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Trade and Real Wages of the Rich and Poor: Evidence from Brazil and Mexico*

Zheli He†

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Trade liberalization affects real-wage inequality through two channels: the distribution of nominal wages across workers and, if the rich and the poor consume different bundles of goods, the distribution of price indices across consumers. I provide a unified framework incorporating both channels by allowing for nonhomothetic preferences and worker heterogeneity across jobs. I parametrize the model for 40 regions using sector-level trade and production data and find that China's productivity growth decreases the relative nominal wage of the poor and the relative price index for the poor in Mexico and Brazil. On net, real-wage inequality falls in the two countries in the baseline case.

1. INTRODUCTION

Import competition shocks may impact individuals' real wages through their nominal wages and their consumer price indices. The changes in their nominal wages depend on changes in producer prices and the jobs in which they are employed, which are determined by characteristics such as age, gender, and educational attainment. On the other hand, the changes in their consumer price indices depend on changes in the prices of the baskets of goods that they consume, which are determined by their nominal wages in addition to prices. A vast majority of the literature focuses on the effect of trade on the distribution of nominal wages. A small number of studies consider its differential impact on consumer price indices. In this paper, I provide a unified framework that incorporates both the *expenditure channel* (i.e., changing consumer price indices), and the *income channel* (i.e., changing nominal wages), to measure the distributional effects of trade on a large cross-section of regions.[1]

I build a model combining demand heterogeneity across consumers with productivity heterogeneity across workers. On the demand side, I use the Almost-Ideal Demand System (AIDS) to capture nonhomothetic preferences. This demand specification allows the consumption baskets of high-income and low-income individuals to differ so that price changes resulting from import competition shocks have a differential impact on their consumer price indices. On the supply side, I use a Ricardo-Roy model of the labor market parametrized with a Fréchet distribution to capture the heterogeneity of workers across jobs.[2] Individuals have comparative advantage across sectors—based on their age, gender, and educational attainment—and, therefore, sort into different sectors. Consequently, price changes resulting from import competition shocks have a differential impact on individuals' nominal wages depending on the sectors in which they work. In addition, I also allow individuals to differ in their absolute advantage, such that labor groups differ in their average productivity and, therefore, have different nominal wages regardless of individuals' sectoral choices.[3] This assumption generates a potential link between the skill distribution and the wage distribution and, as a result, a potential correlation between the changes in individuals' nominal wages and the changes in their consumer price indices.

I parametrize the model for a sample of 40 regions (27 European countries and 13 other large regions) and 35 sectors using a range of datasets including the World Input–Output Database (WIOD) and the Integrated Public Use Microdata Series, International (IPUMS-I). WIOD provides information on bilateral

[1] I focus on labor earnings, which are the main source of income for most people.

[2] As discussed in Costinot and Vogel (2015), a Ricardo-Roy model is a trade model in which production functions are linear, as in the original Ricardian model, but one in which countries may be endowed with more than one factor, as in the Roy model. When the number of factors in each country is equal to 1, the R-R model collapses to the Ricardian model. But regardless of the particular application, the key feature of R-R models is that factors' marginal products are constant, and hence so are marginal rates of technical substitution. As a result, comparative advantage (i.e., relative differences in productivity) drives the assignment of factors to sectors around the world.

[3] Workers in a labor group share the same observable characteristics such as age, gender, and educational attainment.

trade flows and production data.[4] I derive a sectoral nonhomothetic gravity equation that allows me to estimate the elasticity of substitution and the income elasticity of goods as follows.[5] First, I estimate the elasticity of substitution by projecting regions' sectoral expenditure shares onto trade costs. Second, I estimate the income elasticity of each good using the following insight: if high-income regions spend relatively more on a good, then I infer that this good is high-income elastic. IPUMS-I provides publicly available nationally representative survey data for 82 regions that are coded and documented consistently across regions and over time. It reports individual-level information including age, gender, educational attainment, labor income, and sector of work. This rich database enables me to estimate the Fréchet dispersion parameter of the within-group distribution of efficiency units across sectors, which determines the extent of worker reallocation and, thus, the responsiveness of group average wages to changes in sectoral output prices. In addition, I am able to estimate the comparative advantage of different labor groups across sectors based on observed worker sorting patterns. Intuitively, if a worker type (relative to another worker type) is more likely to sort into a sector (relative to another sector), then I infer that they are relatively more productive in that sector. Using the estimates of group average wages and other parameters, I can back out the absolute advantage of different labor groups.

With these parameter estimates, I conduct a number of counterfactual analyses to quantify the effects of an increase in Chinese import competition on real-wage inequality in Mexico and Brazil. In the baseline case, I consider China's productivity growth between 1995 and 2007 before adjusting for intermediate goods.[6] I find that, in Mexico, individuals whose nominal wages are initially at the 10th percentile of the distribution experience a 6.09% reduction in their consumer price indices, while individuals whose nominal wages are at the 90th percentile see their consumer price indices decrease by 2.61%. Similarly, I find that, in Brazil, China's productivity growth leads to a 3.63% reduction in consumer price indices for the 10th percentile and a 0.73% increase for the 90th percentile. These results arise because the prices of low-income elastic manufacturing goods decrease relative to high-income elastic service goods, which benefit poor individuals who spend relatively more on these goods. Although the former experience a decline in their relative nominal wages because they are more likely to work in manufacturing sectors, this income effect is more than offset by their much lower consumer price indices. Rising Chinese import competition increases the real wages of the poor by 2.05 percentage points more than those of the rich in Mexico, and by 3.23 percentage points more in Brazil. To assess the robustness of these findings, I also conduct several

[4] One important feature of the WIOD is that it includes the input–output transactions of a region with itself. Typically, the domestic market accounts for the large majority of demand for most production.

[5] The sectoral nonhomothetic gravity equation based on the AIDS was first derived in Fajgelbaum and Khandelwal (2016). However, their model assumptions imply that there is no change in relative income across consumers.

[6] Hsieh and Ossa (2016) also report China's productivity growth after adjusting by the share of value-added in gross production in order to take into account the effect of intermediate goods. Since productivity shocks propagate through input–output linkages, these estimates fall substantially. I also consider the effects of China's productivity growth after adjusting for intermediate goods in this paper.

sensitivity analyses including using China's productivity growth after adjusting for intermediate goods as well as alternative values of income elasticities. I obtain similar results in all cases.[7]

A vast body of research has examined the impact of trade on the distribution of earnings across workers. Most recently, Galle, Rodriguez-Clare, and Yi (2017) develop the notion of "risk-adjusted gains from trade" to evaluate the full distribution of welfare changes in one measure which generalizes the specific-factors intuition to a setting with endogenous labor allocation. Similarly, I examine changes in relative nominal wages across labor groups that result from changes in relative demand across sectors driven by international trade. Burstein, Morales, and Vogel (2018) instead focus on changes in workforce composition, occupation demand, computerization, and labor productivity as the driving forces behind changes in relative wages between labor groups in the US. Their study is one of the first to use an assignment framework with many labor groups, equipment types, and occupations parametrized with a Fréchet distribution, which I follow in my supply-side specification.[8] There are a small number of studies that have considered price indices as a channel through which trade liberalization can affect inequality. For example, Fajgelbaum and Khandelwal (2016) develop a methodology to measure the unequal gains from trade through the expenditure channel using only aggregate statistics. I extend this approach to incorporate the differential impact of import competition shocks on individuals' nominal wages. In contrast, Faber (2014) exploits barcode-level microdata from the Mexican Consumer Price Index and studies the relative price effect of NAFTA on the differential change in the cost of living between rich and poor households.[9] Atkin, Faber, and Gonzalez-Navarro (2018) draw on a new collection of Mexican microdata to estimate the effect of foreign supermarket entry on household welfare. They consider both the price index effect and the income effect, but focus only on the gains from retail FDI. I complement the existing literature by incorporating both expenditure and income channels as well as their interaction in a unified framework to analyze the heterogeneous impact of counterfactual trade shocks across individuals in a large set of regions.

To my knowledge, there are only three case studies that have looked at these two channels jointly. Porto (2006) studies the distributional effects of Mercosur, a regional trade agreement between Argentina, Brazil, Paraguay, and Uruguay, during the 1990s. Nicita (2009) extends Porto's approach by adding a link from

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[7] In He (2017), I consider a counterfactual exercise in which there is a 5% reduction in all bilateral trade costs among the 40 regions in my sample. I also re-examine the impact of a significant increase in US manufacturing imports from China on real-wage inequality in the US while accounting for both channels and their interaction. Please refer to that paper for more details.

[8] See also Adão (2016), Galle, Rodriguez-Clare, and Yi (2017), and Dix-Carneiro and Kovak (2015). I do not incorporate some of the mechanisms that have been studied in the literature linking international trade to inequality through the earnings channel. For example, Yeaple (2005), Verhoogen (2008), Bustos (2011), Burstein and Vogel (2016) and Bloom et al. (2018) show that trade liberalization increases the measured skill bias of technology by reallocating resources from less to more skill-intensive firms within industries and/or inducing firms to increase their skill intensity. A major difficulty is the lack of a comprehensive, matched employer-employee dataset that covers the period of rising inequality in many regions, which is usually confidential. In addition, these papers highlight the role of firms because the standard neoclassical theory of trade is inconsistent with the empirical finding that nominal wage inequality goes up everywhere in response to trade liberalization. I show that in a neoclassical setting, nonhomothetic preferences allow the model to be fully consistent with the data. Therefore, which mechanism is more important becomes an open question.

[9] Relevantly, Faber and Fally (2018) use detailed matched US home and store scanner microdata to explore the implications of firm heterogeneity for household price indices across the income distribution.

trade policy to domestic prices and studies the trade liberalization that took place in Mexico during 1990–2000. Marchand (2012) allows the tariff pass-through to differ across geographical regions and studies the trade reforms in India between 1988 and 2000. The structure of my model allows me to estimate the effects for more regions. By looking at a wide range of regions, I am able to identify general patterns across regions with different characteristics. I am also able to conduct model-based counterfactuals of different trade shocks which are important for policymakers. In addition, as critiqued in Goldberg and Pavcnik (2007), the predictions of these studies depend in a crucial way on estimates of the degree of pass-through from trade policy changes to product prices as well as wage-price elasticities. These are difficult to estimate consistently with time-series data on wages and prices in a setting when many other policies change contemporaneously with trade.

The remainder of the paper proceeds as follows. In section 2, I describe my multisector Armington model of trade with nonhomothetic preferences on the demand side and heterogeneous labor with comparative advantage across sectors on the supply side. Section 3 contains a description of the data, and estimation strategy, and the results are presented in section 4. In section 5, I discuss my counterfactual results. Section 6 concludes.

2. THE MODEL

A. The environment

I study an economy with N regions indexed by $n \in \mathcal{N} = \{1, \ldots, N\}$ and J final good sectors indexed by $j \in \mathcal{J} = \{1, \ldots J\}$. Each good is defined as a sector-region of origin pair. Within any $(j, n) \in \mathcal{J} \times \mathcal{N}$, output is homogeneous, and the market is perfectly competitive. In region n, there is a continuum of heterogeneous workers indexed by $z \in \mathcal{Z}^n$ with measure L^n.[10] They are grouped into a finite number of types indexed by $\lambda \in \Lambda$ with measure $L^n(\lambda)$ based on observable characteristics: age, gender, and education. I assume that types are mutually exclusive.

B. Definition of welfare change

Consider home region h and a set of infinitesimal changes in log prices, $\left\{\widehat{p_{(j,n)}^h}\right\}_{(j,n)\in\mathcal{J}\times\mathcal{N}}$ and log wages, $\{\widehat{w_z}\}_{z\in\mathcal{Z}^h}$.[11] I define the local welfare change of individual z as the equivalent variation associated with this set of changes:[12]

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[10] My model is static, so I am not taking any stand on the accumulation of skills in response to import competition shocks. I take each region's endowments of skills as given for now, but introducing dynamics into the framework would be a boon.

[11] $\widehat{p_{(j,n)}^h} \equiv d\ln(p_{(j,n)}^h)$ is the infinitesimal change in the log prices, and $\widehat{w_z} \equiv \partial\ln(w_z)$ is the infinitesimal change in the log wages.

[12] Please see Appendix 7.1 for the derivation of the local welfare change as the equivalent variation.

$$\widehat{u_z} = \sum_j \sum_n s^z_{(j,n)} \left(-\widehat{p^h_{(j,n)}}\right) + \widehat{w_z}.$$

Here, $s^z_{(j,n)}$ is the initial individual expenditure share on good (j,n). Individuals' welfare is affected in two ways. The first is changes in their cost of living resulting from changes in prices, which I refer to as the expenditure effect. Specifically, it is price changes applied to the preshock expenditure shares. A decrease in prices reduces the cost of living and therefore increases individuals' welfare. The second is the changes in their nominal wages, which I refer to as the income effect.

I can further decompose the local welfare change for individual z into three components:

$$\underbrace{\widehat{u_z}}_{total effect} = \underbrace{\sum_j \sum_n s^z_{(j,n)} \left(-\widehat{p^h_{(j,n)}}\right)}_{expenditure effect} + \underbrace{\widehat{w_z}}_{income effect}$$

$$= \underbrace{\sum_j \sum_n S^h_{(j,n)} \left(-\widehat{p^h_{(j,n)}}\right)}_{aggregate expenditure effect \equiv \widehat{E^h}} + \underbrace{\sum_j \sum_n \left(s^z_{(j,n)} - S^h_{(j,n)}\right) \left(-\widehat{p^h_{(j,n)}}\right)}_{individual expenditure effect \equiv \widehat{\psi_z}}$$

$$+ \underbrace{\widehat{w_z}}_{income effect}.$$

The total effect is the sum of the aggregate expenditure effect, $\widehat{E^h}$, the individual expenditure effect, $\widehat{\psi_z}$, while the income effect, $\widehat{w_z}$. $S^h_{(j,n)}$ is region $h's$ aggregate expenditure share on good (j,n). The aggregate expenditure effect can be thought of as the impact of import competition shocks on the cost of living either in the absence of within-country inequality or under homothetic preferences. This effect is the same across all individuals within a region h. On the other hand, the individual expenditure effect implies that if individual z spends more on good (j,n), then the price decrease of that good increases their welfare by a larger amount.

C. Nonhomothetic preferences

I use the Almost-Ideal Demand System (AIDS), introduced by Deaton and Muellbauer (1980), to capture the nonhomotheticity in consumer preferences. It gives an arbitrary first-order approximation to any demand system and satisfies the axioms of order, aggregates over consumers without invoking parallel linear Engel curves, is consistent with budget constraints, and is simple to estimate. The AIDS allows consumption baskets of high-income and low-income individuals to differ so that price changes resulting from import competition shocks can have a differential impact on their consumer price indices. It belongs to the family of Log Price-Independent Generalized Preferences defined by the following indirect utility function:

$$v\left(w_z, \mathbf{p}^h\right) = F\left[\left(\frac{w_z}{a(\mathbf{p}^h)}\right)^{1b(\mathbf{p}^h)}\right],$$

where $F[\cdot]$ is a continuous, differentiable, and strictly increasing function. The AIDS is the special case that satisfies:

$$a(\mathbf{p}^h) = \exp\{\alpha + \sum_j \sum_n \alpha^h_{(j,n)} \ln p^h_{(j,n)} +$$

$$\frac{1}{2}\sum_j \sum_n \sum_{j'} \sum_{n'} \gamma_{(j,n)(j',n')} \ln p^h_{(j,n)} \ln p^h_{(j',n')}\Bigg\}$$

$$b(\mathbf{p}^h) = \exp\left\{\sum_j \sum_n \beta_{(j,n)} \ln p^h_{(j,n)}\right\},$$

where $a(\mathbf{p}^h)$ is a homothetic price aggregator which captures the cost of a subsistence basket of consumption goods. α is the outlay required for a minimal standard of living, when prices are unity. $\alpha^h_{(j,n)}$ is importer h's taste for good (j,n). $\gamma_{(j,n)(j',n')}$ is the cross elasticity between two goods (j,n) and (j',n'). $b(\mathbf{p}^h)$ is a nonhomothetic price aggregator which captures the relative price of high-income elastic goods. Goods for which $\beta_{(j,n)} > 0$ have positive income elasticity, while goods for which $\beta_{(j,n)} < 0$ have negative income elasticity. For AIDS to be a proper demand system, the following parametric restrictions need to be satisfied:[13]

$$\sum_j \sum_n \alpha^h_{(j,n)} = 1$$

$$\sum_j \sum_n \beta_{(j,n)} = 0$$

$$\sum_j \sum_n \gamma_{(j,n)(j',n')} = 0$$

$$\gamma_{(j,n)(j',n')} = \gamma_{(j',n')(j,n)}.$$

Applying Shephard's Lemma to the indirect utility function, I can derive the individual expenditure shares as follows:

$$s^z_{(j,n)} = s_{(j,n)}(w_z, \mathbf{p}^h)$$

$$= \alpha^h_{(j,n)} + \sum_{j'} \sum_{n'} \gamma_{(j,n)(j',n')} \ln p^h_{(j',n')} + \beta_{(j,n)} \ln\left(\frac{w_z}{a(\mathbf{p}^h)}\right).$$

[13] Under these constraints, the budget share equations share the properties of a demand function, that is, they are homogeneous of degree 0 in prices and total expenditure, the sum of budget shares add up to 1, and they satisfy the symmetry of the Slutsky matrix.

