

# PER CAPITA INCOME AND THE DEMAND FOR SKILLS

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## Abstract

Almost all of the literature about the growth of income inequality and the relationship between skilled and unskilled wages approaches the issue from the production side of general equilibrium (skill-biased technical change, international trade). We add a role for income-dependent demand interacted with factor intensities in production. We explore how income growth and trade liberalization influence the demand for skilled labor when preferences are non-homothetic and income-elastic goods are more intensive in skilled labor, an empirical regularity documented in Caron, Fally and Markusen (2014). We simulate the sector-neutral productivity improvements and reductions in trade costs which correspond to the growth in income and exports observed between 1995 and 2010. Relative to what we would obtain with homothetic preferences, we show that these changes lead to significant increases in the skill premium, especially in developing countries. Our results are mostly driven by productivity growth shifting consumption towards skill-intensive goods, but non-homothetic preferences also matter when evaluating the effect of trade cost changes on the skill premium. Overall, the negative effect of trade cost reductions on the skill premium predicted for developing countries under homothetic preferences (Stolper-Samuelson) is strongly mitigated, and sometimes reversed.

**Keywords:** Non-homothetic preferences, skill premium, per capita income, structural change, international trade.

**JEL Classification:** F10, O10, F16, J31.

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# 1 Introduction

Over the past three decades, the large increase in income inequality, especially between skilled and unskilled workers, has led to a large body of research aiming to explain these changes, often focusing on the roles of trade and (or versus) skill-biased technological change.<sup>1</sup> Other recent work has highlighted the role of several alternative channels in explaining these changes, such as trade and offshoring through Heckscher-Ohlin-type mechanisms,<sup>2</sup> heterogeneous technology adoption across firms,<sup>3</sup> changes in matching patterns between heterogeneous workers and firms,<sup>4</sup> and quality upgrading encouraged by trade liberalization.<sup>5</sup> While this significant body of work concentrates on the production side of general equilibrium, there is a smaller literature that considers shifting patterns of demand across sectors which require different types of skills.<sup>6</sup> The sources of these demand shifts are in some cases modeled explicitly and in others simply taken as exogenous. Our paper fits with some of this demand-driven literature, though we link characteristics of goods in consumption to characteristics of goods in production in a very explicit way. We will first describe our approach, and then explain how it relates to other literature later in the section.

In this paper, we illustrate how income growth and reductions in trade costs affect the skill premium when preferences are non-homothetic. Our results rely on the correlation between income elasticity in consumption and skill intensity in production across goods, shown to be very large in Caron, Fally and Markusen (2014). This correlation implies that homogeneous productivity growth across sectors is no longer neutral for the skill premium in general equilibrium. It implies that as countries become richer, their consumers increase their relative consumption of goods that are more skill-intensive in production, thereby increasing the returns to skilled labor relative to those of unskilled labor. The effects of trade cost reductions on the skill premium also differ when preferences are non-homothetic and when income-elastic goods are more skill intensive: the net skilled-labor content of trade and the effect of trade-driven income growth are both different under these conditions.

To quantify these mechanisms, our analysis proceeds in three steps. In step 1, we describe a model of production, trade and consumption in general equilibrium. In step 2, we estimate the preference, trade cost and technology parameters of the model. We take a cross-sectional approach which allows us to identify the role of income in explaining shifts in consumption. In step 3, we simulate various counterfactual equilibria to quantify and illustrate the impact of productivity growth and trade cost reductions on the skill premium. Before proceeding, we wish to emphasize that while we do show that non-homothetic preferences push the model's predictions closer to observed estimates of the skill premium, our methodology does not permit us to evaluate the contributions of growth and trade relative to the alternative theories of the skill premium mentioned above.

The first step of our analysis is to develop a model combining non-homothetic preferences with a

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<sup>1</sup>Katz and Murphy (1992), Goldberg and Pavcnik (2007), Autor et al. (2015)

<sup>2</sup>Krugman (2000), Feenstra and Hanson (1997)

<sup>3</sup>Bustos (2011), Burstein and Vogel (2017).

<sup>4</sup>Card et al. (2013), Helpman et al. (2017)

<sup>5</sup>Hallak (2010), Feenstra and Romalis (2014), Fielser, Eslava and Xu (2016)

<sup>6</sup>Buera and Kaboski (2012), Johnson and Keane (2013)

standard multi-sector and multi-factor model on the supply side. Consumption patterns are derived from “constant relative income elasticity” (CRIE) preferences as in Caron et al (2014) and Fieler (2011). The supply-side structure is an extension of Costinot et al. (2012) and Eaton and Kortum (2002) with multiple factors of production and an input-output structure as in Caliendo and Parro (2014). The model can be used to derive first-order approximations of the response of the skill premium to uniform changes in productivity and trade costs, with and without taking into account the demand for intermediate goods. These approximations help develop the intuition behind the mechanisms and emphasize the role played by the correlation between income elasticity and skill intensity.

