Skill premium and trade puzzles: A solution linking production factors and demand

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Abstract

International trade theory is a general-equilibrium discipline, yet most of the standard portfolio of research focuses on the production side of general equilibrium. In addition, we do not have a good understanding of the relationship between characteristics of goods in production and characteristics of preferences. This paper conducts an empirical investigation into the relationship between a good's factor intensity in production and its income elasticity of demand in consumption. In particular, we find a strong and significant positive relationship between skilled-labor intensity in production and income-elasticity of demand for several types of preferences, with and without accounting for trade costs and differences in prices. Counter-factual simulations yield a number of results. We can explain one third or more of "missing trade", and show an important role for per-capita income in understanding trade/GDP ratios, the choice of trading partners, and the composition of trade. Furthermore, an equal rise in productivity in all sectors in all countries leads to a rising skill premium in all countries, with particularly large increases in developing countries.

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JEL Classification: F10, O10, F16, J31.

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1 Introduction

International trade theory is a general-equilibrium discipline. Yet it is probably fair to suggest that most of the standard portfolio of research focuses on the production side of general equilibrium. Price elasticities of demand do play a role in oligopoly models and, of course, a preference for diversity is important in all models, not just monopolistic competition. Income elasticities of demand are, however, generally assumed to be either one (homothetic preferences) or zero (so-called quasi-homothetic preferences used in oligopoly models). The emphasis on non-homothetic preferences and the role of non-unitary income elasticities of demand that were so crucial in the work of Linder (1961) for example, largely disappeared from trade theory over the last few decades.

Beyond a lack of focus on the demand side of general equilibrium, we have sharply limited set of theoretical and empirical results on possible relationships between the demand and supply sides of general equilibrium; that is, not much is understood about whether certain characteristics of goods in production are correlated with other characteristics of preferences and demand. The purpose and focus of our paper is to explore such a relationship empirically. In particular, we explore a systematic relationship between factor intensities of goods in production and their corresponding income elasticities of demand in consumption. If such a relationship does exist, this can contribute to understanding a number of empirical puzzles in trade as discussed by Markusen (2011). These puzzles include: i) the mystery of the missing trade, ii) a home bias in consumption, iii) larger trade volumes among rich countries, and iv) a growing skill premium with rising per-capita income.

We provide a discussion of alternative representations of non-homothetic preferences and equations for the share of total expenditures across goods: (1) the linear expenditure system, derived from Stone-Geary preferences, (2) Deaton and Muellbauer's almost ideal demand system (AIDS), and (3) what we will term "constant relative income elasticity" (CRIE) preferences, recently used in Fieler (2011). While we present estimated income elasticities for all three, we focus on the latter in the presentation of our benchmark model. We carefully control for supply-side effects, which could potentially bias estimates of income elasticities. If rich countries tend to have a comparative advantage in particular industries, consumption in these industries might be larger (goods available at lower prices) and estimates of income elasticities in these industries might be upward-biased if we do not control for such patterns of comparative advantage. We provide a two-step estimation strategy by first estimating gravity equation in each industry and then use estimated parameters to structurally control for supply-side effects in a second step.[1] While the estimation of models with non-homothetic preferences has been

[1] As a robustness check, we additionally control for actual prices using data from the International Comparison

considered as challenging in the past, our method is actually quite simple to implement.[2]

Our data is from the GTAP7 data set. It comprises 94 countries with a wide range of income levels, 56 broad sectors including manufacturing and services, and 5 factors of production: skilled labor, unskilled labor, capital, land, and other natural resources. This is an excellent harmonized data set for our purposes, since it includes production, expenditure and trade data, and input-output tables. However, the broad categories of goods and services make it not very suitable for discussing issues related to product quality and within-industry heterogeneity.

Our results show that the income elasticity of demand varies largely across industries. Moreover, income elasticities of demand are significantly related in both economic and statistical terms to the skill intensity of a sector, with a correlation over 50%. Controlling for supply reduces this estimated correlation which remains at about 40% and highly statistically significant. The relationship to capital intensity is positive but much weaker in economic terms and not statistically significant, consistent with Reimer and Hertel (2010), while the relationship to natural-resource intensity is negative.

The results of the estimation are then used to assess the role of non-homotheticity in explaining emrpirical trade puzzles mentioned above and examine counter-factuals on simulations of the estimated general-equilibrium system of equations and inequality. In addition to the income-elasticity / factor-intensity relationship, results include the following.

First, we can explain at least one third of the "missing trade" puzzle in Heckscher-Ohlin framework. A systematic relationship between income elasticity of demand and skill intensity in production generates a strong correlation between consumption patterns and specialization in production. The correlation between supply and demand is 77% in the data. While trade cost can explain about a third of this correlation, non-homotheticity are as much as important quantitatively. In terms of factor content, similar results show that non-homothetic preferences can explain a large fraction of "missing trade".

Second, per-capita income helps us understand the choice of trading partners, in particular the higher share of rich countries' trade with rich-country partners (an important focus in Fieler, 2011). In our framework, per-capita income contributes to understanding the composition of consumption across industries which itself has large effects on trade. On aggregate, we show a role for per-capita income in understanding observed trade-to-GDP ratios.

Finally, we conduct a general-equilibrium simulation in which we raise the productivity of all countries by 1% and 10%. As speculated on in Markusen (2011), this shifts demand toward

Program (ICP).

[2]Moreover, a similar (if not the same) structural empirical implementation could be derived from alternative models. Our model is based on Eaton and Kortum (2002) combined with non-homothetic preferences such as in Fieler (2011), but a similar method to estimate price indices can be derived from Dixit-Stiglitz-Krugman trade model such as the "supplier access" variable in Redding and Venables (2004).

higher income-elasticity goods, which are on average skilled-labor intensity. The counter-factual generates rising skill premium (wage inequality) in all countries, but particularly in developing countries.

Literature

Early papers exploring the factor-intensity / income-elasticity relationship are Markusen (1986), Hunter and Markusen (1989), Hunter (1991), and Bergstrand (1990). A particular focus of this literature is on the volume of trade in aggregate and among sets of countries, and its relationship to a world of identical and homothetic preferences as generally assumed in traditional trade theory. A general conclusion of this research was that non-homotheticity reduces trade volumes among countries with different endowments and per-capita income levels, though trade among high-income countries can increase. Matsuyama (2000) uses a competitive Ricardian model to arrive at a similar prediction.

There has been a renewed interest in the role of preferences in explaining trade volumes recently, including Reimer and Hertel (2010), Fieler (2011), Bernasconi (2009), Martinez-Larzoso and Vollmer (2010), Simonovska (2010), and Cassing and Nishioka (2011).

Previous papers have emphasized the role of consumption patterns in explaining part of the "missing trade" puzzle but our results present several contributions. In a recent paper, Cassing and Nishioka (2011) show that allowing for richer consumption patterns play a more important role than allowing for heterogeneous production technics. They do not however specifically estimate non-homothetic preferences to examine how much of the missing trade puzzle can actually be attributed to non-homotheticity. Both Cassing and Nishioka (2010) and Reimer and Hertel (2010) put an emphasis on capital intensity, which is positively but not strongly correlated with income elasticity of demand, but do not differentiate skilled vs. unskilled labor and thus underestimate the role of identical and non-homothetic preferences in explaining missing factor content trade.[3]

Closest to our paper is Fieler (2011). She estimates demand and supply side characteristics by combining a similar preference structure and gravity equations. However, she only uses aggregate trade flows between countries in her estimation and does not examine patterns of consumption and trade across industries. Moreover, her model relies on the assumption that countries with higher average productivity have a comparative advantage in the production of goods that can be easily traded (low-theta goods). On the contrary, our estimation strat-

[3]Among other papers, most of the attention has been put on the home bias or the border effect (e.g. Trefler, 1995). Here, we directly estimate the border effect, or equivalently a home bias in consumption, in the first-step gravity equation for each industry and control for it to compare homothetic and non-homothetic preferences.

egy allows and controls for any pattern of comparative advantage.[4] After estimating gravity equations by industry, we find that income elasticities are not significantly correlated with industry-specific trade cost coefficients, but we do find significant relationships between income elasticities and patterns of comparative advantage of rich countries.

To our knowledge, our paper is the first to investigate a demand-side explanation for the rising skill-premium. Previous research has emphasized the role of skill-biased technological change (Autor et al, 1998), outsourcing and competition from low-wage countries (Feenstra and Hanson, 1999). We find that, quantitatively, productivity growth combined with non-homothetic preferences has a comparable if not larger impact on the relative demand for skilled labor.

There are also certainly some topic areas where per-capita income plays a key role. One is a large and growing literature on product quality where per-capita income clearly matters: if a consumer is to buy one unit of a good, consumers with higher incomes buy higher quality goods. In addition, the distribution of income within a country matters, and a fairly general result is that higher inequality leads to a higher aggregate demand for high-quality products. We view this literature as important and most welcome. Note that within-industry reallocations would only reinforce the mechanisms described in our model. If high-quality goods are associated with both higher income elasticities and stronger skill intensity, the same mechanisms would apply for within-industry reallocations as for the between-industry reallocations described in our paper. Concerning within-country inequalities, we find very similar results – if not stronger – when taking into account and using data on different deciles and quintiles of within-country income distributions.

2 Theoretical framework

2.1 Model set-up

Demand

There are several industries, indexed by k. Each industry corresponds to a continuum of product varieties indexed by $j_k \in [0,1]$. Preferences take the form:

$$U = \sum_k \alpha_{1,k} Q_k^{\frac{\sigma_k - 1}{\sigma_k}}$$

[4]See footnote 3 in Section 2.1 of our paper for more details.

where $\alpha_{1,k}$ is a constant (for each industry k) and Q_k is a CES aggregate:

$$Q_k = \left(\int_{j_k=0}^{1} q(j_k)^{\frac{\eta_k - 1}{\eta_k}} dj_k\right)^{\frac{\eta_k}{\eta_k - 1}}$$

Preferences are identical across countries, but non-homothetic as long as σ_k varies across industries. Homotheticity requires $\sigma_k = \sigma$ in which case we are back to traditional CES preferences.

These preferences are used in Fieler (2011), with early analyses and applications found in Hanoch (1975) and Chao et al (1982). To the best of our knowledge, there is no common name attached to these preferences, so we will refer to them as constant relative income elasticity (CRIE) tastes. As shown in Fieler (2011) and below, the ratio of income elasticities of demand between sectors i and j is given by σ_i/σ_j, which is constant.

A key difference with Fieler (2010) is in the terminology. While her elasticity of substitution (σ_τ) vary according to the "type" of good τ, our elasticities vary depending on the industry k. This difference is motivated by out empirical objectives. Fieler (2010) uses aggregate data while we examine disaggregated trade and expenditure data by industry. Since we are interested in differences in income elasticities across sectors, we treat instead each "type" as a sector. Instead of τ we denote sectors by k.

Another small difference is that Fieler (2010) implicitly assumes that σ_k is equal to the elasticity of substitution η_k between varieties of the same sector, but this restriction is not needed here.

The CES price index of goods from industry k in country n is $P_{nk} = \left(\int_0^1 p_{nk}(j_k)^{1-\eta_k} dj_k\right)^{\frac{1}{1-\eta_k}}$ Given this price index, individual expenditures ($P_{nk}Q_{nk}$) in country n for goods in industry k equal:

$$x_{nk} = \lambda_n^{-\sigma_k} \alpha_{2,k} (P_{nk})^{1-\sigma_k} \tag{1}$$

where λ_n is the lagrangian associated with the budget countraint of individuals in country n, and $\alpha_{2,k} = (\alpha_{1,k}\frac{\sigma_k - 1}{\sigma_k})^{\sigma_k}$. The lagrangian λ_n is determined by the budget constraint: total expenses must equal total income. In general there is no analytical expression for λ_n.

The income elasticity of demand for goods industry k in country n equals:

$$\varepsilon_{nk} = \sigma_k \cdot \frac{\sum_{k'} x_{nk'}}{\sum_{k'} \sigma_{k'} x_{nk'}} \tag{2}$$

In particular, income elasticity for good 1 relative to income elasticity for good 2 equals the ratio $\frac{\sigma_1}{\sigma_2}$ and is constant across countries. Note that CRIE preferences precludes any inferior good: the income elasticity of demand is always positive for any good.

Another important feature of income elasticities is that they decrease with income. A larger income induces a larger fraction of expenditures in high-σ_k industries, Hence, the consumption-weighted average of σ_k is larger (denominator in expression 2 above) which yields lower income elasticities.

Production

We assume that factors of production are perfectly mobile across sectors but immobile across countries. We denote by w_{fn} the price of factor f in country n.

We assume a Cobb-Douglas production function for each sector with constant return to scale. Factor intensities are denoted by β_{fk} and vary across industries but are supposed to be common across countries. Total factor productivity $z_{ik}(j_k)$ varies by country, industry and variety.

As common in the trade literature, we assume iceberg transport costs $d_{nik} > 1$ from country i to country n in sector k. The unit cost of supplying variety j_k to country n from country i equals:

$$p_{nik}(j_k) = \frac{d_{nik}}{z_{ik}(j_k)} \prod_f (w_{fi})^{\beta_{fk}}$$

There is perfect competition for the supply of each variety j_k. Hence, the price of variety j_k in country n in industry k equals:

$$p_{nk}(j_k) = \min_i \{p_{nik}(j_k)\}$$

We follow Eaton and Kortum (2002) and related papers and assume that productivity is a random variable with a Frechet distribution. This setting generates gravity within each sector. Productivity is independently drawn in each country i and industry k, with a cumulative distribution:

$$F_{ik}(z) = \exp\left[-(z/z_{ik})^{-\theta_k}\right]$$

where z_{ik} is a productivity shifter reflecting average TFP of country i in sector k. As in Eaton and Kortum (2002), θ_k is related to the inverse of productivity dispersion across varieties within each sector k. Note that we also assume $\theta_k > \eta_k - 1$ to insure a well-defined CES price index within each industry (Eaton and Kortum, 2002).

We allow the dispersion parameter θ_k to vary across industries (in Fieler, 2010, it varies across types). In keeping with Costinot, Donaldson and Komunjer (2010), we also allow the shift parameter z_{ik} to vary across exporters and industries. This relax one key assumption made by Fieler (2010) that $z_{ik}^{\theta_k}$ is constant across industries. This allows us more flexibility on the supply side and control for Ricardian comparative advantage forces.[5]

Endowments

Each country is populated by a number L_i of individuals. The total supply of factor f is fixed in each country and denoted by F_{if}.

As a first approximation, each person is endowed by F_{if}/L_i units of factor F_{fi}. This implies that there is no within-country income inequality. We relax this assumption in section (5.4) and examine how within-country income inequalities affect our estimates.

2.2 Equilibrium

A list of notations and variables is available in the appendix.