According to this equation, if individuals have relatively low nominal wages, then they spend relatively more on low-income elastic goods. Under the AIDS, I can describe the market by the behavior of a representative consumer with the inequality-adjusted average nominal wage, $\widetilde{w}^h = \overline{w}^h e^{\Sigma^h}$. It depends on the average nominal wage in region h, $\overline{w}^h$, and the Theil index, $\sum h \equiv \mathbb{E}[\frac{w^h}{\overline{w}^h}\ln(\frac{w^h}{\overline{w}^h})]$, a measure of inequality within a region.[14] Deriving the aggregate expenditure shares in region h is therefore straightforward:

$$S^h_{(j,n)} = s_{(j,n)}\left(\widetilde{w}^h, \mathbf{p}^h\right)$$

$$= \alpha^h_{(j,n)} + \sum_{j'} \sum_{n'} \gamma_{(j,n)(j',n')} \ln p^h_{(j',n')} + \beta_{(j,n)} \ln\left(\frac{\widetilde{w}^h}{a(\mathbf{p}^h)}\right). (1)$$

Similarly, adjusted for the price level, $a\left(\mathbf{p}^h\right)$, if region h has a higher inequality-adjusted average nominal wage, $\widetilde{w}^h$, either because of a higher average nominal wage or higher inequality, then it spends relatively more on high-income elastic goods.

It is convenient to rewrite the individual expenditure effect under the AIDS as:

$$\widehat{\psi_z} = \sum_j \sum_n \left(s^z_{(j,n)} - S^h_{(j,n)}\right)\left(-\widehat{p^h_{(j,n)}}\right)$$

$$= -\ln\left(\frac{w_z}{\widetilde{w}^h}\right) \underbrace{\sum_j \sum_n \beta_{(j,n)} \widehat{p^h_{(j,n)}}}_{\widehat{b^h}}.$$

Intuitively, for an individual z who has a lower nominal wage relative to the representative consumer in the region, if the price of a low-income elastic good goes down, he or she is better off and vice versa. Note that I do not have to observe each individual z's expenditure share on each good (j,n) in order to compute the changes in their consumer price indices as long as $\boldsymbol{\beta} = \{\beta_{(j,n)}\}$ has been estimated.

Plugging in the above expression for $\widehat{\psi_z}$, I can write the local welfare change of individual z under the AIDS that corresponds to an infinitesimal change in prices and nominal wages as follows:

$$\widehat{u_z} = \widehat{E^h} - \ln(\frac{w_z}{\widetilde{w}^h})\widehat{b^h} + \widehat{w_z}.$$

If I only consider first-order effects, that is, the effect of import competition shocks through changes in the prices of goods and returns to labor, and not in the quantities sold or purchased (Nicita,2009), then I can derive the global welfare change of individual z from the initial trade equilibrium, tr, to a counterfactual scenario, cf, as follows:[15]

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[14] The Theil index is a measure of inequality that takes the minimum $\sum = 0$ if the distribution is concentrated at a single point. In the case of a log-normal expenditure distribution with variance σ^2, it is $\sum = \frac{1}{2}\sigma^2$.

[15] Please see Appendix 7.2 for the derivation of the aggregate and individual expenditure effects without substitution effects.

$$\underbrace{u_z^{tr\to cf}}_{total\ effect} = \underbrace{(\frac{E_{cf}^h}{E_{tr}^h})}_{aggregate\ expenditure\ effect} \underbrace{(\frac{w_z^{tr}}{\widetilde{w}_{tr}^h})^{-\ln(b_{cf}^h/b_{tr}^h)}}_{individual\ expenditure\ effect} \underbrace{(\frac{w_z^{cf}}{w_z^{tr}})}_{income\ effect}$$

$$\frac{E_{cf}^h}{E_{tr}^h} = \prod_{(j,n)} (\frac{p_{(j,n)}^{h,tr}}{p_{(j,n)}^{h,cf}})^{S_{(j,n)}^h}$$

$$-\ln(\frac{b_{cf}^h}{b_{tr}^h}) = -\sum_j \sum_n \beta_{(j,n)} \ln(\frac{p_{(j,n)}^{h,cf}}{p_{(j,n)}^{h,tr}}). (2)$$

In this case, I hold the expenditure shares, which are a function of current prices and income, constant. This is used by Nicita (2009), Porto (2006), etc., to measure the welfare gains from a cheaper consumption basket induced by trade liberalization.[16]

Since I am able to estimate own-price and cross-price demand elasticities, I can also directly calculate the global welfare change of individual z with substitution effects according to the definition of equivalent variation, which takes into account the possible response of expenditure shares to price changes:[17]

$$\frac{\ln(w_z^{tr} + u_z^{tr\to cf}) - \ln a(\boldsymbol{p}_{tr}^h)}{\ln b(\boldsymbol{p}_{tr}^h)} = \frac{\ln w_z^{cf} - \ln a(\boldsymbol{p}_{cf}^h)}{\ln b(\boldsymbol{p}_{cf}^h)},$$

which implies,

$$u_z^{tr\to cf} = \exp\{[\frac{\ln w_z^{cf} - \ln a(\boldsymbol{p}_{cf}^h)}{\ln b(\boldsymbol{p}_{cf}^h)}] * \ln b(\boldsymbol{p}_{tr}^h) + \ln a(\boldsymbol{p}_{tr}^h)\} - w_z^{tr}. (3)$$

I divide $u_z^{tr\to cf}$ by w_z^{tr} to compute welfare changes in percentage terms. In both cases, if $u_z^{tr\to cf} < 1$, individual z is worse off after the change and vice versa.

D. Heterogeneous labor with comparative advantage across sectors

My supply-side specification allows for heterogeneous labor with comparative advantage across sectors so that different labor types sort into different sectors. As a result, price changes resulting from import competition shocks can have a differential impact on their nominal wages. I use a Ricardo-Roy model of the labor market parametrized with a Fréchet distribution. In this environment, workers with different unobservable characteristics but identical observable characteristics may be allocated to different sectors in a competitive equilibrium.[18] In particular, an arbitrary worker z of type λ draws a vector of efficiency units across different sectors from a Fréchet distribution:[19]

[16] Nicita (2009) and Porto (2006) use the observed share of income spent on goods from household surveys to measure the effect of trade liberalization on household utility through consumption.

[17] Please refer to Appendix 7.3 for more details.

[18] I assume that the labor market is perfectly competitive, that is, there is no friction. Dix-Carneiro and Kovak (2015) finds that workers' median costs for switching sectors range from 1.4 to 2.7 times individual annual average wages but these vary tremendously across individuals with different observable characteristics. For example, female, less-educated, and older workers face substantially higher costs of switching as a fraction of

$$G(\boldsymbol{\epsilon}(z);\lambda) = \Pr[e(z;j) \leq \epsilon(z;j)\ \forall j]$$
$$= \exp\{-\epsilon(z;j)^{-\theta(\lambda)}\},$$

where $\theta(\lambda) > 1$ governs within-type dispersion of efficiency units across sectors. Worker z inelastically supplies $\epsilon(z;j)$ efficiency units of labor if he or she chooses to work in sector j.

Production requires only one factor, labor.[20] The production function in region h, sector j, using l efficiency units of labor type λ is:[21]

$$y^h(l;\lambda,j) = A^h A^h(\lambda) T^h(\lambda,j) l.$$

A^h is region $h's$ aggregate productivity. $A^h(\lambda)$ is the productivity of type λ workers in region h and $T^h(\lambda,j)$ is the productivity of type λ workers in region h who choose to work in sector j. $A^h(\lambda)$ captures the absolute advantage of type λ workers in region h, while $T^h(\lambda,j)$ captures the comparative advantage of type λ workers in region h and sector j. Consider the partial equilibrium in which output prices, $\{p^h_{(j,h)}\}_{j\in\mathcal{J}}$, are given. Perfect competition and free entry entail that the per-efficiency-unit wage, $x^h(\lambda,j)$, of a worker of labor type λ working in sector j in region h is:

$$x^h(\lambda,j) = p^h_{(j,h)} A^h A^h(\lambda) T^h(\lambda,j).$$

Worker $z \in \mathcal{Z}^h(\lambda)$ with realization of the vector of efficiency units $\boldsymbol{\epsilon}(z) = \{\epsilon(z;j)\}_{j\in\mathcal{J}}$ needs to choose the sector that maximizes labor earnings, which are the product of their draw of efficiency units and per-efficiency-unit wage:

$$w_z = \max_j w_z(j) = \epsilon(z;j) \cdot x^h(\lambda,j).$$

The Fréchet distribution implies that the probability of a type λ worker choosing to work in sector j in region h is:

$$\pi^h(\lambda,j) = \frac{\left[p^h_{(j,h)} A^h A^h(\lambda) T^h(\lambda,j)\right]^{\theta(\lambda)}}{\sum_{j'\in\mathcal{J}} \left[p^h_{(j',h)} A^h A^h(\lambda) T^h(\lambda,j')\right]^{\theta(\lambda)}}$$

individual wages. This increases the probability of unemployment of the low-skilled and biases the gains from trade toward the high-skilled and high-income.

[19] Fréchet distributions of productivity shocks across factors have been imposed in the recent closed-economy models of Lagakos and Waugh (2013) and Hsieh et al. (2018) as well as the open economy models of Burstein, Morales, and Vogel (2018) and Costinot, Donaldson, and Smith (2016). Sector and region characteristics are assumed to be perfectly observed by the econometrician, but factor characteristics are not.

[20] For simplicity, I abstract from capital in my production function. Capital may matter for two reasons. First, it may generate comparative advantage across sectors. This is very similar to introducing Hicks-neutral capital, where capital is more important in some sectors than others. That would generate technological differences at the region–sector level. Capital reallocation reinforces labor reallocation in response to import competition shocks. Second, capital may be differentially complementary to different types of labor. In that case, there is a large number of cross elasticities I need to estimate, which is challenging. In addition, I do not feature complementarity between different types of equipment and heterogeneous workers across sectors as in Burstein, Morales, and Vogel (2018) because I do not have data to compute the share of total hours worked by each labor group that is spent using different equipment types across sectors.

[21] Cross-region difference in Ricardian-type region–sector productivity is driven by both technology and factor endowment in Ricardo-Roy models, and they offer variations of Factor Price Equalization, Rybczynski, and Stolper-Samuelson theorems. See Costinot and Vogel (2015) for a detailed discussion.

$$= \frac{x^h(\lambda, j)^{\theta(\lambda)}}{x^h(\lambda)^{\theta(\lambda)}},$$

where $x^h(\lambda) \equiv \left(\sum_j x^h(\lambda, j)^{\theta(\lambda)}\right)^{\frac{1}{\theta(\lambda)}}$. With a higher $\theta(\lambda)$, which implies that there is less dispersion of efficiency units across sectors, a change in price or a change in productivity affects the factor allocation even more.

As a result, the worker sorting pattern is determined by comparative advantage:

$$\frac{\left[\frac{\pi^h(\lambda', j')}{\pi^h(\lambda', j)}\right]^{\frac{1}{\theta(\lambda')}}}{\left[\frac{\pi^h(\lambda, j')}{\pi^h(\lambda, j)}\right]^{\frac{1}{\theta(\lambda)}}} = \frac{\left[\frac{T^h(\lambda', j')}{T^h(\lambda', j)}\right]}{\left[\frac{T^h(\lambda, j')}{T^h(\lambda, j)}\right]}.$$

If type λ' workers (relative to type λ workers) have a comparative advantage in sector j' (relative to sector j), then they are more likely to sort into sector j', adjusted for potentially different values of $\theta(\lambda)$ and $\theta(\lambda')$. For larger $\theta(\lambda')$, that is, less dispersion in efficiency units among type λ' workers, it is even more likely for them to sort into sector j', in which they have a comparative advantage.

The distribution for $w_z = \max_j w_z(j)$ conditional on $z \in \mathcal{Z}^h(\lambda)$ is:

$$\Pr\left(w_z \leq w | z \in \mathcal{Z}^h(\lambda)\right) = \exp\{-x^h(\lambda)^{\theta(\lambda)} w^{-\theta(\lambda)}\}.$$

This is also distributed Fréchet with the scale parameter, $x^h(\lambda)$, the average per-efficiency-unit wage of labor type λ across the sectors, along with the dispersion parameter, $\theta(\lambda)$.[22]

The average nominal wage, $\bar{w}^h$, and the Theil index, $\sum h$, in region h can also be expressed in terms of $x^h(\lambda)$ and $\theta(\lambda)$:

$$\bar{w}^h = \sum_\lambda \frac{L^h(\lambda)}{L^h} \Gamma(\lambda) x^h(\lambda) \quad (4)$$

$$\Sigma^h = \frac{1}{\bar{w}^h} \sum_\lambda \frac{L^h(\lambda)}{L^h} \Gamma(\lambda) \left(x^h(\lambda) \ln x^h(\lambda) - \frac{\Psi(\lambda)}{\theta(\lambda)} x^h(\lambda)\right) - \ln \bar{w}^h, \quad (5)$$

where $\Gamma(\lambda) \equiv \Gamma\left(1 - \frac{1}{\theta(\lambda)}\right)$ is the gamma function, and $\Psi(\lambda) \equiv \Psi\left(1 - \frac{1}{\theta(\lambda)}\right)$ is the digamma function.

E. General equilibrium

In the general equilibrium, output prices, $\{p^h_{(j,h)}\}_{j \in \mathcal{J}}$, are determined by the market-clearing conditions:

$$\sum_\lambda y^h\left(L^h(\lambda)\pi^h(\lambda, j); \lambda, j\right) = \sum_n \tau^n_{(j,h)} D^n_{(j,h)} \ \forall j \in \mathcal{J}, \quad (6)$$

[22] Burstein and Vogel (2016) find that the wage distribution implied by the assumption of Fréchet distributions is a good approximation to the observed distribution of individual wages.

where $y^h = A^h A^h(\lambda) T^h(\lambda, j) \Gamma(\lambda) \pi^h(\lambda, j)^{1-\frac{1}{\theta(\lambda)}} L^h(\lambda)$ is the supply of sector j good by labor type λ in region h.[23] $\tau^n_{(j,h)}$ is the bilateral trade costs between export region h and import region n in sector j. $D^n_{(j,h)} = (S^n_{(j,h)} \bar{w}^n L^n)/p^n_{(j,h)}$ is region n's demand for good (j, h), where $S^n_{(j,h)}$ is given by equation (1), and $\bar{w}^n$ is given by equation (4). It depends on region n's wage distribution, i.e., $\bar{w}^n$ and Σ^n, as well as the vector of prices that consumers face in that region $\mathbf{p}^n$, i.e., $p^n_{(j,h)} = \tau^n_{(j,h)} p^h_{(j,h)}$. Since these output prices enter both the demand side and the supply side nonlinearly, I apply the Gauss-Jacobi algorithm, an iterative method, to solve the system of market-clearing equations numerically.[24] I also appeal to the Implicit Function Theorem to show that the price equilibrium that I find numerically is locally isolated as a function of the parameters.[25] That is, in response to a small perturbation, if there exists an equilibrium, then the system stays in the neighborhood of that equilibrium. I find no quantitative evidence of multiple equilibria.[26]

F. Discussion

This paper serves as an extension of two recent papers that have studied heterogeneous welfare implications of trade. It extends Fajgelbaum and Khandelwal (2016) by introducing multiple factors and worker reallocation across sectors and extends Galle, Rodriguez-Clare, and Yi (2017) by introducing nonhomothetic preferences.[27] More specifically, if income elasticities, $\beta_{(j,n)} = 0 \; \forall j \in J, n \in N$—that is, the demand system—are homothetic, the model collapses to the one described in Galle, Rodriguez-Clare, and Yi (2017). On the other hand, if $T^h(\lambda, j) = 1 \; \forall h \in N, \lambda \in \Lambda, j \in J$—that is, there is no comparative advantage of different labor types across sectors—then the model collapses to the one described in Fajgelbaum and Khandelwal (2016).[28] My supply-side specification also follows Burstein, Morales, and Vogel (2018) closely, who use an assignment framework with many labor groups, equipment types, and occupations parametrized with a Fréchet distribution to quantify the impact of workforce composition, occupation demand, computerization, and labor productivity on changes in US between-group inequality.

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[23] Please see Appendix 7.4 for the derivation of the total supply.
[24] I demonstrate the existence of an equilibrium numerically.
[25] Please refer to Appendix 7.5 for a brief discussion of the Gauss-Jacobi Algorithm and the local property of the equilibrium.
[26] I have tried multiple starting points, and the system always converges to the same equilibrium.
[27] The model in Galle, Rodriguez-Clare, and Yi (2017) combines three components: a multisector version of the Eaton and Kortum (2002) model as in Costinot, Donaldson, and Komunjer (2012); a Roy model of the allocation of heterogeneous labor to sectors with a Fréchet distribution as in Lagakos and Waugh (2013); and the existence of different labor groups differing in their pattern of comparative advantage across sectors. Similarly, in my model, if $\theta(\lambda) \to 1 \; \forall \lambda$, then the supply side has the same welfare and counterfactual implications as the model in which labor is sector-specific. On the other hand, if $\tau^n_{(j,h)} \to \infty \; \forall n \neq h$ and $\Lambda = 1$, then economy h is in autarky and collapses to the Roy model in Lagakos and Waugh (2013) and Hsieh et al. (2018).
[28] There are still differences between my model and Galle, Rodriguez-Clare, and Yi (2017) and Fajgelbaum and Khandelwal (2016) even under these assumptions. For example, both of these papers explicitly model cross-country differences in sectoral productivity driven by technology. I do not, since in my model, differences in skill endowments across countries generate the variation in specialization across sectors. In addition, within-country inequality in Fajgelbaum and Khandelwal (2016) is generated by the variation in the endowment of the single factor of production across consumers, while in this paper, it is generated by the difference in their absolute advantage.

