
355	Rubber	0.22	0.62	3.68
356	Plastic	0.23	0.68	2.11
361	Pottery	0.18	0.57	1.9
362	Glass	0.18	0.66	3.5
369	Other Non-Metallic	0.25	0.65	4.72
371	Iron and Steel	0.21	0.63	6.98
372	Non-Ferrous Metal	0.22	0.66	12.68
381	Fabricated Metal	0.25	0.56	2.91
382	Machinery	0.35	0.62	3.81
383	Electrical Machinery	0.35	0.7	3.04
384	Transport	0.32	0.62	4.6
385	Scientific	0.47	0.67	2.07
	Mean	0.27	0.66	4.36

Source: Own computations using data of Bartelsman et al (2000) and Broda & Weinstein (2006). Skill Intensity is defined as the ratio of non-production workers over total employment. Capital intensity is defined as 1 minus the share of total compensation in value added mid-nineties. The overall fit is very good with an R-square of 0.80 and a *within* R-square of 0.47. This implies that for a given sector productivity $\frac{A_{jk}}{A_{USk}}$, the transport costs due to the gravity type variables in our regression account for approximately half of the variation in $\frac{\tilde{A}_{ijk}}{\tilde{A}_{iUSk}}$ across importers. In addition ρ - the fraction of the variance of the error term that is due to $\frac{A_{jk}}{A_{USk}}$ - is 74%. Both facts corroborate our interpretation of the sector-country fixed effect as an exporter-sector specific productivity measure.

Recall that the sign of the coefficients reflects the impact of the relevant variable on transport costs multiplied by the negative term $\frac{1-\epsilon_k}{\epsilon_k}$, so that a negative coefficient implies that an increase in the dependent variable increases relative transport costs.

Differences in distance have a large and very significant negative effect on our relative raw productivity measure (i.e. increase transport cost) in all sectors. Differences in bilateral sectoral tariffs between country j and the US are also negative and significant for all sectors except Other Chemicals (sector 352). Indicators for common language between the importer and the exporter have a significant positive effect on raw productivity (i.e. reduce the transport cost) in all sectors but Iron and Steel (371) and Non-ferrous Metals (372), while having English as a common language with the importer has a negative effect in some sectors, since it is the language spoken in the US. The fact that one of the exporters has a common border with the importer has a significantly positive effect on raw productivity only for some sectors. The last variable we include, having a common colonial past between exporter and importer, has a positive impact on our raw productivity in all sectors but Footwear (324) and Paper (341)[14].

Having run regression (2.16), we use (2.17) to construct sectoral productivities. We compute almost 1500 sectoral TFPs for each period (twenty-four by country for

[14]Overall, of all estimated significant coefficients, only one has a wrong sign: common english language in the sector Footwear.

Table 2.2: Regression Coefficients

Isic Rev. 2	Sector Name	Difference Distance	Difference Tariff	Common Language	Common English	Common Border	Common Colony
311	Food	-0.272	-0.003	0.098	-0.100		0.230
		(0.009)	(0.001)	(0.026)	(0.017)		(0.04)
313	Beverages	-0.274	-0.003	0.217	-0.074	0.191	0.149
		(0.018)	(0.002)	(0.046)	(0.028)	(0.074)	(0.069)
321	Textiles	-0.348	-0.017	0.139	-0.093		0.217
		(0.013)	(0.002)	(0.034)	(0.023)		(0.047)
322	Apparel	-0.372	-0.026	0.142			0.342
		(0.022)	(0.003)	(0.045)			(0.063)
323	Leather	-0.515	-0.055	0.310	-0.096		0.441
		(0.025)	(0.005)	(0.069)	(0.045)		(0.09)
324	Footwear	-0.244	-0.010	0.164	0.073	0.288	
		(0.018)	(0.002)	(0.042)	(0.028)	(0.069)	
331	Wood	-0.138	-0.017	0.086		0.108	0.053
		(0.007)	(0.002)	(0.014)		(0.027)	(0.019)
332	Furniture	-0.597	-0.104	0.252		0.260	0.456
		(0.033)	(0.009)	(0.072)		(0.125)	(0.098)
341	Paper	-0.304	-0.014	0.085			
		(0.009)	(0.003)	(0.025)			
342	Printing	-0.438	-0.058	0.550	-0.465	0.275	0.538
		(0.021)	(0.009)	(0.058)	(0.034)	(0.089)	(0.082)
351	Chemicals	-0.240	-0.004	0.048	-0.084	0.063	0.098
		(0.009)	(0.002)	(0.029)	(0.017)	(0.036)	(0.039)
352	Other Chemicals	-0.275		0.202	-0.064		0.142
		(0.008)		(0.032)	(0.019)		(0.039)
355	Rubber	-0.311	-0.060	0.157	-0.046	0.148	0.105
		(0.016)	(0.005)	(0.044)	(0.026)	(0.065)	(0.056)
356	Plastic	-0.646	-0.052	0.369	-0.089		0.250
		(0.026)	(0.004)	(0.066)	(0.043)		(0.094)
361	Pottery	-0.511	-0.063	0.465			0.279
		(0.035)	(0.006)	(0.079)			(0.118)
362	Glass	-0.393	-0.027	0.198		0.187	0.110
		(0.015)	(0.004)	(0.049)		(0.073)	(0.062)
369	Other Non-Metallic	-0.288	-0.019	0.081		0.139	0.096
		(0.012)	(0.004)	(0.031)		(0.049)	(0.041)
371	Iron and Steel	-0.211	-0.018				0.102
		(0.007)	(0.003)				(0.027)
372	Non-Ferrous Metal	-0.138	-0.012		-0.040		0.078
		(0.005)	(0.003)		(0.009)		(0.016)
381	Fabricated Metal	-0.437	-0.045	0.234	-0.100	0.113	0.315
		(0.016)	(0.004)	(0.042)	(0.027)	(0.069)	(0.062)
382	Machinery	-0.276	-0.022	0.225	-0.121		0.217
		(0.011)	(0.004)	(0.032)	(0.022)		(0.045)
383	Electrical Machinery	-0.329	-0.046	0.278	-0.059		0.254
		(0.015)	(0.004)	(0.045)	(0.029)		(0.06)
384	Transport	-0.248	-0.031	0.105		0.148	0.194
		(0.015)	(0.003)	(0.039)		(0.06)	(0.063)
385	Scientific	-0.398	-0.036	0.395	-0.221		0.419
		(0.02)	(0.006)	(0.061)	(0.04)		(0.092)
	Observations	42217					
	R-square	0.80					
	R-square Within	0.47					
	rho	0.74					

Panel with Fixed Country-Industry Effect. Robust Standard Deviation in parenthesis

Table 2.3: Descriptive Statistics - Middle of the 90's

exporter	Mean	S.D.	Lowest TFP		Highest TFP	
ARG	0.48	0.27	Pottery	0.08	Food	1.25
AUS	0.91	0.30	Pottery	0.45	Textiles	1.57
AUT	1.04	0.27	Furniture	0.46	Scientific	1.53
BEL	1.12	0.26	Pottery	0.36	Leather	1.61
BGD	0.15	0.08	Electrical Machinery	0.06	Scientific	0.36
BOL	0.27	0.12	Plastic	0.10	Apparel	0.54
BRA	0.47	0.20	Pottery	0.09	Food	0.99
CAN	0.72	0.15	Footwear	0.48	Paper	1.01
CHL	0.44	0.28	Plastic	0.16	Beverages	1.15
CHN	0.16	0.06	Transport	0.09	Plastic	0.31
CIV	0.42	0.21	Fabricated Metal	0.13	Food	0.97
COL	0.27	0.13	Plastic	0.10	Food	0.57
CRI	0.45	0.17	Plastic	0.17	Non-Ferrous Metal	0.81
CYP	0.70	0.26	Fabricated Metal	0.37	Transport	1.35
DNK	1.41	0.22	Pottery	0.91	Rubber	1.69
ECU	0.23	0.11	Plastic	0.08	Food	0.53
EGY	0.25	0.09	Electrical Machinery	0.11	Non-Ferrous Metal	0.42
ESP	0.83	0.14	Leather	0.52	Other Non-Metallic	1.09
FIN	0.81	0.23	Pottery	0.16	Iron and Steel	1.17
FRA	0.97	0.18	Leather	0.67	Beverages	1.54
GBR	0.94	0.17	Furniture	0.64	Beverages	1.42
GER	0.99	0.11	Footwear	0.76	Textiles	1.27
GHA	0.24	0.14	Fabricated Metal	0.06	Food	0.64
GRC	0.44	0.14	Pottery	0.08	Food	0.64
GTM	0.37	0.18	Electrical Machinery	0.15	Food	0.74
HND	0.21	0.12	Leather	0.06	Transport	0.54
HUN	0.38	0.20	Leather	0.09	Apparel	1.09
IDN	0.32	0.15	Transport	0.15	Furniture	0.78
IND	0.18	0.11	Pottery	0.07	Furniture	0.59
IRL	1.10	0.31	Pottery	0.11	Beverages	1.65
ISL	0.92	0.31	Furniture	0.23	Iron and Steel	1.39
ISR	0.93	0.20	Leather	0.52	Machinery	1.30
ITA	1.13	0.20	Electrical Machinery	0.81	Furniture	1.57
JOR	0.22	0.10	Leather	0.06	Beverages	0.40
JPN	0.89	0.28	Leather	0.36	Rubber	1.39
KEN	0.15	0.06	Rubber	0.07	Pottery	0.27
KOR	0.53	0.13	Furniture	0.28	Rubber	0.83
LKA	0.20	0.06	Machinery	0.11	Furniture	0.35
MAR	0.26	0.11	Leather	0.09	Chemicals	0.47
MEX	0.45	0.15	Leather	0.24	Beverages	0.82
MLT	0.63	0.19	Pottery	0.28	Chemicals	0.94
MUS	0.45	0.18	Leather	0.23	Food	0.83
MYS	0.60	0.21	Other Non-Metallic	0.35	Apparel	1.24
NLD	1.32	0.19	Pottery	0.69	Beverages	1.59
NOR	1.24	0.33	Printing	0.59	Paper	1.68
PAK	0.20	0.15	Printing	0.07	Furniture	0.63
PAN	0.37	0.09	Plastic	0.24	Chemicals	0.57
PER	0.30	0.18	Leather	0.12	Food	0.86
PHL	0.31	0.15	Rubber	0.13	Furniture	0.75
POL	0.26	0.11	Pottery	0.08	Iron and Steel	0.45
PRT	0.58	0.14	Furniture	0.29	Beverages	0.91
ROM	0.14	0.04	Leather	0.06	Iron and Steel	0.23
SEN	0.38	0.24	Fabricated Metal	0.08	Scientific	0.92
SGP	1.19	0.33	Pottery	0.41	Textiles	1.67
SLV	0.50	0.16	Printing	0.22	Glass	0.73
SWE	1.15	0.20	Leather	0.76	Textiles	1.53
THA	0.26	0.11	Beverages	0.13	Furniture	0.58
TTO	0.28	0.11	Electrical Machinery	0.12	Beverages	0.47
TUN	0.22	0.08	Leather	0.08	Chemicals	0.35
TUR	0.39	0.15	Pottery	0.13	Food	0.65
URY	0.61	0.27	Plastic	0.21	Apparel	1.16
USA	1.00	0	Food	1.00	Food	1.00
VEN	0.27	0.14	Furniture	0.07	Non-Ferrous Metal	0.57
ZAF	0.56	0.25	Printing	0.22	Food	1.00
ZWE	0.16	0.07	Fabricated Metal	0.06	Iron and Steel	0.26

sixty-four countries[15]). Table 2.3 summarizes some information about these productivities in the mid-nineties. We present the country mean of TFP across industries[16], the standard deviation, and the sectors with maximum and minimum TFP for each country in our sample.

First, we observe that there is a strong correlation between a country's income per worker and average relative TFP in manufacturing. Poor countries tend to have far lower sectoral productivities than rich ones, but within countries relative productivities vary a lot across sectors. Taking for example Pakistan, we measure an average relative manufacturing TFP of 0.20 of the US level. This hides a large amount of heterogeneity across sectors: a productivity of 0.63 with respect to the US level in Furniture (322) and one of only 0.07 in the sector Printing (341). In general, Plastics (356), Fabricated Metals (381), and Transport Equipment (384) are sectors in which many of the poor countries tend to be least productive relative to the US, while Footwear (324) and Furniture (332) are the sectors in which rich countries seem to have their smallest productivities relative to the US, although these patterns are not as clear for poor nations. Many poor countries have their highest relative productivities in the sectors Food (311) and Apparel (322) while again, there is no clear pattern in which sectors rich countries are the most productive relative to the US.

The panels of figures 2.1 and 2.2 show scatter plots of estimated sectoral productivities against the log GDP per worker in the mid-nineties for eight out of the

[15]For some countries we cannot compute TFP for all sectors either because of missing production data or because the country does not export to enough countries in a sector, so we drop the sector from (2.16). Ivory Coast is the country with the smallest number of sectors for which we obtain productivity measures, fifteen and only in nine (out of sixty-four) countries we construct productivities for less than twenty sectors. The complete set of productivity estimates is available upon request and will soon be online under http://www.pablofleiss.com.

[16]These means of sector productivities cannot be interpreted as aggregate manufacturing productivity indices in terms of economic theory, since we would need to take into account agents' preferences for a proper aggregation. Nevertheless, they give some sense of the magnitude of average sectoral productivity differences across countries.

twenty-four sectors (the first sector of each 2 digit classification, i.e. 311, 321....)[17]. Again, there is a high correlation between sectoral productivity and log GDP per worker in all sectors. While this is true for all sectors, the magnitude of productivity differences varies a lot across sectors. For example, the relation between log income per worker and productivity is much more pronounced in the sector Metal Products (381) than in Food (311). We also note that in general, the richest European countries tend to be more productive than the US in most manufacturing sectors.

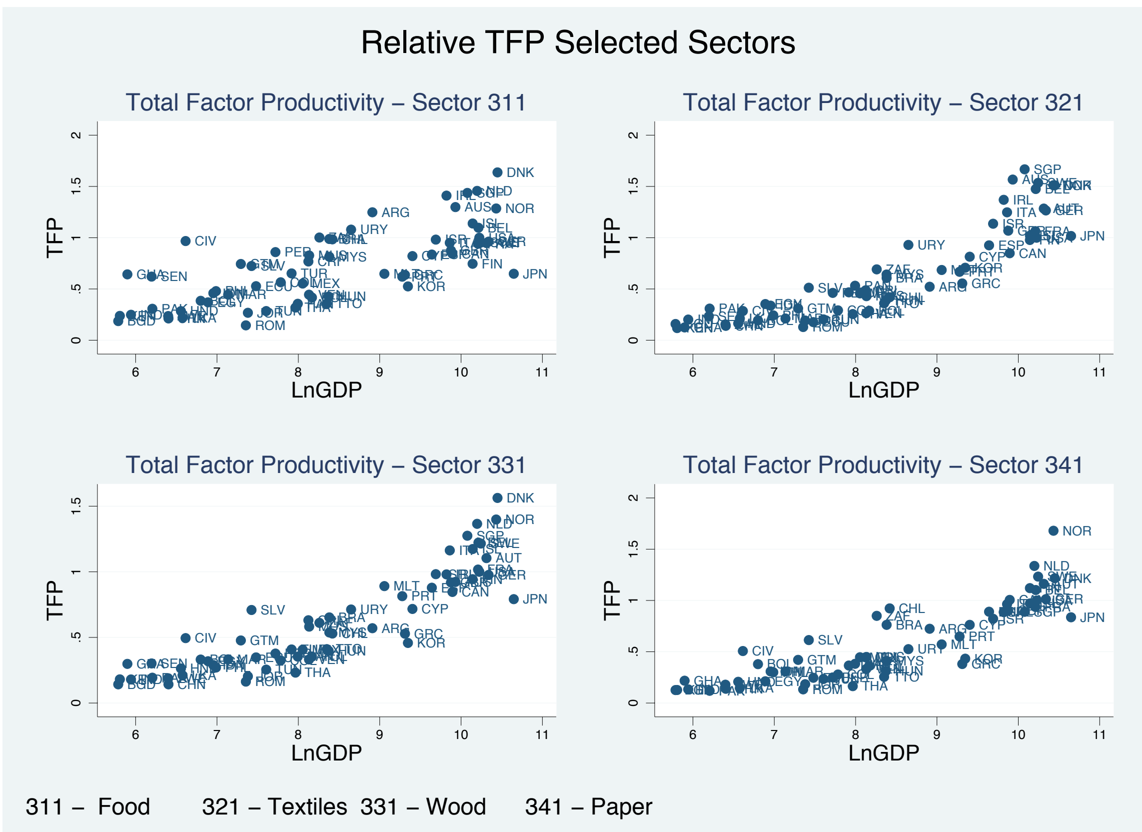


Figure 2.1: Relative TFP selected sectors

At this point it seems interesting to compare our mean sectoral productivities for manufacturing with the aggregate productivities found in the Development Accounting literature. To this end we compute weighted averages (by value added) of

[17]We present these eight scatters to exemplify our results. They extend to the sectors within the same 2 digit classification.