Equilibrium is defined by the following equations. On the demand side, total expenditures X_{nk} of country n for sector k simply equals population L_n times individual expenditures as shown in (1). This gives:

$$X_{nk} = L_n(\lambda_n)^{-\sigma_k}\alpha_{2,k}(P_{nk})^{1-\sigma_k} \tag{3}$$

where λ_n is the lagrangian associated with the budget constraint. To determine λ_n, we thus need to take the budget constraint into account:

$$L_n e_n = \sum_k X_{nk} \tag{4}$$

On the supply side, each industry mimics an Eaton and Kortum (2002) economy. In particular, given the Frechet distribution, we obtain a gravity equation for each industry. We folllow Eaton and Kortum (2002) notations, with the addition of industry subscripts. By denoting X_{nik} the value of trade *from* country i *to* country n, we obtain a gravity equation:

$$X_{nik} = \frac{S_{ik}(d_{nik})^{-\theta_k}}{\Phi_{nk}} X_{nk} \tag{5}$$

Here, S_{ik}, which we call the "supplier fixed effect" is inversely related to the cost of production in country i and industry k. It depends on the total factor productivity parameter z_{ik}, factor prices and factor intensities:

[5] By assuming that $T_i = z_{ik}^{\theta_k}$ is constant across industries in each country i, Fieler (2010) imposes more productive countries to have a comparative advantage in the production of high-θ goods. In other words, since θ governs the elasticity of trade to trade costs, Fieler (2010) thus imposes rich countries to have a comparative advantage in goods that can be more easily traded. We do not rely on this assumption in this paper.

$$S_{ik} = z_{ik}^{\theta_k} \left(\prod_f (w_{fi})^{\beta_{fk}} \right)^{-\theta_k} \tag{6}$$

As in Fieler (2010), the parameter θ_k is inversely related to the dispersion of productivity within sectors ("types" in Fieler, 2010), which means that differences in productivity and factor prices across countries have a stronger impact on trade flows in sectors with higher θ_k. In turn, we define Φ_{nk} as the sum of exporter fixed effects deflated by trade costs. Φ_{nk} plays the same role as the "multilateral trade resistance index" as in Andersen and Van Wincoop (2003):

$$\Phi_{nk} = \sum_i S_{ik}(d_{nik})^{-\theta_k} \tag{7}$$

The Φ_{nk} is actually cosely related to the price index, as in Eaton and Kortum (2002). We have:

$$P_{nk} = \alpha_{3,k}(\Phi_{nk})^{-\frac{1}{\theta_k}} \tag{8}$$

and $\alpha_{3,k} = \left[\Gamma\left(\frac{\theta_k+1-\eta_k}{\theta_k}\right)\right]^{\frac{1}{\eta_k-1}}$ (Γ denotes the gamma function)

Finally, two other market clearing conditions are required to pin down factor prices and income. Given the Cobb-Douglas production function, total income from a particular factor equals the sum of total production weighted by this factor intensity coefficient β_{fk}. With factor supply F_{fi} and factor price w_{fi} for factor f in country i,factor market clearing implies:

$$F_{fi}w_{fi} = \sum_{n,k} \beta_{fk} X_{nik} \tag{9}$$

In turn, per-capita income is determined by:

$$L_i e_i = \sum_f F_{fi} w_{fi} \tag{10}$$

By Walras' Law, trade is balanced at equilibrium.

2.3 Implications: the role of non-homothetic preferences

2.3.1 Trade patterns

While preferences are identical across countries, large differences in income per capita can result in large differences in consumption patterns when preferences are non-homothetic. In this section, we illustrate how non-homotheticity affects trade patterns when there is a systematic relationship between preference parameters and characteristics of the supply side, e.g. intensity in skilled labor. This is supported by our empirical analysis, showing in particular that there is a positive correlation across sectors between skill intensity (parameter β_{fk}) and income elasticity (proportional to σ_k).

Let's first consider the case with no trade cost (assuming $d_{nik} = 1$). In this case, the share of consumption corresponding to imports from i in industry k is the same for all importers (country n): $\frac{X_{nik}}{X_{nk}} = \frac{S_{ik}}{\sum_j S_{jk}}$. Moreover, prices are the same in all countries when there is no trade cost. Summing over all industries, total import penetration by country i in country n is:

$$\frac{X_{ni}}{X_n} = \sum_k \left(\frac{S_{ik}}{\sum_j S_{jk}}\right)\left(\frac{\alpha_{4,k}\lambda_n^{-\sigma_k}}{\sum_{k'} \alpha_{4,k'}\lambda_n^{-\sigma_{k'}}}\right) \tag{11}$$

where $X_n = L_n e_n$ is total expenditures in country n, $X_{ni} = \sum_k X_{nik}$ is total bilateral trade from country i to n, and $\alpha_{4,k}$ is an industry constant incorporating common prices. The first term in parentheses is the share of imports from i in consumption of k – in other words this term reflects the comparative advantage of country i in sector k. The second is the share of industry k in final consumption of country n.

Aggregate import penetration by country i in country n obviously depends on industry composition of both supply and demand, but the latter has generally been neglected by previous work. If preferences are homothetic, $\sigma_k = \sigma$ is common across industries and we obtain that import penetration is the same across all importers n (for a given exporter i). When preferences are non-homothetic and σ_k varies across industries, exporters with a comparative advantage in high-σ industries have a relatively larger penetration in rich countries (low λ_n), while exporters with a comparative advantage in low-σ industries have a relatively larger penetration in poor countries (high λ_n). As we will show empirically, rich countries are those that have a comparative advantage in high-σ industries and that it can quantitatively explain large differences in trade volumes across country pairs depending on each partner's income.

Note that trade costs can potentially provide an alternative expanation of why import penetration varies across markets. On the supply side, proximity reduces unit costs. On the demand side, consumption might be biased towards goods produced locally if their price is lower (e.g. Saudi Arabia consuming more petroleum). The latter argument requires that the elasticity of substitution be larger than one. These effects of trade costs reinforce the patterns described above. In our framework, a general expression for import penetration of exporter i in market n yields:

$$\frac{X_{ni}}{X_n} = \sum_k \left(\frac{S_{ik} d_{nik}^{-\theta_k}}{\Phi_{nk}}\right)\left(\frac{\alpha_{5,k}\lambda_n^{-\sigma_k}\Phi_{nk}^{\frac{\sigma_k-1}{\theta_k}}}{\sum_{k'} \alpha_{5,k'}\lambda_n^{-\sigma_{k'}}\Phi_{nk'}^{\frac{\sigma_{k'}-1}{\theta_{k'}}}}\right) \tag{12}$$

where $\Phi_{nk} = \sum_j S_{jk} d_{njk}^{-\theta_k}$ by definition (equation 7) and $\alpha_{5,k} = \alpha_{2,k}\alpha_{3,k}^{1-\sigma_k}$ is an industry constant.

In the empirical section, we thus need to carefully examine the distinct contribution of trade costs and non-homotheticity.

2.3.2 Missing factor content of trade

One reason why comparative advantage may be related to consumption patterns is that the income elasticity of demand is correlated with the intensity in skillled labor. Such a correlation can also shed light on the "missing trade" puzzle, as we describe now.

Standard Heckscher-Ohlin models assume homothetic preferences. This assumption implies that, under free trade, consumption shares over different industries are the same across all countries. We show in this section that accounting for non-homothetic preferences can yield very different predictions in terms of factor content of trade. In particular, it can potentially explain why poor countries trade so little with rich countries even if their endowments differ largely. The intuition is simple. When the income elasticity of demand is correlated with skill intensity, consumption by rich countries is biased towards skill-intensive industries. If richer countries have larger endowments in skilled labor relative to unskilled labor, it implies that rich countries have stronger taste for goods that are more likely to be produced by rich countries. A similar intuition applies to capital if the income elasticity of demand is correlated with capital intensity and if richer countries are relatively more endowed in capital.

These intuitions can be simply illustrated in our framework. We define factor content of trade T_{fn} as the *value* of factor f required to produce exports minus imports: $T_{fn} = \sum_k \beta_{fk} \Big(\sum_{i \neq n} X_{nik} - \sum_{i \neq n} X_{ink} \Big)$. After simple reformulations, we can decompose T_{fn} in two terms:

$$
\begin{aligned}
T_{fn} &= \underbrace{s_n \sum_k \bar{Y}_k \beta_{fk} \left[\frac{Y_{nk}}{s_n \bar{Y}_k} - 1 \right]}_{T_{fn}^{HOV}} - \underbrace{s_n \sum_k \bar{Y}_k \beta_{fk} \left[\frac{X_{nk}}{s_n \bar{Y}_k} - 1 \right]}_{T_{fn}^{CB}} && (13) \\
&= \qquad T_{fn}^{HOV} \qquad - \qquad T_{fn}^{CB} && (14)
\end{aligned}
$$

where $Y_{nk} = \sum_i X_{ink}$ denotes the value of production of country n in sector k, $\bar{Y}_k = \sum_n Y_{nk}$ denotes the value of world's production in sector k, and s_n denotes the share of country n in world's GDP. Note that we define factor content in terms of factor reward instead of quantities (number of workers or machines).[6]

[6] Standard HOV estimation assumes factor price equalization. Under this assumption, both approaches are equivalent. When FPE is violated, for instance when factor productivity differ across countries, predicted factor content has to be adjusted for such differences if written in terms of factor units (e.g. number of workers of machines). No adjustment is necessary if we focus on values, i.e. factor supply times factor prices. This approach greatly simplifies the exposition of the main intuitions and better illustrate the contribution of non-homothetic preferences compared to homothetic preferences without providing too much details on factor prices.

In the bracket terms, the ratio $\frac{X_{nk}}{s_n Y_k}$ equals the share of consumption for k in country n relative to the share of consumption for k in the world. The ratio $\frac{Y_{nk}}{s_n Y_k}$ equals the share of production in sector k in country n relative to the share of production in sector k in the world. Homothetic preferences and free trade would imply that the second term in brackets is null: $\frac{X_{nk}}{s_n Y_k} - 1 = 0$. Hence, when preferences are homothetic, the expression above can be simplified and yields:

$$T_{fn} = T_{fn}^{HOV} = w_{fn} F_{fn} - s_n \sum_i w_{fi} F_{fi} \tag{15}$$

Under factor price equalization, w_{fn} is the same across countries, and the above expression corresponds to the standard prediction of factor content trade in the Heckscher-Ohlin-Vanek model. This equations states that the content of factor f in exports of a country n should equal the total value of the supply of factor f in this country minus the value of the world's supply of this factor adjusted by the share s_n of country n in world GDP.

Equation (15) is violated when preferences are not homothetic and $\frac{X_{nk}}{s_n Y_k} - 1$ differs from zero. Equation (15) needs to be corrected by a consumption term T_{fn}^{CB} (where "CB" stands for consumption bias). In particular, if relative consumption $\frac{X_{nk}}{s_n Y_k}$ is positively correlated with production $\frac{Y_{nk}}{s_n Y_k}$, then T_{fn}^{CB} is correlted with T_{fn}^{HOV} and predicted factor trade is smaller. It can explain why trade in factor content is smaller than predicted by models with homothetic preferences. In the empirical section, we verify that these two terms $\frac{X_{nk}}{s_n Y_k}$ and $\frac{Y_{nk}}{s_n Y_k}$ are indeed strongly corrrelated across countries and industries and that T_{fn}^{CB} is correlated with T_{fn}^{HOV} across countries and factors.

The consumption bias in the extended predicted factor content of trade expression above can be reexpressed as:

$$T_{fn}^{CB} = \sum_k \beta_{fk} X_{nk} - s_n \sum_k \beta_{fk} \bar{Y}_k \tag{16}$$

where the right-hand-side reflects a difference between the factor content of country n's consumption and the average world's consumption. For skilled labor, we show in the empirical section that T_{fn}^{CB} is strongly correlated with income.

Again, trade costs might also explain similar correlations between supply and demand, across industries and in terms of factor content. In the empirical section, we disentangle the effect of each (trade costs vs. fitted non-homothetic demand) and show that non-homotheticity plays an important role.

2.3.3 Skill premium

The correlation betwen skill intensity and income elasticity not only affects trade patterns and trade volumes, but also has important implications for the skill premium. In particular, it can generates a positive effect of productivity growth on the skill premium. The intuition is simple. As productivity increases, people become richer, they consume more goods from income-elastic industries which, as we show, are more intensive in skilled labor.[7] This yields an increase in the demand for skilled labor relative to unskilled labor and thus increases the relative wage of skilled workers.

On the contrary, with homothetic preferences, uniform productivity growth across countries is neutral in terms of skill premium (and trade patterns). Also note that international trade is not key here. The same effect still holds in a closed economy. For a closed economy, with only skilled and unskilled labor, we can derive the elasticity of the skill premium sp_n (wage of skilled workers divided by the wage of unskilled workers) to TFP increase $d\log z_n$:

$$\frac{d\log sp_n}{d\log z_n} = \frac{1}{1+\xi_n}\sum_k (sh^H_{nk} - sh^L_{nk})\varepsilon_{nk} \tag{17}$$

where ε_{nk} is the income elasticity in sector k, country n, and $sh^H_{nk} \equiv \frac{\beta_{Hk}X_{nk}}{\sum_{k'}\beta_{Hk'}X_{nk'}}$ is the share of sector k in the total employed of skilled labor in country n (and sh^L_{nk} refers to to the share of unskilled workers in sector k), and ξ_n is defined in the appendix.

We can see that this term is positive if income elasticity ε_{nk} is correlated with the demand for skilled labor vs. unskilled labor (term in $sh^H_{nk} - sh^L_{nk}$). Hence TFP growths generates a growth of the skill premium.

The term ξ_n reflects a feedback effect of the skill premium increase on the composition of consumption. When the skill premium increases, the relative price of skill-intensive goods increases, the relative demand for skill intensive goods tends to decrease and thus the relative demand for skilled workers tends to decrease. We can expect this feedback to be small compared to the direct effect and: $\xi_n \approx 0$. This provides an approximation of the elasticity of skill premium to technology:

$$\frac{d\log sp_n}{d\log z_n} \approx \sum_k (sh^H_{nk} - sh^L_{nk})\varepsilon_{nk} \tag{18}$$

Generally, this equation also provides a good approximation of the skill premium increase even if skilled and unskilled labor are not the only factors of production. We will show later how this approximation compared to simulated skill premium increases as a response to a TFP increase.

In this expression, the effect of technology on the skill premium is larger for larger income elasticities (*ceteris paribus*). As income elasticities decrease with income (or productivity), we might expect this expression to yield smaller values for richer countries.

[7]Assuming that the evolution of income is not driven by an accumulation of skills, which can of course mitigate the increase in the skill premium.

Although income elasticities are larger for poorer countries, the expression above does not necessarily decrease with income. The second derivative of expression (18) w.r.t to productivity is:

$$\frac{d^2 \log sp_n}{d \log z_n^2} \approx -\frac{\sum_k x_{nk}(\varepsilon_{nk}-1)^2}{\sum_k x_{nk}} + \frac{\sum_k (sh^H_{nk} - sh^L_{nk})\varepsilon^2_{nk}}{\sum_k (sh^H_{nk} - sh^L_{nk})\varepsilon_{nk}} - \sum_k (sh^H_{nk}+sh^L_{nk})\varepsilon_{nk} \tag{19}$$

The first term corresponds to the decrease in income elasticity with income (which is referred to as the "within" effect in Section 4.3), whereas the other two terms corresponds to changes in the weights $sh^H_{nk} - sh^L_{nk}$ ("between" effect). The between effect is negative if there is more scope for reallocation of skilled workers than unskilled workers across sectors.[8]

3 Estimation

The goal of this section is two-fold. We first estimate income elasticities of demand and then test for positive correlation between income elasticity and skill intensity.