3. DATA

For the demand-side estimation, I use mainly the World Input–Output Database (WIOD), which provides information on bilateral trade flows and production data for 40 regions (27 European countries and 13 other large regions) and 35 sectors in the economy. It also distinguishes between final consumption and intermediate uses.[29] The schematic outline of a World Input–Output Table is presented in figure 1.

For the supply-side estimation, I use mainly the Integrated Public Use Microdata Series, International (IPUMS-I), which provides publicly available nationally representative survey data for 82 regions that are coded and documented consistently across regions and over time. It also provides individual-level data with labor incomes and worker characteristics. I divide the workers in the IPUMS-I dataset into 18 disjoint groups, Λ, by age (15–24, 25–49 and 50–74), gender (male and female), and educational attainment (ED0–2: less than primary, primary, and lower secondary education; ED3–4: upper secondary and postsecondary nontertiary education; and ED5–8, tertiary education).

FIGURE 1. SCHEMATIC OUTLINE OF A WORLD INPUT–OUTPUT TABLE (WIOT)

			Use by country-industries							Final use by countries			Total use
			Country 1			…	Country M			Country 1	…	Country M	
			Industry 1	…	Industry N	…	Industry 1	…	Industry N		…		
Supply from country-industries	Country 1	Industry 1											
		…											
		Industry N											
	……												
	Country M	Industry 1											
		…											
		Industry N											
Value added by labour and capital													
Gross output													

4. PARAMETRIZATION

A. Supply-side parameters

On the supply side, I calibrate $\theta(\lambda)$, the worker-type-specific Fréchet dispersion parameter; $L^h(\lambda)/L^h$, the fraction of type λ workers in region h; A^h, region $h's$ aggregate productivity; $A^h(\lambda)$, the productivity of type λ workers in region h and $T^h(\lambda, j)$, the productivity of type λ workers in region h who choose to work in sector j.

To calibrate the worker-type-specific Fréchet dispersion parameter $\theta(\lambda)$, I follow the methodology in Lagakos and Waugh (2013) and Hsieh et al. (2018) and match the moments of the empirical distribution of

[29] I do not use the UN Comtrade Database because it does not have information on the input–output transactions of a region with itself.

within-type worker wages.[30] In particular, the mean and the variance of nominal wages within a labor group satisfy:

$$\frac{VAR[w_z|z \in \mathcal{Z}^h(\lambda)]}{E[w_z|z \in \mathcal{Z}^h(\lambda)]^2} = \frac{\Gamma\left(1 - \frac{2}{\theta(\lambda)}\right)}{\Gamma\left(1 - \frac{1}{\theta(\lambda)}\right)^2} - 1.$$

I restrict my sample in the following way: I drop workers who are younger than 15 years old, are self-employed or work part-time (<30 hours per week), do not report positive labor earnings, or have missing information on age, sex, or education. I also drop the top and bottom 1% of earners to remove potential outliers, and to minimize the impact of potential cross-region differences in top-coding procedures. All calculations in my analysis are weighted using the applicable sample weights. I measure w_z as the annual labor earnings; $\epsilon(z;j)$ captures both the hours worked and efficiency units of worker z who chooses to work in sector j; $\theta(\lambda)$ reflects dispersion in both the hours worked and efficiency units of type λ workers; and $L^h(\lambda)$ is the headcount of type λ workers.

I use IPUMS-I to calibrate $\theta(\lambda)$ for 16 regions.[31] Since the estimates of $\theta(\lambda)$ are very close across the 16 regions for each labor type λ, I use the average of these estimates for all regions and assume that $\theta(\lambda)$ does not change over time. I back out $x^h(\lambda)$ using $\mathbb{E}[w_z|z \in \mathcal{Z}^h(\lambda)] = x^h(\lambda)\Gamma(1 - \frac{1}{\theta(\lambda)})$ for the 16 regions. Since all earnings data in IPUMS-I are in local currency units, I use the official exchange rate (LCU per US$, period average) from the World Bank to convert all values to US$. I also find that output-side real GDP per capita has strong explanatory power for $x^h(\lambda)$, so I use the predicted values of $x^h(\lambda)$ for the rest of the regions.[32]

Since IPUMS-I does not provide information on $L^h(\lambda)/L^h$ for all of the 40 regions, I use the following complementary datasets. First, I use Eurostat, which provides information on full-time and part-time employment by age, gender, and educational attainment. It includes 27 European countries in WIOD. Second, I use UNdata, which has information for Russia, Australia, Korea, and China on the population 15 years of age and over, also by age, gender, and educational attainment. This dataset comes from UNSD Demographic Statistics–United Nations Statistics Division. Third, I use National Statistics, Republic of China (Taiwan), and finally, Population Statistics of Japan.

In order to estimate the sector-level nonhomothetic gravity equation, which I explain in detail in the next section, I need to compute the inequality-adjusted average nominal wage of each region, which requires an estimate of its average nominal wage as well as its Theil index. Table 1 reports my estimates of the average

[30] This approach is also implemented in section D.4 in Burstein, Morales, and Vogel (2018)

[31] The list of regions can be found in Appendix 8.1.1.

[32] I obtain the data on output-side real GDP at chained PPPs (in millions of 2005 US$) and population from the Penn World Tables.

labor earnings and the Theil index for the 40 regions based on equations (4) and (5). I estimate $\overline{w}^h$ and $\sum h$ for the years 2005, 2006, and 2007, and then take the average.

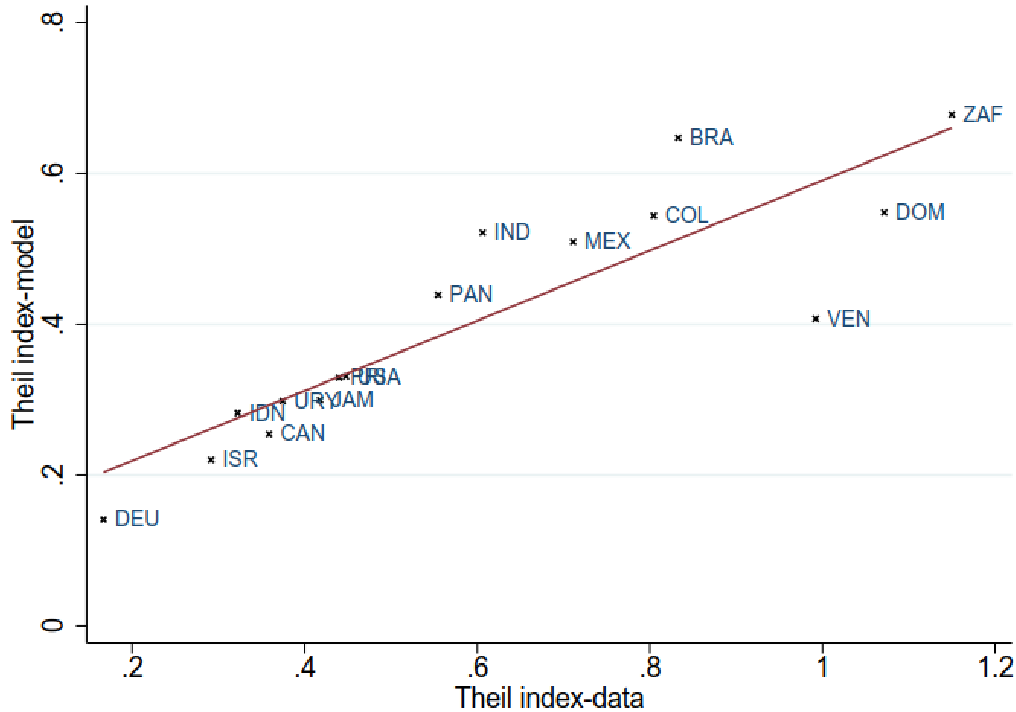
Recall that the Theil index, $\sum h \equiv \mathbb{E}[\frac{w^h}{\overline{w}^h}\ln(\frac{w^h}{\overline{w}^h})]$, measures the level of inequality within a region, which in my framework is the dispersion in labor incomes. I construct Theil indices using labor earnings of the population aged between 15 and 74 for the 16 regions in IPUMS-I where the required income data are available. In figure 2, I compare these Theil indices calculated from the data with those implied by my model based on equation (5). Their correlation is significantly positive at 0.8795.

In figure 3, I plot my model-implied labor earnings per capita against output-side GDP per capita. My measure of income per capita tracks the data very well. These parameter implications provide evidence that my model assumptions on the supply side do well at matching the data.

As discussed above, the worker sorting pattern can be used to calibrate $T^h(\lambda, j)$. In each region h, there are $\Lambda * J = 18 * 35 = 630$ parameters to calibrate. I pick $j = 1$ as the benchmark sector such that $T^h(\lambda, j = 1) = 1\ \forall\lambda$. This assumption leads to 18 normalizations. In addition, comparative advantage, $\frac{\left[\frac{\pi^h(\lambda',j')}{\pi^h(\lambda',1)}\right]^{\frac{1}{\theta(\lambda')}}}{\left[\frac{\pi^h(1,j')}{\pi^h(1,1)}\right]^{\frac{1}{\theta(1)}}} = \frac{\left[\frac{T^h(\lambda',j')}{T^h(\lambda',1)}\right]}{\left[\frac{T^h(1,j')}{T^h(1,1)}\right]} = \frac{T^h(\lambda\prime,j\prime)}{T^h(1,j\prime)}$, provides 17*34=578 additional equations for $\lambda' \neq 1$ and $j' \neq 1$. In order to pin down $T^h(\lambda, j)$, I further impose that $\frac{1}{\Lambda}\sum_\lambda T^h(\lambda, j) = 1\ \forall j \neq 1$. This last condition is automatically satisfied for $j = 1$ under the aforementioned normalization, and it generates another 34 equations. Neither the normalization nor the additional restriction prevents $T^h(\lambda, j)$ from capturing the comparative advantage of different labor types in different sectors. As a result, I have 630 equations to solve for 630 unknowns, which ensures exact identification. Finally, I rescale $T^h(\lambda, j)$ such that $\frac{1}{J}\sum_j T^h(\lambda, j) = 1\ \forall\lambda$ to avoid the systematic bias caused by the arbitrary picking of $j = 1$ as the benchmark sector. Intuitively, labor groups with higher levels of education are more productive in any other sector than agriculture. Consequently, they have higher $T^h(\lambda, j)\ \forall j \neq 1$, which leads to a downward bias in $A^h(\lambda)$ as described below. To calibrate $T^h(\lambda, j)$, I need data on $\pi^h(\lambda, j) = L^h(\lambda, j)/L^h(\lambda)$, where $L^h(\lambda, j)$ is the headcount of type λ workers in region h that choose to work in sector j. IPUMS-I provides information on individual characteristics (age, gender, and educational attainment) and sector of work for 22 countries.[33] I calculate the OECD and non-OECD averages of $T^h(\lambda, j)$ for a given (λ, j), and apply them to the remaining regions based on their membership of the OECD. In the case that no labor group of a country works in a sector, I set $T^h(\lambda, j) = 0$ for that sector j and $\forall\lambda$.

[33] The list of regions can be found in Appendix 8.1.2.

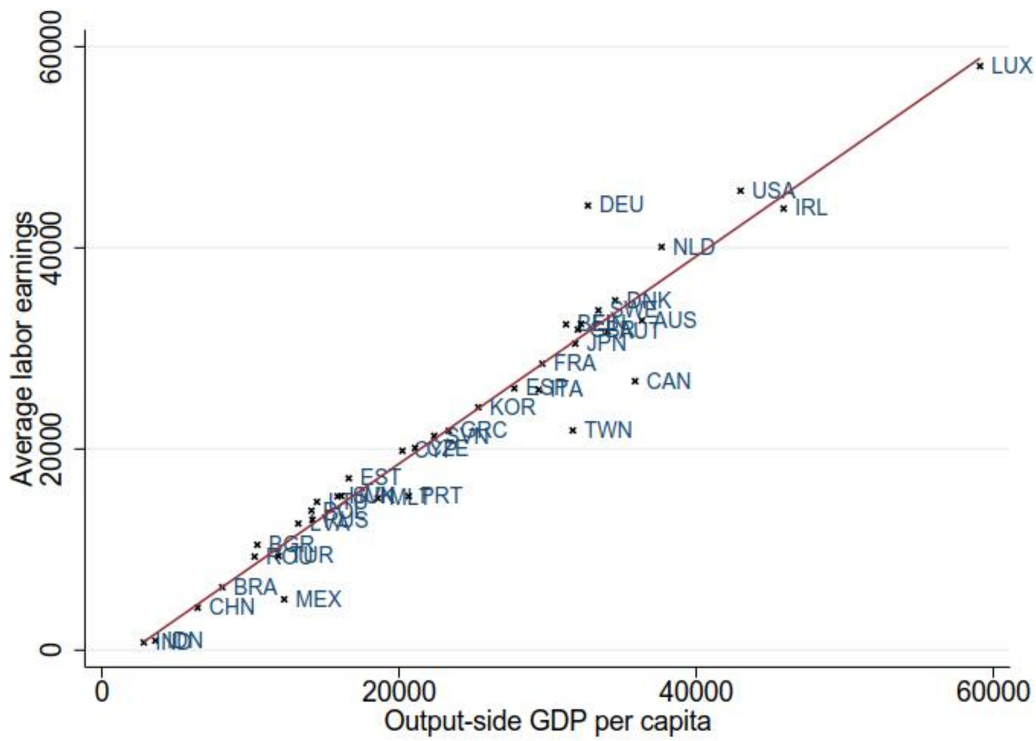
FIGURE 2. THEIL INDICES



To calibrate $A^h(\lambda)$, the productivity of group λ workers in region h, I adjust the average per-efficiency-unit wage of labor group λ, $x^h(\lambda)$, relative to labor group 1, $x^h(1)$, by the estimates of their comparative advantages, $T^h(\lambda, j)$ and $T^h(1, j)$.[34] I assume that $A^h(\lambda = 1) = 1\ \forall h$, that is, the absolute advantage of labor group 1 is 1 in every country.[35] Figure 4 is a bar chart that plots the average $A^h(\lambda)$ across regions for each of the 18 labor groups by age, gender, and educational attainment. As expected, for those who are of the same age and gender, the less education one receives, the lower the average value of $A^h(\lambda)$. In addition, for those who are of the same gender and have the same level of education, the younger the worker is, the lower the average value of $A^h(\lambda)$. Finally, a female worker has lower average $A^h(\lambda)$ than her male counterpart. Zooming in on education, I aggregate the 18 labor groups into three broad categories. The bar chart on the right illustrates that less-educated individuals have lower $A^h(\lambda)$ on average, regardless of their age and gender. This implies that less-educated workers have lower nominal wages once comparative advantages are controlled for. Finally, I rescale $A^h(\lambda)$ such that $\sum_\lambda A^h(\lambda) = \frac{1}{N}\sum_h \left(\sum_\lambda A^h(\lambda)\right) \forall h \in N$. In this way, $A^h(\lambda)$ still reflects the productivity advantage of labor group λ relative to labor group 1 in region h. However, a larger dispersion in $A^h(\lambda)$ across labor groups no longer leads to an upward bias in a region's average income level as predicted by the model.

[34] Please see Appendix 8.2 for more details.
[35] Please refer to table 4 for a description of the characteristics of each labor group.