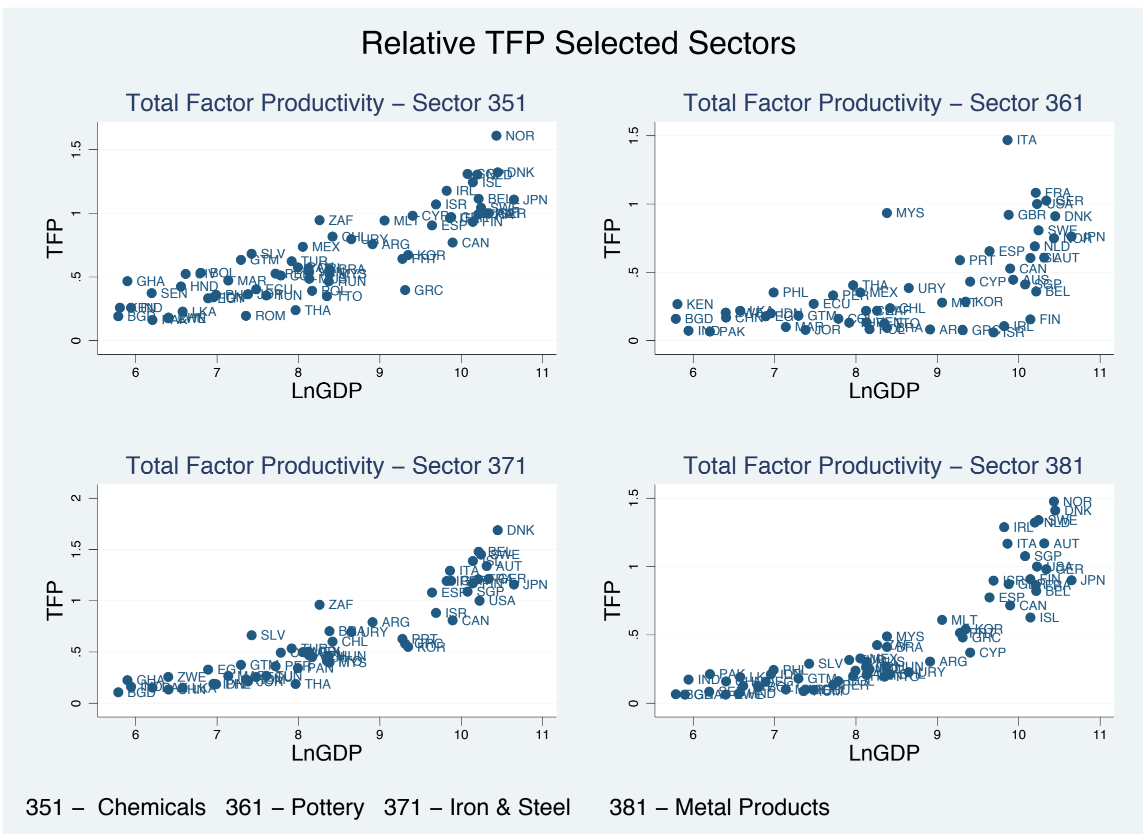


Figure 2.2: Relative TFP selected sectors (continued)

our sectoral TFPs and correlate them with aggregate productivities constructed from production and endowment data.[18] Figure 2.3 shows a scatter plot of our aggregate manufacturing productivity against the aggregate economy productivity indices computed as Solow residuals. We note that there is a very strong correlation between the two sets of productivity estimates. The correlation coefficient between the two sets of productivities is 0.68. Productivity differences in manufacturing tend to be even larger than aggregate ones. This is driven by the fact that European countries seem to be more productive in manufacturing than at the aggregate economy level. Note also that a number of poor countries, like Tunisia, Egypt, Guatemala, and Venezuela that are close to the US productivity level according to the Solow residual method are estimated to be far less productive than the US in manufacturing when using our methodology.

To get an even better feeling for the productivity differences between rich and poor countries we split the countries in two samples: developing countries (with income per worker below 8000 US Dollars in 1995) and developed countries. Figure 2.4 shows a histogram of sector productivities for the mid-nineties for both subsamples, where each observation is given by a sector-country pair. We observe that the productivity distribution of developing countries is left skewed, so that most sectoral productivities are far below the US level, with a long tail on the right, meaning that there are a few developing countries that are more productive than the US in certain sectors. Developed countries' have a relatively symmetric productivity distribution with a mean sectoral productivity that is slightly below one, and a significant variation to both sides, ranging from around 0.2 to 1.5 of the US level.

Figure 2.5 shows the evolution of the relative productivities of developing countries

[18] We use data on income, capital stocks, and human capital per worker for 1996 from Caselli (2005) and follow Hall and Jones (1999) in calculating TFP using the formula $y_c = A_c \left(\frac{K_c}{Y_c}\right)^{\alpha/(1-\alpha)} h_c$.

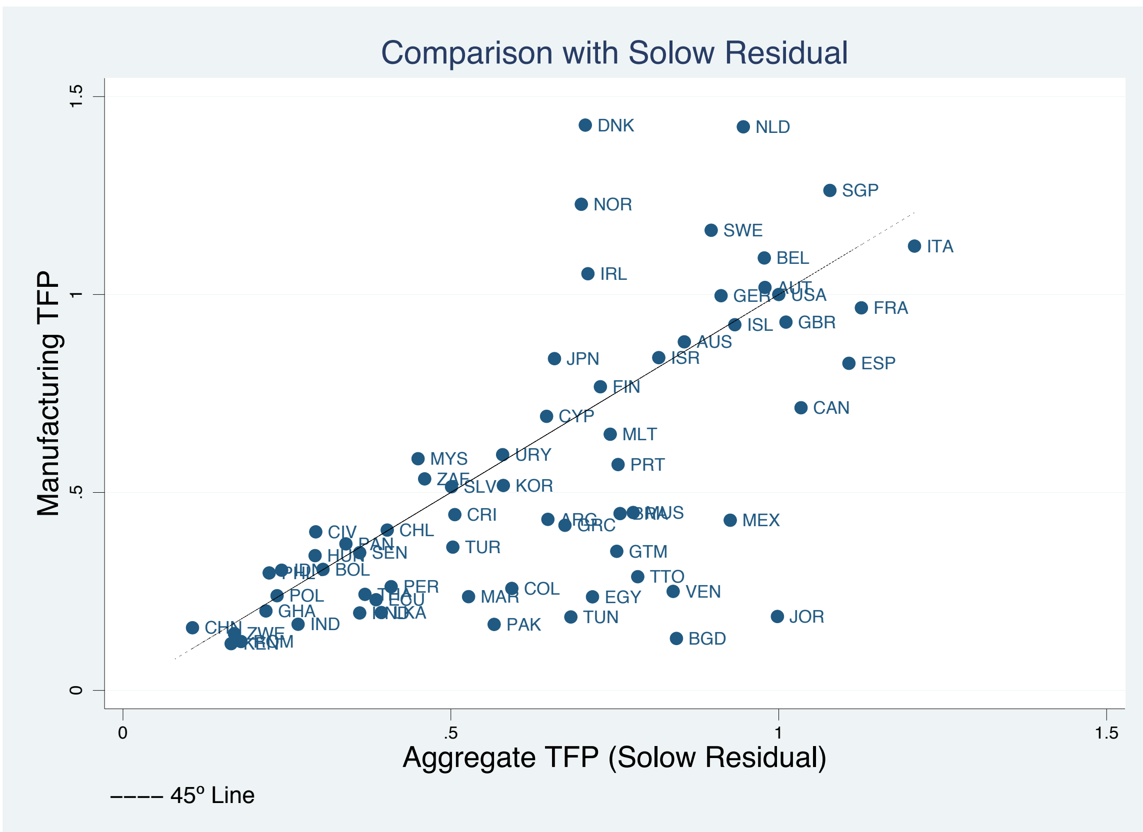


Figure 2.3: Aggregate Manufacturing TFP vs. TFP Solow Residual

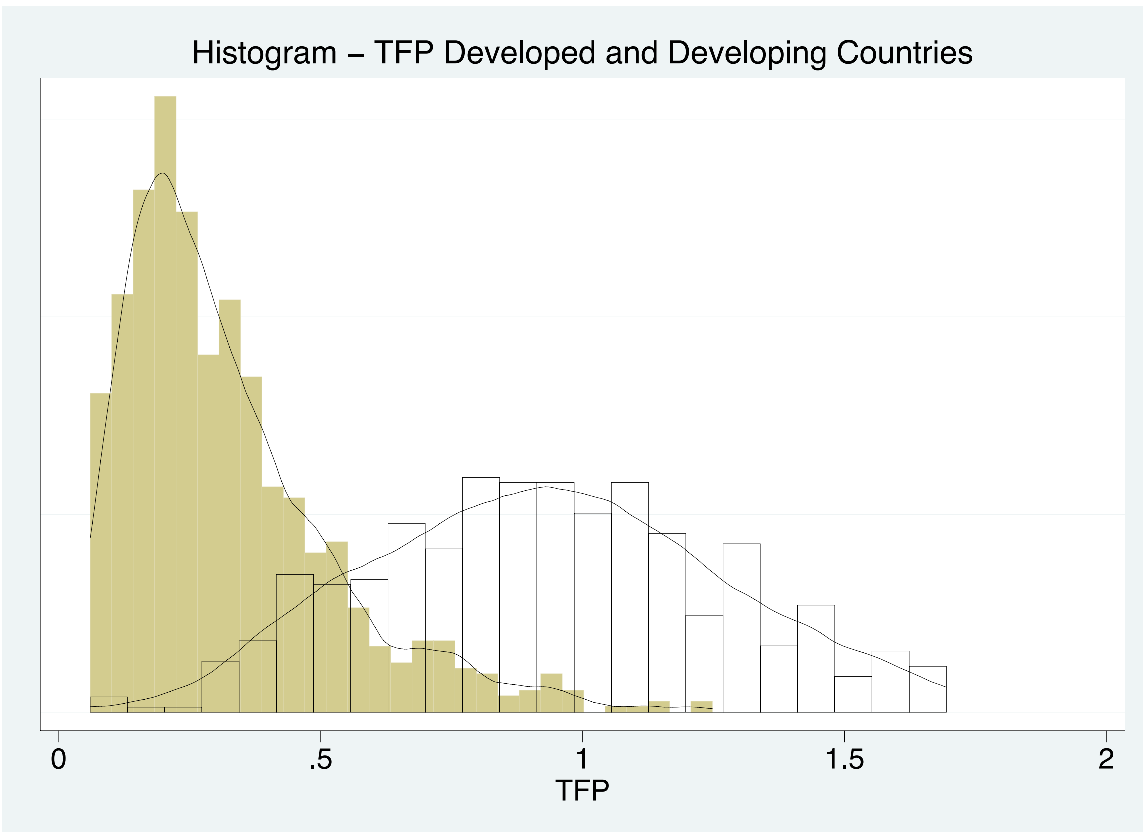


Figure 2.4: Histogram TFPs rich and poor countries

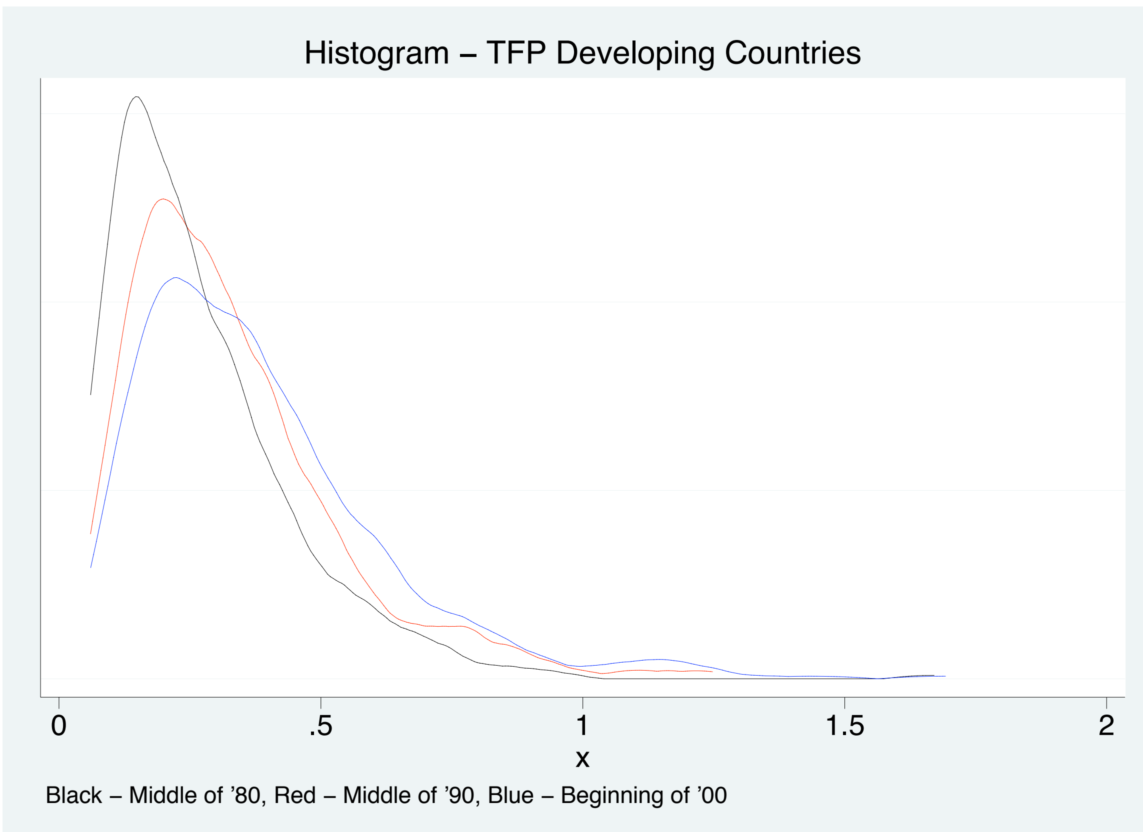


Figure 2.5: Histogram TFPs evolution in poor countries

over time. The black line is the histogram of developing countries' productivities in the mid-eighties, the red line is the histogram for the mid-nineties and the blue line the one for the beginning of this century for the sample of twenty-two developing countries for which we have data for all three periods. We see that the distribution is shifting to the right over time, meaning that over this twenty year period poor countries are slowly catching up in sectoral TFP relative to the US. [19] The countries in our sample that have on average experienced the fastest convergence in TFP towards the US level over these two decades (annualized growth rates in parenthesis) are China (5.1%), Uruguay (4.67), Argentina (4.3%), Egypt (4.1%), and Poland (4%), while the countries with the greatest divergence were Jordan (-3.6%), Panama (-2%), Kenia (-1.2%), and Ecuador (-0.3%). The sectors in which developing countries have on average experienced the fastest speed of catch up are Pottery (4.9%), Printing and Publishing (3.7%), Electrical Machinery (3.4%), and Other Chemicals (3.3%), while the ones with the lowest speed of convergence are Beverages (-0.8%), Transport Equipment (-0.7%), Food (-0.6%), and Industrial Chemicals (0.7%).

Our productivity estimates also allow us to construct "Ricardian" style curves of comparative advantage due to productivity differences for any country pair. The panels of Figure 2.6 depict productivities arranged in a decreasing order according to the magnitude of relative productivity differences with the US for four representative countries: Germany, Spain, Uruguay, and Zimbabwe. Here, for example, we see that Spain's comparative advantage relative to the US is greatest in the sectors Other Non Metallic Mineral Products (369), Iron and Steel (371), and Rubber Products (355), while the sectors with the greatest comparative disadvantage are Printing and Publishing (342) and Plastic Products (356). The comparative advantage of Zimbabwe,

[19] This finding is different from what is found with the Solow residual approach, according to which aggregate productivity differences have become larger in the last two decades. See, for example, (Acemoglu (2007)). However, our sample includes only two African economies (Kenia and South Africa), which is the continent that has fared by far worst during this period.

on the other hand, is largest in the sectors of Apparel (322), with a productivity of less than 25% of the US level and Non Ferrous Metals (372), and smallest in the sectors of Plastic Products (356) and Footwear (324) with productivities around 5% of the US level.