3.1 Estimation of income elasticities: identification

Demand by industry (in value) is determined as in Equation (3) or equivalently Equation (1) for individual expenditures. In log, this gives:

$$\log x_{nk} = -\sigma_k . \log \lambda_n + \log \alpha_{2,k} + (1-\sigma_k). \log P_{nk} \tag{20}$$

where $\alpha_{2,k}$ is a preference parameter to be considered as an industry fixed effect. In addition, demand should satisfy the budget constraint, which pins down λ_n. The larger is income, the smaller is λ_n.

If there is no trade cost ($d_{nik} = 1$), the price index P_{nk} is the same across countries and cannot be distinguished from an industry fixed effect. If richer countries' consumption is larger in a particular sector relative to other sectors, this sector can be associated with a larger elasticity σ_k.

When trade is not free ($d_{nik} > 1$), the price index P_{nk} plays a key role in controlling for supply-side effects. As richer countries have a comparative advantage in skill intensive industries, the price index is relatively lower in these industries. Conversely, poor countries have a

[8]Formally, the between effect is negative if and only if the variance of income elasticity weighted by skilled labor is larger than the variance of income elasticity weighted by unskilled labor:

$$\sum_k sh^H_{nk}\big(\varepsilon_{nk} - \sum_{k'} sh^H_{nk'}\varepsilon_{nk'}\big)^2 > \sum_k sh^L_{nk}\big(\varepsilon_{nk} - \sum_{k'} sh^L_{nk'}\varepsilon_{nk'}\big)^2$$

comparative advantage in unskilled labor intensive industries and thus have a lower price index in these industries relative to other industires. As the elasticity of substitution between industries is larger than one, these differences in price indices in turn affect consumption patterns. If we do not control for P_{nk}, we might conclude by mistake that skill intensive sector have larger income elasticity.

Hence we put a particular care into correcting for supply-side effects through P_{nk}. We proceed in two steps. The main goal of the first step is to obtain a proxy for $\log P_{nk}$. According to the equilibrium condition (8) on the price index, $\log P_{nk}$ depends linearly on $\log \Phi_{nk}$ which can be identified using gravity equations. Then, with an estimate of the price index (or equivalently Φ_{nk}), we can estimate the demand equation (20) above.

As a robustness check, we estimate the demand equation using actual price data instead or in addition to using $\log \Phi_{nk}$ (Section 5).

Step 1: Gravity equation estimation and identification of Φ_{nk}

By taking the log of trade flows in Equation (5), we get:

$$\log X_{nik} = \log S_{ik} - \theta_k \log d_{nik} + \log X_{nk} - \log \Phi_{nk}$$

We estimate this equation by including importer and exporter fixed effects and approximating transport costs d_{nik} by a series of variables. We do not have data on transport costs by industry and country pairs. We specify that transport costs depend on physical distance, border effect, common language, colonial link and contiguity, as usual in the gravity equation literature:

$$\begin{aligned} \log d_{nik} \;&=\; \delta_{Dist,k} \log Dist_{ni} \;-\; \delta_{Contig,k}.Contiguity_{ni} \;-\; \delta_{Lang,k}.CommonLang_{ni} \\ &\quad -\; \delta_{Colony,k}.ColonialLink_{ni} \;-\; \delta_{HomeBias,k}.I_{n=i} \end{aligned}$$

Parameters $\delta_{var,k}$ capture the elasticity of trade costs w.r.t. each trade cost variable var.[9] It is indexed by sector k: we allow the effect of distance, contiguity, common language, etc. to differ across industries.

Incorporating the expression for trade costs into trade flows, we obtain:

$$\begin{aligned} \log X_{nik} \;&=\; FX_{ik} + FM_{nk} - \beta_{Dist,k} \log Dist_{ni} \;+\; \beta_{Contig,k}.Contiguity_{ni} \\ &\quad +\; \beta_{Lang,k}.CommonLang_{ni} \;+\; \beta_{Colony,k}.ColonialLink_{ni} \;+\; \beta_{HomeBias,k}.I_{n=i} \end{aligned}$$

[9]Note that d_{nik} also captures a potential home bias in preferences. A home bias would be equivalent to multiplying d_{nik} by a scalar larger than one whenever trade occurs between two different countries, which is equivalent to the border effect in this framework.

where FM_{nk} refers to importer fixed effects and FX_{ik} to exporter fixed effects, and $\beta_{var,k} = \theta_k \delta_{var,k}$ for each trade cost variable var. Note that i refers to the exporter and n to the importer (following Eaton and Kortum 2002 notations). Since all coefficients to be estimated are sector specific, we estimate this gravity equation separately for each sector.

According to the model, importer and exporter fixed effects contain valuable information and correspond to $FM_{nk} = \log X_{nk} - \log \Phi_{nk}$ and $FX_{ik} = \log S_{ik}$. A first way to estimate Φ_{nk} would be to use importer fixed effects. However, since we use Φ_{nk} as a means to control for supply-side effects, it is arguably better to use supply-side characteristics to estimate Φ_{nk}.[10] We follow a strategy developed by Redding and Venables (2004)[11]. Following Equation (7) defining Φ_{nk}, we use the estimate of S_{ik} and $\theta_k \log d_{nik}$ (using all transport cost proxies and their coefficients) to construct a structural estimate of Φ_{nk}:

$$\begin{aligned}\widehat{\Phi}_{nk} \;=\; & \sum_i \exp\Big(\widehat{FX}_{ik} - \widehat{\beta}_{Dist,k} \log Dist_{ni} \;+\; \widehat{\beta}_{Contig,k}.Contiguity_{ni} \\ & + \widehat{\beta}_{Lang,k}.CommonLang_{ni} \;+\; \widehat{\beta}_{Colony,k}.ColonialLink_{ni} \;+\; \widehat{\beta}_{HomeBias,k}.I_{n=i}\Big)\end{aligned}$$

This constructed $\widehat{\Phi}_{nk}$ varies across industries and countries in an intuitive way. It is the sum of all potential exporters' fixed effect (reflecting unit costs of production) deflated by distance and other trade cost variables. When country n is close to an exporter that has a comparative advantage in industry k, i.e. an exporter associated with a large exporter fixed effect FX_{ik} (large S_{ik}), our constructed $\widehat{\Phi}_{nk}$ is relatively larger for this country n reflecting a lower price index of goods from industry k in counry n. Note that $\widehat{\Phi}_{nk}$ also accounts for domestic supply in each industry k (when $i = n$).

Such a method would fit various structural frameworks. If our model were based on Dixit-Stiglitz-Krugman framwork instead of Eaton-Kortum, price indices by importer and industry could be obtained in the same way. This would also account for the range of available varieties when it is endogenous and would also fit a model such as Chaney (2008) that yield a gravity equation in trade flows by industry.

Step 2: Demand system estimation and identification of σ_k

We now have an estimate of Φ_{nk} but the price index is proportional to $(\Phi_{nk})^{\frac{1}{\theta_k}}$, not Φ_{nk}, and θ_k is more difficult to estimate. θ_k corresponds to the elasticity of trade flows to trade costs and thus appears in the gravity equation. However it cannot be directly identified from $\delta_{var,k}$. For instance, the coefficient in the gravity equation associated with distance is the product of

[10] An alternative method using importer fixed effects yields very similar estimations of Φ_{nk}.
[11] See also Fally, Paillacar and Terra (2010).

θ_k and $\delta_{Dist,k}$.

We pursue four different approaches: 1) we callibrate θ_k using estimates from the literature; 2) we do not impose any restriction on θ_k; 3) we assume that $\theta_k = \theta$ is constant across sectors and estimate θ; 4) in order to better illustrate the role of trade costs, we also estimate demand elasticities by assuming that there is no trade cost.

In all cases the estimated equation is subject to the budget constraint to identify λ_n. For any country n, we impose:

$$\sum_k \hat{x}_{nk} = e_n$$

where e_n is observed expenditure per capita.

D1) In a first specification, we take a strong stand on θ_k and assume that it equals 4. This imposes a strong link between income elasticities of demand and price elasticities. Alternatively, we take a value of 8 (specification D1'). The first choice is close to Simonovska and Waugh (2010) estimates of 4.12 and 4.03. Donaldson (2008), Eaton, Kortum and Kramarz (2010), Costinot, Donaldson and Komunjer (forthcoming) provide alternative estimates that range between 3.6 and 5.2. The second choice ($\theta = 8$) is in line with Eaton and Kortum (2002) estimate of 8.28. Given our estimate of $\widehat{\Phi}_{nk}$ and the parameter $\hat{\theta}$, the final demand system to be estimated is:

$$\log x_{nk} = -\sigma_k . \log \lambda_n + \log \alpha_{5,k} + (\sigma_k - 1) . \frac{\log \widehat{\Phi}_{nk}}{\hat{\theta}} + \varepsilon_{nk}$$

where $\alpha_{5,k}$ is an sector fixed effect.

D2) In an other specification, we take an opposite approach and do not impose any constraint on the price elasticity of demand. Given our estimate of $\widehat{\Phi}_{nk}$, the final demand system to be estimated is:

$$\log x_{nk} = -\sigma_k . \log \lambda_n + \log \alpha_{5,k} + \mu_k . \log \widehat{\Phi}_{nk} + \varepsilon_{nk}$$

where $\alpha_{5,k}$ is an sector fixed effect, and μ_k is a sector specific coefficient (to be estimated) capturing a combination of σ_k and θ_k. μ_k is identified given how expenditure depends on price levels proxied by Φ.

D3) As an alternative approach, we assume that $\theta_k = \theta$ is constant across countries (as in the first specification) but we do not impose any value. Instead, we use this restriction to identify θ. Given $\widehat{\Phi}_{nk}$, the final demand system to be estimated is:

$$\log x_{nk} = -\sigma_k . \log \lambda_n + \log \alpha_{5,k} + \frac{(\sigma_k - 1)}{\theta} . \log \widehat{\Phi}_{nk} + \varepsilon_{nk}$$

where $\alpha_{5,k}$ is an sector fixed effect.

D4) As a benchmark, we also estimate a demand system assuming that there is no trade cost and prices are the same across all countries. The final demand system to be estimated is then:

$$\log x_{nk} = -\sigma_k . \log \lambda_n + \log \alpha_{4,k} + \varepsilon_{nk}$$

where $\alpha_{4,k}$ is an sector fixed effect capturing prices indices.

In all cases, given the inclusion of industry fixed effects, λ_n can be identified only up to a constant. To see this, we can multiply λ_k by a common multiplier λ' and multiply the industry fixed effect α_k by $(\lambda')^{\sigma_k}$. Using $\lambda_k \lambda'$ instead of λ_k and $\alpha_k (\lambda')^{\sigma_k}$ instead of α_k in the demand system generates the same demand and the same expenditures by industry. We thus normalize $\lambda_{USA} = 1$ for the US.

A similar issue arises for the identification of σ_k in specifications D2 and D4. In these cases, σ_k can be estimated only up to a common multiplier. By multiplying σ_k by a common multiplier σ' and replacing λ_n by $\lambda_n^{\frac{1}{\sigma'}}$, we obtain the same demand by industry and the same total expenditures (maintaining the normalization of the lagrangian to unity for the US).

This is not an issue if we focus on the income elasticity of demand which equals the ratio of σ_k to the weighted average of $\sigma_{k'}$ across sectors (weighted by consumption). For instance, in the no-trade-cost specification (D4), we can verify that relative σ's can be pinned down by the formula:

$$\frac{\sigma_k}{\sigma'_k} = \frac{\log x_{nk} - \log x_{n'k}}{\log x_{nk'} - \log x_{n'k'}}$$

for any pair of countries (n, n') and any pair of industries (k, k'). Ratios $\frac{\sigma_k}{\sigma'_k}$ and fitted consumption shares are then sufficient to derive income elasticities of demand in line with Equation (2).

The above demand systems are estimated using constrained non-linear least squares.[12] Bootstrapped standard errors for the estimates of σ_k, income elasticities and other variables are obtained by resampling the set of regions.

[12] We minimize the sum of squared errors on log consumption, weighted by world consumption by industry in order to avoid putting too much weight on a few small sectors. Very close results are obtained by minimizing unweighted sums of error squares in logs or alternatively in consumption shares (see robustness section 5). The optimization procedure is implemented in GAMS and solved using the Conopt3 NLP solver.

3.2 Data

Our empirical analysis is almost entirely based on the Global Trade Analysis Project (GTAP) version 7 dataset (Narayanan and Walmsley, 2008). GTAP contains consistent and reconciled production, consumption, endowment and trade data for 57 sectors of the economy, 5 production factors, and 94 countries in 2004. The set of sectors covers both manufacturing and services and the set of countries covers a wide range of per-capita income levels. The list of countries can be found in the appendix.

To estimate gravity equations (21) by industry, we use gross bilateral trade flows from GTAP measured including import tariffs, export subsidies and transport cost (c.i.f.). Demand systems are estimated over all 94 available countries using final demand values based on the aggregation of sectoral private and public expenditures. Some sectors in GTAP are used primarily as intermediates and correspond to extremely low consumption shares of final demand. 6 sectors for which less than 5% of output goes to final demand (coal, oil, gas, ferous metals, metals n.e.c. and minerals n.e.c.) are assumed to be used exclusively as intermediates and are dropped from the demand estimations. We also drop "dwellings" from our analysis.[13] We are left with 50 sectors (see Table 2 for the list of sectors).

Factor usage data, by sector, are directly available in GTAP and cover capital, skilled and unskilled labor, land and other natural resources. Skilled versus unskilled labor disaggregation in GTAP is only reliable for a subset of European countries and 6 non-European countries (USA, Canada, Australia, Japan, Taiwan and South Korea). Data on the use of skilled and unskilled labor in other countries are extrapolated using this set of benchmark countries.[14] Most often, skilled labor is defined on an occupational basis. In most of our analysis, we measure factor intensities by the average factor intensities across this subset of countries with reliable data. Section 5.3 examines measures based on alternative sets of countries and sectors.

Bilateral variables on physical distance, common language, colonial link and contiguity are obtained from CEPII.[15]

3.3 Demand system estimation results

Results on gravity equation (step 1) are very standard. More detailed results on the gravity equation are presented in the appendix section. In brief, there is significant variation in distance and border effect coefficients across industries. As usually found in the gravity equation literature, the coefficient for distance is on average close to -1, while the border effect is large.

[13] This sector is associated with large measurement errors in consumption and factor intensities.
[14] See: https://www.gtap.agecon.purdue.edu/resources/download/4183.pdf
[15] See: http://www.cepii.fr/anglaisgraph/bdd/distances.htm

Coefficients for other trade cost proxies are significant for most industries.

We now focus on the final demand estimation (step 2). Parameters to be estimated are λ_n, σ_k and the industry fixed effects α_k. Summary statistics are reported in Table 1.