In a second step, we estimate preference, trade cost and technology parameters. Our estimations rely on the Global Trade Analysis Project (GTAP) dataset. In order to test whether our mechanisms have quantitative relevance in explaining changes in the skill premium going back several decades, we estimate our model using version 5 of the dataset (Dimaranan and McDougall, 2002), which is based on 1997 data. GTAP 5 comprises 66 countries with a wide range of income levels, 56 broad sectors including manufacturing and services, and 5 factors of production including the disaggregation of skilled and unskilled labor.<sup>7</sup> This dataset is uniquely suited to our purposes, as it contains a consistent and reconciled cross-section of production, input-output, consumption and trade data. However, the broad categories of goods and services make it unsuitable for the discussion of issues related to product quality and within-industry heterogeneity.

We follow the same estimation method as Caron et al (2014). We first estimate gravity equations within each sector, which allows us to identify patterns of comparative advantage and to construct price indices across importers and sectors. We then estimate consumer preferences, adjusting for these price index differences. To account for endogeneity, we also instrument prices with indices that do not depend on domestic demand. This strategy allows us to estimate and identify price and income elasticity parameters for a large range of sectors, which is usually complicated by the lack of consistent price and expenditure data, as well as by endogenous prices. We find that per capita income plays a crucial role in determining demand patterns across countries and sectors. Income-elasticity in consumption varies largely across goods and is highly correlated with skill intensity in production, as also documented in Caron et al (2014), with an estimated correlation above 40 percent across all goods, whether or not we exclude services.

In a third step, we use our estimates of preferences, trade cost and technology parameters for counterfactual simulations in general equilibrium. Our objective is to quantitatively assess whether historical rates of growth in income and trade liberalization may have affected the skill premium, with a focus on the role of non-homothetic changes in consumption. To do so, we first calibrate growth in productivity and reductions in trade costs to match observed growth in real per capita income and trade/GDP ratios between 1995 and 2010. Counterfactuals then examine how these productivity and trade shocks affect the skill premium, allowing for non-homotheticity in demand. Even if these shocks are uniform across sectors, their effects are not. Our simulation results reveal an increase in the skill

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<sup>7</sup>We also document that all central results hold for more recent data based on 2007 (GTAP8) (Narayanan et al., 2012), which covers 109 countries.

premium in almost all countries. The increases are particularly large in the developing world, with an average of 9.3% in low-income countries. For China, the model predicts a 17% increase in the skill premium; for India, 22%; for Vietnam, 21%. The predicted increase is also substantial in many African countries. Changes are, however, smaller on average in middle- and high-income countries, at 2.4%.

We then decompose these results to disentangle the relative contributions of growth and openness to trade. To pinpoint the role of growth in per capita income, we first re-simulate the changes in the skill premium caused by our estimated 1995-2010 productivity shocks (without considering changes in trade costs). Results suggest a large potential for income growth to affect the skill premium. The strong correlation between skill intensity and income elasticity induces a quantitatively large shift in demand towards skill-intensive goods as per capita income increases. This effect is quantitatively important and explains most of the overall changes in the skill premium found in the unified counterfactual where trade costs also change. This is particularly true for developing countries which are rapidly transitioning out of unskilled-labor intensive sectors such as agriculture and basic manufacturing. Productivity growth alone would have explained a skill premium increase of 14% in China, 23% for India, and on average 9.6% in low-income countries (against 2.4% on average for middle- and high-income countries). We show that the higher increase in low-income countries is not primarily driven by differences in growth rates across countries, and is robust to a number of assumptions underlying our exercise, including the choice of demand system.

Note that the main mechanism in this counterfactual does not rely on trade linkages and we obtain no sizable difference between closed and open economy simulations, except for a few small open countries. On the other hand, input-output linkages play an important role. Industries upstream of skill-intensive industries tend to be skill intensive themselves, but on average less so, such that there is less variation in skill intensities when intermediate goods are accounted for. Still, the correlation between skill intensity and income elasticity is similar with or without intermediates. Thus, while input-output linkages dampen the link between changes in consumption and changes in the skill premium, they by far do not eliminate it.