FIGURE 3. AVERAGE LABOR EARNINGS



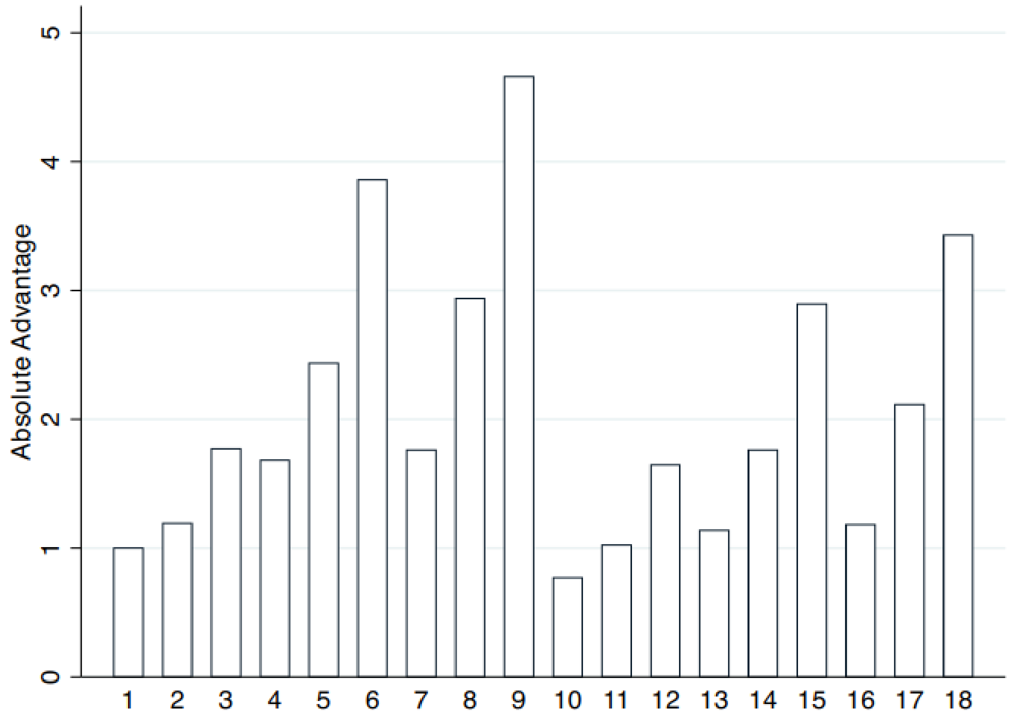
Note that I assume $A^h(\lambda = 1) = 1 \; \forall h$. To accurately capture the difference in average income level, I calibrate a region's aggregate productivity, A^h, relative to country 1, where I assume $A^1 = 1$. Since A^h and output prices cannot be separately identified, I add this parameter to the unknowns, and use the following equation:

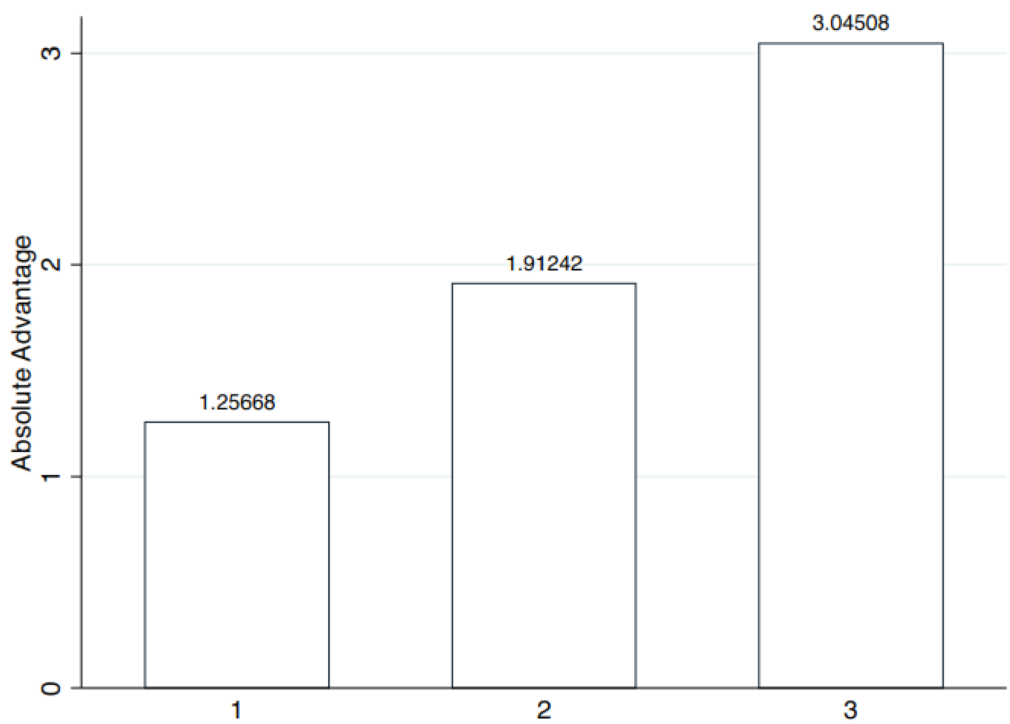
$$\frac{x^h(1)}{x^1(1)} = A^h(\sum_j [p^h_{(j,h)} A^h(1) T^h(1,j)]^{\theta(1)})^{\frac{1}{\theta(1)}} / A^1(\sum_j [p^1_{(j,1)} A^1(1) T(1,j)]^{\theta(1)})^{\frac{1}{\theta(1)}},$$

along with the market-clearing equations to solve for them jointly.[36] Recall that I calibrate $x^h(\lambda)$, the average per-efficiency-unit wage of labor type λ across sectors using data on group-specific average nominal wage as well as the value of $\theta(\lambda)$. I calibrate $T^h(\lambda, j)$ and $A^h(\lambda)$ as stated above.

[36] I have N-1 additional equations to solve for N-1 additional unknowns.

FIGURE 4. $A^h(\lambda)$ AND EDUCATION





B. Demand-side parameters

On the demand side, I follow the estimate strategy in Fajgelbaum and Khandelwal (2016) closely except using my model-implied average nominal wage, $\bar{w}^h$, in equation (4), and the Theil index, $\sum h$, in equation (5). More specifically, I assign 0 to α, the outlay required for a minimal standard of living when prices are unity. I estimate the vector of income elasticities, $\boldsymbol{\beta} = \{\beta_{(j,n)}\}$, the matrix of cross elasticities, $\boldsymbol{\Gamma} = \{\gamma_{(j,n)(j',n')}\}$, and $\alpha^h_{(j,n)}$, and the overall taste in region h for the goods exported by region n in sector j.

On top of the regularity restrictions imposed by the AIDS, I impose additional assumptions on the matrix $\boldsymbol{\Gamma}$ to reduce the number of parameters I estimate:

$$\gamma_{(j,n)(j',n')} = \begin{cases} \frac{\gamma_j}{N} & j = j', n \neq n' \\ -\left(1 - \frac{1}{N}\right)\gamma_j & j = j', n = n'. \\ 0 & j \neq j' \end{cases}$$

In other words, this implies that within the same sector, cross elasticities are the same between goods produced by different regions, and across sectors, there is no substitution.[37]

Under these parametric restrictions, the sectoral nonhomothetic gravity equation is:[38]

$S^h_{(j,n)} \equiv \frac{Y^h_{(j,n)}}{Y^h} = \frac{Y_{(j,n)}}{Y^W} + K^h_{(j,n)} - \gamma_j M^h_{(j,n)} + \beta_{(j,n)}\Omega^h$,(7)

where $\frac{Y_{(j,n)}}{Y^W}$ captures the size of the exporter n in sector j in the world economy; $K^h_{(j,n)} = \alpha^h_{(j,n)} - \sum_{n'} \left(\frac{Y^{n'}}{Y^W}\right) \alpha^{n'}_{(j,n)}$ captures the differences in taste across regions for different goods; $M^h_n = \ln\left(\frac{\tau^h_{(j,n)}}{\bar{\tau}_j{}^h}\right) - \sum_{n'} \left(\frac{Y^{n'}}{Y^W}\right) \ln\left(\frac{\tau^{n'}_{(j,n)}}{\bar{\tau}^{n'}_j}\right)$ captures bilateral trade costs and multilateral resistance, and $\Omega^h = y^h - \sum_{n'} \left(\frac{Y^{n'}}{Y^W}\right) y^{n'}$ is the nonhomothetic component of the gravity equation. For example, a region with a high Ω^h, either because of its high average nominal wage or its high inequality, is predicted to consume more of the high-income elastic goods.

Following Fajgelbaum and Khandelwal (2016), I proxy $K^h_{(j,n)}$ with the product of the exporter fixed effect and region h's expenditure share in sector j relative to the world. Since I do not directly observe the trade costs between region pairs, I proxy them with bilateral observables.

To be more specific, I assume importer h's taste for good (j,n), $\alpha^h_{(j,n)}$, can be decomposed into an exporter effect, a_n, a sector effect, a_j, and an importer taste for that sector, ε^h_j:

[37] Normalization by the number of regions N is mainly for notational simplicity.

[38] Please see Appendix 8.3 for the derivation of the sector-level nonhomothetic gravity equation.

$$\alpha_{(j,n)}^h = a_n(a_j + \varepsilon_j^h).$$

Under the additional assumptions for $\boldsymbol{\Gamma}$, aggregate expenditure shares are:

$S_{(j,n)}^h = \alpha_{(j,n)}^h - \gamma_j \ln p_{(j,n)}^h + \frac{\gamma_j}{N}\sum_{n'=1}^N \ln p_{(j,n')}^h + \beta_{(j,n)} y^h$.(8)

Therefore, the sectoral expenditure shares become:

$S_j^h = \sum_n S_{(j,n)}^h = \bar{\alpha}_j^h + \bar{\beta}_j y^h$,(9)

where $\bar{\alpha}_j^h = \sum_n \alpha_{(j,n)}^h$ and $\bar{\beta}_j = \sum_n \beta_{(j,n)}$. In the absence of nonhomotheticity, $\bar{\beta}_j = 0\ \forall j$. In that case, the upper tier is Cobb-Douglas with fixed expenditure shares, $\{\bar{\alpha}_j^h\}_{j\in\mathcal{J}}$. I further impose the restriction that $\sum_{n=1}^N \alpha_n = 1$. This re-expresses $K_{(j,n)}^h = a_n(S_j^h - S_j^W) - a_n\bar{\beta}_j\Omega^h$.[39]

I assume that the bilateral trade costs take the form $\tau_{(j,n)}^h = (d_n^h)^{\rho_j}(l_n^h)^{-\delta_j^l}(b_n^h)^{-\delta_j^b}$, where bilateral distance, common language, and border information is obtained from CEPII's Gravity Dataset. This re-expresses $M_{(j,n)}^h = \rho_j \triangle_n^h - \delta_j^l L_n^h - \delta_j^b B_n^h$, where $\triangle_n^h \equiv \ln\left(\frac{d_n^h}{\bar{d}^h}\right) - \sum_{n'} \frac{Y^{n'}}{Y^W}\ln\left(\frac{d_n^{n'}}{\bar{d}^{n'}}\right)$ and $\bar{d}^{n'} = \exp\left(\frac{1}{N}\sum_n \ln d_n^{n'}\right)$. L_n^h and B_n^h are defined in the same way. To separately identify γ_j, I again follow Fajgelbaum and Khandelwal (2016) and set the elasticity of trade costs with respect to distance, $\rho^j = \rho = 0.177$.

Recall that $\Omega^h = y^h - \sum_{n'}\left(\frac{Y^{n'}}{Y^W}\right) y^{n'}$, where $y^h = \ln(\frac{\bar{w}^h}{a(p^h)}) + \sum h$. I proxy the homothetic price aggregator, $a(p^h)$, with a Stone index: $a(p^h) = \sum_n S_n^h \ln(p_{nn}(d_n^h)^\rho)$, where p_{nn} are the quality-adjusted prices estimated in Feenstra and Romalis (2014).[40] I obtain estimates of $\bar{w}^h$ and $\sum h$ from the supply side as reported in the last section.

The estimating equation that I take to the data is the following:

$\frac{Y_{(j,n)}^h}{Y^h} - \frac{Y_{(j,n)}}{Y^W} = a_n(S_j^h - S_j^W) - (\gamma_j\rho)\triangle_n^h + (\gamma_j\delta_j^l)L_n^h + (\gamma_j\delta_j^b)B_n^h + \tilde{\beta}_{(j,n)}\Omega^h + \epsilon_{(j,n)}^h$,(10)

where $\tilde{\beta}_{(j,n)} = \beta_{(j,n)} - a_n\bar{\beta}_j$. To separately identify $\beta_{(j,n)}$, I need to estimate a_n (in the same equation) and $\bar{\beta}_j = \sum_n \beta_{(j,n)}$ from $S_j^h = \bar{\alpha}_j^h + \bar{\beta}_j y^h = \sum_n \alpha_{(j,n)}^h + \bar{\beta}_j y^h = a_j + \bar{\beta}_j y^h + \varepsilon_j^h$. The left-hand side of the equation is computed from WIOD, using average flows between 2005 and 2007 to smooth out

[39] Please see Appendix 8.4 for the derivation of $K_{(j,n)}^h$.

[40] Deaton and Muellbauer (1980) show that the Stone index is an excellent approximation to the homothetic price aggregator in their application to postwar British data. Atkin (2013) and Fajgelbaum and Khandelwal (2016) follow the same strategy. Because $a(p^h)$ is independent from nonhomotheticies and can be interpreted as the cost of a subsistence basket of goods, I follow Fajgelbaum and Khandelwal (2016) to use the quality-adjusted prices in Feenstra and Romalis (2014) to compute it. They estimate quality and quality-adjusted price indexes for 185 countries over 1984–2011 in an extended monopolistic competition framework where, in addition to choosing price, firms simultaneously choose quality subject to nonhomothetic demand. They find that the observed differences in export unit values are attributed predominantly to quality, with very small remaining differences in quality-adjusted export prices. Since richer countries (with higher utility) may import higher quality and richer (more productive) countries export higher quality goods, it is more appropriate to use quality-adjusted prices to calculate $a(p^h)$.

any temporary shocks. In the benchmark, I compute expenditure shares as a percentage of total expenditures. As a robustness check, I compute expenditure shares as a percentage of final consumption. Finally, to estimate $\alpha_{(j,n)}^{h}$, I assume that it can be decomposed into an exporter effect, a_n, a sector-specific effect, a_j, and an importer specific taste for that sector, ε_j^h: $\alpha_{(j,n)}^{h} = a_n(a_j + \varepsilon_j^h)$ as before. I use the estimate of a_n from equation (10) and that of $a_j + \varepsilon_j^h$ from equation (9).[41]

Table 2 reports my estimates of the cross-substitution elasticities between different suppliers of a good within each sector. Note that the sector-level nonhomothetic gravity equations add up to a single-sector gravity equation. The sum of my estimates of γ_j across sectors is 0.24. It is very close to the estimate in Fajgelbaum and Khandelwal (2016). Estimating a translog gravity equation, Novy (2013) reports $\gamma = 0.167$, while Feenstra and Weinstein (2017) reports a median γ of 0.19.

Table 3 reports my estimates of the sectoral income elasticities, $\beta_j = \sum_n \beta_{(j,n)}$. The corresponding elasticities for food, manufacturing, and services are -0.022, -0.0051, and 0.0271, respectively. I find that the service sectors have higher income elasticity, as expected.

Figure 5 plots the sectoral income elasticity computed from total expenditures and final consumption against the exporter's log average income. The correlation coefficient is about 0.4 using either measure. I find a positive relationship which implies that high-income regions specialize in the production of high-income elastic goods, which is consistent with previous findings in Hallak (2006), Khandelwal (2010), Hallak and Schott (2011), and Feenstra and Romalis (2014). The null hypothesis that all income elasticities are zero is rejected.

[41] Note that the aggregate expenditure share in equation (1) is a nonlinear function in $\alpha_{(j,n)}^{h}$ and, $\{p_{(j,h)}^{h}\}_{j\in J}$ $\forall h$, the output prices in the general equilibrium, given the estimates of γ_j and $\beta_{(j,n)}$. An alternative, which I do not pursue here, would be to use $S_{(j,n)}^{h}$ as an initial guess for $\alpha_{(j,n)}^{h}$ and solve for prices. Then, given these prices, to solve for an updated value of $\alpha_{(j,n)}^{h}$, which is used in the next iteration, and continue the process until convergence.

FIGURE 5. AVERAGE INCOME AND INCOME ELASTICITY OF PRODUCTION

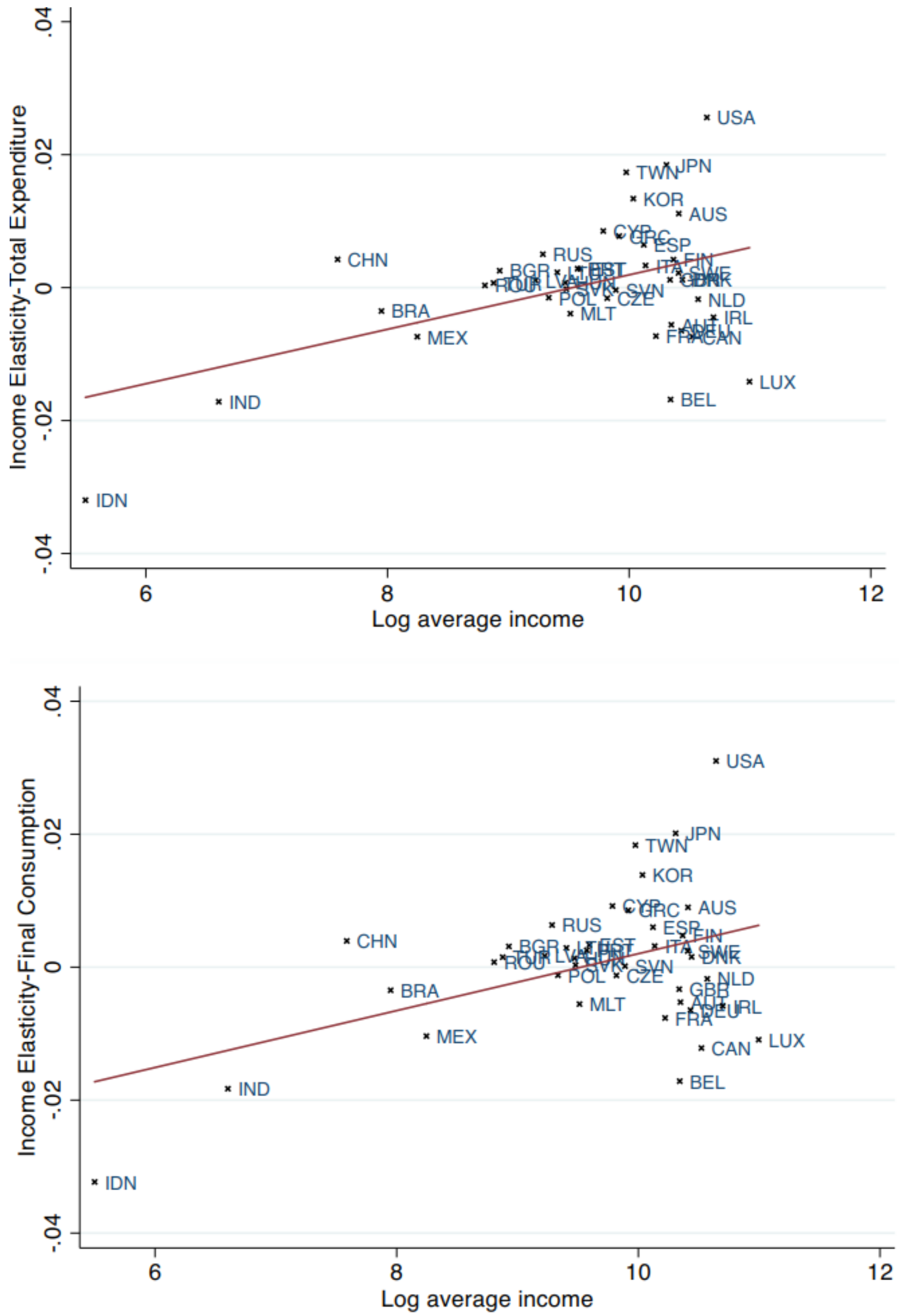


Figure 6 plots the sectoral income elasticity against the skill intensity of each sector. I find that skill-intensive sectors produce goods that have high income elasticity. The correlation coefficient is 0.4 when I use total expenditures to estimate the sectoral income elasticity. This implies that a decline in the relative price of low-income elastic goods is correlated with a decline in the relative price of goods in non-skill-intensive sectors.