With an R2 equal to 0.75, the specification with no trade costs (D4) already fits the data well. The weighted R2[16] equals 0.90. The inclusion of trade costs in specifications (D1)-(D3) significantly improves the fit, as the coefficients associated with $\widehat{\Phi}_{nk}$ are jointly significant. In the unconstrained-θ_k specification (D2), we can simply test whether coefficients associated with $\widehat{\Phi}_{nk}$ are jointly null which yields a F-stat of 16.07 and clearly rejects this hypothesis.

Table 1: NLLS estimation of demand: regression statistics

Specification:	(D1) $\theta = 4$	(D4) No trade cost	(D2) Unconstrainted θ_k	(D3) Common θ	(D1') $\theta = 8$
Correlation σ_k with D1 specification ($\theta = 4$)	1	0.881	0.838	0.978	0.924
Weighted av. of σ_k	2.76	/	/	1.49	4.47
F-stat: $\sigma_k = \sigma$	4.62	19.60	8.63	5.05	4.07
Correlation log λ_n with log per capita income	-0.985	-0.999	-0.986	-0.986	-0.986
θ (calibrated or estimated)	4	/	/	1.17	8
Average coeff for Φ_{nk}	0.507	/	0.532	0.518	0.486
R2	0.731	0.568	0.607	0.596	0.609
weighted R2	0.914	0.903	0.918	0.915	0.914
Observations	4700	4700	4700	4700	4700

Notes: NLLS regressions: step 2 of the estimation procedure described in the text. Weighted by industry size (world's expenditure by industry). Bootstrapped standard errors and F-test (100 draws).

Imposing homotheticity (i.e. common $\sigma_k = \sigma$ across industries) yields a R2 = 0.52 (and a weighted-R2 = 0.882).[17] This is significantly lower. The F-stat associated with imposing common σ_k across industries shows that homotheticity is clearly rejected in all specifications D1 to D4 (third row of Table 1).

The estimated σ_k can be used to compute income elasticity estimates according to equation 2, using fitted median-income-country expenditure shares as weights.[18] In our preferred

[16] with variance and average weighted by world production by industry

[17] Allowing for trade costs with homothetic preferences increases the R2 to 0.58, which is still lower than the R2 for non-homothetic preferences without trade costs (D4).

[18] With CRIE preferences, the ratio of income elasticities between two sectors does not depend on the choice of the reference country.

Table 2: Estimated income elasticity by sectors

GTAP code	Sector name	Income elast.	Std error	Skill intensity
gro	Cereal grains nec	0.362*	0.040	0.177
pdr	Paddy rice	0.490*	0.150	0.187
oap	Animal products nec	0.498*	0.067	0.160
osd	Oil seeds	0.588*	0.158	0.178
frs	Forestry	0.596*	0.115	0.147
v_f	Vegetables, fruit, nuts	0.601*	0.102	0.151
ctl	Bovine cattle, sheep, goats, horses	0.621*	0.078	0.157
pcr	Processed rice	0.654*	0.126	0.272
vol	Vegetable oils and fats	0.696*	0.066	0.260
fsh	Fishing	0.712*	0.092	0.220
p_c	Petroleum, coal products	0.740*	0.047	0.338
c_b	Sugar cane, sugar beet	0.777	0.206	0.165
sgr	Sugar	0.800*	0.142	0.253
b_t	Beverages and tobacco products	0.802*	0.031	0.264
tex	Textiles	0.847*	0.055	0.239
wht	Wheat	0.854	0.139	0.166
ely	Electricity	0.923*	0.036	0.409
ofd	Food products nec	0.944*	0.036	0.249
nmm	Mineral products nec	0.944	0.072	0.259
cns	Construction	0.963*	0.023	0.253
wtp	Water transport	0.963	0.087	0.287
cmt	Bovine meat products	0.972	0.068	0.239
ocr	Crops nec	0.974	0.108	0.143
mil	Dairy products	0.990	0.046	0.236
lum	Wood products	1.001	0.085	0.228
atp	Air transport	1.028	0.047	0.297
crp	Chemical, rubber, plastic products	1.039	0.051	0.318
otp	Transport nec	1.046	0.052	0.271
omt	Meat products nec	1.051	0.075	0.236
fmp	Metal products	1.065	0.053	0.257
otn	Transport equipment nec	1.107	0.057	0.280
ome	Machinery and equipment nec	1.111	0.030	0.322
osg	Public Administration and services	1.112*	0.019	0.549
ppp	Paper products, publishing	1.115	0.039	0.289
trd	Trade	1.119	0.036	0.276
wtr	Water	1.123	0.048	0.410
lea	Leather products	1.126	0.041	0.234
mvh	Motor vehicles and parts	1.135	0.030	0.288
wap	Wearing apparel	1.138	0.050	0.230
cmn	Communication	1.161*	0.049	0.469
ros	Recreational and other services	1.164*	0.042	0.454
omf	Manufactures nec	1.210*	0.037	0.248
ele	Electronic equipment	1.28*	0.050	0.326
ofi	Financial services nec	1.292*	0.054	0.476
obs	Business services nec	1.327*	0.039	0.449
pfb	Plant-based fibers	1.363	0.171	0.194
rmk	Raw milk	1.367*	0.077	0.148
isr	Insurance	1.378*	0.046	0.473
wol	Wool, silk-worm cocoons	1.543*	0.167	0.195
gdt	Gas manufacture, distribution	2.209*	0.160	0.403

Notes: Income elasticity by sector estimated at median-income country; NLLS estimations (specification imposing $\theta = 4$); bootstrapped standard errors; * denotes 5% significance.

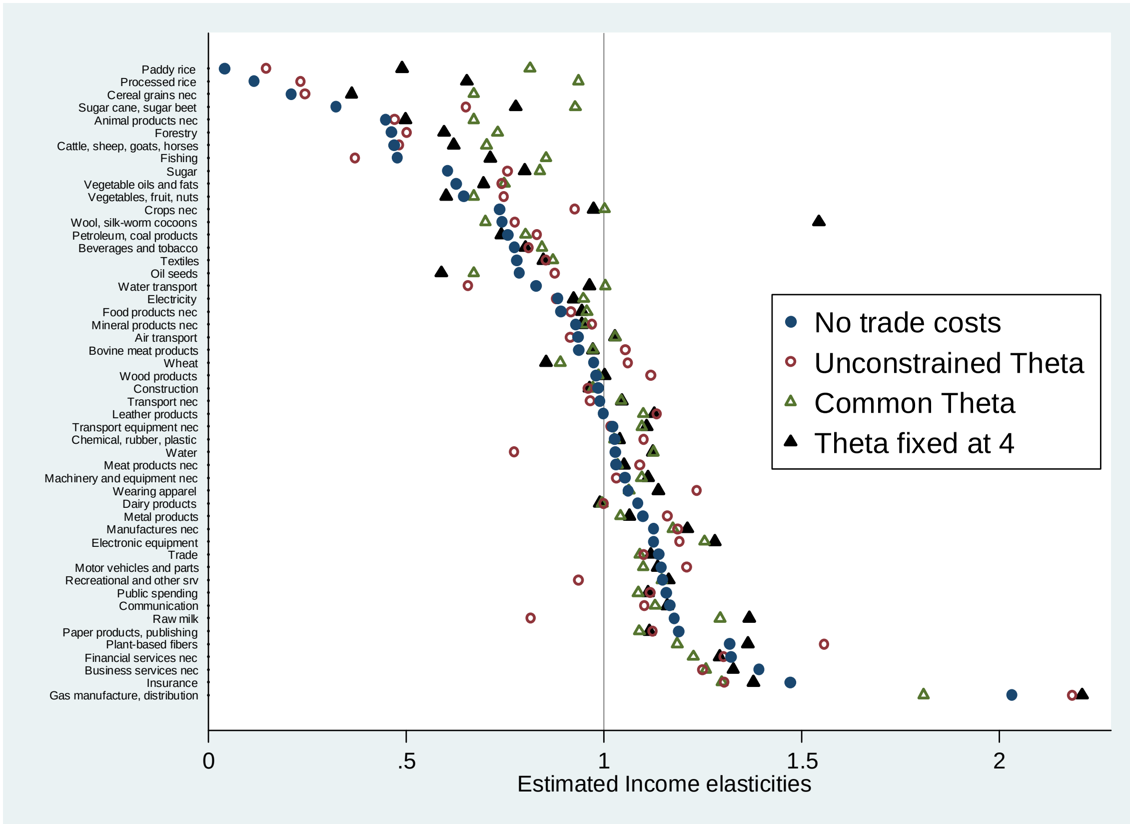

Figure 1: Income elasticity across specifications

specification (D1), estimates range from 0.33 for Cereal grains to 2.12 for gas manufacture and distribution with a clear dominance of agricultural sectors at the low end and service sectors at the high end. 30 out of 50 estimates are significantly different than 1 (at 95 %) as shown in Table 2.

The distribution of estimated income elasticities is quite similar across specifications. In particular, the choice of θ does not affect estimates of σ_k and income elasticities. As shown in Table 1 (first row), the correlation between estimated σ_k in other specifications and estimated σ_k in specification D1 ($\theta = 4$) is always above 80%. This is also the correlation between income elasticities among specification since income elasticities are proportional to σ_k. Sectors where income elasticities vary the most across specifications are the smallest ones in terms of final demand (see Figure 1).

For robustness, these are compared with estimates using more standard demand systems in section 5 and are found to be well correlated.

3.4 Correlation with factor intensities

We now investigate the relationship between income elasticities and factor intensities across sectors. Altough the implications of such a relationship will be best illustrated in section 4, we first demonstrate its significance through simple correlations. Table 3 reports correlation coefficients between skill intensity and income elasticities (or, equivalently, the σ's) estimated under different assumptions about trade costs and factor intensity.[19]

Our measures of factor intensity correspond to the ratio of skilled labor, capital or natural resource (including land) to total labor input. They are computed including the factor usage embedded in the intermediate sectors used in each sector's production.[20] As shown in section 5, our results are robust to different measures of factor intensities. Our results are also robust to different demand specifications. Table 3 reports estimations with CRIE preferences, while alternative demand systerms are examined in section 5.

Table 3: Correlation between income elasticity and skill intensity

Dependent varriable:	Income elasticity					
	(1)	(2)	(3)	(4)	(5)	(6)
Specification	$\theta = 4$	$\theta = 4$	No trade cost	No trade cost	Unconstrainted Theta	Common Theta
Skill intensity	0.485	0.360	0.569	0.443	0.533	0.442
	[0.041]**	[0.143]**	[0.037]**	[0.134]**	[0.033]**	[0.059]**
Capital intensity		-0.052		-0.076		
		[0.163]		[0.127]		
Natural resources int.		-0.188		-0.243		
		[0.131]		[0.135]*		
Observations (sectors)	50	50	50	50	50	50

Notes: Dependent variable: income elasticity by sector evaluated at median-country income; beta coefficients; bootstrapped standard errors in brackets; * significant at 5%; ** significant at 1%.

We find that skill intensity is positively and significantly correlated with income elasticity, natural resources intensity is negatively correlated, and capital intensity exhibits a small weakly positive correlation (we report bootstrapped standard errors in Table 3). As expected, the correlation with skill intensity diminishes if we account for trade costs and control for supply-side effects. This is illustrated in Figure 2 and also seen by comparing column (1) versus

[19] Lewis and Linzer (2005) show that the use of estimated dependent variables does not lead to important biases provided that we compute heteroskedasticity-robust standard errors.

[20] Total factor usage is computed using a Leontiev inversion of country-specific input-output tables as provided by GTAP

(3) in Table 3. This correlation remains however particularly large and above 40% in most specifications.

Part of this large correlation can be explained by the composition of consumption into services vs. manufacturing industries, with the former being generally associated with a larger income elasticity. However, even after excluding service industries, the correlation is above 30% in all specifications.

It is interesting to see that capital intensity would otherwise be positively correlated with income elasticity, as found by Reimer and Hertel (2010), but this correlation is not as large as for skill intensity (less than 10% in most specifications) and not robust to controlling for skill intensity as shown in columns (2) and (4) of Table 3.

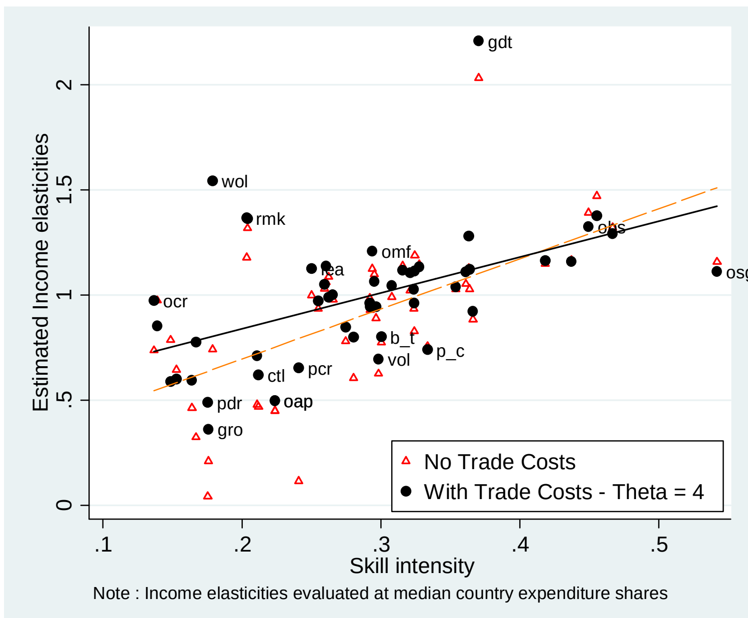

Figure 2: Income elasticity and skill intensity correlation

These results show a large correlations between per capita income and consumption patterns depending on skill intensity. We emphasize the demand side. One may be worried, however, that these results are driven by differences in skill endowment across countries rather than differences in per capita income. In GTAP data, the fraction of skilled labor is indeed correlated at 88% with per capita income. In order to check the robustness of our results with respect to differences in education, we re-estimated income elasticities for subsets of countries with smaller variations in skilled labor endowment (and still large variations in per capita income). If we restrict the set of countries to those within the inter-quartile range in skilled-labor endowments (eliminating countries with extreme quartiles in skill endowment), the correlation between estimated income elasticities and skill intensity remains very high for the main specifications

(45.7% instead of 48.5% for the specification in column 1 of Table 3) while the correlation between per capita income and education is sensibly lower (60% instead of 88%). A more extreme exercise is to select specific groups of countries where the correlation between income and education becomes zero by construction. In thes cases we find again very large correlations between skill intensity and (re-estimated) income elasticity, showing that our main results are not driven by differences in education across countries.

4 Implications for trade, skill premium and welfare

4.1 Consumption patterns and missing trade

Sector-level correlation between income elasticities and factor intensities can help explain a part of the observed country-level correlation between relative specializations in consumption, $\frac{Y_{nk}}{s_n Y_k}$, and production, $\frac{X_{nk}}{s_n Y_k}$. The higher this correlation the smaller the predicted trade. As argued in sections 2.3.1 and 2.3.2, correlations between supply and demand affects trade both in terms of volume and factor content.