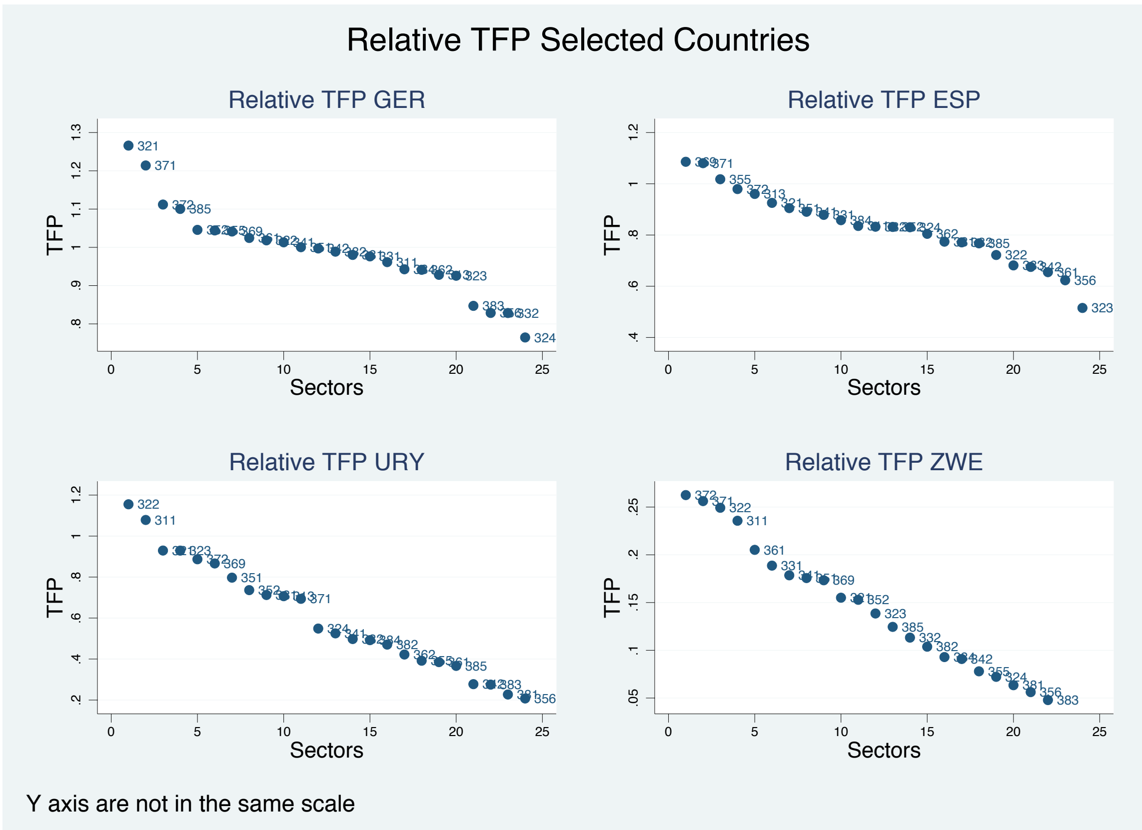


Figure 2.6: Ricardian Comparative Advantage relative to US

As a further application we check if productivity differences between developing and industrialized countries are systematically related to sector characteristics. Table 2.4 shows the result of regressing log(TFP) relative to the US in the mid-90's on sectoral human capital intensity and the interaction of human capital intensity and log income per worker controlling for country fixed effects. Productivity differences relative to the US in poor countries are systematically larger in human capital intensive sectors but this effect disappears in richer countries. Repeating the same exercise

	log(TFP)	log(TFP)	log(TFP)	log(TFP)
skill	-20.322			-10.855
	(3.375)***			(3.312)***
skill*	1.96			1.015
income	(0.364)***			(0.363)***
capital		4.78		5.754
		(1.534)***		(1.595)***
capital*		-0.406		-0.513
income		(0.165)**		(0.172)***
R&D			-14.061	-14.052
			(4.217)***	(3.951)***
R&D*			1.461	1.454
income			(0.453)***	(0.428)***
Country Fixed Effects	Yes	Yes	Yes	Yes
Observations	1447	1447	1447	1447
Countries	64	64	64	64

Table 2.4: TFP and Sector Characteristics Bootstrapped standard deviations in parenthesis. Significant at 1% (***), 5% (**) and 10%(*) level.

with sectoral physical capital intensity gives us the opposite result - the coefficient for capital intensity is positive and the interaction term is negative, so that poor countries seem to be relatively more productive in physical capital intensive sectors.[20] Finally, we relate relative productivities to sectoral R&D intensity as measured with sectoral investment in R&D in the US as a fraction of sectoral value added. Again, poor countries have systematically larger productivity gaps in R&D intensive sectors, an effect that is mitigated as countries become richer.

2.6 Robustness

In this section we perform several robustness checks on our productivity estimations. We try alternative econometric specifications and then discuss the effects of changing particular assumptions of our model. Moreover, we compare our productivities

[20]We do not want to overemphasize these results because they may be - even though this is unlikely - partially due to mismeasurement of sectoral factor income shares. See the appendix for an analysis of measurement errors in factor income shares.

with those computed as Solow residuals for the few countries and sectors where this measure can be constructed.

2.6.1 Hausman Taylor

One potential weakness of our productivity estimates is that we have not estimated the effect of differences in factor prices and proportions but calibrated it. If trade is not systematically related to these factors, our productivity estimates could be biased. In order to avoid such concerns, we show that our results are robust to directly estimating the effect of factor intensities and elasticities.

An alternative specification rearranges (2.14) such that we can write trade relative to production as a function of TFP, factor cost, and bilateral variables:

$$\left(\frac{M_{ijk}}{M_{iUSk}}\frac{\tilde{Q}_{USk}}{\tilde{Q}_{jk}}\right) = \left(\frac{A_{jk}}{A_{iUSk}}\right)^{\epsilon_k}\left[\prod_{f\in F}\left(\frac{w_{fj}}{w_{fUS}}\right)^{\alpha_{fk}}\right]^{-\epsilon_k}\left(\frac{\tau_{ijk}}{\tau_{iUSk}}\right)^{1-\epsilon_k} \tag{2.18}$$

Then, using the fact that $\alpha_{capk} = 1 - \alpha_{sk} - \alpha_{uk}$, we can write

$$\begin{aligned} &\log\left(\frac{M_{ijk}}{\tilde{Q}_{jk}}\right) - \log\left(\frac{M_{iUSk}}{\tilde{Q}_{USk}}\right) = \qquad (2.19)\\ &\epsilon_k log\left(\frac{A_{jk}}{A_{USk}}\right) - \epsilon_k\left[\log\left(\frac{r_j}{r_{US}}\right) + \sum_{f\neq cap}\alpha_{fk}log\left(\frac{w_{fj}}{r_j}\right) - \alpha_{fk}log\left(\frac{w_{fUS}}{r_{US}}\right)\right]\\ &+(1-\epsilon_k)log\left(\frac{\tau_{ijk}}{\tau_{iUSk}}\right) \end{aligned}$$

Under the condition that productivities are not correlated with relative factor prices within a country, which we assume to hold for now, a consistent estimator for $\left(\frac{A_{jk}}{A_{iUSk}}\right)$ can be obtained from the following two step procedure.

In the first step, we regress our dependent variable on sector-country dummies and bilateral variables

$$\log\left(\frac{M_{ijk}}{\tilde{Q}_{jk}}\right) - \log\left(\frac{M_{iUSk}}{\tilde{Q}_{USk}}\right) = D_{jk} + \beta_k log\left(\frac{\tau_{ijk}}{\tau_{iUSk}}\right) + u_{ijk} \tag{2.20}$$

Having obtained the first stage estimates, we regress the sector-country dummy on factor prices weighted by factor intensities as well as country and sector dummies,

$$\hat{D}_{jk} = D_j + D_k + \sum_{f \neq cap} \beta_{fk} \left[\alpha_{fk} log \left(\frac{w_{fj}}{r_j} \right) - \alpha_{fk} log \left(\frac{w_{fUS}}{r_{US}} \right) \right] + \nu_{jk}, \tag{2.21}$$

for $h \in \{s, u\}$ in order to obtain a measure of sectoral TFP, which is computed using the relation

$$\left(\frac{A_{jk}}{A_{iUSk}} \right) = exp \left[1/\epsilon_k (D_j + D_k + \nu_{jk}) + log \left(\frac{r_j}{r_{US}} \right) \right]. \tag{2.22}$$

This procedure is similar to the Hausman-Taylor GMM estimator, which allows some of the right hand side variables to be correlated with the fixed effects and at the same time to estimate the coefficients of the variables that do not vary by importing country. However, the Hausman-Taylor procedure requires instrumenting all variables that are potentially correlated with the fixed effects, which is not feasible. The two step procedure provides (under our assumptions) consistent estimates of sectoral TFPs without requiring us to make too specific assumptions about which set of variables is correlated with the error term.

Table 2.5 reports the results of this regression. Differences in tariffs and in distance have a very significant negative impact on relative normalized trade in all sectors and the other bilateral variables have the expected sign and are mostly significant. The fit of the first stage has an R-square of 0.64. In the second stage the interactions between factor intensities and the relative price of skilled and unskilled labor are highly significant. The R-square of the second stage is 0.55, implying that country and sector dummies and the Heckscher-Ohlin components explain around half of the country-sector specific variation.

The productivities obtained with this procedure are again very similar to our baseline set of productivities. The first columns of table 2.6 show correlations and rank correlations by sector between these two sets of productivities. For most sectors correlations are around 0.99 with an overall correlation of 0.95. Still, we prefer the mixed calibration and estimation approach of the baseline model because it does not require any assumptions on the correlations between the independent variables and the country-sector fixed effect and because not all of the coefficients in this specification have the correct magnitudes.

Table 2.5: Coefficients, Hausman-Taylor Regression

		First Stage						Second Stage	
Isic Rev 2	Sector Name	Difference Distance	Difference Tariff	Common Language	Common English	Common Border	Common Colony	Relatively Skill	Relatively Unskill
311	Food	-1.440	-0.016	0.510	-0.529	0.136	1.227	-14.242	-7.6
		(0.054)***	(0.005)***	(0.141)***	(0.091)***	(0.215)	(0.214)***	(1.988)***	(0.601)***
313	Beverages	-1.079	-0.014	0.856	-0.290	0.751	0.589	-10.493	-5.416
		(0.071)***	(0.007)**	(0.18)***	(0.111)***	(0.292)**	(0.271)**	(2.041)***	(1.796)***
321	Textiles	-1.349	-0.064	0.540	-0.362	-0.004	0.841	-6.215	-3.801
		(0.054)***	(0.008)***	(0.134)***	(0.088)***	(0.203)	(0.182)***	(1.477)***	(0.269)***
322	Apparel	-1.201	-0.090	0.424	0.094	0.234	1.115	-17.248	-3.798
		(0.08)***	(0.01)***	(0.155)***	(0.096)	(0.243)	(0.207)***	(1.758)***	(0.343)***
323	Leather	-1.146	-0.123	0.686	-0.213	0.074	0.985	-6.16	-5.167
		(0.061)***	(0.012)***	(0.157)***	(0.102)**	(0.227)	(0.203)***	(1.615)***	(0.338)***
324	Footwear	-1.005	-0.043	0.706	0.304	1.195	-0.105	-7.504	-4.558
		(0.075)***	(0.009)***	(0.18)***	(0.118)***	(0.286)***	(0.252)	(2.147)***	(0.342)***
331	Wood	-1.239	-0.155	0.817	-0.112	0.951	0.481	-14.735	-3.969
		(0.061)***	(0.021)***	(0.135)***	(0.096)	(0.246)***	(0.174)***	(1.446)***	(0.287)***
332	Furniture	-1.232	-0.213	0.564	-0.119	0.515	0.946	-13.989	-3.296
		(0.069)***	(0.018)***	(0.154)***	(0.101)	(0.26)**	(0.203)***	(1.259)***	(0.308)***
341	Paper	-1.710	-0.080	0.413	-0.076	0.301	0.252	-10.515	-3.237
		(0.057)***	(0.015)***	(0.165)**	(0.103)	(0.217)	(0.215)	(1.84)***	(0.524)***
342	Printing	-1.130	-0.150	1.418	-1.198	0.708	1.388	-1.437	-6.863
		(0.054)***	(0.023)***	(0.151)***	(0.087)***	(0.229)***	(0.212)***	(0.522)***	(0.491)***
351	Chemicals	-1.349	-0.022	0.272	-0.473	0.356	0.552	-8.352	-8.3
		(0.049)***	(0.011)**	(0.161)*	(0.098)***	(0.202)*	(0.22)**	(1.272)***	(0.933)***
352	Other Chemic	-1.270	-0.006	0.931	-0.291	0.272	0.657	-12.864	
		(0.047)***	(0.013)	(0.152)***	(0.089)***	(0.241)	(0.187)***	(1.259)***	
355	Rubber	-1.145	-0.221	0.580	-0.170	0.544	0.386	-1.956	-3.064
		(0.058)***	(0.019)***	(0.16)***	(0.098)*	(0.238)**	(0.208)*	(1.248)	(0.341)***
356	Plastic	-1.327	-0.112	0.738	-0.172	0.380	0.514	-7.392	-4.08
		(0.057)***	(0.009)***	(0.139)***	(0.092)*	(0.274)	(0.198)***	(1.177)***	(0.355)***
361	Pottery	-0.966	-0.121	0.849	0.081	0.056	0.523	-14.707	-3.61
		(0.07)***	(0.011)***	(0.162)***	(0.112)	(0.288)	(0.224)**	(1.718)***	(0.34)***
362	Glass	-1.374	-0.093	0.720	-0.074	0.637	0.390	-15.683	-2.853
		(0.054)***	(0.013)***	(0.177)***	(0.102)	(0.258)**	(0.218)*	(1.542)***	(0.346)***
369	Other Non-Metal	-1.354	-0.089	0.436	-0.138	0.629	0.458	-14.9	-0.796
		(0.056)***	(0.018)***	(0.153)***	(0.106)	(0.233)***	(0.194)**	(1.207)***	(0.376)**
371	Iron and Steel	-1.470	-0.120	-0.137	-0.134	0.104	0.807	-18.398	-0.458
		(0.054)***	(0.021)***	(0.162)	(0.112)	(0.21)	(0.207)***	(1.65)***	(0.397)
372	Non-Ferrous	-1.782	-0.140	0.034	-0.516	-0.322	1.005	-19.678	-2.493
		(0.069)***	(0.037)***	(0.185)	(0.123)***	(0.258)	(0.226)***	(1.613)***	(0.433)***
381	Fabricated Metal	-1.271	-0.131	0.681	-0.292	0.329	0.917	-4.467	-3.099
		(0.048)***	(0.011)***	(0.123)***	(0.079)***	(0.202)	(0.179)***	(0.844)***	(0.289)***
382	Machinery	-1.035	-0.084	0.838	-0.453	0.176	0.820	-6.047	-3.022
		(0.044)***	(0.015)***	(0.12)***	(0.083)***	(0.192)	(0.174)***	(0.613)***	(0.349)***
383	Electrical Machin	-0.968	-0.141	0.807	-0.164	0.364	0.761	-4.113	-4.495
		(0.047)***	(0.011)***	(0.135)***	(0.09)*	(0.237)	(0.185)***	(1.074)***	(0.577)***
384	Transport	-1.140	-0.138	0.537	-0.146	0.651	0.896	-7.412	-2.051
		(0.068)***	(0.016)***	(0.188)***	(0.118)	(0.278)**	(0.293)***	(1.01)***	(0.438)***
385	Scientific	-0.796	-0.077	0.784	-0.445	0.316	0.856		-9.907
		(0.043)***	(0.011)***	(0.127)***	(0.083)***	(0.215)	(0.192)***		(0.509)***
	Observations	42217						42217	
	R-square	0.64						0.55	
	R-square Within	0.46						0.35	
	rho	0.47						0.61	

Standard deviations in parenthesis. Significant at the 1% (***), 5% (**), and 10% (*) level

Table 2.6: Robustness of TFP estimates

		Hausman-Taylor		Number of Firms		Heckman		Heterogeneous Firms		Eaton and Kortum		Solow Residual		
isic	Sector Name	Correl	Spearman	Correl	Spearman	Correl	Spearman	Correl	Spearman	Correl	Spearman	isic	Correl	Spearman
311	Food	0.99	0.99	0.93	0.94	0.94	0.95	0.68	0.78	0.92	0.92	31	0.55	0.49
313	Beverages	0.97	0.96	0.91	0.95	0.91	0.94	0.81	0.85	0.91	0.89			
321	Textiles	0.94	0.95	0.91	0.93	0.93	0.92	0.63	0.83	0.93	0.96	32	0.33	0.24
322	Apparel	0.99	0.99	0.70	0.78	0.71	0.72	0.61	0.68	0.85	0.85			
323	Leather	0.98	0.99	0.71	0.83	0.79	0.81	0.78	0.82	0.82	0.86			
324	Footwear	0.96	0.97	0.89	0.92	0.90	0.89	0.58	0.78	0.85	0.90			
331	Wood	0.85	0.88	0.95	0.96	0.97	0.96	0.61	0.75	0.96	0.96	33	0.40	0.12
332	Furniture	0.98	0.97	0.52	0.76	0.68	0.73	0.73	0.72	0.72	0.64			
341	Paper	0.90	0.92	0.94	0.97	0.92	0.97	0.70	0.78	0.97	0.96	34	0.44	0.38
342	Printing	0.97	0.97	0.75	0.90	0.88	0.86	0.80	0.83	0.92	0.91			
351	Chemicals	0.97	0.97	0.93	0.94	0.93	0.92	0.57	0.66	0.93	0.95	35	0.13	0.1
352	Other Chemic	0.94	0.94	0.95	0.97	0.94	0.97	0.70	0.79	0.95	0.96			
355	Rubber	0.90	0.91	0.89	0.93	0.93	0.94	0.74	0.82	0.96	0.96			
356	Plastic	0.98	0.98	0.84	0.94	0.86	0.94	0.83	0.95	0.85	0.84			
361	Pottery	0.97	0.98	0.36	0.63	0.19	0.54	0.25	0.54	0.79	0.72	36	0.15	0.19
362	Glass	0.96	0.97	0.83	0.88	0.82	0.85	0.68	0.76	0.96	0.95			
369	Other Non-Metal	0.91	0.94	0.96	0.95	0.95	0.95	0.74	0.83	0.98	0.98			
371	Iron and Steel	0.83	0.89	0.97	0.98	0.97	0.98	0.65	0.78	0.96	0.97	37	0.78	0.73
372	Non-Ferrous	0.85	0.88	0.97	0.97	0.98	0.98	0.67	0.74	0.95	0.94			
381	Fabricated Metal	0.95	0.96	0.85	0.89	0.85	0.86	0.76	0.81	0.96	0.95	38	0.43	0.26
382	Machinery	0.93	0.95	0.88	0.93	0.85	0.92	0.73	0.84	0.96	0.95			
383	Electrical Machin	0.94	0.96	0.81	0.91	0.80	0.90	0.76	0.84	0.96	0.94			
384	Transport	0.86	0.91	0.85	0.91	0.84	0.90	0.56	0.70	0.92	0.93			
385	Scientific	0.96	0.97	0.35	0.78	0.39	0.79	0.40	0.80	0.86	0.81			

This approach to estimating sectoral productivities also allows to assess the importance of Ricardian productivity differences for explaining bilateral trade. To do so, we compare the fit of the first step (2.20) with the one of a model with country specific productivities and a Heckscher-Ohlin component that ignores Ricardian productivities.[21]

$$\log\left(\frac{M_{ijk}}{\tilde{Q}_{jk}}\right) - \log\left(\frac{M_{iUSk}}{\tilde{Q}_{USk}}\right) = \tag{2.23}$$
$$D_j + D_k + \sum_{f \neq cap} \beta_{fk}\left[\alpha_{fk} log\left(\frac{w_{fj}}{r_j}\right) - \alpha_{fk} log\left(\frac{w_{fUS}}{r_{US}}\right)\right] + \beta_k log\left(\frac{\tau_{ijk}}{\tau_{iUSk}}\right) + u_{ijk}$$

The adjusted R-square of this model is 0.5 compared to the 0.63 obtained by using Ricardian productivities, so there is a 13% gain in fit by introducing Ricardian productivity differences.[22] Also the Akaike information criterion tells us that the Ricardian model does much better in terms of fit.[23]

2.6.2 Heterogeneous Firms and Zeros in Bilateral Trade

Up till now we have assumed that firms are homogeneous and that there are no fixed costs to export, so that all firms in a sector of country j are predicted to export to every country i. In reality, only a fraction of firms exports and very few firms export to several destinations. In addition, we have ignored zeros in bilateral trade flows, which are quite prevalent in the data[24], hence our estimates are conditioned on observing positive trade flows. In a recent paper Helpman, Melitz and Rubinstein (2007) argue that one needs to take these facts into account in order to obtain unbiased estimates for the impact of distance and other bilateral variables on trade flows

[21] This model is very popular in the literature. See, for example, Trefler (1995), Davis and Weinstein (2001).