We then examine how preferences affect the relationship between trade liberalization and the skill premium by re-simulating the estimated 1995-2010 changes in trade costs (holding productivity fixed at 1995 levels). We highlight and quantify four channels through which non-homothetic preferences affect results. The first channel reflects how non-homothetic preferences affect predicted trade patterns and the strength of Stolper-Samuelson forces. The standard Stolper-Samuelson argument, which holds with homothetic preferences, suggests that in countries abundant in unskilled labor, the direct effect of trade cost reductions is a decrease in the relative demand for skilled workers, while the reverse is true for skill-abundant countries. Our results suggest that the introduction of non-homothetic preferences into the model substantially moderates this prediction. As documented in Caron et al (2014), non-homothetic preferences lead to less trade between high-income and low-income countries, and smaller net factor content of trade in skilled and unskilled labor. This weakens the Stolper-Samuelson effect, especially for developing countries for which the net factor content of trade is significantly lower under

non-homotheticity.

A second channel highlights the income effect of trade. As trade costs decline, gains from trade make countries richer. Similar to the effect productivity growth, consumption thus shifts towards income-elastic and skill intensive goods. Simulations show that the trade-induced income effect is quantitatively significant in many developing countries. We also illustrate the role of input-output linkages (which magnify our results) and general-equilibrium feedbacks (which mitigate our results), but we find that these last two channels only moderately affect the first two.

Combined, these effects suggest that non-homothetic preferences generate a higher skill premium for the same amount of trade liberalization in all but the richest countries. The difference is strong in developing countries, many of which see the negative effect of trade on the skill premium under homotheticity disappear altogether.

Our simulated changes in the skill premium suggest that demand-driven mechanisms may have played a quantitatively important role in driving observed changes in relative wages – comparable in magnitude to other mechanisms discussed in the literature such as skill-biased technological change (Autor et al., 1998). These alternative mechanisms are likely to confound and interact with demand-side forces and are not captured in our model, so we cannot identify the relative importance of non-homothetic preferences. Still, a simple correlation exercise suggests that they might help explain patterns of historical growth in the skill premium across countries, especially for low-income countries where growth in both income and the skill premium has been strongest and where our effect is strongest. For 40 countries, we compare our simulated estimates to observed 1995 to 2010 changes in the skill premium described in the WIOD dataset (e.g., Cravino and Sotelo 2018). We find that allowing for non-homothetic preferences significantly increases the correlation between observed and simulated changes in the skill premium. For several countries, the effect is remarkable. In China, for instance, the 17% simulated increase relative to the homothetic case can be contrasted with the 51% increase observed in the WIOD data. In rich countries the effect is smaller, but not negligible: the mechanism generates an increase in the skill premium that represents about 20% of the observed increase in the US over that period (Parro, 2013).

As noted earlier, there is a large literature on the skill premium. Since we are not attempting to run a horse race among approaches, our review of the literature is not exhaustive and omits numerous papers focusing on skill-biased technical change and standard Heckscher-Ohlin type trade mechanisms. These models and results are clearly empirically important, but for the sake of exposition we instead focus on work more related to our own, i.e. related to the demand side.

In the international trade literature, Markusen (2013) theoretically identified the potential consumption-driven impacts on the skill premium which we quantify. In a stylized model, he postulates that non-homothetic preferences and a possible correlation between income elasticity in consumption and skill intensity in production would cause neutral productivity growth to increase the relative wage of skilled workers. Caron, Fally and Markusen (2014) show that the correlation is empirically strong and illustrate the consequences for trade patterns, trade-to-GDP ratios, and the missing trade puzzle.

Here, we examine and quantify the implications of this correlation for the skill premium.<sup>8</sup>

More generally, this paper is part of a renewed interest in non-homothetic preferences in open-economy settings in the trade literature. Fieler (2011), Simonovska (2015), Fajgelbaum and Khandelwal (2016) also incorporate non-homotheticities in consumption, adding to a literature initiated by Markusen (1986), Flam and Helpman (1987), Matsuyama (2000) among others. While related to our work in terms of non-homotheticity, these papers concentrate on issues other than the skill premium, such as explaining trade volumes and patterns, and markups in relation to per-capita incomes. Matsuyama (2019) pushes this literature further by endogenizing the relationship between non-homothetic preferences and differential productivity growth rates across sectors and patterns of specialization.