We are first interested in the correlation between country's specializations in demand and production across countries and industries. We compare a combination of cases with and without non-homothetic demand and with and without trade costs. In the first row of Table 4, we calculate the correlation between $\frac{Y_{nk}}{s_n Y_k}$ and $\frac{X_{nk}}{s_n Y_k}$. The first term reflects production relative to world's production of goods k multiplied by country n's share of world GDP. We use actual data on production to compute this term. The second term reflects country n's consumption relative to world's production of goods k scaled by country n's share of world GDP. In columns (1) to (4), we use fitted demand $\hat{X}_{nk}$ from our second-stage estimations and in column (5) we use actual consumption X_{nk}.

In column (1), we impose homothetic preferences (i.e. common $\sigma_k = \sigma$ across industries) and assume that there is no trade cost. These two assumptions are made in standard Heckscher-Ohlin models. In this case, the correlation is obviously zero since consumption patterns should be the same across all countries. In column (2), we allow for trade costs. Trade costs generate a positive correlation between consumption and production when the elasticity of consumption (by industry) to price indices is larger than unity. The correlation that we obtain is 23% (across countries and industries) and significantly positive at 1%. Though, this correlation obtained with fitted homothetic demand is much lower than the 77% correlation observed in the data (column 5).

Allowing for non-homotheticity significantly increases this correlation between supply and demand. Even if we assume no trade cost and common prices across countries, and even if

Table 4: Correlation between supply and demand

	(1)	(2)	(3)	(4)	(5)	
Preferences:	Homothetic		Non-homothetic		Data	Dimension
Correcting for trade costs:	No	Yes	No	Yes		
Correlation between supply and demand	0	0.23	0.31	0.46	0.77	n x k
Correlation between T_{nf}^{HOV} and Consumption bias T_{nf}^{CB}	0	0.78	0.50	0.91	0.99	n x f
Normalized by country size	0	0.77	0.85	0.87	0.92	n x f
Corrected HOV slope test	0.39	0.56	0.44	0.65	1	n x f
Variance test: $\frac{Var(T_{fn}^{HOV}-T_{fn}^{CB})}{Var(T_{fn}^{HOV})}$	1	0.39	0.75	0.19	0.04	n x f

Notes: Dependent variable: income elasticity by sector evaluated at median-country income; beta coefficients; bootstrapped standard errors in brackets; * significant at 5%; ** significant at 1%.

preferences are still assumed to be identical across countries, allowing for non-homotheticity in preferences can generate larger correlation between supply and demand. As shown in column (3), by using fitted demand from the no-trade-cost specification (D4) we obtain a correlation of 31%. In column (4), we further account for trade costs and differences in price indices across countries and we find a correlation of 46% (specification D1 imposing $\theta_k = 4$).[21] This is much closer to the 77% correlation observed in the data.

In terms of factor content, such correlations between consumption and supply should generate smaller factor content trade, as argued in section 2.3.2. Predicted factor content of trade (PFCT) can be expressed as the difference between standard Heckscher-Ohlin PFCT, denoted T_{nf}^{HOV}, and a consumption bias term denoted T_{nf}^{CB} which is null in the special case where preferences are homothetic and trade costs are null (see equation 13). Again we calculate T_{nf}^{HOV} using actual production data and T_{nf}^{CB} using either fitted demand (columns 1 to 4) or actual consumption (column 5).[22]

The second row of Table 4 shows that trade costs can already explain a large correlation between consumption and supply factor content even if preferences are assumed to be homothetic (column 2). This correlation is 78% across countries and factors (against 0% if we assume

[21] Similar and even larger correlations are found for alternative specifications.

[22] Here we measure factor content by assuming a common matrix for all countries, i.e. the same coefficients β_{nk}. Note that all variables are in values (e.g. wages instead of number of workers) which mitigates cross-country differences related to differences in factor prices.

no trade cost). This is consistent with Davis and Weinstein (2001) who also attribute an important part of the missing trade puzzle to trade costs. In column (3), we find that allowing for non-homotheticity but assuming zero trade cost can generate a 50% correlation between HOV PFCT T_{nf}^{HOV} and the consumption bias. Allowing for both non-homotheticity and the presence of trade costs further increases the correlation to 91%, which is closer to the very large correlation observed in the data (99%!). One may be worried however that these correlations between T_{nf}^{HOV} and T_{nf}^{CB} are driven by a few large countries such as the US and China. After scaling down these variables and dividing by country size, the observed correlation in the data is slightly lower (92% as shown in column 5 of the third row). After rescaling, our results exhibit an even more important role for non-homotheticity. Allowing for non-homothetic preferences in a zero-trade-cost framework (column 3) yields a larger correlation between supply and demand than allowing for trade costs with homothetic preferences (column 2).

In the fourth row of Table 4, we regress measured factor content of trade on $T_{nf}^{HOV} - T_{nf}^{CB}$ where T_{nf}^{CB} is computed using fitted demand. Similar results are found whether it is rescaled or not. By construction, the regression coefficient equals one when we compute the consumption bias T_{nf}^{CB} using actual data (column 5). In the first case (column 1), we impose homothetic demand and zero trade costs, which means that the regressor is simply T_{nf}^{HOV}. In this case, the coefficient is 0.36, which means that measured factor content trade (FCT) is only a third of the predicted FCT that is not corrected for differences in consumption patterns. In column (2), the coefficient is larger (0.56) which means that allowing for trade costs already closes the gap between predicted and measured FCT. Allowing for non-homothetic preferences also improve the coefficient (column 3 and 4) with of course an even smaller gap between predicted and measure FCT when we also account for trade costs.

Finally, an alternative way to quantify the contribution of non-homothetic preferences to the missing trade puzzle is to examine the variance of predicted trade in terms of factor content ("variance test"). In the last row, we compute: $\frac{Var(T_{fn}^{HOV} - T_{fn}^{CB})}{Var(T_{fn}^{HOV})}$. When preferences are assumed to be homothetic and trade costs are null, this ratio equals one since the fitted consumption bias term is zero (first column). When trade costs are added, it considerably reduces the variance of predicted factor content trade as we could expect. As can be seen, the variance is reduced by two thirds just by accounting for trade costs. However, one can see that adding non-homothetic preferences further reduces the variance by half (the ratio drops from 0.4 to 0.2).

Correlations and regressions across countries and factors can be also examined factor by factor. We find that the use of skilled labor is key in explaining why non-homothetic preferences play such an important role. In Figure 3, we plot a measure of skilled-labor content of

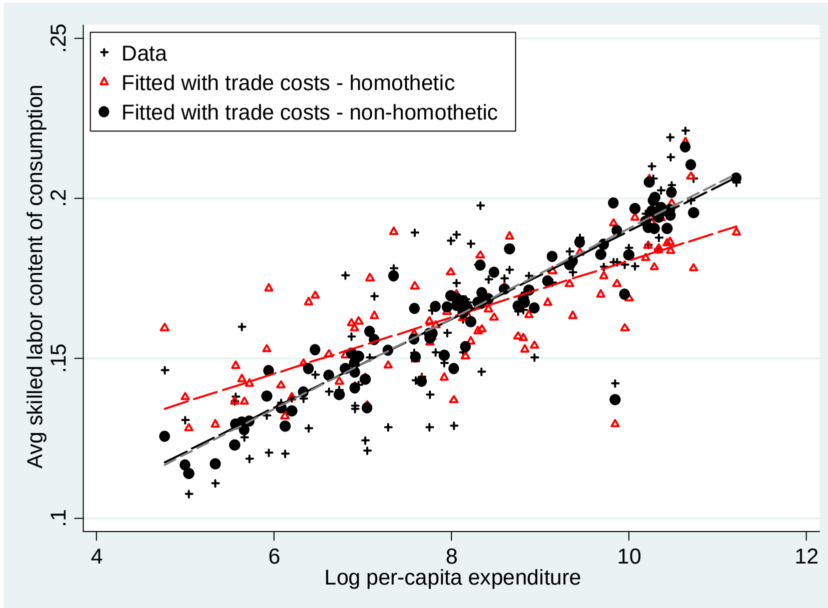

Figure 3: Skilled-labor content of consumption and per capita income

consumption against per capita income (in log) where the former is defined as:

$$\frac{\sum_k \beta_{fk} X_{nk}}{\sum_k X_{nk}} \tag{21}$$

We can either use actual consumption or fitted consumption with different assumptions. With homothetic preferences and no trade costs, final demand for industry k in country n is proportional to world consumption in industry k, and expression 21 should be the same for all countries. When we allow for trade costs, rich countries tend to spend more in skilled-labor intensive industries, even if preferences are homothetic, because goods are relatively cheaper in these industries. We show however in Figure 3 that a better fit is obtained with both trade costs and non-homothetic preferences.

4.2 Trade patterns

Can non-homothetic preferences explain why there is so small volumes of North-South trade in comparison to North-North trade?[23] Results from the previous section shed light on the role of non-homothetic preferences in explaining net trade and its factor content. In particular, our results are related to industry compositions of demand and production. Given that a large fraction of trade is intra-sectoral, it is legitimate to ask whether non-homotheticity can also

[23]see Fieler (2010), Waugh (2010) among others.

play a role (quantitatively) in explaining patterns of gross trade volumes.

As argued in section 2.3.1, non-homotheticity can potentially explain differences in import penetration across markets depending on the importer's income and the exporter's structure of comparative advantage. In particular, if a country has a comparative advantage in high-income-elastic industries (high-σ_k), such a country is more likely to export to rich importers than developing countries.

This argument can be illustrated using equation 11 on import penetration in the simple case with no trade cost. Using this formula, we can examine how import penetration by poor exporting countries depends on the importer's level of income. To be more precise, we compute import penetration from devloping countries in market n:

$$X_n^{South}/X_n = \sum_k \left(\frac{Y_k^{South}}{Y_k^{South} + Y_k^{North}} \right) \left(\frac{\hat{\alpha}_{4,k} \hat{\lambda}_n^{-\hat{\sigma}_k}}{\sum_{k'} \hat{\alpha}_{4,k'} \hat{\lambda}_n^{-\hat{\sigma}_{k'}}} \right)$$

where Y_k^{South} refers to total production in industry k by developing countries (annual per capital income less than \$10K), Y_k^{North} to total production by developed countries, and where $\hat{\alpha}_k$, $\hat{\lambda}_n$ and $\hat{\sigma}_k$ are estimated coefficients from the final demand equation (specification D4 assuming no trade cost).

Since income elasticity (or equivalently σ_k) is highly correlated with skill intensity and since developing countries have a comparative advantage in unskilled-labor-intensive tasks (the correlation coefficient between skill intensity and $\frac{Y_k^{South}}{Y_k^{South}+Y_k^{North}}$ is -0.8), we can expect developing countries to have a smaller penetration in richer countries which consume more goods from skill-intensive industries. Note also that import penetration does not depend on the importer's income if preferences are homothetic and trade costs are absent.

In Figure 4, we plot X_n^{South}/X_n as a function of the importer's average income per capita (in log). As shown in this figure, differences in consumption patterns across industries can generate large differences in import penetration between rich and poor countries. Given our estimated demand parameters, in a situation with no trade cost, import penetration by developing countries can vary from 50% in markets with the lowest per capital income (e.g. Ethiopia) to only 20% in the richest markets (e.g. Luxembourg). Symmetrically, import penetration by developed countries varies from 50% in the poorest markets to 80% in the richest.

Conversely, we can investigate what fraction of exports goes towards rich importers. Since developing countries tend to have a comparative advantage in unskilled-labor-intensive industries, we can expect poorer countries to have a smaller share of exports towards developed countries.

These results solely reflects changes in consumption patterns and do not account for trade

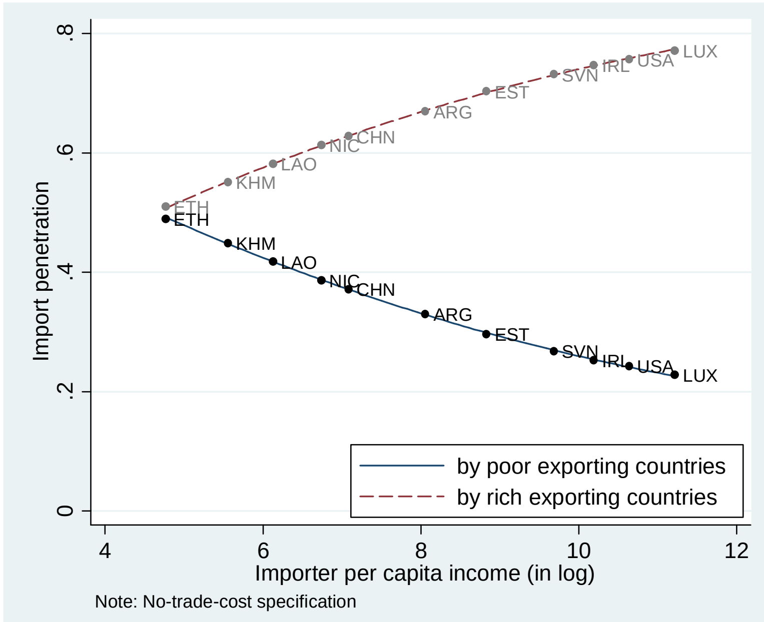

Figure 4: Import penetration by developing countries depending on importer's income

costs. As developed countries are closer to other developed countries and vice versa, trade costs can also contribute to such a correlation between import penetration by developing countries and importers' income. An interesting question is whether these trade costs are sufficient to quantitatively replicates trends in observed patterns.

Using estimates from both steps of our estimations, we can construct predicted trade flows $\widehat{X}_{nik}$ (from country i to country n in sector k) using the gravity equation 5:

$$\widehat{X}_{nik} = \frac{\widehat{S}_{ik}\widehat{(d_{nik})^{-\theta_k}}}{\widehat{\Phi}_{nk}}\widehat{X}_{nk}$$

where $\widehat{S}_{ik}$, $\widehat{(d_{nik})^{-\theta_k}}$ and $\widehat{\Phi}_{nk}$ are constructed using estimates from the gravity equation (see step 1 of the estimation procedure) and where $\widehat{X}_{nk}$ is fitted demand from the final step of the demand estimation. We can compare fitted demand with non-homothetic preferences with fitted demand imposing homotheticity (i.e. common $\sigma_k = \sigma$ across industries). Accounting for trade costs in both cases, we can examine for each country: i) the share of trade (import + exports) with rich partners; ii) the ratio of trade over GDP.

Figure 5 plots the share of trade with rich partners (annual per capita income above $\$10K$) in manufacturing industries against per capita income (in log). As we can see, homothetic preferences with trade costs can already generate a positive correlation since richer countries are more likely to be closer to rich countries and trade with them. Not surprisingly, however, non-homothetic preferences magnify this correlation. In particular, we can observe substantial differences in predicted shares for the poorest countries.