[22] We obtain very similar results regarding the importance of Ricardian productivity differences when comparing (2.16) with a restricted version that allows only for country specific TFP differences.

[23] AIC drops from 171455 for the restricted model to 157827 for the Ricardian model.

[24] In the mid-90's 8907 out of 51029 possible trade flows are zero in our sample.

when modelling the volume of bilateral trade with gravity type regressions. Firm heterogeneity matters because the number of firms engaged in bilateral trade (the extensive margin) varies systematically with trade costs. Only the most productive firms can sell enough to recoup the fixed costs to export to destinations with high marginal trade costs. Not considering the extensive margin mixes the impact of trade barriers on the number of firms with the effect on exports per firm and it leads to biased estimates.

Zeros in bilateral trade matter because of sample selection. Observing positive trade flows is not random because many of the variables that determine bilateral fixed costs to trade -and therefore firms' decision whether to export or not- also affect the variable cost to trade and hence our measure of raw productivity. Country-sector pairs with large observed barriers that trade a lot are likely to have low unobserved trade barriers, which may violate our assumption that the unobserved variation of raw productivity across importers for a given exporter-sector is not systematic.

In this section we check if our productivity estimates are robust once controlling for these factors. We follow the approach suggested by Helpman et al. (2007), which forces us to use a somewhat different specification for our productivity estimates and obliges us to use information on the number of firms active in the exporting country, which we consider less reliable than the data on aggregate production. Nevertheless, our results on productivities remain quite similar.

Since the derivation of the estimating equations of this extension requires a fair amount of additional algebra, we just present here the final specification and refer the interested reader to the appendix for the derivations.

We assume that the inverse of a firm's productivity is drawn from a distribution with a cumulative distribution function $G_{jk}(a) = 1/A_{jk}G(a)$ with support $[a_{Lk}, a_{Hk}]$ that can be written as the product of a country-sector specific term and a distribution that is invariant across countries. One can show that A_{jk}, which can be interpreted as an average of the sectoral efficiency level in the exporting country and that we refer to as sectoral productivity[25] can be recovered from the following expression.

$$E[\log(\tilde{A}_{ijk})|X_{ijk}, T_{ijk} = 1] = \tag{2.24}$$
$$\log(A_{jk}) + D_{ik} + \beta_k X_{ijk} + \frac{1}{\epsilon_k - 1} E[\log(V_{ijk})|T_{ijk} = 1] + E[e_{ijk}|T_{ijk} = 1],$$

where $E[\log(\tilde{A}_{ijk})|.]$ is the mathematical expectation of "raw productivity" conditional on a vector of bilateral variables X_{ijk} and on observing positive trade flows, $T_{ijk} = 1$. The term $E[\log(V_{ijk})|T_{ijk} = 1]$ controls for the fraction and the productivity composition of exporters from country j that export to country i in sector k and $E[e_{ijk}|T_{ijk} = 1]$ controls for the sample selection because of unobservable trade barriers that affects both the decision to export and the volume of trade, while D_{ik} is a importer-sector dummy. In the appendix we derive consistent estimators for this conditional expectation that can be implemented with a two-step selection model. For each destination firms first choose whether to export or not and if so how much to export.

Table 2.6 shows the results of our productivity estimates with different specifications. Again we report correlations and rank correlations with our baseline productivity estimates. The first specification ignores the issues of sample selection and heterogeneous firms to check how much results are affected by using the number of firms instead of aggregate production in our productivity estimations (columns labelled 'number of firms'). We can see that the results are quite similar with an overall correlation with our baseline productivity estimates of 0.89. In the next columns we

[25] A more standard definition of sectoral productivity would be $\breve{A}_{jk} \equiv A_{jk} \left(\int_{a_{Lk}}^{a_{jk}} a^{1-\epsilon_k} dG(a) \right)^{\frac{1}{1-\epsilon_k}}$, a weighted mean of firm productivities. The cutoff a_{jk} is endogenous and depends on the level of competition in the exporting country. See Melitz (n.d.). Our definition disregards the effect of firm selection on the level of sectoral productivity.

take care of the issue of zero trade flows by estimating a standard Heckman-selection model (columns labelled 'Heckman'). The inverse Mill's ratio enters positively and significantly in all sectors, so that there is indeed sample selection towards countries with low unobserved trade barriers[26]. However, results for productivities change very little compared to the specification that only uses the number of firms. Finally, we simultaneously control for sample selection and the extensive margin of trade (via a 3rd order polynomial approximation) of $E[log(V_{ijk})|T_{ijk}] = 1$ (columns labelled 'heterogeneous firms'). Even though these terms are all significant[27], correlations and rank correlations for our productivities remain around 0.9, so that our baseline specification seems to be robust.

2.6.3 Eaton and Kortum's (2002) Model

An alternative model for estimating sectoral productivities from trade data is the Eaton and Kortum (2002) model of trade. This is a Ricardian model that can easily be extended to the Heckscher-Ohlin style trade. Chor (2006) uses a version of this model to divide comparative advantage into different components, by proxying for technology differences with observables but is not specifically interested in measuring sectoral TFPs. Finicelli et al. (2008) apply the baseline Eaton-Kortum model to calibrate aggregate manufacturing TFPs for a number of OECD economies, focusing on the role of competition on TFP, which we disregard in our discussion. While we define productivity as the average technology level, they focus on the effect of trade openness on the firm composition and hence on the aggregate productivity.

The model assumes a fixed measure of varieties $n \in [0, 1]$ in each sector and perfect competition so that firms price at their (constant) marginal cost and countries source a given variety exclusively from the lowest cost supplier. The price of variety n of

[26] Results not reported but available on request.
[27] Results not reported but available on request.

sector k produced in country j as perceived by country i consumers is

$$\hat{p}_{ijk}(n) = \frac{1}{A_{jk}(n)} \prod_{f \in F} \left(\frac{w_{fj}}{\alpha_{fk}} \right)^{\alpha_{fk}} \tau_{ijk}. \tag{2.25}$$

Here, $A_{jk}(n)$ is stochastic and parameterized such that $log(A_{jk}(n)) = \lambda_{jk} + \beta_k \epsilon_{ik}(n)$, where $\epsilon_{ik}(n)$ follows a Type I extreme value distribution with spread parameter β_k. This distribution has a mode of λ_{jk} and $E[log(A_{jk})] = \lambda_{jk} + \beta_k * \gamma$, where γ is a constant.

Using the assumption of perfect competition and the properties of the extreme value distribution it can be shown that exports of country j to country i in sector k as a fraction of $i's$ sectoral absorption are given by Π_{ijk}, the probability that country j is the lowest cost supplier of a variety n to country i in sector k.[28]

$$\frac{M_{ijk}}{\sum_{j \in J} M_{ijk}} = \Pi_{ijk} = \frac{\left[\prod_{f \in F} \left(\frac{w_{fj}}{\alpha_{fk}} \right)^{\alpha_{fk}} \tau_{ijk} \right]^{-1/\beta_k} exp(1/\beta_k \lambda_{jk})}{\sum_{j \in J} \left[\prod_{f \in F} \left(\frac{w_{fj}}{\alpha_{fk}} \right)^{\alpha_{fk}} \tau_{ijk} \right]^{-1/\beta_k} exp(1/\beta_k \lambda_{jk})} \tag{2.26}$$

Consequently, normalizing with imports from the US,

$$\frac{M_{ijk}}{M_{iUSk}} = \frac{\Pi_{ijk}}{\Pi_{iUSk}} = \frac{\left[\prod_{f \in F} \left(\frac{w_{fj}}{\alpha_{fk}} \right)^{\alpha_{fk}} \tau_{ijk} \right]^{-1/\beta_k} exp(1/\beta_k \lambda_{jk})}{\left[\prod_{f \in F} \left(\frac{w_{fUS}}{\alpha_{fk}} \right)^{\alpha_{fk}} \tau_{iUSk} \right]^{-1/\beta_k} exp(1/\beta_k \lambda_{USk})}. \tag{2.27}$$

Taking logs, we get

$$\log \left(\frac{M_{ijk}}{M_{iUSk}} \right) = 1/\beta_k \left(\lambda_{jk} - \lambda_{USk} \right) - 1/\beta_k \sum_{f \in F} \alpha_{fk} \log \left(\frac{w_{fj}}{w_{fUS}} \right) - 1/\beta_k \log \left(\frac{\tau_{ijk}}{\tau_{iUSk}} \right). \tag{2.28}$$

Thus, we obtain $E \left[\frac{log(A_{jk})}{log(A_{USk})} \right] = \lambda_{jk} - \lambda_{USk}$.[29]

The main difference between this specification and our model is that it requires no information on exporters' production. Relative exports depend exclusively on the

[28]For the derivations, see Eaton and Kortum (2002) or Chor (2006).

[29]Note that this is an estimate of the underlying technology parameter and not directly of realized TFP, which is the weighted average productivity of active firms only.

relative probabilities of offering varieties in the importing market at the lowest cost, which depends only on bilateral variables, factor prices, and productivity.

To obtain productivity estimates from this model, we can either calibrate it by using information on the spread parameter β_k from other studies, or estimate it using our two step procedure.

When trying to estimate the equations with a two stage procedure analogous to (2.20) and (2.21), many of the coefficients of relative factor prices have the wrong sign, so this specification seems to be performing poorly. Alternatively, we can apply the hybrid calibration and estimation exercise by first constructing raw productivities and then regressing these on bilateral variables. In order to do so, we require estimates of β_k. Chor reports an aggregate value of β of around 12.41^{-1}, Eaton and Kortum estimate β to lie between 2.44^{-1} and 12.86^{-1}. While the relative order of countries is meaningful for any β, the absolute size of productivity differences is very sensitive to the choice of β. Choosing a β of 12.41^{-1} (Chor's estimate) gives productivity estimates that are very similar to the ones obtained with our baseline model,[30] as can be seen in Table 2.6, where we report correlations and rank correlations by sector. When setting β equal to 2.44^{-1}, absolute productivity differences explode.

Hence, the Eaton-Kortum model seems to be a good alternative for estimating sectoral productivities. Its main advantage is that it does not require information on production, the drawback is that one has to estimate the spread parameter of the sectoral productivity distribution that is hard to pin down.

2.6.4 Pricing to the Market and Endogenous Mark-ups

Mark-ups charged by exporting firms may depend on the level of competition in the destination market (Melitz and Ottaviano (2005)), Saur (2007)). In this subsection

[30] The aggregate correlation is 0.89.

we study how our productivity estimation procedure is affected by the presence of pricing to the market. For doing so, we go back to our baseline model and slightly modify agents' utility function to make marginal utility bounded, so that consumers' demand drops to zero whenever a variety becomes too expensive.

$$u_{ik} = \left[\sum_{b \in B_{ik}} \ln(x_{bk} + 1) \right] \tag{2.29}$$

The demand for a sector k variety produced in country j by consumers in country i is now given by

$$x_{ijk} = \max\{ \frac{1}{\mu_{ik} \tau_{ijk} p_{ijk}} - 1, 0 \}, \tag{2.30}$$

where μ_{ik} is the shadow price of sector k budget sub-constraint for country i consumers. Solving country j producers' profit maximization problem, one finds that exporters price discriminate across markets and set prices in destination i equal to a mark-up over their marginal cost that depends inversely on the toughness of competition in the export market, so that $p_{ijk} = \left(\frac{\frac{1}{A_{jk}} \prod_{f \in F} \left(\frac{w_{fj}}{\alpha_{fk}} \right)^{\alpha_{fk}}}{\mu_{ik} \tau_{ijk}} \right)^{1/2}$. Substituting into the definition of bilateral trade and simplifying we obtain

$$M_{ijk} = \mu_{ik}^{-1} \left\{ 1 - \left[\mu_{ik} \tau_{ijk} \frac{1}{A_{jk}} \prod_{f \in F} \left(\frac{w_{fj}}{\alpha_{fk}} \right)^{\alpha_{fk}} \right]^{1/2} \right\} N_{jk}, \tag{2.31}$$

whenever bilateral trade is positive.[31] Dividing by M_{iUSk}, taking logs and rearranging we get

$$\log \left(\frac{M_{ijk}}{M_{iUSk}} \right) - \log \left(\frac{N_{jk}}{N_{USk}} \right) \approx \left(\frac{A_{jk}}{A_{USk}} \prod_{f \in F} \left(\frac{w_{fUS}}{w_{jk}} \right)^{\alpha_{fk}} \frac{\tau_{iUSk}}{\tau_{ijk}} \right)^{1/2} \tag{2.32}$$

We see that the shadow price, μ_{ik} -which is related to mark-ups and the level of competition in the export market- drops from the equation since exporters from

[31]Endogenous markups are an alternative explanation to fixed cost to exporting for observing zeros in bilateral trade.

country j and the US face the same level of competition in a given market i, but the relationship is no longer log linear. Moreover, N_{jk} cannot be replaced with aggregate production any more since the production level of individual firms q_{jk} depends on the trade weighted level of competition in the destination markets and prices charged in those markets, $N_{jk} \sum_{i \in I_{jk}} p_{ijk} q_{ijk} \tau_{ijk} = \tilde{Q}_{jk}$. Hence, our productivity estimation procedure remains approximately valid as long as we use the number of firms in the exporting country instead of aggregate production.

2.6.5 Trade in Intermediates

In this section we study how our specification is affected by the usage of tradable intermediate goods in production. Ethier (1982), Rivera-Batiz and Romer (1991), and others formalize the idea that having access to more varieties of differentiated intermediate goods through trade may boost sectoral productivity. Recently, Jones (2008) has emphasized that sectoral productivity may be crucially determined by linkages across sectors through the use of intermediate inputs, which may potentially lead to large multiplier effects of relatively small distortions. These ideas can easily be incorporated into our framework. We modify the production function in a way such that firms use not only capital and different labor types but also varieties of differentiated intermediates produced by other firms (and potentially in other countries) as inputs. Assuming that firms spend a fixed fraction of their revenues on intermediates of each sector the cost function now becomes

$$TC(q_{ik}) = (f_{ik} + q_{ik}) \frac{1}{A_{ik}} \left[\prod_{f \in F} \left(\frac{w_{fi}}{\alpha_{fk}} \right)^{\alpha_{fk}} \right]^{1-\beta_k} \left[\prod_{k'=1}^{K} \left(\sum_{b \in B_{ik'}} \hat{p}_{bk'}^{1-\epsilon_{k'}} \right)^{\frac{\sigma_{k'}}{1-\epsilon_{k'}}} \right]^{\beta_k}, \quad (2.33)$$

where $\sum_{k'=1}^{K} \sigma_{k'} = 1$ and $\epsilon_{k'} > 1$. Firms in sector k are assumed to spend a fraction, $\sigma_{k'} \beta_k$, of their revenues on a CES aggregate of differentiated intermediate inputs produced by sector k' with elasticity of substitution $\epsilon_{k'}$.

Demand for intermediates by firms from sector k in country i for sector k' intermediates produced in country j can be found applying Shepard's Lemma to (2.33),

$$x_{ijkk'} = \frac{\hat{p}_{ijk'}^{-\epsilon_{k'}} \sigma_{k'} \beta_k N_{ik} TC(q_{ik})}{P_{ik}^{1-\epsilon_{k'}}}. \tag{2.34}$$

These demand functions can be easily aggregated over sectors k and combined with consumers' demand for varieties to get total bilateral demand for sector k' varieties. Hence, trade in intermediates does not change the value of imports from country j relative to those from the US, nor does it affect the functional form of our raw productivity measure relative to the US (2.14).