FIGURE 6. SKILL INTENSITY AND SECTORAL INCOME ELASTICITY

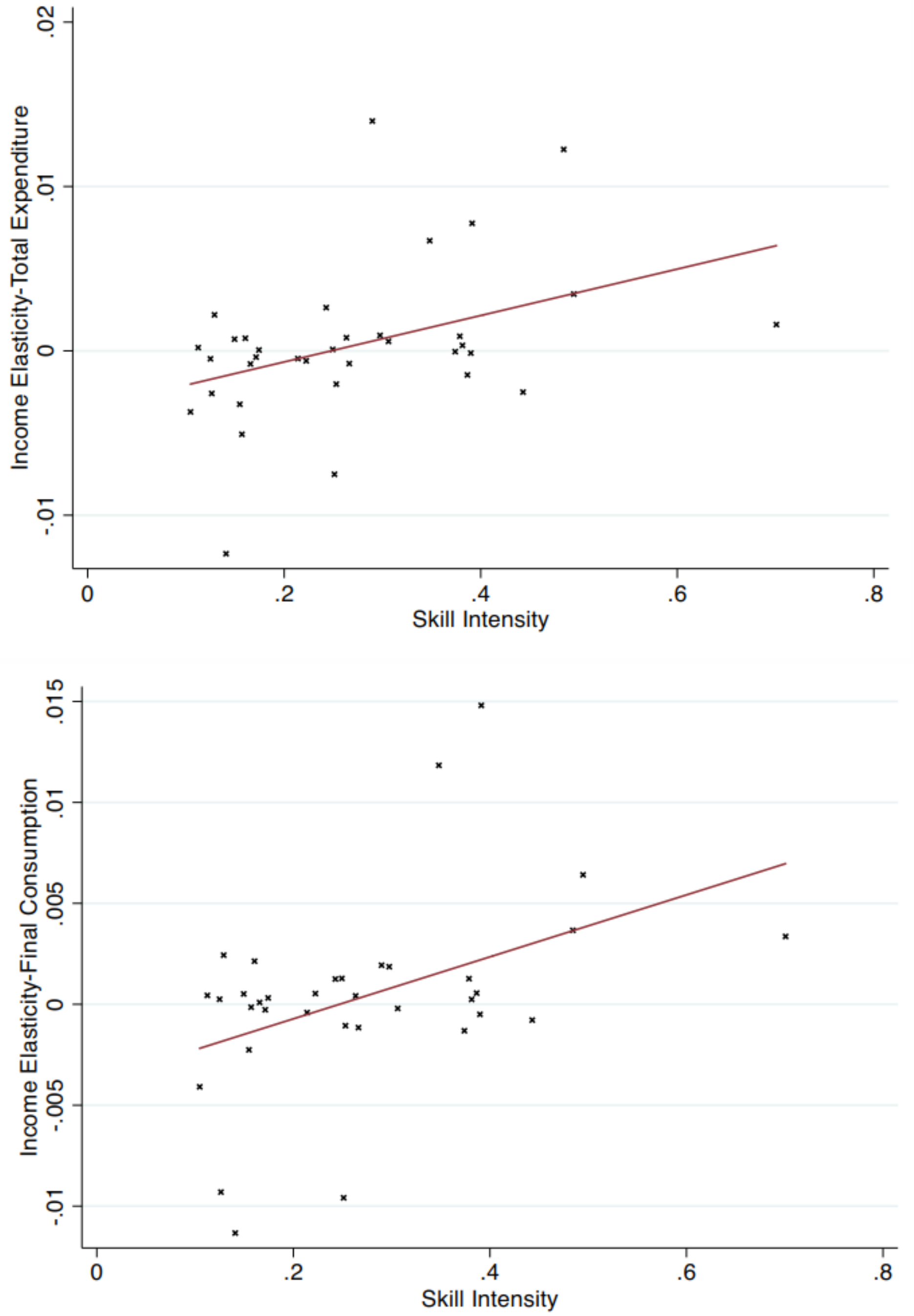
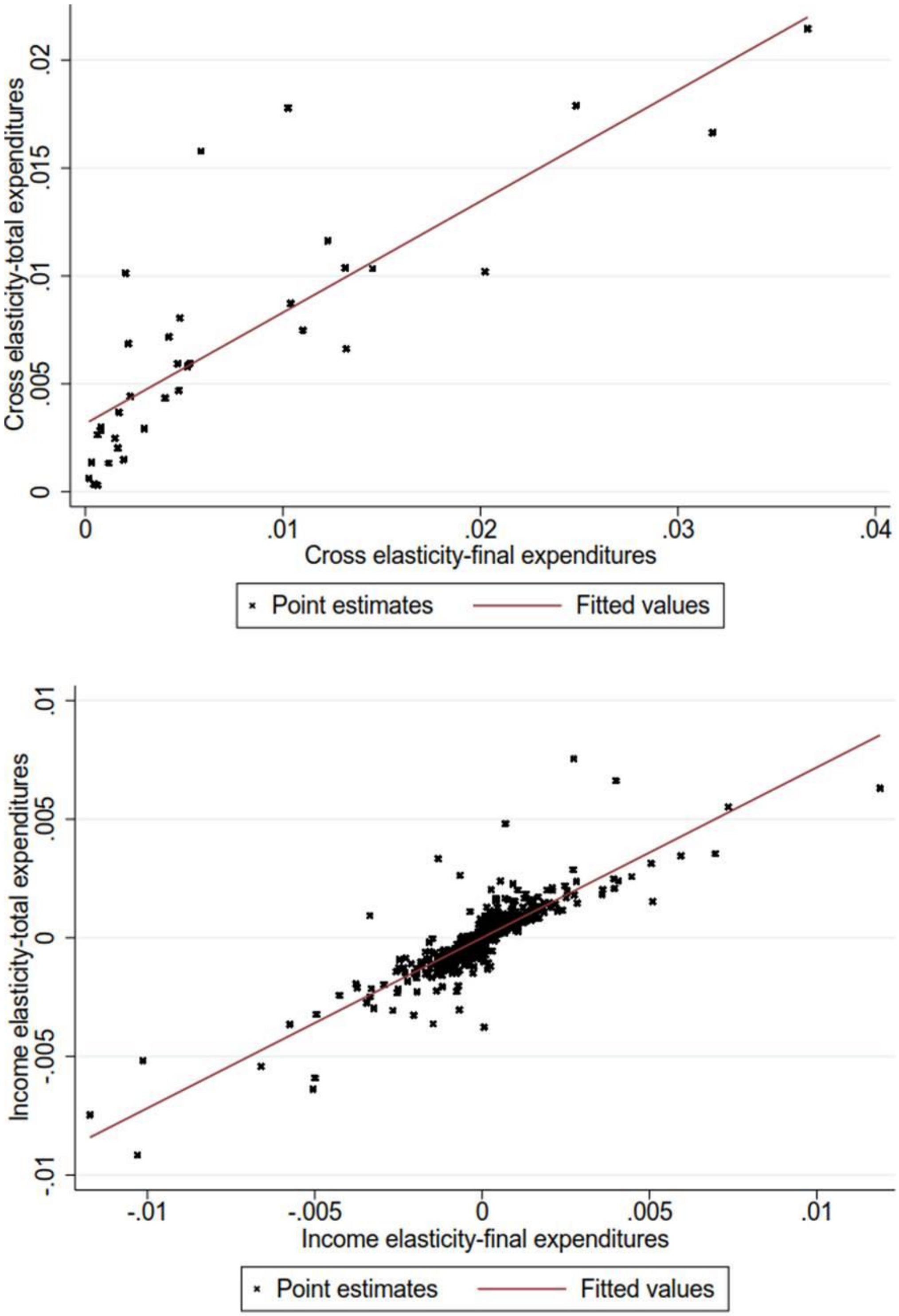


FIGURE 7. INCOME AND CROSS ELASTICITIES



5. COUNTERFACTUALS

In the counterfactuals, I focus on the global welfare change of individual z with substitution effects, which can be calculated using equation (3). To compute welfare changes through the expenditure channel, I assume that there are no changes in nominal wages, i.e., $w_z^{cf} = w_z^{tr}$. To compute welfare changes through the income channel, I assume that there are no changes in consumer prices, i.e., $\ln a(\boldsymbol{p}_{cf}^h) = \ln a(\boldsymbol{p}_{tr}^h)$ and $\ln b(\boldsymbol{p}_{cf}^h) = \ln b(\boldsymbol{p}_{tr}^h)$. To compute welfare changes through both channels, I add up these two components. To clarify, in the counterfactuals, I attribute the total welfare changes to the expenditure channel and the income channel when both channels are active. In He (2017), I study the interaction of the two channels by comparing the welfare changes when both channels are active to those when only one channel is active, e.g. $\beta_{(j,n)} = 0\ \forall j \in J, n \in N$ or $T^h(\lambda, j) = 1\ \forall h \in N, \lambda \in \Lambda, j \in J$, by resolving the model with these restrictions on the parameters. Finally, I divide $u_z^{tr\to cf}$ by w_z^{tr} to compute welfare changes in percentage terms.

Recall that a reduction in the relative price of low-income elastic goods, $b(\boldsymbol{p}^h)$, makes low-income individuals better off through a cheaper consumption basket. Meanwhile, a decline in a sector's output price decreases the relative nominal wage of the labor groups that disproportionately work in that sector in the initial equilibrium.[42]

A. The impact of Chinese competition on Mexico

In this section, I analyze the effects of China's productivity growth on real-wage inequality in Mexico, taking into account both the expenditure channel and the income channel. I use the results in Hsieh and Ossa (2016) for changes in productivity in China at the sector level. In the baseline case, I apply their estimated annual growth rate of measured productivity before adjusting for intermediate goods. For example, consider the food, beverages, and tobacco sector, in which China's productivity grew at an average rate of 12.3% each year between 1995 and 2007. To simulate this productivity growth, I increase $T^{chn}(\lambda, j = Food, Beverages, and\ Tobacco)\ \forall\lambda$ by 302.3% $(1.123^{12} - 1)$ over this 12-year period, and estimate the welfare changes of individuals at different points in the income distribution in every region in my sample from the baseline parametrization to the general equilibrium with China's productivity growth.

I find that $\ln a(\mathbf{p}^{mex})$—the homothetic price aggregator, which captures the cost of a subsistence basket of consumption goods—goes down by 0.0621, while $\ln b(\mathbf{p}^{mex})$—the nonhomothetic price aggregator, which captures the relative price of high-income elastic goods—goes up by 0.0204.[43] The

[42] For a general discussion of whether the expenditure or the income channel dominates, please refer to Appendix 9.1.

[43] $\ln a(\mathbf{p}^{mex})$ decreases from 0.0411 to -0.021. In other words, $a(\mathbf{p}^{mex})$ decreases by $(\exp(0.0411) - \exp(-0.021))/\exp(0.0411) = 6.02\%$. In the meantime, $\ln b(\mathbf{p}^{mex})$ increases from 1.1348 to 1.1552. That is, $b(\mathbf{p}^{mex})$ increases by 2.06%.

former evaluates how much the general price level decreases as a result of this shock, and the latter provides information on how much the relative price facing high-income individuals increases relative to low-income ones. If I only consider changes in the prices of manufacturing goods in Mexico, I find that $\ln a(\mathbf{p}^{mex})$ decreases by 0.0874. On the other hand, if I only consider changes in the prices of nonmanufacturing goods, $\ln a(\mathbf{p}^{mex})$ increases by 0.0253. In other words, the decline in the general price level is driven entirely by cheaper manufacturing goods while being dampened by nonmanufacturing goods that have become more expensive.

Table 5 reports the welfare changes through the expenditure channel, the income channel, and both channels in Mexico in percentage terms.[44] Why does the expenditure channel benefit the poor while the income channel benefits the rich? Consider first the manufacturing sectors. The total supply of Chinese manufacturing goods increases because productivity is higher in these sectors and more workers choose to work there. A larger fraction of workers of all types choose to work in manufacturing sectors because they have become more productive there. Consequently, the prices of Chinese manufacturing goods go down. As consumers substitute toward these cheaper goods, demand for manufacturing goods produced by other countries declines, which decreases their prices.

Next, consider nonmanufacturing sectors. In China, since more workers choose to work in manufacturing sectors, fewer workers work in nonmanufacturing sectors, given that total labor supply remains unchanged. Therefore, the total supply of Chinese nonmanufacturing goods decreases, which increases their prices. As consumers substitute away from these more expensive goods, demand for nonmanufacturing goods produced by other countries goes up, which increases their prices.

Since the prices of low-income elastic manufacturing goods go down, while the prices of nonmanufacturing goods, which are mostly high-income elastic service goods, go up, the expenditure channel benefits the poor. On the other hand, since high-income individuals who are more skilled are more likely to work in skill-intensive sectors which are high-income elastic, the income channel benefits the rich. More specifically, I find that individuals whose nominal wages are at the 10th percentile of the initial distribution experience a reduction in their consumer price indices that is 3.48 percentage points larger than those at the 90th percentile. In the meantime, while the 10th percentile see their nominal wages go down by 0.2%, the 90th percentile see their nominal wages go up by 1.19%.[45]

Combining both effects, those at the 10th percentile gain 2.05 percentage points more compared to the 90th percentile in terms of real wages as a result of China's productivity growth. That is, the pro-rich bias of

[44] Please refer to Appendix 9.2 for a more detailed explanation of the magnitude of welfare gains in my model.

[45] Burstein and Vogel (2016) study the consequences of international trade on the wage of college relative to noncollege workers (the skill premium). They find that as a result of moving from autarky to the 2006 baseline parametrization, the average change in the absolute value of the skill premium is 1.1% when only the Heckscher-Ohlin mechanism is active and there is only skill-abundance-induced comparative advantage, which matches my model specification. In other words, the small relative income effect that I have found is consistent with their results.

the income effect is more than offset by the pro-poor bias of the expenditure effect, which again underlines the importance of taking both channels into account when assessing the distributional effects of import competition shocks.

B. The impact of Chinese competition on Brazil

I obtain qualitatively similar results when I analyze the effects of China's productivity growth on real-wage inequality in Brazil as reported in table 6. More specifically, I find that individuals whose nominal wages are at the 10th percentile of the initial distribution experience a reduction in their consumer price indices that is 4.36 percentage points larger than those at the 90th percentile. In the meantime, while the 10th percentile see their nominal wages go up by 0.87%, the 90th percentile see their nominal wages go up by 2.05%. Combining both effects, the 10th percentile gain 3.23 percentage points more compared to the 90th percentile in terms of real wages as a result of China's productivity growth.

C. Productivity growth adjusting for intermediate goods

Hsieh and Ossa (2016) also adjust China's productivity growth by the share of value-added in gross production in order to take into account the effect of intermediate goods. As expected, these estimates are significantly lower, which reflects the fact that productivity shocks propagate through input–output linkages. Again, take the food, beverages, and tobacco sector as an example, China's productivity grew at an average rate of 3.5% each year between 1995 and 2007 after adjusting for intermediate goods. To simulate this productivity growth, I increase $T^{chn}(\lambda, j = Food, Beverages, and\ Tobacco)\ \forall\lambda$ by 51.1% $(1.035^{12} - 1)$ over this 12-year period, and estimate the welfare changes of individuals at different points in the income distribution in the general equilibrium. Table 7 reports the welfare changes through the expenditure channel, the income channel, and both channels in percentage terms in Mexico, and table 8 reports those in Brazil. Since annual growth rates are considerably lower than before, the magnitude of welfare changes is also considerably lower. However, I still obtain the results that the expenditure channel benefits the poor while the income channel benefits the rich in both countries.