Conversely, work on trade and the skill premium has mostly focused on the supply side. A few papers have confirmed Stolper-Samuelson effects for developing countries (e.g. Robertson 2004 for Mexico, Gonzaga et al. 2006 for Brazil), which are often at odds with increasing wage inequality that we observe in most countries (Goldberg and Pavcnik 2007). Most of the recent literature on trade and the skill premium thus aims to explain why trade may lead to a larger increase (a more positive or less negative change) in the skill premium than suggested by the standard Heckscher-Ohlin model. Bustos (2011) proposes a mechanism whereby access to foreign markets triggers the adoption of skill-biased technologies and provides supportive evidence from Argentinian firm-level data. Burstein and Vogel (2017) also examine how the heterogeneous effect of trade across firms influences the relative demand for skilled labor, and show that this within-sector reallocation channel can be potentially much larger than standard Heckscher-Ohlin channels. Costinot and Vogel (2010) indicate that poor countries facing large demand for skill-intensive goods from rich countries might experience a positive effect of trade on the skill premium, but do not examine this claim empirically. Cravino and Sotelo (2018) show that a reduction in trade costs leads to a relative expansion of the service sector relative to the manufacturing sector when those are strong complements. Since service activities are more intensive in skilled labor, this leads to a larger increase in the skill premium.

Non-homotheticity in consumption also plays an important role in the literature on trade and quality (e.g. Hallak, 2010, Feenstra and Romalis, 2014). If the production of higher-quality goods requires relatively more skilled labor, the idea developed here can be applied to link the skill premium to the demand for quality.<sup>9</sup> Opening to trade with richer countries, as well as increasing income per capita, should lead to increasing demand for higher-quality goods and an increase in the skill premium. The link between quality and skilled labor is present in the work of Fieler et al. (2018) who, without explicitly modeling final demand, examine the effect of trade liberalization in Colombia. They argue that opening to trade led to an increase in the demand for skilled workers due to the increase in the quality of goods being produced.

Since our model and approach rely on shifts in the composition of demand across sectors, at least two papers that provide strong evidence for these shifts should be noted. In the literature

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<sup>8</sup>A working paper version, Caron et al. (2012), included some of our results on the skill premium. The working paper had to be split in two and these results are not part of the published version, Caron et al. (2014).

<sup>9</sup>A very recent paper by Jaimovich et al. (2019) exploits that idea, focusing on quality upgrading.

examining the source and consequences of structural change, Buera and Kaboski (2012) discuss how productivity growth leads to an increase in the skill premium. They develop and calibrate a two-sector model in which growth leads to a higher share of services that are more skill intensive. They do not, however, estimate or quantify the role of non-homothetic preferences, nor do they discuss the correlation between skill intensity and income elasticity beyond the two-sector approach. Our estimated income elasticities tend to be larger for services sectors, but the correlation between skill intensity and income elasticity holds even when we exclude services. Since it holds for traded goods, the correlation also has implications for the composition of trade and can help us explain why trade has a less negative or even positive effect on the skill premium in developing countries relative to standard models (though the impact of non-homothetic preferences is still substantial for these countries).

A second paper is Johnson and Keane (2013), who examine how sectoral shifts in consumption influence the demand for many different types of labor. In particular, they document the importance of demand shifts across occupations, such as the shift toward (heavily female) service occupations.<sup>10</sup> However, Johnson and Keane (2013) do not model or explain these sectoral demand shifts, a primary purpose of our paper.

Finally, a growing literature examines the differential effect of trade on the cost of living across workers and households within a country. This channel has been examined, among others, by Fajgelbaum and Kandelwahl (2016), Nigai (2016) and He and Zhang (2017).<sup>11</sup> For most countries, Fajgelbaum and Kandelwahl (2016) estimate that poor households gain relatively more from trade through cost-of-living effects, while Nigai (2016) tends to find the opposite. He and Zhang (2017) extend Fajgelbaum and Kandelwahl (2016) to allow for worker sorting across multiple sectors, and show that the effect of trade on the cost of living can be quantitatively larger than the effects on nominal income. While we acknowledge that cost-of-living effects matter for welfare, we focus here on the channels through which trade (and growth) affects the skill premium in nominal terms.<sup>12</sup> Our approach is closer to the Heckscher-Ohlin tradition of multiple factors of production, so we can easily analyze skilled versus unskilled wages and distinguish sectors by factor intensities, which is exactly what we have in our data.

The rest of the paper is organized in three sections. We describe our theoretical framework in Section 2, our empirical strategy and estimation results in Section 3, and the quantitative implications for the skill premium in Section 4.

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<sup>10</sup>Paraphrasing, they document a number of other facts that cast doubt on the proposition that skill-biased technical change is the main culprit behind the skill premium.

<sup>11</sup>See also Porto (2006) for Argentina, Faber (2014), Cravino and Levchenko (2016) for Mexico, Faber and Fally (2017) for the US.

<sup>12</sup>Our approach allows us to generate predictions of the change in the relative wage of skilled vs. unskilled workers even if there is no available data on initial wages by skill category in most of the developing countries in our sample. Adjusting for cost-of-living effects would instead require data on initial wage differences between types of workers and the distribution within each type.