Since we do not explicitly take into account that firms use intermediates our measured productivity is $\breve{A}_{jk} \equiv A_{jk} \left[\prod_{k'} \left(\sum_{b \in B_{jk}} \hat{p}_b^{1-\epsilon_{k'}} \right)^{\frac{\sigma_{k'}}{1-\epsilon_{k'}}} \right]^{-\beta_k}$. This implies that in countries and sectors where more varieties of intermediates are available and cheaper on average, measured productivity is higher. To the extent that intermediate inputs are non-tradable, like transport or government services, low productivity in other sectors leads to high prices of these intermediate inputs and consequently to lower measured sectoral productivity.

2.6.6 Comparing Estimates with Solow Residuals

To assess the validity of our method for computing sectoral TFPs we compare our productivity estimates with TFPs constructed from the OECD STAN database for the few countries and sectors where this is feasible. We assume sectoral production functions to be Cobb-Douglas with sectoral factor income shares equal to the ones of the US. For reasons of data availability, we are limited to 11 countries,[32] two factors -capital and efficient labor-, and eight sectors[33].

[32] Austria, Belgium, Canada, Finland, France, Italy, Netherlands, Norway, Spain, United Kingdom, and United States.

[33] Those sectors are 31,32,...,38. Data is limited by the availability of information on gross fixed capital formation.

We compute the Cobb-Douglas value added TFP index as

$$\frac{A_{jk}}{A_{USk}}\frac{p_{jk}}{p_{USk}} = \left(\frac{VA_{jk}}{VA_{USk}}\right)\left(\frac{K_{USk}}{K_{jk}}\right)^{\alpha_k}\left(\frac{H_{USk}}{H_{jk}}\right)^{1-\alpha_k} \tag{2.35}$$

Note that we do not have information on sectoral price indices, so that our TFP measures are contaminated by relative prices, which may potentially severely bias these productivity indices[34]. To make our baseline productivities comparable with the ones computed from STAN, we aggregate trade data to fit the STAN definitions and construct wages for workers with no education.

Table 2.6 presents correlations and Spearman rank correlations between TFPs computed with our baseline specification and from the STAN database. The overall correlation between the two measures is 0.34 and the rank correlation is 0.3. These aggregate numbers hide a large variation in fit by sector. Rank correlation are quite high for sectors 37 (0.73) and 31 (0.49) but very low for sectors 35 (0.1) and 33 (0.12).[35] Interestingly, the sectors with poor fit are those with high transport costs for which relative prices tend to vary much more across countries. Overall, the correlations are not overwhelming, but there clearly is a positive relation between the results of the two methods. One has to take into account that we have not only used different approaches but also completely different datasets to compute the two sets of TFPs and that variation in relative prices may be severely distorting their comparability. In the end, the relative success of this robustness check together with the high correlation of our aggregate TFPs with the more reliable aggregate measures obtained using Hall and Jones' method makes us confident that we are indeed capturing productivity differences with our TFP measures constructed from trade data.

[34]Harrigan (1999) constructs international comparable sectoral price indices for some manufacturing sectors and finds large differences in sectoral prices even across a small number of OECD economies.

[35]Productitivities in sector 35 are not directly comparable, because we have removed some subsectors where exports depend mostly on the availability of oil resources from our dataset.

2.7 Productivity Differences and Theories of Development

In this section we apply the estimates of sectoral productivity to test a number of development theories that have implications for sectoral productivity differences across countries. For the sake of space we focus on three examples - research and technology spillovers, human capital and technology adoption and financial development - that in our opinion show particularly well the advantages of the productivity estimates. [36]

International technology spillovers are a prominent explanation both for the persistent differences in cross country productivity levels and for the stability of the world income distribution (Parente and Prescott (1994), Howitt (2000)). Klenow and Rodriguez-Clare (2005) review a class of models where the world growth rate is driven by technological progress through research and development at the frontier. Cross country knowledge spill-overs guarantee a stable world income distribution even in the presence of persistent differences in R&D investment rates across countries. There is an advantage of backwardness in the sense that countries that are further away from the frontier experience faster technology improvements. For a given distance to the frontier higher R&D investment rates lead to faster rates of technology adoption. When applied at the sector level Klenow and Rodriguez-Clare (2005)'s model has several predictions that can be assessed using our sector productivities. First, since there is an advantage of backwardness, TFP growth will be higher the further away a sector is from the frontier - a convergence effect. Second, the effect of a higher R&D investment rate on the steady state TFP level relative to frontier is larger in those sectors where the frontier grows faster. Third, the impact of a higher R&D

[36]In the working paper version we test a number of other theories and show that 1) productivity differences between rich and poor countries are largest in sectors with intermediate skill intensities (Acemoglu and Zilibotti (2001)), 2) productivity levels in sectors that depend a lot on specific inputs are significantly larger in countries with good contracting institutions (Nunn (2007)).

investment rate on the TFP growth rate relative to frontier is larger in those sectors where the frontier grows faster. Empirical evidence for these mechanisms is relatively limited. At the aggregate level Coe and Helpman (1995) and Eaton and Kortum (1999) provide evidence for R&D spillovers, whereas Griffith, Redding and Reenen (2004) use sectoral TFP growth rates in manufacturing in 12 OECD countries for the period 1974-1990 and find support for the hypothesis that R&D investment facilitates technology adoption.

To examine the effect of R&D investment on technology adoption, we perform the following exercises. To check the first prediction, we regress the level of log TFP relative to the US in the mid-90's[37] on the interaction of countries' R&D investment rates, R_j/Y_j, and the sectoral R&D investment rate in the US, R_{USk}/Y_{USk}, which we take as a proxy for the growth rate of the sectoral technology frontier, controlling for sector- and country-specific effects.

$$\log\left(\frac{A_{jk}}{A_{USk}}\right) = \beta_1 X_{jk} + D_k + D_j + \epsilon_{jk}, \tag{2.36}$$

where $X_{jk} = (R_j/Y_j) * (R_{USk}/Y_{USk})$, D_j and D_k are country- and sector fixed effects and ϵ_{jk} is an i.i.d. error term. Data on countries' R&D investment rates come from the Lederman and Saenz (2005) database and sectoral R&D investment rates in the US, defined as R&D expenditure as a fraction of sectoral value added, are constructed using data from the National Science Foundation.

To investigate the second and third prediction, we regress the growth rate of sectoral TFP relative to the US between the mid-80's and the mid-90's on the initial level of sectoral TFP and the interaction of countries' R&D investment rates and the sectoral R&D investment rate in the US.

[37] Our results also hold for the other periods for which we have computed TFPs.

$$\Delta \log \left(\frac{A_{jk}}{A_{USk}} \right) = \beta_1 X_{jk} + \beta_2 \log \left(\frac{A_{jk0}}{A_{USk0}} \right) + D_k + D_j + \epsilon_{jk}, \tag{2.37}$$

where X_{jk} is again the R&D interaction term and $\log \left(\frac{A_{jk0}}{A_{USk0}} \right)$ is the initial level of TFP relative to the US. We expect the coefficient on the initial level of sectoral TFP to be negative and the coefficient of the interaction term to be positive.

The first two columns of table 2.7 report the results of the previous specifications. The R&D interaction has a significant positive effect on relative TFP levels both in the level and in the growth rate specification. There is also clear evidence for a convergence effect - the coefficient for the initial TFP level enters strongly negatively in the growth rate specification.

Another class of models emphasizes the role of human capital for the adoption of new technologies (e.g. Nelson and Phelps (1966), Caselli and Coleman (2006)). In a classical paper Nelson and Phelps (1966) develop a one sector economy where higher levels of human capital help to adopt new technologies from a world technology frontier that grows at an exogenous rate. The main predictions of their model are twofold. First, that countries with higher levels of human capital have higher productivity levels relative to the world technology frontier because new technologies are adopted faster. Second, countries with higher human capital levels experience faster aggregate TFP growth relative to the technology frontier. Country level growth regressions that try to assess the effect of human capital levels on output or TFP growth provide only weak support for these predictions.[38] This may be due to the usual problems faced by this type of regressions, like the limited number of observations and multicollinearity (Durlauf, Johnson and Temple (2005)), as well as problems more specific to human capital, such as an attenuation bias due to mismeasured schooling data

[38]Romer (1990), Barro (1991), and Benhabib and Spiegel (2005) find a significant effect of schooling levels on output growth, while Cohen and Soto (2001) find no link.

(Cohen and Soto (2001), or missing information on differences in schooling quality (Hanushek and Kimko (2000)).

Our productivity estimates allow us to test a sectoral version of the Nelson-Phelps model, which helps to overcome some of the above mentioned problems.

Ciccone and Papaioannou (2007) build a multi-sector version of the Nelson-Phelps model and assume that technological progress is skill biased in the sense that the technology frontier grows faster in skill intensive sectors. They show that if the rate of technology adoption depends on a country's total endowments of human capital, productivity levels as well as productivity growth rates relative to the frontier are higher in skill intensive sectors if a country has a higher level of human capital. They empirically implement their model by regressing sectoral growth rates of value added and employment in manufacturing on the interaction of sectoral skill intensity, α_{sk}, and countries' initial human capital endowments, H_j, as measured by the average years of schooling in the population in 1980 for a large sample of countries and find support for the hypothesis that countries with higher initial levels of human capital grow faster in human capital intensive sectors.

Compared to Ciccone and Papaioannou (2007) our information on sectoral TFP relative to the US gives us several advantages. First, we can test if the *level* of sectoral TFP is significantly higher in skill intensive sectors if countries have larger endowments of human capital. Second, we can test if sectoral growth rates of *productivity* are indeed higher in skill intensive sectors if countries have larger endowments of human capital, while Ciccone and Papaioannou (2007) cannot control for accumulation of other factor inputs at the sectoral level, such as physical or human capital, that may affect sectoral value added or employment growth.

To evaluate the predictions of the multi-sector Nelson-Phelps model, we regress both the level and the growth rate of sectoral TFP relative to the US, whose productivity we take as the one of the frontier, on the human capital interaction, $\alpha_{sk} * H_j$. For the regression in levels we consider the mid-nineties, while for the second specification we take the growth rate of sectoral TFP relative to the US between the mid-80's and the mid 90's. The econometric specification is again analogous to (2.36) and (2.37). Once more, we control for sector- and country fixed effects in all regressions.

Looking at columns 3 and 4 of table 2.7 we see that the coefficient of the human capital interaction term is positive and significant at the 1% level both in the level and in the growth rate specification.[39]

A last application relates our sectoral productivities to financial development. In a seminal article Rajan and Zingales (1998) show that industries, which are more dependent on external finance, grow faster in financially developed countries, thereby providing evidence for a causal relationship of finance on growth. The main advantage of our sectoral productivity estimates is that we can address the specific channel through which financial development affects growth. The empirical finance-growth literature has difficulties to assess whether financial development leads to growth by easing financial constraints and increasing the amount of investment firms are able to undertake or by channelling investment towards more efficient uses.[40] This is because reliable sectoral investment series are not available for most countries. We provide evidence for the second channel by showing that financial development leads to significantly higher relative productivity levels as well as growth rates in

[39]While the results for TFP levels should be interpreted with some caution, since they may reflect a mismeasurement of the Heckscher-Ohlin effect in the construction of our productivity estimates, we are more confident about the validity of our results on TFP growth rates, where no such critique applies. Nevertheless, to be sure we are not measuring some kind of Rybczynski effects, we have experimented with including an interaction between human capital intensity and the change in human capital endowments, which was never significant and did not affect the significance of the human capital interaction in levels.

[40]An exception is Jayaratne and Strahan (1996) who exploit several bank liberalization episodes in different US states to show that bank branch deregulation has increased the efficiency but not the amount of bank credit in the US.

sectors that depend more on external finance. Our empirical strategy closely follows Rajan and Zingales. External financial dependence, $EXTFIN_k$, is measured by the fraction of sectoral investment that US firms cannot finance from internal cash flow and is taken from Rajan and Zingales (1998). To proxy for the tightness of credit constraints, we use sectoral financial dependence and interact it with country-level financial development, $PRIV_j$, as measured by private credit as a fraction of GDP in 1995 from Beck, Demirgc-Kunt and Levine (2000). First, we regress (log) sectoral productivity in the mid-90's on the $EXTFIN_k * PRIV_j$ interaction using specification (2.36) and controlling for sector and country fixed effects. Column five of table 2.7 shows that financial development has a significantly (at the one percent level) positive effect on relative productivities in sectors that depend more on outside finance. Next, we regress the growth rate of sectoral TFP on the same interaction using specification (2.37), controlling for sector and country fixed effects. Again, we find a significant (at the one percent level) positive coefficient of the financial interaction variable, which corroborates the idea that financial development affects the efficiency of investment.

Finally, we include all the previous dependent variables simultaneously in the level and the growth rate specification. In the both specifications all dependent variables have the expected sign and remain significant, except for the R&D interaction, which becomes insignificant.

	log(TFP)	TFP growth	log(TFP)	TFP growth	log(TFP)	TFP growth	log(TFP)	TFP growth
R&D	1.716	1.35					0.683	0.244
interaction	(0.418)***	(0.579)**					(0.435)	(0.599)
HC			0.584	0.579			0.502	0.56
interaction			(0.136)***	(0.202)***			(0.147)***	(0.255)**
Financial					0.553	0.597	0.476	0.627
interaction					(0.093)***	(0.141)***	(0.145)***	(0.238)***
$log(TFP_{85})$		-0.675		-0.565		-0.576		-0.733
		(0.142)***		(0.107)***		(0.099)***		(0.154)***
Sector Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	995	895	1278	1163	1402	1218	886	829
Countries	43	40	56	55	62	58	38	37

Table 2.7: Productivity and Theories of Development. Bootstrapped standard errors in parentheses. significant at 1% (***), 5% (**), 10% (*) level.

2.8 Conclusion

In this paper we have estimated sectoral manufacturing total factor productivities (TFP) for more than sixty countries at all stages of development by using information contained in bilateral sectoral trade data. To this end we have derived structural estimation equations from a hybrid Ricardo-Heckscher-Ohlin model with transport costs. Differences in sectoral TFP have been estimated as observed trade that cannot be explained by differences in factor intensities and prices or by differences in trade barriers across countries. The main advantage of our methodology is that it allows us to overcome severe data limitations which render the application of traditional methods for TFP computations that rely on information on sectoral inputs and outputs in physical units unfeasible for virtually all developing countries. To compute sectoral productivities, we only need data on bilateral trade, aggregate factor prices, and (depending on the model) sectoral production values.

Our results show that productivity differences in manufacturing sectors are large and systematically related to income per capita. In addition, productivity variation between rich and poor countries is more pronounced in skilled labor and R&D intensive sectors. We also find that some poor countries have higher productivities than the US in a small set of sectors. Moreover, our methodology permits to compute bilateral rankings of comparative advantage that are due to productivity for any pair of countries.

We have performed a series of robustness checks and have shown that productivity estimates are neither very sensitive to the specific estimation method, nor to the particular trade model we used in deriving our structural estimation equations.

Finally, we have related our productivity estimates to a number of theories on productivity differences, like technology spillovers, human capital and technology adoption, and financial development that have predictions for the variation of sectoral productivities across countries and have demonstrated that there is a strong correlation between variation in sectoral TFP and proxies for the above factors. Moreover, we found Ricardian productivity differences are very important in explaining bilateral sectoral trade patterns.

Appendix Chapter 1

.1 Data

To make my results comparable with the development accounting literature I follow Caselli (2005) as closely as possible in the construction of the data. Data are from two main sources: The first one is the Penn World Table (Version 6.2), which provides the data for income per worker and physical capital stocks in purchasing power parities. The other main source is the Global Trade Analysis Project (GTAP) Version 6, which has information on input-output tables and bilateral sectoral trade data at 57 sector aggregation for the year 2001.[41]. Data on income and endowments are available for 96 countries, while the sample size for input-output tables and trade data is 53.

Capital stocks for 2001 are computed from the PWT using the perpetual inventory method, ie $K_{ct} = I_{ct} + (1-\delta)K_{ct-1}$. Here, I_{ct} is real aggregate investment in PPP[42]. Following Caselli, I choose a depreciation rate, δ, of 6% per year, and $K_0 = I_0/(g+\delta)$ where I_0 is investment in the first year with available data and g is the average

[41] The sectors are: paddy rice, wheat, other grains, vegetables, oil seeds, sugar cane, plant based fibres, other crops, cattle, animal products, raw milk, wool, forestry, fishing, coal, oil, gas, other minerals, cattle and sheep meat, other meat, vegetable oils, dairy products, processed rice, sugar, other food, beverages and tobacco, textiles, wearing apparel, leather products, wood products, paper and publishing, petroleum, chemicals and rubber, mineral products, ferrous metals, other metals, metal products, motor vehicles, transport equipment, electronic equipment, machinery, other manufactures, electricity, gas distribution, water, construction, trade, other transport, water transport, air transport, communication, financial services, insurance, business services, recreational services, education and health, dwellings

[42] Computed as RGDPL*POP*KI, where RDGPL is real GDP per capita computed with the Laspeyres index, POP is population and KI is the investment share of RGDPL.

geometric growth rate for investment between that year and 1970.

Human capital is constructed from average years of schooling in the population over 25 in the year 1999. Data on average years of schooling are from Barro and Lee (2001). These are converted into human capital following Caselli (2005) using the formula $h = e^{\phi(s)}$, where $\phi(s)$ is piecewise linear with slope 0.134 for $s <= 4$, 0.101 for $4 < s <= 8$ and 0.068 for $s > 8$. Aggregate human capital is computed as $Hc = h_c L_c$, where L_c is the number of workers computed from the Penn World Tables as RGDPPCH*POP/RGDPWOK. Here, RGDPCH is real GDP per capita using the chain series method and RGDPWOK is real GDP per worker constructed with the same method.