D. Sensitivity analysis

In this section, I examine how robust my results are to different plausible values of income elasticities, $\boldsymbol{\beta} = \{\beta_{(j,h)}\}$, which are the most important parameters that determine the distributional effects of China's productivity growth.

i. Income elasticities as a function of income per capita

As mentioned in section 4, I find that high-income regions specialize in the production of high-income elastic goods, consistent with many previous empirical findings. Instead of estimating income elasticities directly from the nonhomothetic gravity equation, I restrict them to being a function of exporter income. This provides me with an alternative approach to estimate income elasticities, which is used in Feenstra and Romalis (2014), etc. This imposes more structure on the estimates by specifying a linear relationship between the income elasticity of a good and the average income level of the producing country, and the standard errors are expected to be smaller compared to the benchmark case where income elasticities are fully flexible. Specifically, I assume that $\beta_{(j,h)} = c + d_j \ln\overline{w}^h$. I allow $\beta_{(j,h)}$ to vary across j because the distributional effects of the expenditure channel and the income channel depend in a crucial way on the differences in income elasticities across sectors.[46] The restriction that $\sum_j \sum_h \beta_{(j,h)} = 0$ implies that $c = -\frac{1}{NJ}\sum_j d_j \sum_h \ln\overline{w}^h$, which I impose to estimate the sectoral Engel curve.[47] More specifically, the sectoral expenditure shares are: $S_j^n = \sum_h S_{(j,h)}^n = \sum_h \alpha_{(j,h)}^n + \sum_h \beta_{(j,h)} y^n + \epsilon_j^n$, where $\sum_h \beta_{(j,h)} = Nc + d_j \sum_h \ln\overline{w}^h = -\frac{1}{J}\sum_j d_j \sum_h \ln\overline{w}^h + d_j \sum_h \ln\overline{w}^h = \sum_h \ln\overline{w}^h (d_j - \frac{1}{J}\sum_j d_j)$. As a result, $S_j^n = \sum_h \alpha_{(j,h)}^n + (d_j - \frac{1}{J}\sum_j d_j)(\sum_h \ln\overline{w}^h) y^n + \epsilon_j^n$. Suppose the coefficients of $(\sum_h \ln\overline{w}^h) y^n$ are $E_1, E_2, \dots E_J$, then I have $J-1$ equations to solve for J unknowns, $d_1, d_2, \dots d_J$.[48] I assume that $d_1 = 0$ since the agricultural sector is expected to have the lowest income elasticity. Once I have $d_2, \dots d_J$, I can solve for c and then $\beta_{(j,h)}$. I find that d_j is higher in service sectors, that is, income elasticities increase with exporter income at a faster rate, which also implies that the estimates of $\beta_{(j,h)}$ are higher in service sectors. However, $\beta_{(j,h)}$ estimated this way does not suggest as much variation across h as before because d_j is small in magnitude. Table 9 and 10 report the welfare changes in percentage terms in Mexico and in Brazil as a result of China's productivity growth before adjusting for intermediate goods. Table 11 and 12 report these after adjusting for intermediate goods. The patterns of welfare changes from the expenditure channel and the income channel are the same as in the baseline case, but the combined effect no longer decreases monotonically across the income distribution. For some income deciles, the income channel outweighs the expenditure channel.

ii. Sectoral income elasticities estimated from Mexico's household expenditure survey

[46] A more general specification would be: $\beta_{(j,h)} = c_j + d_j \ln\overline{w}^h$, but that increases the number of parameters to be estimated. Alternatively, I can impose that: $\beta_{(j,h)} = c_j + d \ln\overline{w}^h$, that is, income elasticity increases with exporter income at the same rate across sectors, but each sector starts at a different level.

[47] As Fajgelbaum and Khandelwal (2016) point out, the gravity equation identifies $\beta_{(j,n)} - a_n \bar{\beta}_j$ which under the restriction equals $\frac{a_n N - 1}{NJ}\sum_j d_j \sum_h \ln\overline{w}^h + d_j \ln\overline{w}^h - d_j a_h \sum_h \ln\overline{w}^h$. I can solve for $\{d_j\}_{j\in J}$ by imposing this to estimate the nonhomothetic gravity equation, but given its complexity, I have not pursued this strategy yet.

[48] It can be shown that if $d_1, d_2, \dots d_J$ satisfy $d_2 - \frac{1}{J}\sum_j d_j = E_2, \dots, d_J - \frac{1}{J}\sum_j d_j = E_J$, then they also satisfy $d_1 - \frac{1}{J}\sum_j d_j = E_1$.

Since the focus of the analysis is on Mexico and Brazil, I also use the estimated sectoral elasticities from Mexico's household expenditure survey as a robustness check.[49] In particular, $\bar{\beta}_j$ is obtained from $s_j^z = \bar{\alpha}_j - \bar{\beta}_j \ln a(\boldsymbol{p}^{mex}) + \bar{\beta}_j \ln(w_z) + \epsilon_j^{mex}$. As Fajgelbaum and Khandelwal (2016) point out, this check addresses the concern that variation in consumer expenditures within countries may not be accurately reflected in aggregate expenditures across countries. I find that it is still the case that the food sectors have a negative income elasticity, while the service sectors have a higher positive income elasticity than the manufacturing sectors, as in the baseline case. I then re-estimate $\boldsymbol{\beta} = \{\beta_{(j,h)}\}$ and $\boldsymbol{\alpha} = \{\alpha_{(j,h)}^n\}$ from the nonhomothetic gravity equation, imposing these sectoral income elasticities, and recompute the welfare changes. I still obtain qualitatively and quantitatively similar results. See tables 13 and 14 for results following China's productivity growth before adjusting for intermediate goods, and tables 15 and 16 for these after adjusting for intermediate goods.

iii. Increasing and decreasing income elasticities by a factor of 2

In this final sensitivity analysis, I apply an adjustment factor of 2 to the estimates of income elasticities and rerun the counterfactuals to examine the extent to which my results are affected by alternative values of $\boldsymbol{\beta} = \{\beta_{(j,h)}\}$. It is still guaranteed that income elasticities add up to zero when a common adjustment factor is applied to the estimate of each $\beta_{(j,h)}$. Picking 2 as the adjustment factor is also arbitrary, but this exercise examines whether the same results remain qualitatively as a result of significant changes in the estimates. Tables 17, 18, 19, and 20 report the results when income elasticities increase by a factor of 2, and tables 21, 22, 23, and 24 report the results when they decrease by a factor of 2. I find that it is still the case that welfare changes decrease monotonically through the expenditure channel and increase monotonically through the income channel across the income distribution. However, the combined effect no longer decreases monotonically, even though the 10th percentile always gain more compared to the 90th percentile in both Mexico and Brazil following China's productivity growth.

6. CONCLUSION

What is the impact of import competition shocks on the distribution of real wages in a large cross-section of regions? The vast majority of the literature focuses on the effect of trade on the distribution of nominal wages. A small number of studies consider its differential impact on consumer price indices. To my knowledge, there are only three case studies that have combined both channels to examine how real wages of different groups of people are affected in individual countries—specifically, Argentina, Mexico, and India.

[49] I thank Juan Blyde for providing me with these estimates.

I build a model combining demand heterogeneity across consumers with productivity heterogeneity across workers to quantify the distributional effects of import competition shocks for a wide range of regions taking both channels into account. By looking at a large set of regions, I am able to identify general patterns across regions with different characteristics. I am also able to conduct model-based counterfactuals of different trade shocks, which are important for policymakers. I use sector-level trade and production data to estimate the parameters of the model. In the baseline case, I find that as a result of China's productivity growth between 1995 and 2007, the larger decline in the poor's consumer price indices more than offsets their lower relative nominal wages in both Mexico and Brazil. More specifically, in Mexico, real wages in the 10th percentile increase by 2.05 percentage points more than in the 90th percentile, while the difference is 3.23 percentage points in Brazil. In He (2017), I also show that there is an important interaction between the two channels, and therefore, estimating the two effects separately and adding them up leads to a significant bias. These results highlight the importance of combining both channels in order to measure the distributional effects of import competition shocks accurately.

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APPENDIX TO SECTION 2

A. Welfare change as equivalent variation

Consider the set of changes $\left\{\widehat{p^h_{(j,n)}}\right\}_{(j,n)\in\mathcal{J}\times\mathcal{N}}$ and $\{\widehat{w_z}\}_{z\in Z_h}$. The resulting change in the indirect utility is:

$$\widehat{v_z} = \sum_j \sum_n \frac{\partial \ln v\left(w_z, \mathbf{p}^h\right)}{\partial \ln p^h_{(j,n)}} \widehat{p^h_{(j,n)}} + \frac{\partial \ln v\left(w_z, \mathbf{p}^h\right)}{\partial \ln w_z} \widehat{w_z}.$$

The equivalent variation, $\widehat{u_z}$, is the proportional change in income at the original prices to induce the same proportional change in indirect utility:

$$\widehat{v_z} = \frac{\partial \ln v\left(w_z, \mathbf{p}^h\right)}{\partial \ln w_z} \widehat{u_z}.$$

They imply, with the help of Roy's identity,

$$\widehat{u_z} = \widehat{w_z} + \sum_j \sum_n \left(\frac{\partial \ln v\left(w_z, \mathbf{p}^h\right)}{\partial \ln p^h_{(j,n)}} \Big/ \frac{\partial \ln v\left(w_z, \mathbf{p}^h\right)}{\partial \ln w_z} \right) \widehat{p^h_{(j,n)}}$$

$$= \widehat{w_z} + \sum_j \sum_n - s^z_{(j,n)} \widehat{p^h_{(j,n)}}.$$

B. Global welfare change without substitution effects

Integrate the aggregate expenditure effect, $\widehat{E^h} = \sum_j \sum_n S^h_{(j,n)} \left(-\widehat{p^h_{(j,n)}}\right)$,

$$\int \partial \ln E^h = \sum_j \sum_n S^h_{(j,n)} (-\int \partial \ln p^h_{(j,n)})$$

$$\ln E^h = -\sum_j \sum_n \ln[(p^h_{(j,n)})^{S^h_{(j,n)}}]$$

$$E^h = \exp(-\sum_j \sum_n \ln[(p^h_{(j,n)})^{S^h_{(j,n)}}])$$

$$= \Pi_{(j,n)} \exp(-\ln[(p^h_{(j,n)})^{S^h_{(j,n)}}])$$

$$= \Pi_{(j,n)} (p^h_{(j,n)})^{-S^h_{(j,n)}}.$$

As a result,

$$\frac{E^h_{cf}}{E^h_{tr}} = \prod_{(j,n)} (\frac{p^{h,tr}_{(j,n)}}{p^{h,cf}_{(j,n)}})^{S^h_{(j,n)}}.$$

Integrate the individual expenditure effect, $\widehat{b^h} = \sum_j \sum_n \beta_{(j,n)} \widehat{p^h_{(j,n)}}$,

$$b^h = \prod_{(j,n)} (p^h_{(j,n)})^{\beta_{(j,n)}}$$

$$\frac{b^h_{cf}}{b^h_{tr}} = \prod_{(j,n)} (\frac{p^{h,cf}_{(j,n)}}{p^{h,tr}_{(j,n)}})^{\beta_{(j,n)}}$$

$$-ln(\frac{b^h_{cf}}{b^h_{tr}}) = -\sum_j \sum_n \beta_{(j,n)} \ln(\frac{p^{h,cf}_{(j,n)}}{p^{h,tr}_{(j,n)}}).$$

C. Global welfare change with substitution effects

The basic AIDS model is developed from a particular cost (expenditure) function taken from the general class of price-independent, generalized logarithmic (PIGLOG) cost functions. In the case of the AIDS the cost function is of the form:

$$\ln C(\boldsymbol{p}^h, U) = (1-U)\ln(a(\boldsymbol{p}^h)) + U\ln(d(\boldsymbol{p}^h)),$$

where $\boldsymbol{p}^h$ is a vector of prices in region h. U denotes the utility index and $a(\boldsymbol{p}^h)$ is a translog price index given by:

$$\ln a(\boldsymbol{p}^h) = \alpha + \sum_j \sum_n \alpha^h_{(j,n)} \ln p^h_{(j,n)} + \frac{1}{2}\sum_j \sum_n \sum_{j\prime} \sum_{n\prime} \gamma_{(j,n)(j\prime,n\prime)} \ln p^h_{(j,n)} \ln p^h_{(j\prime,n\prime)},$$

and

$$\ln d(\boldsymbol{p}^h) = \ln a(\boldsymbol{p}^h) + \beta\, \Pi_j \Pi_n (p^h_{(j,n)})^{\beta_{(j,n)}}.$$

Note that the utility index can be scaled to correspond to cases of subsistence ($U = 0$) and bliss ($U = 1$), in which case, $a(\boldsymbol{p}^h)$ and $d(\boldsymbol{p}^h)$ can be interpreted as representing the cost of subsistence and bliss, respectively. Nominal wages, w_z, for a utility-maximizing consumer will equal the value of the cost function. Therefore, I invert the cost function and solve for U, the indirect utility function, $v(w_z, \boldsymbol{p}^h)$.

$$v(w_z, \boldsymbol{p}^h) = \frac{\ln w_z - \ln a(\boldsymbol{p}^h)}{\ln d(\boldsymbol{p}^h) - \ln a(\boldsymbol{p}^h)}$$

$$= \frac{1}{\beta} \ln[(\frac{w_z}{a(\boldsymbol{p}^h)})^{\frac{1}{d(\boldsymbol{p}^h)}}].$$

The global welfare change of individual z under the AIDS between an initial scenario under trade and a counterfactual scenario is calculated according to the definition of equivalent variation as follows:

$$\frac{\ln(w_z^{tr} + u_z^{tr\rightarrow cf}) - \ln a(\boldsymbol{p}_{tr}^h)}{\ln d(\boldsymbol{p}_{tr}^h) - \ln a(\boldsymbol{p}_{tr}^h)} = \frac{\ln w_z^{cf} - \ln a(\boldsymbol{p}_{cf}^h)}{\ln d(\boldsymbol{p}_{cf}^h) - \ln a(\boldsymbol{p}_{cf}^h)},$$

For notational simplicity, denote

$$\ln b(\boldsymbol{p}^h) = \ln d(\boldsymbol{p}^h) - \ln a(\boldsymbol{p}^h) = \beta\, \Pi_j \Pi_n (p_{(j,n)}^h)^{\beta_{(j,n)}}.$$

which implies,

$$u_z^{tr\rightarrow cf} = \exp\{[\frac{\ln w_z^{cf} - \ln a(\boldsymbol{p}_{cf}^h)}{\ln b(\boldsymbol{p}_{cf}^h)}] * \ln b(\boldsymbol{p}_{tr}^h) + \ln a(\boldsymbol{p}_{tr}^h)\} - w_z^{tr}.$$