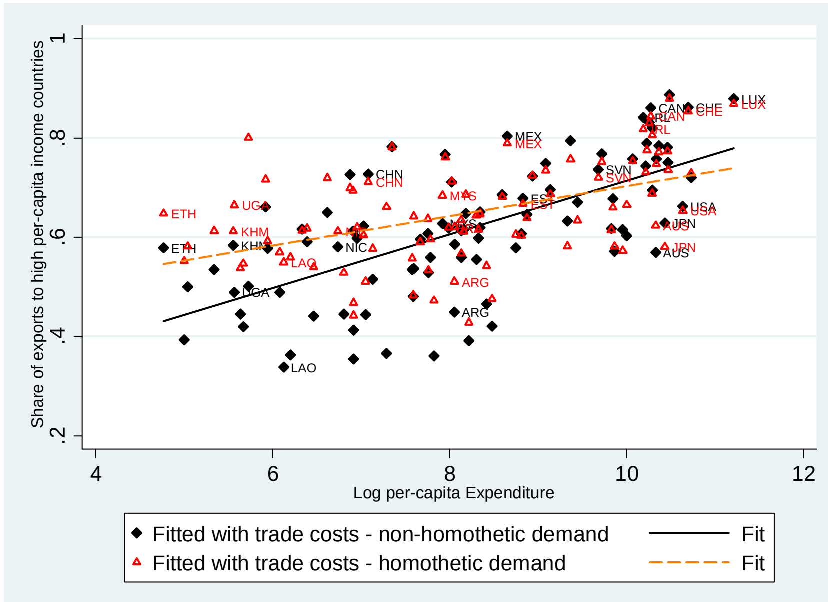

Figure 5: Share of trade with rich partners (imports and exports)

Since rich countries are also the largest markets in terms of GDP[24], a country's level of openness (trade/GDP) is likely to depend largely on whether such a country has a large penetration in the richest markets. Figure 6 plots the ratio of trade over GDP agains per capita income (in log). We find indeed that the predicted ratio of Trade/GDP is slightly smaller for developing countries when we allow for non-homotheticity in preferences. Conversly, this ratio is larger for rich countries since they have a larger market penetration in other rich markets.

Note that these results are solely driven by differences in consumption patterns across countries. We take the same trade cost and supply-side estimates in the homothetic and non-homothetic cases. Hence, unlike Fieler (2010), these results are not driven by an implicit correlation between trade cost elasticities and comparative advantage. Moreover, we find no significant correlation between income elasticities and the elasticity of trade to distance (the correlation for manufacturing industries is smaller than 10% in all specifications and not statistically significant), which means that richer countries do not have stronger preferences for goods that can be more easily traded.

[24]Developed countries account for 80% of total GDP in our sample of 94 countries.

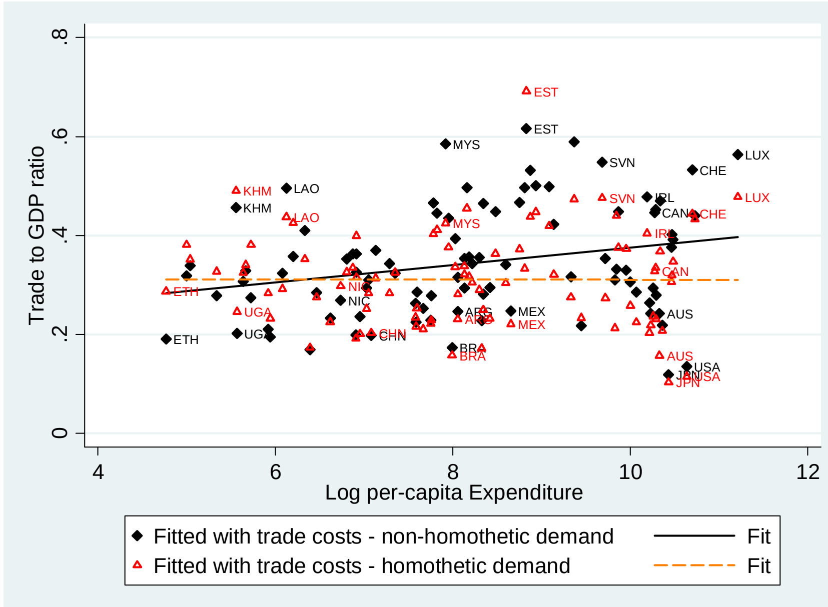

Figure 6: Fitted Trade/GDP ratio across countries

4.3 Productivity growth and the skill premium

As argued in Section 2.3.3, non-homothetic preferences can also shed light on why the skill premium has been increasing for a large number of countries (see Goldberg and Pavcnik, 2007, for empirical evidence on the skill premium increase). When preferences are homothetic, an homogenous increase in productivity in all countries should neither affect the patterns of trade nor the relative demand for skilled labor. However, when preferences are non-homothetic and when the income elasticity of demand is positively correlated with the skill intensity of production, an increase in productivity makes consumer richer which in turn induces a relative increase in consumption in skill-intensive industries (high-income elastic industries) and thus raises the relative demand for skilled labor.

This is a new demand-driven explanation contrasting with previous studies that have focused on the supply side. In this section, we examine how much skill premium increase our model can quantitatively generate. Two approaches are used: i) we simulate a 1% increase in productivity (TFP) in all countries[25] and examine how it affects the skill premium in open or closed economies; ii) we use the approximation provided in equation (18) to investigate differences across countries.

We use estimated parameters to simulate and solve the economy in general equilibrium. Both demand-side and supply-side parameters are taken from our estimations (gravity equation

[25] The same elasticities are obtained by simulating a 10% increase in TFP.

and final demand estimation, specification D1). Note that, in our simulated general-equilibrium model, factor prices and income adjust and slightly differ from oberved values, but not by much. Equilibrium conditions are equations (3) to (10) described in section 2.2. Details are provided in the appendix section.

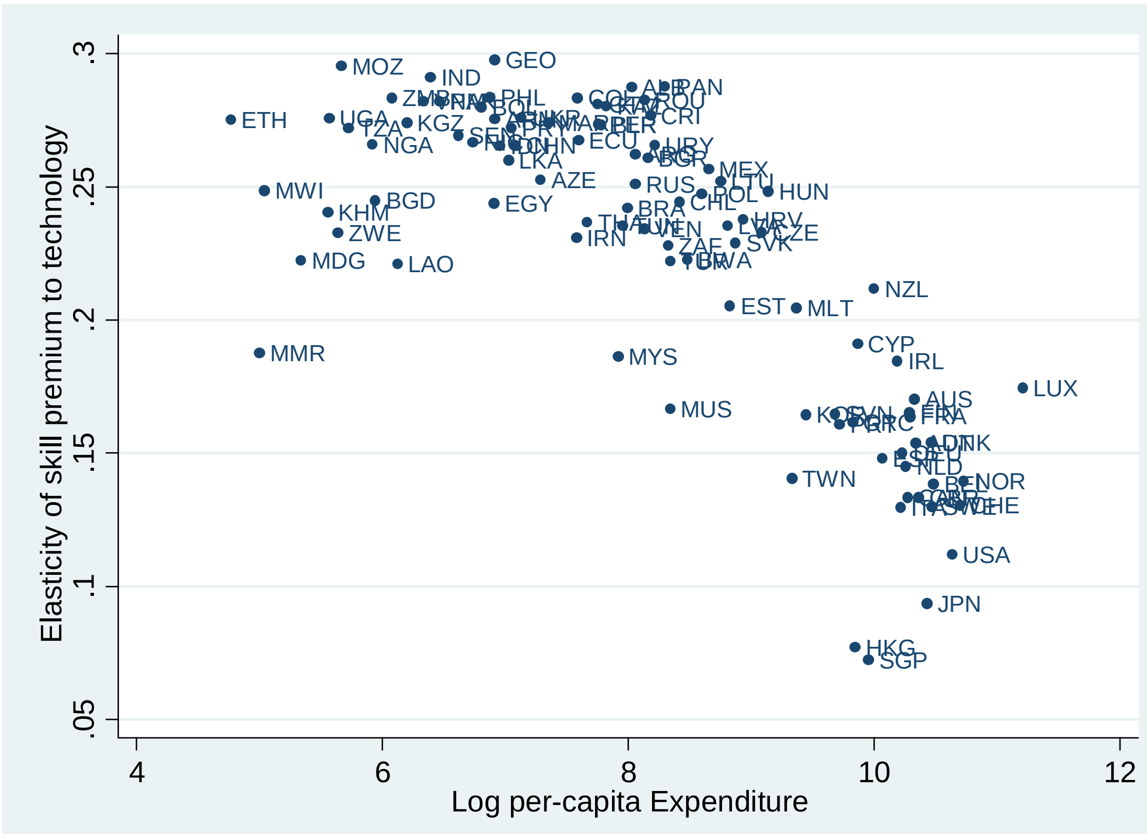

Figure 7: Elasticity of skill premium to TFP

Figure 7 illustrates the elasticity of the skill premium to technology when we simulate a 1% TFP increase in all countries. Our simulations show that this effect is large and stronger for poor countries. For instance, the elasticity of the skill premium to productivity is about 0.25 for China. With an annual productivity growth of about 8%, this yields an increase of the skill premium of 20% every decade. For South American countries, the elasticity is also above 0.2. With a 5% growth rate in productivity, this would yield a 10% increase in the skill premium every decade. Such a magnitude is large and could explain a big part of the observed increase in the skill premium.[26] For India, our model could explain about half of the skill premium

[26]South American countries seem to have experienced large increases in the skill premium: 68% for Mexico between 1987 and 1993 (Cragg and Epelbaum, 1996), 20% in Argentina between 1992 and 1998 (Gasparini,

increase in he 90's.[27] Even for richer countries, the effect on the skill premium is not negligible. For the US, this could explain about 10% of the skill premium increase during the 80's; this magnitude is comparable to the estimated effect of outsourcing on the skill premium in the US in the 80's.[28]

The main argument on the role of non-homothetic preferences does not involve trade. It also applies to closed economies. In addition to the open-economy simulations, we also simulate a 1% increase in production for all countries in our sample, assuming infinite trade barriers before and after the productivity increase. Interestingly, our simulated skill-premium elasticities are very close to the results obtained in an open-economy framework. This is illustrated in Figure 8, with the open-economy elasticity on the horizontal axis and the closed-economy elasticity on the vertical axis. Simulated elasticities are all close to the diagonal line, with apparently no systematic deviations.

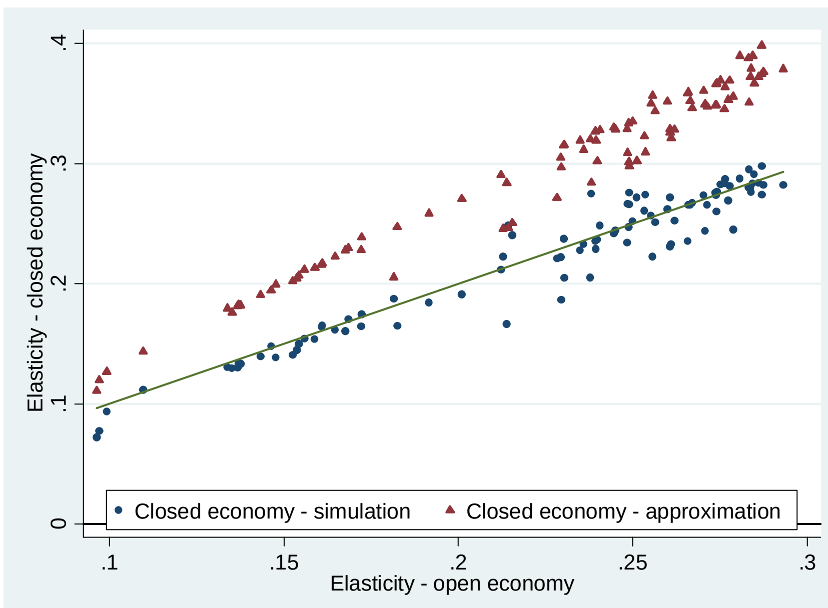

Figure 8: Open-economy vs. closed-economy simulation and approximation

In a closed-economy framework, it is also possible to approximate the skill-premium elasticity to TFP with expression (18). Using our estimates for income elasticities (ε_{nk}) as well

2004), 16% for Colombia between 1986 and 1998 (Attanasio et al, 2004). Given the growth rates during the corresponding periods, our model could explain increases of nearly 20%, 4% and 16% respectively for Mexico, Argentina and Colombia.

[27] According to Kijima (2006), the skill premium increased by 13% between 1987 and 1999, while the growth rate was about 2.2% on average, and our predicted elasticity of skill premium to productivity is larger than 0.25, thus predicting a 6.6% skill premium increase.

[28] In a conservative estimate, Feenstra and Hanson (1999) show that outsourcing can explain about 15% of the skill premium increase.

as labor shares (sh^H_{nk} and sh^L_{nk}) we can obtain an alternative quantitative prediction of the skill-premium elasticity. These values are also plotted on figure 8 (red triangles). As it can be seen, there is a very high correlation between approximated skill-premium elasticity in closed economy with both simulated elasticities in closed and open economy.

By regressing the closed-economy approximations on the closed-economy simulated elasticities, we find a coefficient of 0.741. This coefficient is smaller than one because of general-equilibrium feedback: an increase in the skill premium yields an increase in the relative price of high-income elastic goods which negatively affects relative consumption and the relative income of skilled workers. This feedback effect is embodied in ξ_n (See equation 17 and appendix section): this effect ξ_n is however broadly the same for all countries n. In fact, after multiplying our approximated elasticity by 0.741 as an approximation for $\frac{1}{1+\xi_n}$, we obtain an extremely good approximation of the simulated elasticity in closed economy (R-square of 96.5%).

Our formula from equation (18) also provide a good approximation of the open-economy simulated elasticity. In a regression of the simulated skill premium increase in open economy on the skill premium increase approximation suggested by equation (18), we also obtain a coefficient of 0.74 with an R-square of 87.1%.[29] Hence, our approximation is relevant and can be safely used to examine differences in the skill-premium elasticity across countries.

Why is this effect larger for poor countries? As we have shown in section 2.3.3, the effect on the skill premium strongly depends on the income elasticity of demand. These elasticities decrease with income, which could explain why the effect on the skill premium may be smaller for richer countries. While this mechanism plays a role, other effects are also present. To illustrate this, we split the above skill-premium elasticity into i) an average effect; ii) a term reflecting changes in income elasticity (within effect), iii) a term reflecting difference in labor allocation across sectors (between effect); iv) and a covariance term:

$$\begin{aligned}\textstyle\sum_k (sh^H_{nk} - sh^L_{nk})\varepsilon_{nk} = {} & \underbrace{\sum_k (\bar{sh}^H_k - \bar{sh}^L_k)\bar{\varepsilon}_k}_{Average} + \underbrace{\sum_k (\bar{sh}^H_k - \bar{sh}^L_k)\Delta\varepsilon_{nk}}_{Within} + \underbrace{\sum_k (\Delta sh^H_{nk} - \Delta sh^L_{nk})\bar{\varepsilon}_k}_{Between} \\ & + \underbrace{\sum_k (\Delta sh^H_{nk} - \Delta sh^L_{nk})\Delta\varepsilon_{nk}}_{Covariance}\end{aligned}$$

where $\bar{sh}^H_k$ denotes the average of sh^H_{nk} across countries n;[30] $\bar{\varepsilon}_k$ denotes the average of ε_{nk} across countries n; Δsh^H_{nk} denotes the difference between sh^H_{nk} and its average $\bar{sh}^H_k$; $\Delta\varepsilon_{nk}$ denotes the

[29] In this case, the coefficient is 0.746 with a standard error about 0.02 (open-economy simulation) against 0.01 for the closed-economy simulation. The constant is not significantly different from zero in both cases.