Aggregate income for the year 2001, Y_c, is real GDP in PPP computed with the chain method, defined as RDGPCH*POP.

Since I need an additional data point per country in order to calibrate factor productivities, I construct estimates of average unskilled wages for all countries in the sample. To obtain wage data, I proceed in the following way. As a first step I use data on country labor income shares from Bernanke and Gürkaynak (2002). Following a procedure suggested by Gollin (2002), they have adjusted raw data on labor shares for the labor of self-employed workers, who make up a large fraction of the labor force in most developing countries. Because their dataset includes only 54 countries of my sample, I regress these labor shares on controls and predict labor shares out of sample for the rest of the countries. Right hand side variables include real trade openness from the PWT averaged over 15 years, and regional dummies.

Once labor shares are constructed for all countries, PPP wages are computed as $w_c = \frac{S_{Hc} Y_c}{H_c}$, where S_{Hc} is the labor share in country c. Rental rates are then backed out using the formula $r_c = \frac{Y_c - w_c H_c}{K_c}$.[43]

[43]Caselli and Feyrer (2006) stress that poor countries have a large fraction of capital income that

Direct factor use by industry, V_{ic}, is computed by assuming that sectoral factor use is proportional to payments to the factor by industry. These are scaled such as to fit aggregate factor endowments H_c and K_c. Sectoral payments to capital and labor are from the GTAP (version 6) input-output accounts. Factor use per unit of output V_{ic}/Q_{ic} is computed by converting sectoral gross output from GTAP into international dollars using price indices from the PWT and dividing sectoral factor use by deflated gross output.

Input-output tables $\bar{B}_c$ as well as bilateral sectoral trade data X_c and $M_{cc'}$ are taken from GTAP. Input-output tables are converted into international dollars using PWT price indices. The B-matrix is constructed from the input-output tables, following Trefler and Zhu (2005).

.2 The Productivity Calibration Problem (PCP)

Definition 2: A **Productivity Calibration Problem** (**PCP**) is a collection of goods prices $\{p_i\}$, efficiency adjusted wages $\{\hat{w}_d\}$, efficiency adjusted rental rates $\{\hat{r}_d\}$, numbers of sectoral varieties $\{N_{id}\}$ and factor productivities $\{A_{Hc}\}$, $\{A_{Kc}\}$ such that given a cross section of human capital endowments $\{H_c\}$, physical capital endowments $\{K_c\}$, wages $\{w_c\}$, rentals $\{r_c\}$ and parameters $\{\alpha_i\}$, $\{\beta_i\}$, ϵ, σ and f the following system of equations holds for all $d \in D$:

$$\frac{\sigma}{\sigma-1}[\alpha_i^{\epsilon}\hat{r}_d^{1-\epsilon} + (1-\alpha_i)^{\epsilon}\hat{w}_d^{1-\epsilon}]^{\frac{1}{1-\epsilon}} \geq p_i \tag{38}$$

with

$$\{p_i - \frac{\sigma}{\sigma-1}[\alpha_i^{\epsilon}\hat{r}_d^{1-\epsilon} + (1-\alpha_i)^{\epsilon}\hat{w}_d^{1-\epsilon}]^{\frac{1}{1-\epsilon}}\}N_{id} = 0 \tag{39}$$

goes to non-reproducible capital (land and natural resources) and that this tends to upward-bias measured rental rates in these countries if this factor is not considered separately. Since my model has only two factors and all income must be payed to some factor, the above way to calculate rentals is consistent, even though it might exacerbate differences in rentals.

$$\sum_{i\in I}[\alpha_i^{\epsilon}\hat{r}_d^{1-\epsilon}+(1-\alpha_i)^{\epsilon}\hat{w}_d^{1-\epsilon}]^{\frac{\epsilon}{1-\epsilon}}(1-\alpha_i)^{\epsilon}\hat{w}_d^{-\epsilon}f\sigma N_{id}=\sum_{c\in d}A_{Hc}H_c \tag{40}$$

$$\sum_{i\in I}[\alpha_i^{\epsilon}\hat{r}_c^{1-\epsilon}+(1-\alpha_i)^{\epsilon}\hat{w}_c^{1-\epsilon}]^{\frac{\epsilon}{1-\epsilon}}(\alpha_i)^{\epsilon}\hat{r}_d^{-\epsilon}f\sigma N_{id}=\sum_{c\in d}A_{Kc}K_c \tag{41}$$

$$p_i(\sigma-1)f\sum_{d\in D}N_{id}=\beta_i\sum_{c\in C}Y_c \quad i=1,...,I-1 \tag{42}$$

$$\prod_{i=1}^{I}\left(\frac{N_i^{\frac{1}{1-\sigma}}p_i}{\beta_i}\right)^{\beta_i}=1; \tag{43}$$

$$A_{Hc}=\frac{w_c}{\hat{w}_d} \tag{44}$$

$$A_{Kc}=\frac{r_c}{\hat{r}_d} \tag{45}$$

Regarding the connection between the **PCP** and an **Equilibrium**, one can establish the following relationships.

Lemma 1: If given $\{H_c\}$, $\{K_c\}$, $\{w_c\}$, $\{r_c\}$, parameters $\{\alpha_i\}$, $\{\beta_i\}$, σ and ϵ and f we have that $\{p_i\}$, $\{\hat{w}_d\}$, $\{\hat{r}_d\}$, $\{N_{id}\}$, $\{A_{Hc}\}$, $\{A_{Kc}\}$ are a solution to the **PCP** then $\{p_i\}$, $\{\hat{w}_d\}$, $\{\hat{r}_d\}$, $\{N_{id}\}$ are also an **Equilibrium** given $\{A_{Hc}H_c\} = \{\hat{H}_c\}$, $\{A_{Kc}K_c\} = \{\hat{K}_c\}$.

Proof: Follows from inspecting the equations of **PCP**.

Lemma 2: If given $\{H_c\}$, $\{K_c\}$, $\{\alpha_i\}$, $\{\beta_i\}$, ϵ, σ and f we have that $\{p_i\}$, $\{w_d\}$, $\{r_d\}$, $\{N_{id}\}$ are an **Equilibrium** then they also solve the **PCP** given $\{H_c\}$, $\{K_c\}$, $\{w_d\}$ and $\{r_d\}$ with $\{A_{Hc}\} = \{A_{Kc}\} = \{1\}$.

Proof: Follows from inspecting the equations of **PCP**.

.2.1 Uniqueness of Solution to PCP

Simsek, Ozdaglar and Acemoglu (2006) have derived a sufficient condition for the uniqueness of the solution to nonlinear complementarity problems. If this condition is met it guarantees uniqueness of the solution to **PCP** for the particular parameter values considered.

Let $F : R^n \to R^n$ be a function. The nonlinear complementarity problem is to find a vector x that satisfies the following

$$x \geq 0, F(x) \geq 0 \tag{46}$$

$$x^T F(x) = 0 \tag{47}$$

Note that **PCP** has the structure of a nonlinear complementarity problem.

Denote the set of solutions to (46), (47) by NCP(F). Define the index sets

$$I^{NB}(x) = \{i \in \{1, ..., n\} | x_i > 0\} \tag{48}$$

$$I^F(x) = \{i \in \{1, ..., n\} | F_i(x) = 0\} \tag{49}$$

A.A1: There exists a compact set $C \subset R^n_+$ such that for all x $\in R^n_+ - C$ there exists some $y \in C$ and $i \in 1, ..., n$ such that $(y_i - x_i)F_i(x) < 0$.

A.A2: Let $U^n_+ \subset R^n$ be an open set containing R^n_+ and $F : U^n_+ \to R^n$ be a continuous function that is continuously differentiable at every $x \in NCP(F)$. We have $det(\bigtriangledown F(x)|_J) > 0$ for every $x \in$ NCP(F) and for every index set J such that $I^{NB}(x) \subseteq J \subseteq I^F(x)$.

Theorem (Simsek, Ozdaglar, Acemoglu): Let $U^n_+ \subset R^n$ be an open set containing R^n_+ and $F : U^n_+ \to R^n$ be a continuous function which is continuously differentiable at every x $\in NCP(F)$. Let Assumptions **A.A1** and **A.A2** hold. Then NCP(F) has a unique element.

As noted above the **PCP** is a nonlinear complementarity problem. Continuity can be checked by inspection. In addition, the **PCP** satisfies **A.A1**.

Proof: Let $p^{max} \in R_+ \equiv \beta_i \sum_{c \in C} Y_c$. Let C be the rectangle $(0, (p^{max}, ..., p^{max}))$. Let $F_i(x) = p_i \sum_{d \in D} Q_{id} - \beta_i \sum_{c \in C} Y_c$. Then for all $x \in R^n - C$ we have that $F_i(x) > 0$. Hence, it follows that by choosing $y = 0 \in C$ the condition $(y_i - x_i)F_i(x) < 0$ is satisfied.

The condition that the determinant of the Jacobian must be positive in NCFP(x), can be checked numerically. It is satisfied for all the examples with $\epsilon > 1$. When $\epsilon < 1$ multiple solutions may exist. However, the solution is unique provided that the following additional assumptions are made: 1) Countries are ranked by K_c/H_c and 2) Factor price equalization holds, when a set of countries can have equalized efficient factor prices.

Appendix Chapter 2

.3 Data Description

Bilateral sectoral trade data, M_{ijk}, and sectoral production, $Output_{jk}$, are obtained from the from the World Bank's Trade, Production and Protection database. This dataset merges trade flows and production data from different sources into a common classification: the International Standard Industrial Classification (ISIC), Revision 2. The database potentially covers 100 developing and developed countries over the period 1976-2004. We use trade and production data for the periods 1984-1986, 1994-1996 and 2002-2004, considering 36 importing countries and 64 exporting countries. The 36 importers represent more than $\frac{2}{3}$ of world imports[44]. To mitigate problems of data availability and to smooth the business cycle, we average the data over three years. We exclude, tobacco (314), petroleum refineries (353), miscellaneous petroleum and coal products (354) and other manufactured products not classified elsewhere (390) from the 28 sectors in the ISIC classification because trade data do not properly reflect productivity in those sectors.

For the monetary value of production, $Output_{jk}$, we use information on Gross Output from the Trade, Production and Protection database [45]. The original source of

[44] We have to exclude US as an importer country because we use them as our benchmark country. The countries represent more than 80% of the remaining imports.

[45] Gross Output represents the value of goods produced in a year, whether sold or stocked. It is reported in current dollars. Our results are robust to using Value Added instead.

this variable is the United Nations Industrial Development Organization's (UNIDO) Industrial Statistics. For the years 1994-1996 some data have been updated by Mayer and Zignago (2005) [46]. The production data published by UNIDO is by no means complete, and that is the main limitation in computing productivities [47]. UNIDO also collects data on establishments that we could have used directly, instead using Gross Output data. However, these data are less reliable than production data because different countries use different threshold firm sizes when reporting data to the UNIDO[48].

Sectoral elasticities of substitution, ϵ_k, are obtained from Broda and Weinstein (2006). They construct elasticities of substitution across imported goods for the United States at the Standard International Trade Classification (SITC) 5 digit level of disaggregation for the period 1990-2001. We transform those elasticities to our 3 digit ISIC rev. 2 level of disaggregation by weighting elasticities by US import shares.

Factor intensities, $(\alpha_{ku}, \alpha_{ks}, \alpha_{kcap})$, are assumed to be fixed across countries. This assumption allows us to use factor income share data for just one country, namely the US. To proxy for skill intensity, we follow Romalis (2004), in using the ratio of non-production workers to total employment, obtained from the NBER-CES Manufacturing Industry Database constructed by Bartelsman, Becker and Gray (2000) and converting USSIC 87 categories to ISIC rev 2. Capital intensity is computed as one less the share of total compensation in value added, using the same source. In our three factor model intensities are re-scaled such that $\sum_i \alpha_{k,i} = 1; \qquad i = u, s, cap$[49].

[46] They have updated a previous version of the Trade and Production Database. As in the latest version of the Trade, Production and Protection Database, data from years 94-96 remain the same, the Mayer & Zignago database of 2005 is more complete than the Nicita & Olarreaga database of 2006.

[47] Besides this, we require exporting countries to export at least to 5 importing countries in any given sector during the relevant period.

[48] While the fact that some countries do not consider micro-firms, whereas others do does not change aggregate output numbers much, the number of establishments is indeed severely affected by this inconsistency. For a description of UNIDO's data issues see Yamada (2005).

[49] As in Romalis (2004), $\alpha_{k,cap} = cap.intensity$; $\alpha_{ks} = skill\ intensity * (1 - \alpha_{kcap})$ and $\alpha_{ku} =$

Wages and rental rates at the country level are computed using the methodology exposed in Caselli (2005), Caselli and Coleman (2006) and Caselli and Feyrer (2006). The definition of the rental rate is consistent with a dynamic version of our model in which firms solve an inter-temporal maximization problem and capital markets are competitive[50]. Total payments to capital in country j are $\sum_k p_{jk} MPK_{jk} K_k = p_j MPK_j \sum_k K_k = r_j K_j$ where K_j is the country $j's$ capital stock in physical units and the first equality follows from capital mobility across sectors. Since $\alpha_{j,cap} = \frac{r_j K_j}{P_Y Y}$, where Y is GDP in Purchasing Power Parities, the following holds.

$$r_j = \alpha_{j,cap} \frac{GDP_j}{K_j} \tag{50}$$

Capital stocks in physical units are computed with the permanent inventory method using investment data from the Penn World Table (PWT).[51]. GDP_j is also obtained from the PWT and is expressed in current dollars. $\alpha_{j,cap}$ is country j's aggregate capital income share. We compute the capital share as one minus the labor share in GDP, which we take from Bernanke and Gürkaynak (2002) and Gollin (2002). In turn, the labor share is employee compensation in the corporate sector from the National Accounts plus a number of adjustments to include the labor income of the self-employed and non-corporate employees.

Similarly, to compute the skilled and unskilled wages we use the the following result for the labor share:

$1 - \alpha_{ks} - \alpha_{kcap}$

[50]Firms set the marginal value product equal to the rental rate, $p_{jk} MPK_{jk} = P_{Kj}(interest_j + \delta)$, where P_{Kj} is the price of capital goods in country j, $interest_j$ is the net interest rate in country j and δ is the depreciation rate. This can be seen considering the decision of firms in sector k in country j to buy an additional unit of capital. The return from such an action is $\frac{p_{jk}(t) MPK_{jk}(t) + P_{Kj}(t+1)(1-\delta)}{P_{Kj}(t)}$. Abstracting from capital gains, firms will be indifferent between investing an additional dollar in the firm or in an alternative investment opportunity that has a return $interest_j$, when the above relationship holds. Because capital is mobile across sectors within a country the marginal value product must be equalized across sectors.

[51]For details see Caselli (2005)

$$(1-\alpha_{j,cap}) = \frac{w_u U + w_u \frac{w_s}{w_u} S}{GDP_j} \tag{51}$$

The total labor share is equal to payments to both skilled and unskilled workers relative to GDP. Skilled and unskilled workers are expressed in efficiency units of non-educated workers and workers with complete secondary education.[52]. Thus,

$$U = L_{noeduc} + e^{\beta * \frac{prim.dur.}{2}} L_{prim.incomp.} + e^{\beta * prim.dur.} L_{prim} + e^{\beta * lowsec.dur.} L_{lowsec.} \tag{52}$$

and

$$S = L_{secondary} + e^{2\beta} L_{ter.incomp.} + e^{4\beta} L_{tertiary} \tag{53}$$

Educational attainment of workers over 25 years at each educational level are taken from Barro and Lee (2001) and Cohen and Soto (2001). Information on the duration of each level of schooling in years by country is provided by the UNESCO[53]. Skill premia β by country are obtained from Bils and Klenow (2000) and Banerjee and Duflo (2005). The wage premium $\frac{w_{skill}}{w_u}$ equals $e^{\beta*(prim.dur.+lowsec.dur.)}$. The panels of figure 7 plot the computed skilled and unskilled wages, the wage premium, the capital stock per worker and the rental rate for the countries against log income per worker for the mid-nineties. We observe that although wages of both skilled and unskilled workers are much higher in rich countries, the wage premium is negatively related with income per worker, which gives rich countries a relative advantage in skilled labor intensive sectors. The relation between the rental rate and income per worker is slightly positive. The absence of a strong relationship between the marginal product of capital and income per worker is similar to Caselli and Feyrer (2006) once they correct for price differences and natural capital. Although we do not adjust for

[52]Changing the base of skilled workers from completed secondary to completed primary, incomplete secondary or incomplete tertiary education does not alter the results significantly. Further details about the construction of the wages and rental rates can be found in the referenced papers of Caselli.

[53]Notice that for non-complete levels, we assume that workers have half completed half of the last level (except when we have data of lower secondary duration). For tertiary education we consider a duration of 4 years given lack of data for most of the countries

the fraction of income that goes to natural capital in our three factor model, we do correct for the price level of GDP.