D. Total supply

Output produced by a worker of labor type λ who works in sector j in region h is:

$$A^h A^h(\lambda) T^h(\lambda, j) \boldsymbol{E}(\epsilon_z | z \in \mathcal{Z}^h(\lambda), w_z(j) \geq w_z(j')) \, \forall j' \in J$$

$$= A^h A^h(\lambda) T^h(\lambda, j) \frac{1}{\pi^h(\lambda, j)} \int_0^\infty \epsilon(z, j) Pr\left(\epsilon(z, j) \geq max_{j' \neq j} \epsilon(z, j') \frac{x^h(\lambda, j')}{x^h(\lambda, j)}\right) dG(\epsilon).$$

$$Pr\left(\epsilon(z, j) \geq max_{j' \neq j} \epsilon(z, j') \frac{x^h(\lambda, j')}{x^h(\lambda, j)}\right)$$

$$= \Pi_{j' \neq j} Pr(\epsilon(z, j') \leq \epsilon(z, j) \frac{x^h(\lambda, j)}{x^h(\lambda, j')})$$

$$= \Pi_{j' \neq j} exp(-\epsilon(z, j)^{-\theta(\lambda)} x^h(\lambda, j)^{-\theta(\lambda)} x^h(\lambda, j')^{\theta(\lambda)})$$

$$= exp\left(-\epsilon(z, j)^{-\theta(\lambda)} x^h(\lambda, j)^{-\theta(\lambda)} \sum_{j' \neq j} x^h(\lambda, j')^{\theta(\lambda)}\right).$$

$$G(\epsilon(z, j), \lambda) = exp(-\epsilon(z, j)^{-\theta(\lambda)}).$$

$$dG(\epsilon(z, j), \lambda) = exp(-\epsilon(z, j)^{-\theta(\lambda)}) \theta(\lambda) \epsilon(z, j)^{-\theta(\lambda)-1} d\epsilon.$$

$$A^h A^h(\lambda) T^h(\lambda, j) \boldsymbol{E}(\epsilon_z | z \in \mathcal{Z}^h(\lambda), w_z(j) \geq w_z(j') \, \forall j' \in J)$$

$$= A^h A^h(\lambda) T^h(\lambda, j) \frac{1}{\pi^h(\lambda, j)} \int_0^\infty \epsilon(z, j) exp\left(-\epsilon(z, j)^{-\theta(\lambda)} x^h(\lambda, j)^{-\theta(\lambda)} \sum_{j' \neq j} x^h(\lambda, j')^{\theta(\lambda)}\right).$$

$$exp(-\epsilon(z, j)^{-\theta(\lambda)} x^h(\lambda, j)^{-\theta(\lambda)} x^h(\lambda, j)^{\theta(\lambda)}) \theta(\lambda) \epsilon(z, j)^{-\theta(\lambda)-1} d\epsilon$$

$$= A^h A^h(\lambda) T^h(\lambda, j) \frac{1}{\pi^h(\lambda, j)} \int_0^\infty exp\left(-\epsilon(z, j)^{-\theta(\lambda)} x^h(\lambda, j)^{-\theta(\lambda)} \sum_{j' \in J} x^h(\lambda, j')^{\theta(\lambda)}\right) \theta(\lambda) \epsilon(z, j)^{-\theta(\lambda)} d\epsilon$$

$$= A^h A^h(\lambda) T^h(\lambda, j) \frac{1}{\pi^h(\lambda, j)} \int_0^\infty exp\left(-\epsilon(z, j)^{-\theta(\lambda)} \frac{1}{\pi^h(\lambda, j)}\right) \theta(\lambda) \epsilon(z, j)^{-\theta(\lambda)} d\epsilon.$$

$$Let\ r = \epsilon(z, j)^{-\theta(\lambda)} \frac{1}{\pi^h(\lambda, j)}, then\ dr = \frac{1}{\pi^h(\lambda, j)} (-\theta(\lambda)) \epsilon(z, j)^{-\theta(\lambda)-1} d\epsilon.$$

$$Recall\ that\ \Gamma(t) = \int_0^\infty r^{t-1} e^{-r} dr,$$

$$\Gamma(1 - \frac{1}{\theta(\lambda)}) = \int_0^\infty exp\left(-\epsilon(z, j)^{-\theta(\lambda)} \frac{1}{\pi^h(\lambda, j)}\right) \left(\epsilon(z, j)^{-\theta(\lambda)} \frac{1}{\pi^h(\lambda, j)}\right)^{-\frac{1}{\theta(\lambda)}} dr$$

$$= -\int_0^\infty exp\left(-\epsilon(z, j)^{-\theta(\lambda)} \frac{1}{\pi^h(\lambda, j)}\right) \epsilon(z, j) \pi^h(\lambda, j)^{\frac{1}{\theta(\lambda)}-1} (-\theta(\lambda)) \epsilon(z, j)^{-\theta(\lambda)-1} d\epsilon.$$

$$A^h A^h(\lambda) T^h(\lambda, j) \boldsymbol{E}(\epsilon_z | z \in Z_h(\lambda), w_z(j) \geq w_z(j') \; \forall j' \in J)$$

$$= A^h A^h(\lambda) T^h(\lambda, j) \frac{1}{\pi^h(\lambda, j)} \Gamma(1 - \frac{1}{\theta(\lambda)}) \pi^h(\lambda, j)^{1-\frac{1}{\theta(\lambda)}}$$

$$= A^h A^h(\lambda) T^h(\lambda, j) \Gamma(1 - \frac{1}{\theta(\lambda)}) \pi^h(\lambda, j)^{-\frac{1}{\theta(\lambda)}}.$$

Since there are $L^h(\lambda)\pi^h(\lambda, j)$ workers of labor type λ in region h that choose to work in sector j, the total supply of good (j, h) by labor group λ is $A^h A^h(\lambda) T^h(\lambda, j) \Gamma(1 - \frac{1}{\theta(\lambda)}) \pi^h(\lambda, j)^{1-\frac{1}{\theta(\lambda)}} L^h(\lambda)$.

E. Gauss-Jacobi algorithm and property of the equilibrium

The Gauss-Jacobi algorithm procedure reduces the problem of solving for n unknowns simultaneously in n equations to that of repeatedly solving n equations with one unknown. More specifically, given the known value of the kth iterate, x^k, one uses the ith equation to compute the ith component of unknown x^{k+1}, the next iterate. Formally x^{k+1} is defined in terms of x^k by the following equations:

$$f^1(x_1^{k+1}, x_2^k, x_3^k, \ldots, x_n^k) = 0$$

$$f^2(x_1^k, x_2^{k+1}, x_3^k, \ldots, x_n^k) = 0$$

$$\ldots$$

$$f^n(x_1^k, x_2^k, \ldots, x_{n-1}^k, x_n^{k+1}) = 0.$$

The linear Gauss-Jacobi method takes a single Newton step to approximate the components of x^{k+1}. The resulting scheme is $x_i^{k+1} = x_i^k - \frac{f^i(x^k)}{f_{xi}^i(x^k)}, i = 1, \ldots, n.$

Note that the set of prices enter both the demand side and the supply side nonlinearly. In general, for a system of nonlinear equations, it is not possible to characterize the conditions under which a solution exists or is unique. I appeal to the Implicit Function Theorem to show that the price equilibrium that I have found numerically using the Gauss-Jacobi method is locally isolated as a function of the parameters. It states that if F is continuously differentiable, $F(x^*) = 0$, and $DF(x^*)$ has full rank, then the zero set of F is, near x^*, an N-dimensional surface in R^L. My excess demand functions are continuously differentiable, and the vector of prices set them to 0. Also, the Jacobian matrix of these functions has full rank ($J * N = 1400$).

APPENDIX TO SECTION 4

A. Countries in IPUMS-I

i. Sample used to compute $\theta(\lambda)$ and $x^h(\lambda)$

Brazil (2000), Canada (2001), Colombia (1973), India (2004), Jamaica (2001), Mexico (2000), Panama (2000), United States (2005), Uruguay (2006), Venezuela (2001), Israel (1995), Germany (1970), Puerto Rico (2005), Indonesia (1995), South Africa (2007), Dominican Republic (2002).

ii. Sample used to compute $T^h(\lambda)$

Austria (2001), Brazil (2000), Canada (2001), China (2000), France (1999), Germany (1987), Greece (2001), Hungary (2001), India (1999), Indonesia (2000), Ireland (2002), Italy (2001), Mexico (2000), Netherlands (2001), Poland (2002), Portugal (2001), Romania (2002), Slovenia (2002), Spain (2001), Turkey (2000), United Kingdom (2001) and United States (2000).

B. Absolute advantage $A^h(\lambda)$

$$x^h(\lambda) = \left(\sum_j x^h(\lambda, j)^{\theta(\lambda)}\right)^{\frac{1}{\theta(\lambda)}} = \{\sum_{j\in\mathcal{J}} \left[p^h_{(j,h)} A^h A^h(\lambda) T^h(\lambda, j)\right]^{\theta(\lambda)}\}^{\frac{1}{\theta(\lambda)}}$$

$$= A^h A^h(\lambda)\{\sum_{j\in\mathcal{J}} \left[p^h_{(j,h)} T^h(\lambda, j)\right]^{\theta(\lambda)}\}^{\frac{1}{\theta(\lambda)}}.$$

$$log\ x^h(\lambda) = log\ A^h + log\ A^h(\lambda) + \frac{1}{\theta(\lambda)} log\ \{\sum_{j\in\mathcal{J}} \left[p^h_{(j,h)} T^h(\lambda, j)\right]^{\theta(\lambda)}\}.$$

Take a first-order approximation at $\boldsymbol{p} = \mathbf{1}, \boldsymbol{T} = \mathbf{1}$:

$$log\ x^h(\lambda) = log\ A^h + log\ A^h(\lambda) + \frac{1}{\theta(\lambda)}\{log\ J + \frac{1}{J}\sum_{j\in\mathcal{J}} (\left[p^h_{(j,h)} T^h(\lambda, j)\right]^{\theta(\lambda)} - 1)\}$$

$$= log\ A^h + log\ A^h(\lambda) + \frac{1}{\theta(\lambda)}\{log\ J + \frac{1}{J}\sum_{j\in\mathcal{J}} log\ (\left[p^h_{(j,h)} T^h(\lambda, j)\right]^{\theta(\lambda)})\}$$

$$= log\ A^h + log\ A^h(\lambda) + \frac{1}{\theta(\lambda)} log\ J + \frac{1}{J}[\sum_{j\in\mathcal{J}} log\ p^h_{(j,h)} + \sum_{j\in J} log\ T^h(\lambda, j)]\}.$$

$$log\ x^h(1) = log\ A^h + log\ A^h(1) + \frac{1}{\theta(1)} log\ J + \frac{1}{J}[\sum_{j\in\mathcal{J}} log\ p^h_{(j,h)} + \sum_{j\in J} log\ T^h(1, j)]\}.$$

$$log(\frac{x^h(\lambda)}{x^h(1)}) = log(\frac{A^h(\lambda)}{A^h(1)}) + log\ J(\frac{1}{\theta(\lambda)} - \frac{1}{\theta(1)}) + \frac{1}{J}\sum_{j\in J} log(\frac{T^h(\lambda, j)}{T^h(1, j)}).$$

C. Nonhomothetic gravity equation

Under the additional assumptions on $\mathbf{\Gamma}$,

$$\frac{Y_{(j,n)}^h}{Y^h} \equiv S_{(j,n)}^h = \alpha_{(j,n)}^h - \gamma_j \ln\left(\frac{p_{(j,n)}^h}{P_j^h}\right) + \beta_{(j,n)} y^h,$$

where $P_j^h = \exp\left(\frac{1}{N}\sum_{n'} \ln p_{(j,n')}^h\right)$. Replacing $p_{(j,n')}^h = \tau_{(j,n')}^h p_{(j,n')}^{n'}$, I have:

$$\frac{p_{(j,n)}^h}{P_j^h} = \frac{\tau_{(j,n)}^h}{\exp\left(\frac{1}{N}\sum_{n'} \ln\tau_{(j,n')}^h\right)} \cdot \frac{p_{(j,n)}^n}{\exp\left(\frac{1}{N}\sum_{n'} \ln p_{(j,n')}^{n'}\right)} \equiv \frac{\tau_{(j,n)}^h}{\bar{\tau}_j^h} \cdot \frac{p_{(j,n)}^n}{\bar{p}_j}.$$

Therefore,

$$\frac{Y_{(j,n)}}{Y^W} = \sum_{n'} \frac{Y^{n'}}{Y^W} S_{(j,n)}^{n'}$$

$$= \sum_{n'} \frac{Y^{n'}}{Y^W}\left(\alpha_{(j,n)}^{n'} - \gamma_j \ln\left(\frac{\tau_{(j,n)}^{n'}}{\bar{\tau}_j^{n'}} \cdot \frac{p_{(j,n)}^n}{\bar{p}_j}\right) + \beta_{(j,n)} y^{n'}\right).$$

Subtract the second equation from the first,

$$\frac{Y_{(j,n)}^h}{Y^h} - \frac{Y_{(j,n)}}{Y^W} = \underbrace{\left[\alpha_{(j,n)}^h - \sum_{n'} \frac{Y^{n'}}{Y^W} \alpha_{(j,n)}^{n'}\right]}_{\equiv K_{(j,n)}^h}$$

$$-\gamma_j \underbrace{\left[\ln\left(\frac{\tau_{(j,n)}^h}{\bar{\tau}_j^h} \cdot \frac{p_{(j,n)}^n}{\bar{p}_j}\right) - \sum_{n'} \frac{Y^{n'}}{Y^W} \ln\left(\frac{\tau_{(j,n)}^{n'}}{\bar{\tau}_j^{n'}} \cdot \frac{p_{(j,n)}^n}{\bar{p}_j}\right)\right]}_{\equiv M_{(j,n)}^h}$$

$$+\beta_{(j,n)} \underbrace{\left[y^h - \sum_{n'} \frac{Y^{n'}}{Y^W} y^{n'}\right]}_{\equiv \Omega^h}.$$

D. Differences in tastes across regions

Under the additional assumptions on $\mathbf{\Gamma}$ and $\sum_n \alpha_n = 1$, combined with the equation $\alpha_{(j,n)}^h = \alpha_n(\alpha_j + \epsilon_j^h)$,

$$S_j^h = \sum_n \alpha_{(j,n)}^h + \bar{\beta}_j y^h = \alpha_j + \bar{\beta}_j y^h + \epsilon_j^h.$$

$$S_j^W = \frac{Y_j^W}{Y^W} = \frac{\sum_{n'=1}^N Y^{n'} S_j^{n'}}{Y^W} = \sum_{n'=1}^{N} \frac{Y^{n'}}{Y^W}(\alpha_j + \bar{\beta}_j y^h + \epsilon_j^h).$$

$$S_j^h - S_j^W = \alpha_j - \sum_{n'=1}^{N} (\frac{Y^{n'}}{Y^W})\alpha_j + \epsilon_j^h - \sum_{n'=1}^{N} (\frac{Y^{n'}}{Y^W})\epsilon_j^h + \bar{\beta}_j \Omega^h.$$

$$K_{(j,n)}^h = \alpha_{(j,n)}^h - \sum_{n'=1}^{N} (\frac{Y^{n'}}{Y^W})\alpha_{(j,n)}^{n'} = \alpha_n(\alpha_j + \epsilon_j^h) - \sum_{n'=1}^{N} (\frac{Y^{n'}}{Y^W})\alpha_n(\alpha_j + \epsilon_j^{n'})$$

$$= \alpha_n[\alpha_j - \sum_{n'=1}^{N} (\frac{Y^{n'}}{Y^W})\alpha_j + \epsilon_j^h - \sum_{n'=1}^{N} (\frac{Y^{n'}}{Y^W})\epsilon_j^h] = \alpha_n(S_j^h - S_j^W) - \alpha_n \bar{\beta}_j \Omega^h.$$

APPENDIX TO SECTION 5

A. Net welfare effect

Recall that the nominal wage distribution of labor type λ is:

$$Pr(w_z \leq w | z \in \mathcal{Z}^h(\lambda)) = exp\{-x^h(\lambda)^{\theta(\lambda)} w^{-\theta(\lambda)}\}$$

with scale parameter, $x^h(\lambda) = (\sum_j \, [p^h_{(j,h)} A^h A^h(\lambda) T^h(\lambda,j)]^{\theta(\lambda)})^{\frac{1}{\theta(\lambda)}}$.

$$\frac{\partial x^h(\lambda)}{\partial p^h_{(j,h)}} = x^h(\lambda)^{1-\theta(\lambda)} A^h A^h(\lambda)^{\theta(\lambda)} T^h(\lambda,j)^{\theta(\lambda)} (p^h_{(j,h)})^{\theta(\lambda)-1}.$$

The pass-through from prices to the average wage, $x^h(\lambda)\Gamma(1 - \frac{1}{\theta(\lambda)})$, is:

$$\frac{\partial [x^h(\lambda)\Gamma(1-\frac{1}{\theta(\lambda)})]/[x^h(\lambda)\Gamma(1-\frac{1}{\theta(\lambda)})]}{\partial p^h_{(j,h)}/p^h_{(j,h)}} = \frac{\partial x^h(\lambda)/\partial p^h_{(j,h)}}{x^h(\lambda)/p^h_{(j,h)}}$$

$$= [\frac{x^h(\lambda)}{p^h_{(j,h)} A^h A^h(\lambda) T^h(\lambda,j)}]^{-\theta(\lambda)}$$

$$= \frac{[p^h_{(j,h)} A^h A^h(\lambda) T^h(\lambda,j)]^{\theta(\lambda)}}{\sum_j \, [p^h_{(j,h)} A^h A^h(\lambda) T^h(\lambda,j)]^{\theta(\lambda)}}$$

$$= \pi^h(\lambda,j).$$

Suppose labor group λ is more likely to sort into sector j, then a price increase of the output of sector j increases the average wage of λ by more compared to other labor groups.

Consider the local welfare change of individual z who makes the average wage of labor group λ:

$$\hat{u}_z = \sum_j \sum_n s^z_{(j,n)} (-\frac{\partial p^h_{(j,n)}}{p^h_{(j,n)}}) + \frac{\partial x^h(\lambda)}{x^h(\lambda)}$$

$$= \sum_j \sum_n s^z_{(j,n)} (-\frac{\partial p^h_{(j,n)}}{p^h_{(j,n)}}) + \sum_j \pi^h(\lambda,j) (\frac{\partial p^h_{(j,h)}}{p^h_{(j,h)}})$$

$$= \sum_j (\pi^h(\lambda,j) - s^z_{(j,h)}) (\frac{\partial p^h_{(j,h)}}{p^h_{(j,h)}}) + \sum_j \sum_{n \neq h} s^z_{(j,n)} (-\frac{\partial p^h_{(j,n)}}{p^h_{(j,n)}}).$$

More educated workers are more likely to sort into skill-intensive sectors. They also have higher nominal wages on average and therefore spend relatively more on high-income elastic goods. As I show in section 4, there is a significant positive correlation between the skill intensity of a sector and its income elasticity. Suppose the prices of domestically produced, high-income elastic goods go up. Since both $\pi^h(\lambda,j)$ and $s^z_{(j,h)}$ of these goods are higher for high-income individuals than for low-income individuals, the welfare impact of these price changes depend on whether $\pi^h(\lambda, j)$ or $s^z_{(j,h)}$ dominates. On the other hand, price decreases in foreign goods unambiguously increase welfare. However, whether high-income or low-income individuals benefit more depend on if the prices of high-income elastic or low-income elastic goods fall more. The net effect of these two components determines one's welfare change in response to small changes in goods prices.