[30] sh^H_{nk} is defined as the share of sector k in skilled labor employment in country n, see Section 2.3.3.

difference between ε_{nk} and its average $\bar{\varepsilon}_k$. From this decomposition (Figure 9), both the within and between effects seem equally important in explaining differences across countries. While the within-effect is clearly decreasing with income, as expected, the between effect has an inverted-U shape and is highest for middle-low income countries such as China.

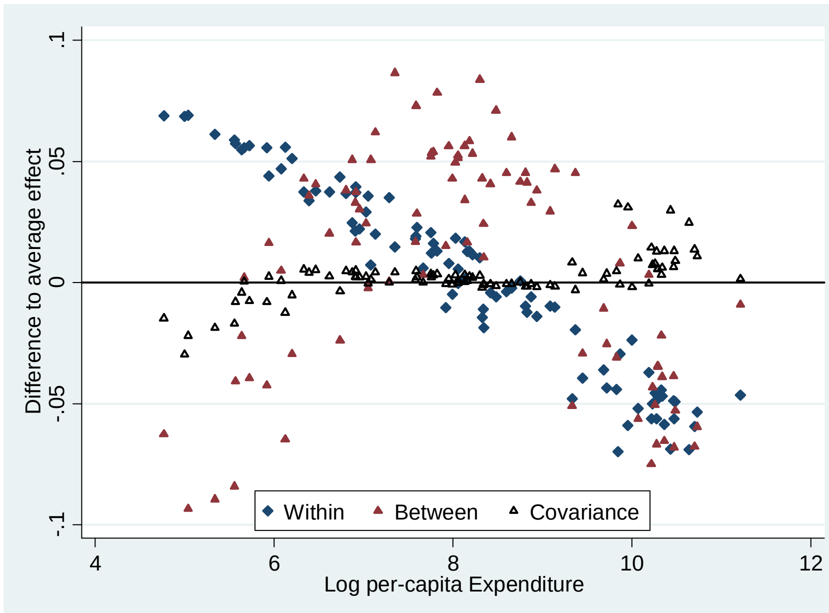

Figure 9: Within and between decomposition of the effect on the skill premium

5 Robustness

We explore the robustness of our results in a variety of dimensions. To save space, all results on the sensitivity of the correlation between skill intensity and income elasticity, our main variable of interest, are summarized in table 5.

5.1 Price data

In section 3, income elasticities are estimated by controlling for supply-side effects using a proxy price index P_{nk} which is constructed from the estimated Φ_{nk} (from the gravity equations). Possible mis-estimation of this unobserved variable might raise concerns that our income elasticity estimates are biased. To test for this, we use actual price data from the 2005 International Comparison Program (ICP) (World Bank 2005), an extensive dataset which includes price indices for a wide range of products and countries. Despite mapping issues, we are able to match ICP price indices to 38 of the 50 sectors and 88 out of 94 countries included in our analysis.

The idea here is not to test wether the estimated P_{nk} perfectly match the actual prices indices, as there are many reasons for them not to. Indeed, a regression of the log of the ICP price index on $\log P_{nk}$ including both country and sector fixed effects reveals a significant but weak correlation (beta correlation coefficient = 0.072, p-value < 0.001).

Rather, we are interested in knowing if the inclusion of ICP price data in demand estimations leads to significantly different income elasticity estimates.

A simple reduced-form log regression of final demand X_{nk} on both price indices (not shown), with both region and sector fixed effects, reveals that the constructed P_{nk} have a stronger explanatory power than the ICP index (beta correlation coefficient of 0.343 versus 0.051, both p-values < 0.01).

Including the ICP price index in the estimation of CRIE demand parameters in a specification similar to (D2) confirms that its predictive power is less than that of the constructed P_{nk}. Indeed, resulting income elasticity estimates are closer to those obtained by ignoring prices entirely (D3). Table 5 displays our correlation of interest when income elasticities are estimated using ICP prices (column 2) and using both indices (column 3). We clearly find that controlling for supply-side characteristics with our proxy price index P_{nk} has a greater impact on demand estimates. Thus, without being a definite test of the validity of our price index proxy, the comparison with external price data suggests that potential mis-estimation of the Φ_{nk} would tend to bias our correlation estimates downwards, if anything.

Table 5: Skilled labor to income elasticity correlation - Robustness across specifications

Demand system:	CRIE				LES	AIDS
Dependent variable:	Log expenditure			Expenditure shares	Expenditure shares	Expenditure shares
Prices:	Phi ($\theta = 4$)	ICP	Both	-	-	-
Region(s):	(1)	(2)	(3)	(4)	(5)	(6)
With robust data	0.488	0.599	0.553	0.682	0.623	0.795
All GTAP	0.476	0.619	0.574	0.734	0.574	0.749
USA	0.447	0.549	0.490	0.629	0.391	0.625
EU	0.489	0.580	0.532	0.651	0.493	0.655
Japan	0.418	0.582	0.589	0.760	0.748	0.829
Observations	50	38	38	50	50	50

Notes : all income elasticities calculated using median country expenditure shares. All correlations are significant at the 1% significance level.

5.2 Alternative demand systems

In order to test how our CRIE income elasticity estimates stack up against other demand systems, we compare them with estimates - generated using the same dataset - from two well-known alternative demand systems which also exhibit non-homothetic behaviour: the linear expenditure system (LES) and the "Almost Ideal Demand System" (AIDS). LES is derived from Stone-Geary preferences and is essentially an origin-displaced Cobb-Douglas function. AIDS, first introduced by Deaton and Muellbauer (1980), is not derived from any particular utility function, but has been widely used for its aggregation properties and its simplicity. Under the assumption of identical relative prices across regions, these demand systems can be shown to yield the following relationship between sectoral consumption shares and per-capita expenditures:

$$\text{LES}: \frac{x_{nk}}{\sum_k x_{nk}} = \alpha_k + \gamma_k \, e_n^{-1} \qquad \text{AIDS}: \frac{x_{nk}}{\sum_k x_{nk}} = \alpha_k + \gamma_k \log e_n$$

Note that the budget constraint imposes $\sum_k \alpha_k = 1$ and $\sum_k \gamma_k = 0$ in both cases. In each case, this relationship is estimated by sector by minimizing errors in expenditure shares (non-linear least squares subject to the budget constraint). For the sake of the comparison, we also reestimate CREI preferences by minimizing errors in expenditure shares (whereas our benchmark estimates minimize errors in log expenditures). The resulting estimates of α_k and γ_k are then used to compute income elasticities ε_{nk} with LES and AIDS:

$$\text{LES}: \varepsilon_{nk} = \alpha_k(\gamma_k + \alpha_k e_n^{-1})^{-1} \qquad \text{AIDS}: \varepsilon_{nk} = 1 + \gamma_k(\alpha_k + \gamma_k \ \log e_n)^{-1}$$

Figure 10 plots the distribution of these income elasticities against the CRIE estimates. All estimates are evaluated at the median country per-capita expenditure level. Clearly, CRIE estimates are in line with both of these alternative demand systems. Spearman coefficients of rank correlation with CRIE estimates are 0.88 for LES and 0.85 for AIDS. Most importantly, columns (5) and (6) of Table 5 confirm that the result of strong correlation between income elasticities and skill intensity is robust across all three demand systems.

Figure 10 also reveals the weakness of the LES demand system : income elasticites are very sensitive to income and converge rapidly to unity as income increases. Thus, even when evaluated at the median country income (as in Figure 10), income elasticities exhibit small deviations to one. AIDS performs better and yields a larger variability which is closer to that generated by CRIE.

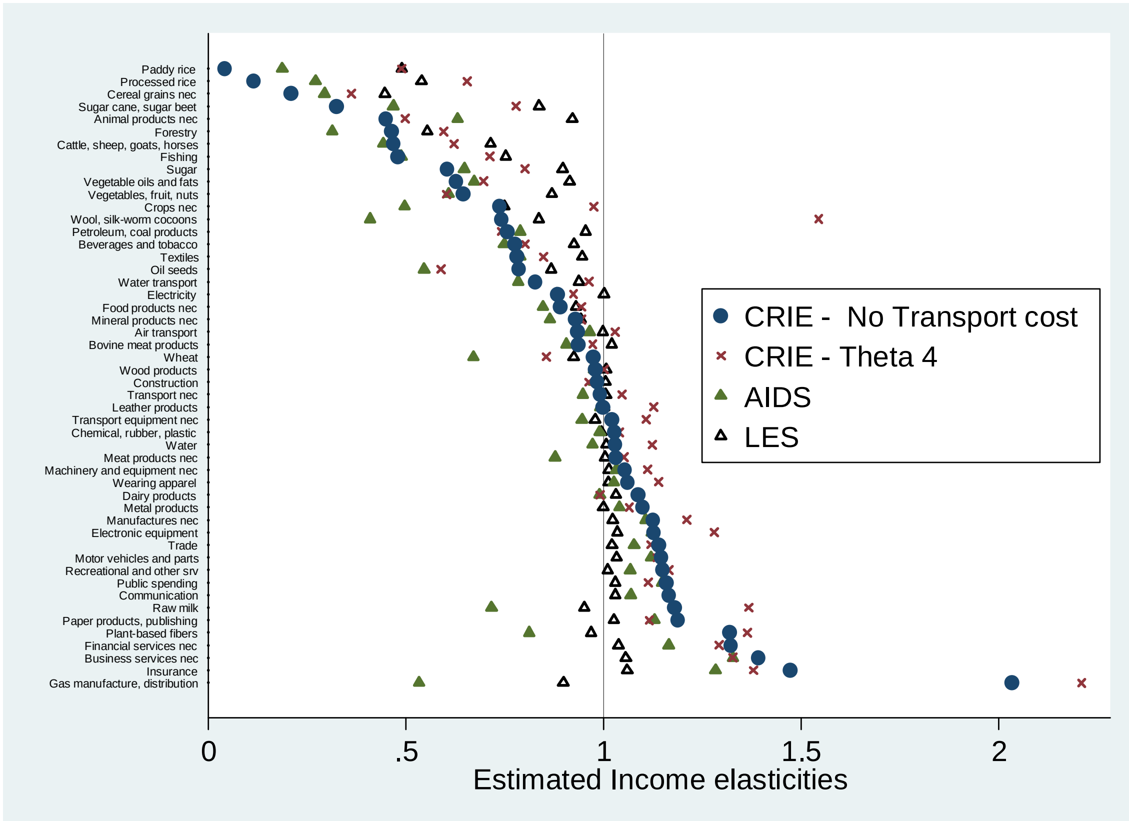

Figure 10: Comparison of distribution of income elasticities across demand systems

5.3 Measurement of skill intensity

All results from the previous sections are estimated using sectoral skill intensity indices which are computed as an average over the subset of countries for which reliable data is available. Table 5 displays the correlation of income elasticities to skill intensity using different regional subsets of the GTAP data : the reliable regions, all GTAP regions, the US, Europe (EU) and Japan. Altough, the correlation seems to generally be smaller for the USA than for the EU and Japan, it remains large and significant for all regions.

5.4 Within-country income distribution

Compared to a hypothetical situation where income is homogenous within each country, within-country income inequalities can reduce the observed variations in consumption patterns between countries. For instance, income inequalities could explain why it is possible to find luxurious cars in Africa (as other high-income elastic goods), while this type of goods is clearly not purchased by any individual with the average income of an African country.

Empirically, income inequalities create a downward bias in the dispersion of estimated income elasticities if we fail to take these inequalities into account (i.e. it biases our estimated income elasticities towards unity). Conversely, accouting for within-country inequalities should *reinforce* the differences in estimated income elasticities across sectors: it would be otherwise difficult to explain the large differences in observed consumption patterns across countries.

To confirm this intuition and test the sensitivity of our results to the inclusion of within-country inequalities, we rely as in Fieler (2010) on World Bank data describing the share of total income held by different percentiles of the population. Available data covers 7 income classes (the first two and last two deciles, as well as the 3 middle quintiles) and 89 of the 94 countries in our sample.

The estimation procedure in section 3 is modified to allow for 7 representative consumers in each country (each representing one population quintile or decile). As expected, resulting income elasticity estimates exhibit larger variations across sectors, although the differences are very small : the mean absolute deviations from one increases from 0.225 to 0.238[31]. The correlation between the two series is 0.995.

Correspondingly, the correlation of these income elasticity estimates with skill intensity increases slightly (from 0.493 to 0.511). Thus, accounting for within-country dispersion in incomes increases the estimated effect of non-homotheticity and makes our results stronger. However, given the small magnitude of the bias, we are comfortable with using the estimates from section 3 for counterfactual analyses.

5.5 Model with intermediate goods

The model above does not explicitly account for intermediate goods. In all the above, we estimate the gravity equation using gross trade flows and we estimate the demand equation using final consumption. This approach is however consistent with a model that does account for intermediate goods under some similarity conditions between final and intermediate goods within each industry.

With intermediate goods, we need to differentiate final demand D_{nk} from total absorption X_{nk} which also includes demand for goods used as intermediates. While the data allows us to separately observe final demand from intermediates goods by industry and destination country, we can only observe trade flows by industry, pooling final goods and intermediate goods together. Hence, it is not possible to separately identify a country's productivity for final goods vs. intermediate goods within the same industry. However, if we assume that goods within

[31] comparing estimates generated with the comparable set of 89 countries

the same industry are produced with similar technics (i.e. same average productivity draw and same use of inputs), we obtain a common supply term S_{ik} for both final goods and intermediate goods. If we further assume that trade costs vary by industry but do not depent on the type of goods within an industry, then we obtain again a gravity equation as in equation 5:

$$X_{nik} = \frac{S_{ik}(d_{nik})^{-\theta_k}}{\Phi_{nk}} X_{nk}$$

where X_{nk} now refers to total absorption and not only final demand. Again, the supplier effect S_{ik} reflects the cost of producing in industry k in country i. This equation can also be estimated as in equation (21), with importer and exporter fixed effects to account for S_{ik} and X_{nk}. As in the model without intermediate goods, we can retrieve the price index (Φ_{nk} to be more precise) by using exporter fixed effects and gravity coefficients.

In terms of final demand, equation 3 is verified by D_{nk} instead of X_{nk}. If x_{nk} (individual consumptin) now denotes final consumption per capita (D_{nk}/N_n), we find that x_{nk} verifies the same demand equations are satisfied and that these equations can be estimated in the same way. Hence this justifies why we use information on final demand to estimate the final demand equation (2nd step) while we use total trade flows to estimate gravity equations (1st step).