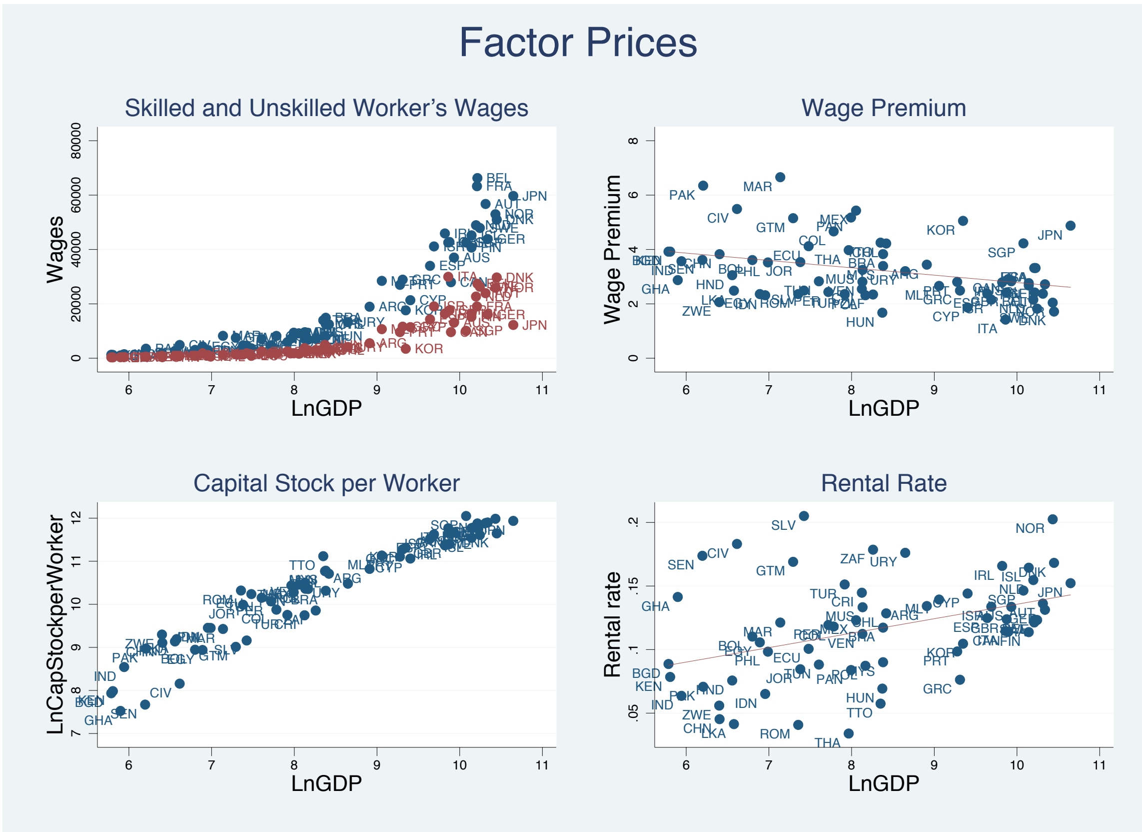


Figure 7: Factor Prices

To compute the productivity measures, we also require a number of bilateral variables commonly used in gravity-type regressions. We take them from two sources: Rose (2004) and Mayer and Zignago (2005). We include bilateral distance from the latter, who have developed a distance database which uses city-level data in the calculation of the distance matrix to assess the geographic distribution of population inside each nation. The basic idea is to calculate the distance between two countries based on bilateral distances between cities weighted by the share of each city in the overall country's population. CEPII also provides a bilateral sectoral tariff database. Tariffs are measured at the bilateral level and for each product of the HS6 nomenclature in the TRAINS database from UNCTAD. Those tariffs are aggregated from TRAINS data in order to match the ISIC Rev.2 industry classification using the world imports as weights for HS6 products.

For the TFP computed as Solow residuals from the OECD STAN database we proceed as follows. Capital stocks are computed with the perpetual inventory method using sectoral gross fixed capital formation from the STAN database[54]. Investment is transformed into international dollars using exchange rates and price indices for investment from the Penn World Table. Finally, we transform investment into constant dollars using a deflator for US fixed nonresidential investment from the BEA National Income and Product Accounts. Labor inputs are constructed from STAN sectoral employment data which we transform to efficient labor by using information on human capital per worker from Caselli (2005). Our output measure is sectoral value added (from STAN).

.4 Derivation of the Productivity Estimates with Heterogeneous Firms

To start out, we introduce heterogeneity in firms' marginal costs.

$$MC(a) = \frac{a}{A_{jk}} \prod_{f \in F} \left(\frac{w_{fj}}{\alpha_{fk}} \right)^{\alpha_{fk}}, \tag{54}$$

where a is an inverse measure of random firm productivity with sector specific cumulative distribution function $G_k(a)$ and support $[a_{Lk}, a_{Hk}]$ that is identical across countries. Aggregate sectoral productivity differences are measured by the term A_{jk}.[55]. In this way we are able to measure which fraction of firms is engaged in bilateral trade, once we filter out average sectoral productivity differences across

[54] For consistency reasons we use a depreciation rate of 6%.

[55] Hence, $G_{jk}(a) = 1/A_{jk}G_k(a)$

countries.

Profits from exporting to country i for producers in sector k of country j with productivity $\frac{A_{jk}}{a}$ can be written as

$$\Pi_{ijk}(a) = \frac{1}{\epsilon_k}\left[\frac{\epsilon_k a \tau_{ijk} \prod_{f\in F}\left(\frac{w_{fj}}{\alpha_{fk}}\right)^{\alpha_{fk}}}{(\epsilon_k - 1)A_{jk}P_{ik}}\right]^{1-\epsilon_k} \sigma_{ik}Y_i - f_{ijk} \tag{55}$$

Firms export from j to i in sector k only if they can recoup the bilateral fixed cost to export. This defines a cutoff productivity level a_{ijk} such that $\Pi_{ijk}(a_{ijk}) = 0$. Hence, only a fraction $G(a_{ijk})$ (potentially zero) of country j's N_{jk} firms export to country i. Define $V_{ijk} = \int_{a_{Lk}}^{a_{ijk}} a^{1-\epsilon_k} dG(a)$ if $a_{ijk} \geq a_{Lk}$ and zero otherwise. We assume that $G(a)$ is such that V_{ijk} is a monotonic function of $G(a_{ijk})$, the proportion of firms of country j exporting to country i in sector k.[56] Then the volume of bilateral trade can be written as

$$M_{ijk} = \left[\frac{\frac{\epsilon_k}{\epsilon_k-1}\tau_{ijk} \prod_{f\in F}\left(\frac{w_{fj}}{\alpha_{fk}}\right)^{\alpha_{fk}}}{A_{jk}P_{ik}}\right]^{1-\epsilon_k} \sigma_{ik}Y_i N_{jk} V_{ijk}. \tag{56}$$

Let $\tilde{A}_{ijk} \equiv \left(\frac{M_{ijk}}{N_{jk}}\right)^{\frac{1}{\epsilon_k-1}} \prod_{f\in F}\left(\frac{w_{fk}}{\alpha_{fk}}\right)^{\alpha_{fk}}$ be our measure of "raw" productivity. Taking logs and rearranging, we obtain again a gravity type relation.

$$\log(\tilde{A}_{ijk}) = \log(A_{jk}) + \frac{1}{\epsilon_k - 1}\log(\sigma_{ik}Y_i) + \log(P_{ik}) + \log\left(\frac{\epsilon_k - 1}{\epsilon_k}\right) + \log(\tau_{ijk}) + \frac{1}{\epsilon_k - 1}\log(V_{ijk}) \tag{57}$$

From this equation we can see a potential source for bias in the productivity estimates. $log(V_{ijk})$, a variable related to the fraction of exporting firms, appears in the equation. Since this variable is correlated with the right hand side variables (see below), all the estimates are biased when omitting this variable. To be more specific, distance affects negatively the profits to export and reduces the number of firms

[56] This is true if 1/a is Pareto, for example.

engaged in bilateral trade. As the same variable also affects our "raw" productivities, the coefficient for distance is biased (upward).

Define the variable Z_{ijk} as the ratio of variable profits to bilateral fixed costs to export for the most productive exporter,

$$Z_{ijk} = \frac{\frac{1}{\epsilon_k}\left[\frac{\epsilon_k a_{Lk}\tau_{ijk}\prod_{f\in F}\left(\frac{w_{fj}}{\alpha_{fk}}\right)^{\alpha_{fk}}}{(\epsilon_k-1)A_{jk}P_{ik}}\right]^{1-\epsilon_k}\sigma_{ik}Y_i}{f_{ijk}}. \tag{58}$$

Hence, we observe postive trade flows from j to i in sector k if and only if $Z_{ijk} \geq 1$.

Using (55) and (58) one can show that $Z_{ijk} = \left(\frac{a_{ijk}}{a_L}\right)^{\epsilon_k-1}$ and that consequently V_{ijk} a monotonic function of Z_{ijk} if $V_{ijk} > 0$. Next, specifying z_{ijk} as the log of Z_{ijk}, we obtain:

$$z_{ijk} = -log(\epsilon_k)+(1-\epsilon_k)log(\frac{\epsilon_k}{\epsilon_k-1})+(\epsilon_k-1)log(P_{ik})+log(\sigma_{ik}Y_i)+(1-\epsilon_k)log(p_{jk})+(1-\epsilon_k)log(\tau_{ijk})-lo \tag{59}$$

We assume that bilateral sectoral variable transport costs can be written as a function of bilateral variables, X_{ijk}, an exporter specific term ϕ_j, an importer specific term ϕ_i and a sector specific term ϕ_k as well as an idiosyncratic normally distributed error term $u_{ijk} \sim N(0, \sigma_u^2)$, so that $\tau_{ijk} = exp(\phi_j + \phi_i + \phi_k + \kappa_k X_{ijk} - u_{ijk})$. For f_{ijk} we make a similar assumption , such that $f_{ijk} = exp(\varphi_j + \varphi_i + \varphi_k + \delta_k X_{ijk} - \nu_{ijk})$, where φ_j, φ_i and φ_k are exporter, importer and sector specific and $\nu_{ijk} \sim N(0, \sigma_\nu^2)$.

Consequently, we can write the latent variable z_{ijk} as

$$z_{ijk} = \xi_k + \xi_i + \xi_j - \gamma_k X_{ijk} + \eta_{ijk}, \tag{60}$$

where ξ_{jk} and ξ_{ik} are exporter, importer and sector specific effects[57] and $\eta_{ijk} = u_{ijk} + \nu_{ijk} \sim N(0, \sigma_u^2 + \sigma_\nu^2)$ is i.i.d (but correlated with the error term in the equation

[57] We cannot control for importer-sector and exporter-sector effects because then many outcomes would be perfectly predicted, as a lot of countries export to all importers in a specific sector.

of trade flows). Hence $z_{ijk} > 0$ if $M_{ijk} > 0$ and zero else. As a next step define the latent variable T_{ijk}, which equals one if $z_{ijk} > 0$ and zero otherwise.

Specify the Probit equation

$$\rho_{ijk} = Pr(T_{ijk} = 1 | X_{ijk}) = \Phi(\xi_k^* + \xi_i^* + \xi_j^* - \gamma_k^* X_{ijk}), \tag{61}$$

where starred coefficients are divided by the standard deviation of the error term, which cannot be estimated separately. Finally, let $\hat{\rho}_{ijk}$ be the predicted probability of exports from j to i in sector k and let $\hat{z}^*_{ijk}$ be the predicted value of the latent variable z^*_{ijk}.

We want to obtain an estimate of "raw" productivity,

$$E[\log(\tilde{A}_{ijk})|X_{ijk}, T_{ijk} = 1] = \log(A_{jk}) + D_{ik} + \beta_k X_{ijk} + E[\frac{1}{\epsilon_k - 1}\log(V_{ijk})|T_{ijk} = 1] + E[e_{ijk}|T_{ijk} = 1] \tag{62}$$

Then a consistent estimation of the log-linear equation requires estimates of $E[\log(V_{ijk})|T_{ijk} = 1]$ and $E[e_{ijk}|T_{ijk} = 1]$. A consistent estimator for $E[e_{ijk}|T_{ijk} = 1] = Cov(\eta, e)/\sigma^2_\eta E(\eta_{ijk}|T_{ijk} = 1)$ is $\beta_{\eta,e,k}\phi(z^*_{ijk})/\Phi(z^*_{ijk}$, the inverse Mill's ratio, and a consistent estimator for $E[\log(V_{ijk}|T_{ijk} = 1]$ can be obtained by approximating the unknown function $\log(V_{ijk}(\hat{z}^*_{ijk}))$ with a polynomial in $\hat{z}^*_{ijk}$.

$$\log(\tilde{A}_{ijk}) = \log(A_{jk}) + D_{ik} + \beta_k X_{ijk} + \beta_{\eta,e,k}\frac{\phi(\hat{z}^*_{ijk})}{\Phi(\hat{z}^*_{ijk})} + \sum_{l=1}^{L} \gamma_{kl}(\hat{z}^*_{ijk})^l + \nu_{ijk} \tag{63}$$

.5 Mismeasurement of Sectoral Factor Income Shares

In our modelling procedure we have assumed that sectoral factor income shares do not vary across countries in order to be able to use the values of the US for these parameters, since reliable information on factor income shares at the sectoral level is not available for most countries. In this section we investigate the bias that may arise from mismeasuring factor income shares. For concreteness, let us focus on income shares of skilled labor. Suppose $\alpha_{skj} = \alpha_{skUS} + \nu_{jk}$. Then with some manipulations productivities can be written as[58]

$$E\left[log(\frac{A_{ijk}}{A_{iUSk}}|actual)\right] \approx E\left[log(\frac{A_{ijk}}{A_{iUSk}}|measured)\right] + E(\nu_{jk})log(\frac{w_{sj}}{w_{uj}}) + \\ E(\nu_{jk})(1 - \alpha_{skUS} - \alpha_{capkUS}) + E[\nu_{jk}(\nu_{jk} - \alpha_{skUS} - \alpha_{capkUS})]. \quad (64)$$

Consequently, if the intensity differences are random, i.e. ν_{jk} is i.i.d. with $E(\nu_{jk}) = 0$ and $Var(\nu_{jk}) = \sigma_{jk}$, we get $E\left[log(\frac{A_{ijk}}{A_{iUSk}}|actual)\right] = E\left[log(\frac{A_{ijk}}{A_{iUSk}}|measured)\right] + \sigma_{jk}$. Hence, on average we tend to underestimate productivities in those sectors and countries that have very - but not systematically - different factor income shares than the US. Since this kind of measurement error is more likely to occur in poor countries, it may lead to underestimation of poor countries' productivities in specific sectors.

If poor countries have a systematically larger income share of skilled labor than the US, the more skill intensive the sector, we tend to predict systematically lower productivities of poor countries in skill intensive sectors. To see this, assume that in poor countries $E(\nu_{jk}) = \overset{(+)}{f}(\alpha_{sUS})$, a positive function of the skilled labor share in the US. Then the bias is negative, provided that the only negative term $-(\alpha_{kUSs} + \alpha_{kUScap})E(\nu_{jk})$ does not dominate the other terms, which are all positive. It is unlikely, however, that poor countries have a systematically larger skilled labor income share in more skill intensive sectors than the US. If technological change is skill biased, the gap in the wage share of skilled labor between rich and poor countries is larger in more skill intensive sectors, so that we actually tend to overestimate the productivity of poor countries in skill intensive sectors. The intuition is that in this case we overestimate the cost of skilled labor inputs in poor countries in skill intensive

[58] To derive this, substitute the definition of skilled labor shares in (2.13), divide by the value of the US, take logs, simplify and use $log(1 + x) \approx x$.

sectors, which have on average higher skill premia than rich ones.

.6 A Two Country General Equilibrium Model

In this section we present a two country general equilibrium version of the model we estimate in the paper which is based on Romalis (2004). Several features of the model in this section are more restrictive than the model estimated in the main text. These assumptions are just made to simplify the exposition and do not affect the basic results of the model.

There are two countries, Home and Foreign ($*$). Transport costs are allowed to be sector specific and asymmetric and are denoted by τ_k and τ_k^*. We assume in this section that there are only two factors of production, capital, K and labor, L The total number of varieties in each sector at the world level is $N_k = n_k + n_k^*$.

It follows from (2.4) that the Home price index in sector k is defined as

$$P_k = \left[n_k p_k^{1-\epsilon_k} + n_k^* (p_k^* \tau^*)^{1-\epsilon_k} \right]^{\frac{1}{1-\epsilon_k}} . \tag{65}$$

A similar expression holds for the Foreign price index.

The revenue of a Home firm is given by the sum of domestic and Foreign revenue and using the expressions for Home and Foreign demand (2.3), we get

$$p_k q_{jk} = \sigma_k Y \left(\frac{p_k}{P_k} \right)^{1-\epsilon_k} + \sigma_k^* Y^* \left(\frac{p_k \tau_k}{P_k^*} \right)^{1-\epsilon_k} . \tag{66}$$

An analogous expression applies to Foreign Firms.

Given the demand structure firms optimally set prices as a fixed mark up over their marginal cost.

$$p_k = \frac{\epsilon_k}{\epsilon_k - 1} \frac{1}{A_{jk}} \left(\frac{w_j}{1-\alpha_k} \right)^{1-\alpha_k} \left(\frac{r_j}{\alpha_k} \right)^{\alpha_k} \tag{67}$$

Since firms can enter freely, in equilibrium they make zero profits and price at their average cost. Combining this with (67), it is easy to solve for equilibrium firm size, which depends positively on the fixed cost and the elasticity of substitution.

$$q_{jk} = q_k = f_k(\epsilon_k - 1) \tag{68}$$

Let us now solve for partial equilibrium in a single sector. For convenience, define the relative price of Home varieties in sector k, to be $\tilde{p}_k \equiv \frac{p_k}{p_k^*}$ and the relative fixed cost in sector k as $\tilde{f}_k \equiv \frac{f_k}{f_k^*}$.