B. Magnitude of welfare gains

In their robustness section, Fajgelbaum and Khandelwal (2016) consider a 5% reduction in the cost of importing in manufacturing sectors, and compare the welfare change of the representative consumer implied by this shock with the welfare changes implied by a standard multisector Armington trade model with Cobb-Douglas preferences across sectors and CES preferences across origins within sectors (e.g., [32]). They find that the aggregate gains estimates are very similar between the two models (correlation of 0.98) and the welfare of the representative consumer increases by between 0.2% and 1.3% across countries.

In He (2017), I conduct a similar counterfactual exercise by decreasing $p^n_{(j,h)}$ by 5% if $j \in M$ and $h \neq n$. Based on my model specifications and calibrated parameters, I find that this reduction in trade costs decreases the homogeneous price aggregator, $a(\mathbf{p}^h)$, by between 0.68% and 2.11% across countries, and the average is 1.26%. The representative consumer in each country h has the inequality-adjusted average nominal wage, $\widetilde{w}^h = \bar{w}^h e^{\Sigma^h}$, and I find that their welfare increases by between 0.13% and 1.85% across countries with an average of 0.73% through the expenditure channel, which is comparable to the findings in Fajgelbaum and Khandelwal (2016). In my main counterfactual exercise, I consider a 5% reduction in all bilateral trade costs, and I find that $a(\mathbf{p}^h)$ decreases by between 4.48% and 5.8% across countries, and the average is 5.36%. In the meantime, the welfare of the representative consumer increases by between 1.65% and 4.49%, and the average is 3.87%. The latter is a trade shock that is roughly 4.25 times larger than the former, and it results in a welfare increase of the representative consumer that is about 5.3 times larger.

Why do I find larger welfare gains from trade liberalization relative to Eaton and Kortum (2002), etc.? They consider a counterfactual where the 19 OECD countries collectively remove the 5% tariff on all imports and find that most countries gain around 1%. The main reason is that allowing for sectoral heterogeneity leads to larger measurement of the aggregate gains from trade. Ossa (2015) shows that in the context of a simple Armington (1969) model in which consumers have CES preferences within industries and goods are differentiated by country of origin, the industry-level formula predicts that a move from autarky to 2007 levels of trade increases real income by three times what the aggregate formula predicts, on average. This conclusion is consistent with the level of welfare gains that I find.

TABLES

TABLE 1. AVERAGE LABOR EARNINGS AND THE THEIL INDEX

Region	Theil	Avg Labor Earnings	Region	Theil	Avg Labor Earnings
AUS	0.29	32780	IRL	0.28	43903
AUT	0.29	31679	ITA	0.27	25886
BEL	0.27	32390	JPN	0.28	30475
BGR	0.28	10476	KOR	0.29	24155
BRA	0.47	6256	LTU	0.27	14747
CAN	0.27	26746	LUX	0.27	58060
CHN	0.34	4227	LVA	0.28	12591
CYP	0.29	19819	MEX	0.35	5061
CZE	0.27	20095	MLT	0.30	15116
DEU	0.26	44207	NLD	0.27	40091
DNK	0.28	34774	POL	0.27	13875
ESP	0.30	26035	PRT	0.30	15313
EST	0.27	17092	ROU	0.29	9306
FIN	0.27	32438	RUS	0.30	12973
FRA	0.28	28482	SVK	0.27	15322
GBR	0.29	31873	SVN	0.27	21312
GRC	0.28	21810	SWE	0.26	33782
HUN	0.27	15292	TUR	0.31	9358
IDN	0.38	948	TWN	0.32	21847
IND	0.51	772	USA	0.31	45671

TABLE 2. CROSS-SUBSTITUTION BETWEEN GOODS

sector	γ_j-total	γ_j-final	sector	γ_j-total	γ_j-final
Agriculture	0.0059	0.0047	Sales, Repair of Motor Vehicles	0.0029	0.0030
Mining	0.0030	0.0008	Wholesale Trade and Commission Trade	0.0116	0.0123
Food, Beverages and Tobacco	0.0087	0.0104	Retail Trade	0.0104	0.0132
Textiles	0.0020	0.0016	Hotels and Restaurants	0.0075	0.0110
Leather and Footwear	0.0004	0.0004	Inland Transport	0.0043	0.0040
Wood Products	0.0014	0.0003	Water Transport	0.0006	0.0002
Printing and Publishing	0.0037	0.0017	Air Transport	0.0013	0.0012
Coke, Refined Petroleum, Nuclear Fuel	0.0044	0.0023	Other Auxiliary Transport Activities	0.0025	0.0015
Chemicals and Chemical Products	0.0069	0.0022	Post and Telecommunications	0.0058	0.0052
Rubber and Plastics	0.0026	0.0006	Financial Intermediation	0.0178	0.0103
Other Non-Metallic Minerals	0.0028	0.0007	Real Estate Activities	0.0179	0.0248
Basic Metals and Fabricated Metal	0.0101	0.0020	Renting of M&Eq	0.0158	0.0059
Machinery	0.0047	0.0047	Public Admin and Defense	0.0166	0.0317
Electrical and Optical Equipment	0.0081	0.0048	Education	0.0066	0.0132
Transport Equipment	0.0060	0.0053	Health and Social Work	0.0102	0.0202
Manufacturing, nec	0.0015	0.0019	Other Community and Social Services	0.0103	0.0145
Electricity, Gas and Water Supply	0.0072	0.0042	Private Households with Employed Persons	0.0003	0.0006
Construction	0.0215	0.0366	sum	0.2434	0.2581

TABLE 3. SECTORAL BETAS

sector	β_j-total	β_j-final	sector	β_j-total	β_j-final
Agriculture	-0.0230	-0.0222	Sales, Repair of Motor Vehicles	0.0031	0.0037
Mining	-0.0081	-0.0007	Wholesale Trade and Commission Trade	0.0011	0.0005
Food, Beverages and Tobacco	-0.0131	-0.0174	Retail Trade	-0.0025	0.0003
Textiles	-0.0066	-0.0048	Hotels and Restaurants	0.0014	0.0034
Leather and Footwear	-0.0010	-0.0009	Inland Transport	-0.0096	-0.0098
Wood Products	-0.0007	0.0003	Water Transport	-0.0009	-0.0013
Printing and Publishing	0.0014	0.0021	Air Transport	0.0007	0.0004
Coke, Refined Petroleum, Nuclear Fuel	-0.0046	0.0000	Other Auxiliary Transport Activities	0.0043	0.0021
Chemicals and Chemical Products	-0.0051	-0.0017	Post and Telecommunications	0.0015	0.0006
Rubber and Plastics	-0.0012	-0.0004	Financial Intermediation	0.0240	0.0060
Other Non-Metallic Minerals	-0.0023	0.0000	Real Estate Activities	0.0103	0.0160
Basic Metals and Fabricated Metal	-0.0022	-0.0001	Renting of M&Eq	0.0243	0.0036
Machinery	-0.0015	-0.0026	Public Admin and Defense	0.0049	0.0091
Electrical and Optical Equipment	-0.0013	-0.0030	Education	0.0019	0.0041
Transport Equipment	-0.0030	-0.0017	Health and Social Work	0.0129	0.0247
Manufacturing, nec	-0.0004	0.0002	Other Community and Social Services	0.0031	0.0047
Electricity, Gas and Water Supply	-0.0018	0.0016	Private Households with Employed Persons	0.0003	0.0007
Construction	-0.0065	-0.0175	sum	0.0000	0.0000

TABLE 4. LABOR GROUPS

labor group	1	2	3	4	5	6	7	8	9
sex	Male	Male	Male	Male	Male	Male	Male	Male	Male
age	15-24	15-24	15-24	25-49	25-49	25-49	50-74	50-74	50-74
edu	ED0-2	ED3-4	ED5-8	ED0-2	ED3-4	ED5-8	ED0-2	ED3-4	ED5-8
labor group	10	11	12	13	14	15	16	17	18
sex	Female	Female	Female	Female	Female	Female	Female	Female	Female
age	15-24	15-24	15-24	25-49	25-49	25-49	50-74	50-74	50-74
edu	ED0-2	ED3-4	ED5-8	ED0-2	ED3-4	ED5-8	ED0-2	ED3-4	ED5-8

TABLE 5. WELFARE CHANGES IN MEXICO BEFORE ADJUSTING FOR INTERMEDIATE GOODS

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	6.09	5.65	5.28	4.93	4.59	4.22	3.81	3.31	2.61
Income	-0.20	-0.05	0.12	0.32	0.52	0.71	0.89	1.06	1.19
Both	5.87	5.59	5.40	5.27	5.12	4.94	4.71	4.38	3.82

TABLE 6. WELFARE CHANGES IN BRAZIL BEFORE ADJUSTING FOR INTERMEDIATE GOODS

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	3.63	2.98	2.49	2.04	1.59	1.13	0.62	0.04	-0.73
Income	0.87	1.19	1.41	1.54	1.59	1.66	1.83	1.98	2.05
Both	4.53	4.21	3.94	3.61	3.20	2.80	2.45	2.02	1.30

TABLE 7. WELFARE CHANGES IN MEXICO AFTER ADJUSTING FOR INTERMEDIATE GOODS

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	2.82	2.70	2.61	2.51	2.42	2.32	2.21	2.07	1.88
Income	-1.55	-1.50	-1.45	-1.39	-1.33	-1.28	-1.22	-1.17	-1.13
Both	1.24	1.17	1.13	1.09	1.06	1.02	0.96	0.88	0.73

TABLE 8. WELFARE CHANGES IN BRAZIL AFTER ADJUSTING FOR INTERMEDIATE GOODS

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	2.85	2.67	2.54	2.41	2.29	2.16	2.02	1.86	1.64
Income	-1.23	-1.14	-1.08	-1.04	-1.03	-1.01	-0.96	-0.91	-0.89
Both	1.59	1.51	1.44	1.35	1.24	1.14	1.05	0.93	0.74

TABLE 9. WELFARE CHANGES IN MEXICO BEFORE ADJUSTING FOR INTERMEDIATE GOODS—SENSITIVITY ANALYSIS I

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	5.13	4.98	4.85	4.73	4.62	4.50	4.36	4.19	3.95
Income	0.69	0.84	1.00	1.19	1.36	1.51	1.67	1.82	1.93
Both	5.86	5.86	5.90	5.97	6.03	6.07	6.09	6.07	5.95

TABLE 10. WELFARE CHANGES IN BRAZIL BEFORE ADJUSTING FOR INTERMEDIATE GOODS—SENSITIVITY ANALYSIS I

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	4.98	4.75	4.58	4.43	4.28	4.11	3.94	3.73	3.46
Income	0.82	1.16	1.43	1.59	1.66	1.73	1.91	2.09	2.16
Both	5.83	5.96	6.07	6.07	5.99	5.91	5.91	5.88	5.68

TABLE 11. WELFARE CHANGES IN BRAZIL AFTER ADJUSTING FOR INTERMEDIATE GOODS—SENSITIVITY ANALYSIS I

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	2.73	2.68	2.64	2.61	2.57	2.53	2.49	2.44	2.37
Income	-1.49	-1.44	-1.40	-1.34	-1.29	-1.24	-1.20	-1.15	-1.12
Both	1.20	1.20	1.21	1.23	1.25	1.26	1.26	1.26	1.23

TABLE 12. WELFARE CHANGES IN BRAZIL AFTER ADJUSTING FOR INTERMEDIATE GOODS—SENSITIVITY ANALYSIS I

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	2.69	2.62	2.57	2.52	2.48	2.43	2.38	2.31	2.23
Income	-1.44	-1.33	-1.26	-1.21	-1.19	-1.17	-1.12	-1.07	-1.05
Both	1.22	1.26	1.29	1.28	1.26	1.23	1.23	1.22	1.16

TABLE 13. WELFARE CHANGES IN MEXICO BEFORE ADJUSTING FOR INTERMEDIATE GOODS—SENSITIVITY ANALYSIS 2

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	5.80	5.09	4.50	3.93	3.36	2.76	2.09	1.27	0.13
Income	0.39	0.51	0.63	0.77	0.91	1.04	1.17	1.30	1.41
Both	6.20	5.61	5.14	4.71	4.27	3.80	3.25	2.55	1.50

TABLE 14. WELFARE CHANGES IN BRAZIL BEFORE ADJUSTING FOR INTERMEDIATE GOODS—SENSITIVITY ANALYSIS 2

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	6.21	5.15	4.35	3.59	2.85	2.07	1.23	0.27	-1.00
Income	1.83	1.96	2.04	2.07	2.05	2.08	2.08	2.19	2.34
Both	8.09	7.15	6.41	5.67	4.90	4.13	3.38	2.51	1.25

TABLE 15. WELFARE CHANGES IN MEXICO AFTER ADJUSTING FOR INTERMEDIATE GOODS—SENSITIVITY ANALYSIS 2

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	2.55	2.36	2.21	2.06	1.91	1.75	1.57	1.35	1.05
Income	-1.19	-1.15	-1.12	-1.07	-1.03	-1.00	-0.96	-0.92	-0.89
Both	1.33	1.19	1.08	0.97	0.86	0.74	0.61	0.43	0.16

TABLE 16. WELFARE CHANGES IN BRAZIL AFTER ADJUSTING FOR INTERMEDIATE GOODS—SENSITIVITY ANALYSIS 2

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	2.64	2.37	2.16	1.96	1.76	1.56	1.33	1.07	0.73
Income	-0.78	-0.74	-0.71	-0.71	-0.71	-0.70	-0.67	-0.63	-0.62
Both	1.84	1.61	1.43	1.24	1.04	0.85	0.66	0.44	0.11

TABLE 17. WELFARE CHANGES IN MEXICO BEFORE ADJUSTING FOR INTERMEDIATE GOODS – INCREASE β BY A FACTOR OF 2

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	8.90	7.29	5.94	4.65	3.37	2.04	0.57	-1.18	-3.53
Income	-0.57	-0.40	-0.21	0.05	0.32	0.55	0.77	0.97	1.12
Both	8.32	6.89	5.73	4.70	3.68	2.57	1.29	-0.28	-2.52

TABLE 18. WELFARE CHANGES IN BRAZIL BEFORE ADJUSTING FOR INTERMEDIATE GOODS—INCREASE β BY A FACTOR OF 2

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	9.56	7.11	5.31	3.68	2.10	0.47	-1.32	-3.32	-5.91
Income	1.75	2.02	2.20	2.29	2.32	2.36	2.50	2.63	2.69
Both	11.35	9.13	7.48	5.90	4.32	2.69	0.99	-0.94	-3.54

TABLE 19. WELFARE CHANGES IN MEXICO AFTER ADJUSTING FOR INTERMEDIATE GOODS—INCREASE β BY A FACTOR OF 2

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	3.40	2.99	2.64	2.30	1.96	1.61	1.21	0.74	0.09
Income	-1.37	-1.32	-1.26	-1.18	-1.11	-1.04	-0.98	-0.92	-0.88
Both	2.01	1.65	1.37	1.11	0.85	0.57	0.24	-0.17	-0.77

TABLE 20. WELFARE CHANGES IN BRAZIL AFTER ADJUSTING FOR INTERMEDIATE GOODS—INCREASE β BY A FACTOR OF 2

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	3.55	2.93	2.46	2.03	1.61	1.17	0.69	0.13	-0.59
Income	-0.73	-0.65	-0.60	-0.57	-0.56	-0.55	-0.51	-0.47	-0.45
Both	2.81	2.27	1.86	1.46	1.05	0.62	0.18	-0.33	-1.04

TABLE 21. WELFARE CHANGES IN MEXICO BEFORE ADJUSTING FOR INTERMEDIATE GOODS -DECREASE β BY A FACTOR OF 2

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	5.45	5.26	5.11	4.97	4.82	4.67	4.49	4.28	3.98
Income	-0.07	0.06	0.21	0.38	0.53	0.69	0.84	0.99	1.12
Both	5.38	5.33	5.33	5.36	5.38	5.38	5.37	5.31	5.13

TABLE 22. WELFARE CHANGES IN BRAZIL BEFORE ADJUSTING FOR INTERMEDIATE GOODS—DECREASE β BY A FACTOR OF 2

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	5.35	5.07	4.86	4.66	4.47	4.27	4.05	3.79	3.45
Income	0.49	0.83	1.05	1.18	1.24	1.32	1.49	1.65	1.71
Both	5.86	5.93	5.95	5.89	5.75	5.63	5.59	5.49	5.21

TABLE 23. WELFARE CHANGES IN MEXICO AFTER ADJUSTING FOR INTERMEDIATE GOODS—DECREASE β BY A FACTOR OF 2

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	2.81	2.76	2.72	2.68	2.64	2.59	2.54	2.48	2.40
Income	-1.68	-1.64	-1.59	-1.54	-1.49	-1.45	-1.40	-1.36	-1.32
Both	1.09	1.08	1.08	1.10	1.11	1.11	1.11	1.10	1.05

TABLE 24. WELFARE CHANGES IN BRAZIL AFTER ADJUSTING FOR INTERMEDIATE GOODS—DECREASE β BY A FACTOR OF 2

Channel(s)	10th	20th	30th	40th	50th	60th	70th	80th	90th
Expenditure	2.78	2.70	2.64	2.59	2.53	2.48	2.41	2.34	2.25
Income	-1.50	-1.40	-1.33	-1.30	-1.28	-1.26	-1.21	-1.16	-1.14
Both	1.24	1.27	1.28	1.26	1.22	1.19	1.18	1.16	1.08