While our estimation strategy is consistent with a model that incorporates intermediate goods, general equilibrium simulations (as in Section 4.3) need to be amended to account for the use of intermediate goods and inter-industry linkages. For simplicity and tractability, we assume Cobb-Douglas production functions for the use of inputs in terms of industry aggregates, and that each industry aggregate is a CES combination of input varieties.[32] The price of producing variety j_k in industry k in country i shipped to country n would be now:

$$p_{nik}(j_k) = \frac{d_{nik}}{z_{ik}(j_k)} \prod_f (w_{fi})^{\beta_{fk}} \prod_{k'} (P^m_{ik'})^{m_{k,k'}}$$

where input output coefficients $m_{k,k'}$ refer to the use of sector k' as input for sector k, with the assumption that $\sum_{k'} m_{k,k'} + \sum_f \beta_{k,f} = 1$ (to ensure constant returns to scale). With the assumption that input demand is CES within each industry, P^m_{ik} is proportional to the final good price index P_{ik} across locations, hence it is also proportional to $\Phi_{ik}^{-\frac{1}{\theta_k}}$ (up to an industry constant denoted $\alpha_{k,5}$). In general equilibrium with intermediate goods, the full system of equilibrium conditions becomes:

[32] The elasticity of substitution between input varieties need not be equal to the elasticity of substitution between final good varieties η_k.

- Final demand:

$$D_{nk} = L_n(\lambda_n)^{-\sigma_k}\alpha_{2,k}(P_{nk})^{1-\sigma_k}$$

- Budget constraint:

$$L_n e_n = \sum_k D_{nk}$$

- Total absorption:

$$X_{ik} = D_{ik} + \sum_{n,k'} m_{k',k} X_{nik'}$$

- Trade:

$$X_{nik} = \frac{S_{ik}(d_{nik})^{-\theta_k}}{\Phi_{nk}} X_{nk}$$

- Price index:

$$P_{nk} = \alpha_{3,k}(\Phi_{nk})^{-\frac{1}{\theta_k}}$$

with

$$\Phi_{nk} = \sum_i S_{ik}(d_{nik})^{-\theta_k}$$

- Cost:

$$S_{ik} = T_{ik}^{\theta_k}\left(\prod_f (w_{fi})^{\beta_{fk}}\right)^{-\theta_k} \prod_{k'} (\alpha_{5,k'}^{-\theta_{k'}} \Phi_{ik'})^{\frac{m_{kk'}\theta_k}{\theta_{k'}}}$$

- Factor market clearing:

$$F_{fi} w_{fi} = \beta_{fk} \sum_{n,k} X_{nik}$$

- Per capita income:

$$L_i e_i = \sum_f F_{fi} w_{fi}$$

[TO BE COMPLETED]

6 Summary and conclusions

We begin the paper with an assertion that a large proportion of both theoretical and empirical research on international trade focuses on the production side of general equilibrium. The purpose of the paper is then to demonstrate that an examination of the role of demand can contribute to explaining a number of persistent puzzles long debated by trade economists. In particular, we are interested in the relationship between certain systematic characteristics of demand and characteristics of goods and services in production.

Most general-equilibrium models of trade assume identical and homothetic preferences across countries. But this assumption seems sharply contradicted by any household budget study we are aware of. While preferences surely differ across households within countries and at a broad aggregate level across countries, it is very clear from budget studies that there is a systematic dependence of expenditures shares across goods and services as a function of per-capita income. This is our starting point: we assume that preferences are identical but non-homothetic across countries. In this case, goods and services differ in their income elasticities of demand or alternatively budget expenditure shares are closely related to per-capita income.

The first empirical task is to estimate a non-homothetic preference model and then back out income elasticities of demand. Both economically and statistically, we find large deviations of these elasticities from the unitary values implied by homothetic preferences. The next step in this analysis is to relate these income elasticities of demand to factor intensities of goods in production. Here we find a high, positive correlation (about 40 percent) between a good's income elasticity of demand and it's skilled-labor intensity in production. This correlation is robust to the inclusion of trade costs and other factors. The percentage of a country's labor force that is skilled is, in turn, highly correlated (about 88 percent) with per-capita income. In addition to this correlation between income elasticity and skill intensity and because of it, we find a significant correlation between demand and supply across goods and services within a country. Again, this controls for trade costs and is not largely driven by these costs.

Structural estimation allows us to calibrate a general-equilibrium system. Our first results assess the contribution of non-homothetic preferences (and their relationship to factor intensities) to the "missing trade" puzzle. Our finding is that we can explain about one third or more of missing trade. This is driven by the supply-demand correlation within countries which is absent with homothetic preferences. Here, we find countries relatively specialized in consuming the same goods that they are specialized in producing.

A second set of results relate to trade patterns and trading partners. Our estimation demonstrated that high-income countries have a comparative advantage in high-income-elasticity goods and services, because these goods are skilled-labor intensive and because the high-income countries are skilled-labor abundant. This suggests that rich countries are more like to export to other rich countries and we verify that this is the case. Since rich countries are also the largest markets in terms of GDP, a country's level of trade/GDP is likely to depend largely on whether such a country has a large penetration into the richest markets. But the largest penetrations into rich markets are by other rich countries as just note. We demonstrate that richer countries have higher trade to GDP ratios, and that this relationship is stronger under non-homothetic demand.

A final set of results shed light on a heated debate from the 1990s: the growing gap between skilled and unskilled wages, where the two main hypotheses both focused on the supply side of the economy. One was a Stolper-Samuelson argument coming from increased import penetration by unskilled-labor-abundant low-income countries into high-income ones, and the other focused on skill-biased technical change. Our simulations show that a uniform Hicks-neutral productivity improvement, equal across all sectors and all countries, leads to an increase in the skill premium in *all* countries. The mechanism is straightforward: higher per-capita income shifts demand toward high-income-elasticity goods, which are skilled-labor intensive. This drives up the relative wage of skilled labor in general equilibrium.

Appendix

Notations

X_{nk}: Total expenditures of country n for sector k

x_{nk}: Individual expenditures in country n for sector k

X_{nik}: Value of trade FROM country i TO country n in sector k (inverting n and i is counter-intuitive but follows Eaton and Kortum, 2002)

e_n: Income in country n

L_i: Population in country i

F_{fn}: Exogenous supply of factor f in country n.

w_{fn}: Price of factor f in country n

z_{ik}: TFP in country i in sector k.

S_{ik}: variable reflecting average unit costs (power $-\theta$) in sector k in country i (taking factor prices into account).

β_{fk}: share of factor f in total cost in sector k (assuming a Cobb-Douglas production function)

σ_k: Parameters from preferences reflecting *relative* income elasticity.

η_k: Elasticity of substitution between varieties within industry k.

θ_k: Technology parameter inversely related to productivity dispersion in sector k.

P_{nk}: CES price index in country n for goods from sector k

λ_n: Lagrangian multiplier for the budget constraint for consumers in country n.

d_{nik}: "Iceberg" transport costs between n and i in sector k.

Proof of equations (17) and (18)

Equation 18 is an approximation for a closed economy by neglecting feedback effects of the skill premium increase on relative prices. By taking nominal income as the numeraire (thus being constant), this amount to state that changes in prices are driven by changes in productivity.

As we focus on one economy, we drop country subscripts. We examine the effect of a homogenous productivity (TFP) increase across alll sectors: $\hat{z}_k = \hat{z}$. Hence:

$$\hat{p}_k \approx -\hat{z}$$

where $\hat{v} = \frac{dv}{v}$ refers to the relative change for any variable v.

Taking first differences in demand, we obtain:

$$\hat{x}_k = -\sigma_k \hat{\lambda} + (1 - \sigma_k)\hat{p}_k = -\sigma_k \hat{\lambda} + (\sigma_k - 1)\hat{z}$$

We need to solve for the change in the budget constraint lagrangian λ. We therefore take the first difference of the budget constraint. Normalizing nominal income to a constant, the following condition must be satisfied:

$$\sum_k \hat{x}_k x_k = 0$$

Inserting demand into the budget constraint, we obtain an expression for the change in lagrangian:

$$\hat{\lambda} = \frac{\sum_k (\sigma_k - 1)x_k}{\sum_k \sigma_k x_k} \hat{z}$$

After incorporating the solution for λ into the change in demand, we obtain:

$$\hat{x}_k = \hat{z}\left(-\frac{\sigma_k \sum_k (\sigma_k - 1)x_k}{\sum_k \sigma_k x_k} + (\sigma_k - 1)\right) = \hat{z}\left(\frac{\sigma_k \sum_k x_k}{\sum_k \sigma_k x_k} - 1\right)$$

Using equation (2) for the income elasticity: $\epsilon_k = \frac{\sigma_k \sum_k x_k}{\sum_k \sigma_k x_k}$, we obtain:

$$\hat{x}_k = \hat{z}(\epsilon_k - 1)$$

We can see in this expression that an improvement in productivity has a similar effect as an increase in income (keeping prices constant as a first approximation). In particular, demands increases more for income-elastic goods.

Having the change in demand for goods, we can now examine the change in the relative demand for skilled labor. We take the first difference of demand for skilled and unskilled labor. In terms of skilled wages:

$$\hat{h} = \frac{\sum_k \hat{x}_k \beta_k x_k}{\sum_k \beta_k x_k} = \sum_k \hat{x}_k sh_k^H \tag{22}$$

In terms of unskilled wages:

$$\hat{w} = \frac{\sum_k \hat{x}_k (1-\beta_k) x_k}{\sum_k (1-\beta_k) x_k} = \sum_k \hat{x}_k sh_k^L \tag{23}$$

Looking for an expression for the increase in skill premium, $\hat{s} = \hat{h} - \hat{w}$, we get:

$$\hat{s} = \hat{z} \sum_k (sh_k^H - sh_k^L)(\epsilon_k - 1) = \hat{z} \sum_k (sh_k^H - sh_k^L)\epsilon_k - \hat{z} \sum_k (sh_k^H - sh_k^L) = \hat{z} \sum_k (sh_k^H - sh_k^L)\epsilon_k$$

Hence the elasticity of the skill premium to the TFP improvement is:

$$\frac{\hat{s}}{\hat{z}} = \sum_k (sh_k^H - sh_k^L)\epsilon_k$$

General formula

Let's now prove equation (17). We continue taking nominal income as the numeraire. This imposes that average wage increase weighted by the corresponding:

$$(\sum_k x_k \beta_k)\hat{h} + (\sum_k x_k (1-\beta_k))\hat{w} = 0$$

Turning to prices, we now consider the effect of factor prices on goods prices. Taking first differences, we get:

$$\hat{p}_k = -\hat{z} + \beta_k \hat{h} + (1-\beta_k)\hat{w}$$

Given the constrained relationship between skilled and unskilled wages, we obtain:

$$\hat{p}_k = -\hat{z} + \Delta\beta_k \hat{s}$$

where $\Delta\beta_k = \beta_k - \frac{\sum_k x_{nk}\beta_k}{\sum_k x_{nk}}$ and reflects the skill intensity of sector k compared to average skill intensity. As in the proof of equation (18), we combine this expression with demand and the budget constraint. We obtain the lagrangian:

$$\hat{\lambda} = \left(\frac{\sum_k (\sigma_k - 1) x_k}{\sum_k \sigma_k x_k}\right)\hat{z} - \left(\frac{\sum_k \sigma_k \Delta\beta_k x_k}{\sum_k \sigma_k x_k}\right)\hat{s}$$

Reincorporating the lagrangian into the demand equation, we obtain:

$$\hat{x_k} = (\varepsilon_{nk} - 1)\hat{z} - \left[(\sigma_k - 1)\Delta\beta_k - \sigma_k \frac{\sum_k \sigma_k \Delta\beta_k x_k}{\sum_k \sigma_k x_k}\right]\hat{s}$$

Denoting a_k the term into bracket above, we obtain ξ_n by weighted a_k by $sh_k^H - sh_k^L$ and rearranging and adding the country subscript:

$$\xi_n = \frac{(\sum_k x_{nk}\beta_k\sigma_k)(\sum_k x_{nk})}{(\sum_k x_{nk}\beta_k)(\sum_k x_{nk}(1-\beta_k))}\left[\frac{\sum_k x_{nk}\beta_k\Delta\beta_k(\sigma_k - 1)}{\sum_k x_{nk}\beta_k\sigma_k} - \frac{\sum_k x_{nk}\Delta\beta_k(\sigma_k - 1)}{\sum_k x_{nk}\sigma_k}\right]$$

Gravity equation estimates

Table 6 below presents the results of the gravity equation estimations (equation 21). The first column shows the average estimated coefficient across industries while the second column shows the standard deviation of the coefficient estimate across industries. These standard errors reflect the variations of the coefficients across industries but do not reflect measurement errors: all coefficient estimates are significant at the 1% level for most industries.

Simulation equations

We have in hand data or estimates for the following variables that can be taken as exogenous:[33]

L_n	from GTAP
σ_k	estimated in the last stage
μ_k	estimated in the last stage
α_k	estimated in the last stage
F_{if}	estimated as the value spent on factors in the data $\sum_{n,k}\beta_{k,f}X_{nik}$
z_{ik}	estimated in the grativy equations as S_{ik}(taken at the power$1/\theta$)
τ_{nik}	estimated in the gravity equations (taken at the power$1/\theta$)

[33]Concerning factor prices we assume that they equal one in the data, which implicitely rescale endowments; this does not matter anyway because the change in factor prices should correspond to the change in factor demand assuming that factor endowment is exogenous and constant.

Table 6: Coefficients from the gravity equation estimations

Variable:	Mean of estimated coeffs across industries	SD of estimated coeffs across industries
Distance (log)	-0.941	0.504
Home bias	4.545	1.982
Contiguity	0.518	0.488
Common lang.	0.378	0.305
Colonial link	0.171	0.444
Exporter FE	Yes	
Importer FE	Yes	
Nb. of industries	50	

Notes: Poisson regressions; dependent variable: trade flows; step 1 of the estimation procedure described in the text. The coefficient above are estimated separately for each industry.

Our demand-parameter estimates are obtained from specification D1 assuming $\theta = 4$. All other variables are simulation outcomes. We need to solve for: λ_n, e_n, X_{nk}, X_{nik}, w_{nf} and S_{ik}. Each equation is associated with the corresponding variable for the mixed-complementarity solver in GAMS:

- Bilateral pricing (associated with X_{nik}):

$$\tau_{nik} T_{ik}^{-1} \prod_f (w_{fi})^{\beta_{fk}} \geq p_{nik}$$

- Trade (associated with p_{nik}):

$$X_{nik} = \frac{p_{nik}^{-\theta}}{\sum_j p_{njk}^{-\theta}} X_{nk}$$

- Price index (associated with X_{nk}):

$$\Big(\sum_j p_{njk}^{-\theta}\Big)^{-\frac{1}{\theta}} \geq P_{nk}$$

- Total demand by sector (coupled with P_{nk}):

$$X_{nk} = L_n (\lambda_n)^{-\sigma_k} \alpha_{6,k} (P_{nk})^{1-\sigma_k}$$

- Budget constraint (associated with λ_n):

$$L_n e_n = \sum_k X_{nk}$$

- Factor market clearing (associated with w_{fi}):

$$F_{fi} w_{fi} = \sum_{n,k} \beta_{fk} X_{nik}$$

- Per capita income (associated with e_n):

$$L_i e_i = \sum_f F_{fi} w_{fi}$$

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