Dividing the Home market clearing condition by its Foreign counter part, one can derive an expression for $\frac{n_k}{n_k^*}$, the relative number of home varieties in sector k.

A sector is not necessarily always located in both countries. In fact, if Home varieties are too expensive relative to Foreign ones, Home producers may not be able to recoup the fixed cost of production and do not enter this sector at Home.

Consequently, if $\tilde{p} \geq \underline{p}_k$, we have that $n_k = 0$ and $n_k^* = \frac{\sigma_k(Y+Y^*)}{f_k^*(\epsilon_k - 1)}$, while if $\tilde{p} \leq \underline{p}_k$, the whole sector is located in Home, $n_k = \frac{\sigma_k(Y+Y^*)}{f_k(\epsilon_k - 1)}$ and $n_k^* = 0$.

For intermediate relative prices of Home varieties sectoral production is split across both countries, and the relative number of home varieties is given by the following expression

$$\frac{n_k}{n_k^*} = \frac{[\sigma_k Y(\tilde{p}_k \tilde{f}_k - \tilde{p}_k^{1-\epsilon_k}(\tau_k^*)^{\epsilon_k - 1}) + \sigma_k^* Y^*(\tilde{p}_k \tilde{f}_k - \tilde{p}_k^{1-\epsilon_k}\tau_k^{1-\epsilon_k})]}{[\sigma_k^* Y^* \tilde{p}_k^{1-\epsilon_k}(\tau_k^*)^{\epsilon_k - 1}(\tilde{p}_k \tau_k^{1-\epsilon_k} - \tilde{p}_k \tilde{f}_k) - \sigma_k Y \tilde{p}_k^{1-\epsilon_k}\tau_k^{1-\epsilon_k}(\tilde{p}_k \tilde{f}_k - \tilde{p}_k^{1-\epsilon_k}(\tau_k^*)^{\epsilon_k - 1})]} \tag{69}$$

for $\tilde{p}_k \in (\underline{p}_k, \bar{p}_k)$, where

$$\underline{p}_k = \left[\frac{(\sigma_k^* Y^* + \sigma_k Y)(\tau_k^*)^{\epsilon_k - 1}\tau_k^{1-\epsilon_k}}{\sigma_k Y \tau_k^{1-\epsilon_k}\tilde{f}_k + \sigma_k^* Y^*(\tau_k^*)^{\epsilon_k - 1}\tilde{f}_k}\right]^{1/\epsilon_k} \tag{70}$$

and

$$\bar{p}_k = \left[\frac{\sigma_k^* Y^* \tau^{1-\epsilon_k} + \sigma_k Y(\tau_k^*)^{\epsilon_k - 1}}{\tilde{f}_k \sigma_k^* Y^* + \tilde{f}_k \sigma_k Y}\right]^{1/\epsilon_k}. \tag{71}$$

Defining the Home revenue share in industry k as $v_k \equiv \frac{n_k p_k x_k^s}{n_k p_k x_k^s + n_k^* p_k^* x_k^{s*}}$ we can derive that $v_k = 0$ if $\tilde{p}_k \geq \bar{p}_k$. On the other hand, v_k is given by $\frac{1}{1+(\frac{n}{n^*})^{-1}\tilde{p}^{-1}\tilde{f}^{-1}}$ if $\tilde{p}_k \in (\underline{p}_k, \bar{p}_k)$ and finally $v_k = 1$ if $\tilde{p}_k \leq \underline{p}_k$.

The model is closed by substituting the pricing condition (2.6) into $\tilde{p}$ and the expressions for v_k in the factor market clearing conditions for Home and Foreign.

$$\sum_{k=1}^{K}(1-\alpha_k)v_k\sigma_k(Y+Y^*) + (1-\alpha_{NT})\sigma_{NT}Y = wL \tag{72}$$

$$\sum_{k=1}^{K}\alpha_k v(k)\sigma_k(Y+Y^*) + \alpha_{NT}\sigma_{NT}Y = rK \tag{73}$$

$$\sum_{k=1}^{K}(1-\alpha_k)(1-v_k)\sigma_k(Y+Y^*) + (1-\alpha_{NT})\sigma_{NT}Y^* = w^*L^* \tag{74}$$

$$\sum_{k=1}^{K}\alpha_k(1-v_k)\sigma_k(Y+Y^*) + \alpha_{NT}\sigma_{NT}Y^* = r^*K^* \tag{75}$$

Here σ_{NT} is the share of expenditure spent on non-tradable goods. Normalizing one relative factor price, we can use 3 factor market clearing conditions to solve for the remaining factor prices.

One can show that the home revenue share in sector k, v_k, is decreasing in the relative price of home varieties $\tilde{p}_k$. This implies that countries have larger revenue shares in sectors in which they can produce relatively cheaply. Cost advantages may arise both because a sector uses the relatively cheap factor intensively and because of high relative sectoral productivity.

.6.1 Romalis' Model

In the special case in which sectoral productivity differences are absent, $\frac{A_k}{A_k^*} = 1$ for all $k \in K$, relative fixed costs of production are equal to one, $\tilde{f}_k = 1 \;\forall\; k \in K$, sectoral elasticities of substitution are the same in all sectors, $\epsilon_k = \epsilon$, trade costs are symmetric and identical across sectors $\tau_k = \tau_k^* = \tau$ and preferences are identical, $\sigma_k = \sigma_k^*$, the model reduces to Romalis (2004) model.

In his framework, the relative price of home varieties, $\tilde{p}_k = \frac{\left(\frac{w}{1-\alpha_k}\right)^{1-\alpha_k}\left(\frac{r}{\alpha_k}\right)^{\alpha_k}}{\left(\frac{w^*}{1-\alpha_k}\right)^{1-\alpha_k}\left(\frac{r^*}{\alpha_k}\right)^{\alpha_k}}$, is decreasing in the capital intensity, α_k, if and only if Home is relatively abundant in capital, i.e. $\frac{K}{L} > \frac{K^*}{L^*}$.

Factor prices are not equalized across countries because of transport costs, which gives Home a cost advantage in the sectors that use its abundant factor intensively. This in turn leads to a larger market share of the Home country in those sectors as consumers shift their expenditure towards the relatively cheap home varieties. This is the intuition for the Quasi-Heckscher-Ohlin prediction that countries are net exporters of those goods which use their relatively abundant factor intensively. The main advantage of this model is that it solves the production indeterminacy present in the standard Heckscher-Ohlin model with more goods than factors whenever countries are not fully specialized and that it provides a direct link between factor abundance and sectoral trade patterns. This makes it ideal for empirical applications.

.6.2 A Ricardian Model

If we make the alternative assumption that all sectors use labor as the only input, i.e. $\alpha_k = 0$ for all $k \in K$ and we order sectors according to home comparative advantage, such that $\frac{A_k}{A_k^*}$ is increasing in k, we obtain a Ricardian model. The advantage of this model is that because of love for variety, consumers are willing to buy both Home and Foreign varieties in a sector even when they do not have the same price. The setup implies that $\tilde{p}_k = \frac{w}{w^*}\frac{A_k^*}{A_k}$ is decreasing in k, so that Home offers lower relative prices in sectors with higher k. Consequently, Home captures larger market shares in sectors with larger comparative advantage since v_k is decreasing in $\tilde{p}_k$ and $\tilde{p}_k$ is decreasing in $\frac{A_k}{A_k^*}$.

.6.3 The Hybrid Ricardo-Heckscher-Ohlin Model

In the more general case comparative advantage is both due to differences in factor endowments and due to differences in sectoral productivities. Note that $\tilde{p}_k$ is given by the following expression:

$$\tilde{p}_k = \frac{\frac{1}{A_k}\left(\frac{w}{1-\alpha_k}\right)^{1-\alpha_k}\left(\frac{r}{\alpha_k}\right)^{\alpha_k}}{\frac{1}{A_k^*}\left(\frac{w^*}{1-\alpha_k}\right)^{1-\alpha_k}\left(\frac{r^*}{\alpha_k}\right)^{\alpha_k}} \tag{76}$$

Assume again that Home is relatively capital abundant, $\frac{K}{L} > \frac{K^*}{L^*}$. Then, conditional on $\frac{w}{r}, \frac{w^*}{r^*}$, Home has lower prices and a larger market share in sectors where $\frac{A_k}{A_k^*}$ is larger. In addition, factor prices depend negatively on endowments unless the productivity advantages are systematically much larger in sectors that use the abundant factor intensively. A very high relative productivity in the capital intensive sectors can increase demand for capital so much that $\frac{w}{r} < \frac{w^*}{r^*}$ even though $\frac{K}{L} > \frac{K^*}{L^*}$. As long as this is not the case, locally abundant factors are relatively cheap and - holding constant productivity differences - this increases market shares in sectors that use the abundant factor intensively.

The model is illustrated in figure 8. In this example, $\epsilon_k = 4$, Home is relatively capital abundant, $\frac{K/L}{K^*/L^*} = 4$, and transport costs are high, $\tau_k = \tau_k^* = 2$. The panels of figure 8 plot Homes' relative productivity, Homes' sectoral revenue share, Homes' relative prices, as well as Homes' net exports, Homes' exports relative to production and Homes' imports relative to production against the capital intensity of the sectors, which is ordered on the zero-one interval. In the first case (solid lines) there are no productivity differences between Home and Foreign. Because Home is capital abundant it has lower rentals and higher wages which leads to lower prices and larger revenue shares in capital intensive sectors. In addition, Home is a net importer in labor intensive sectors and a net exporter in capital intensive ones and its exports relative to production are larger in capital intensive sectors, while its imports relative to production are much larger in labor intensive sectors. This illustrates neatly the Quasi-Heckscher-Ohlin prediction of the model.

In the second case (dashed lines) - besides being more capital abundant - Home also has systematically higher productivities in more capital intensive sectors. This increases home comparative advantage in capital intensive sectors even further. The consequence of higher productivity is an increased demand for both factors that increases home factor prices and makes home even less competitive in labor abundant sectors, while the relative price in capital abundant sectors is lower than without productivity differences. The result is a higher revenue share in capital intensive sectors and more extreme import and export patterns than without productivity differences.

Figure 9 is an example of the Quasi-Rybczynski effect. Initially both Home and Foreign have the same endowments, $\frac{K/L}{K^*/L^*} = 1$, and Home has a systematically higher productivity than Foreign in capital intensive sectors (solid lines), which explains Homes' larger market share in those sectors. In the case with the dashed lines Home has doubled its capital stock, so that now $\frac{K/L}{K^*/L^*} = 2$. This leads to an expansion of production and revenue shares in the capital intensive sectors and a decline of production in the labor intensive sectors. The additional capital is absorbed both through more capital intensive production and an expansion of production in capital intensive sectors. The increased demand for labor in those sectors drives up wages and makes Home less competitive in labor intensive sectors.

Summing up, the general prediction of the Hybrid-Ricardo-Heckscher-Ohlin model is that exporting countries capture larger market shares in sectors in which their abundant factors are used intensively (Quasi-Heckscher-Ohlin prediction) and in which they have high productivities relative to the rest of the world (Quasi-Ricardian prediction). In addition, the model has a Quasi-Rybczynski effect. Holding productivities constant, factor accumulation leads to an increase in revenue shares in sectors that use the factor intensively and a decrease in those sectors that use little the factor.

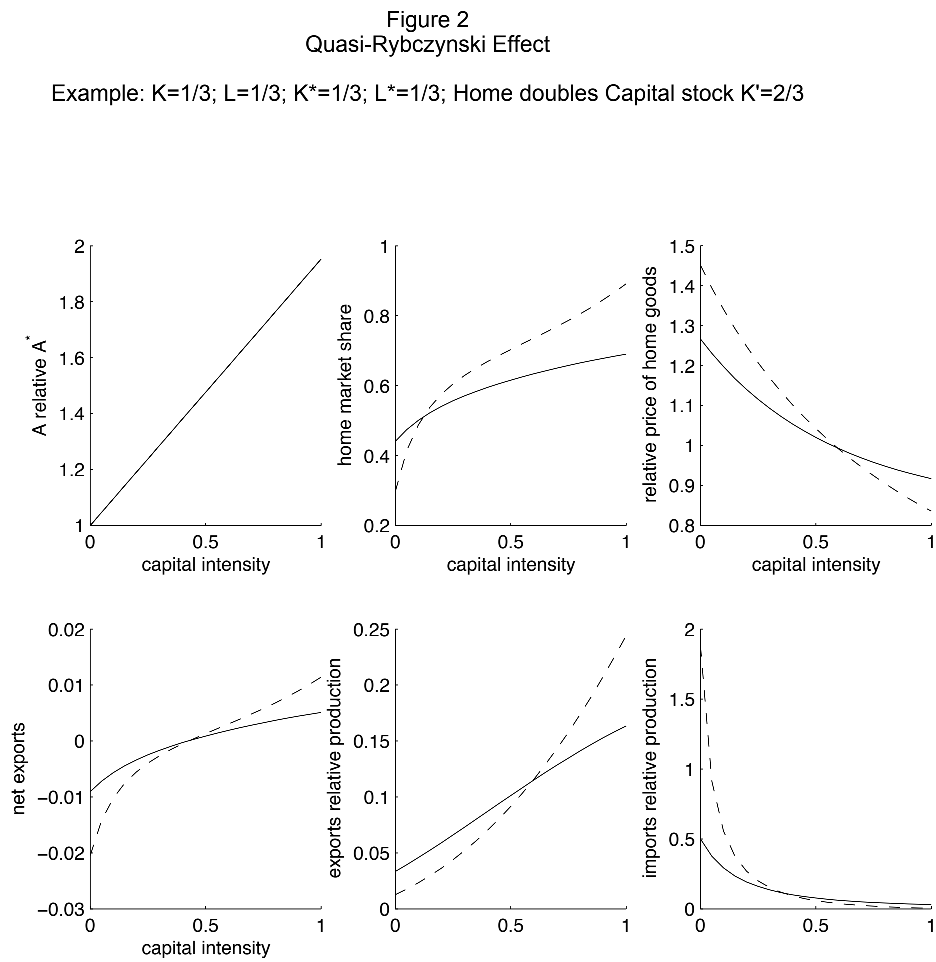


Figure 8: Quasi-Rybczynski effect

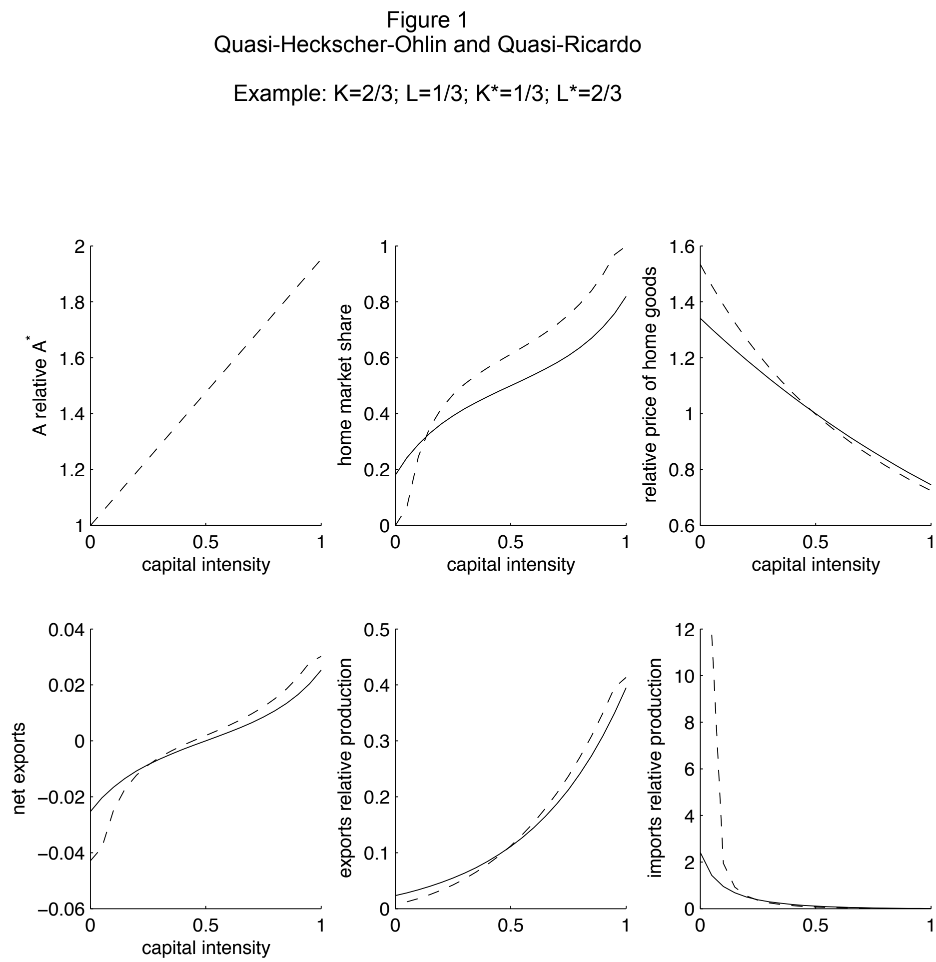


Figure 9: Quasi-Heckscher-Ohlin and Quasi-Ricardo effects

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