## 2 Theoretical framework

### 2.1 Benchmark Model set-up

The model closely follows Caron et al (2014) with the same non-homothetic preferences but a more flexible production function in terms of skilled and unskilled workers.

**Demand** The economy is constituted of heterogeneous industries. In turn, each industry  $k$  is composed of a continuum of product varieties indexed by  $j_k \in [0, 1]$ . Preferences take the form:

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

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

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

Preferences are identical across countries, but non-homothetic if  $\sigma_k$  varies across industries. If  $\sigma_k = \sigma$ , we are back to traditional homothetic CES preferences.<sup>13</sup>

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

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

where  $\lambda_n$  is the Lagrange multiplier associated with the budget constraint of individuals in country  $n$ , and  $\alpha_{2,k} = (\alpha_{1,k} \frac{\sigma_k-1}{\sigma_k})^{\sigma_k}$ . The income elasticity of demand  $\eta_{nk}$  for goods in industry  $k$  and country  $n$  equals:

$$\eta_{nk} \equiv \frac{\partial \log x_{nk}}{\partial \log e_n} = \sigma_k \cdot \frac{\sum_{k'} x_{nk'}}{\sum_{k'} \sigma_{k'} x_{nk'}} \quad (2)$$

(where  $e_n$  denotes per capita income) which implies that the ratio of the income elasticities of any pair of goods  $k$  and  $k'$  equals the ratio of their  $\sigma$  parameters:  $\frac{\eta_{nk}}{\eta_{nk'}} = \frac{\sigma_k}{\sigma_{k'}}$  and is constant across countries. The income elasticity of any given sector, however, decreases as income increases (holding prices fixed).<sup>14</sup>

**Production** We assume a constant-returns-to-scale production function that depends on several factors and bundles of intermediate goods from each industry. We assume that factors of production are perfectly mobile across sectors but immobile across countries. We denote by  $\gamma_{kh}$  the share of the

<sup>13</sup>These preferences are used in Fielor (2011) and Ligon (2016), with early analyses and applications found in Hanoch (1975) and Chao and Manne (1982). To the best of our knowledge, there is no common name attached to these preferences, so we refer to them as constant relative income elasticity (CRIE) tastes.

<sup>14</sup>This property is actually quite general: average income elasticities decrease with income for any Walrasian demand. Note also that CRIE preferences (and separable preferences in general) preclude any inferior good: the income elasticity of demand is always positive for any good.



input bundles from industry  $h$  in total costs of industry  $k$  (direct input-output coefficient), and each input bundle is a CES aggregate of all varieties available in this industry (for the sake of exposition we assume that the elasticity of substitution between varieties is the same as for final goods). We denote by  $w_{if}$  the price of factor  $f$  in country  $i$ . Total factor productivity  $Z_{ik}(j_k)$  varies by country, industry and variety. Labor inputs, comprised of unskilled or low-skill labor ( $f = L$ ) and high-skilled labor ( $f = H$ ), are combined into a CES aggregate with elasticity of substitution  $\rho$ .

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

$$p_{nik}(j_k) = \frac{d_{nik}}{Z_{ik}(j_k)} (c_{ikLab})^{\gamma_{kLab}} \prod_{f \notin Lab} (w_{if})^{\gamma_{kf}} \prod_h (P_{ih})^{\gamma_{kh}} \quad (3)$$

where  $P_{ih}$  is the price index of goods  $h$  in country  $i$  and  $\sum_f \gamma_{kf} + \sum_h \gamma_{kh} = 1$  to ensure constant returns to scale in each industry  $k$ . The cost of labor  $c_{ikLab}$  is a CES aggregate of the wage of high-skilled and low-skilled workers:

$$c_{ikLab} = \left[ \mu_{ikL} w_{iL}^{1-\rho} + \mu_{ikH} w_{iH}^{1-\rho} \right]^{\frac{1}{1-\rho}} \quad (4)$$

Parameters  $\mu_{ikH}$  and  $\mu_{ikL}$  capture the high and low-skilled-labor intensity of sector  $k$  in country  $i$ , and  $\rho$  the elasticity of substitution between types of labor.

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

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

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

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

where  $z_{ik}$  is a productivity shifter reflecting average TFP of country  $i$  in sector  $k$ . As in Eaton and Kortum (2002),  $\theta_k$  is related to the inverse of productivity dispersion across varieties within each sector.<sup>15</sup> As in Costinot, Donaldson and Komunjer (2012), we also allow the shift parameter  $z_{ik}$  to vary across exporters and industries, keeping a flexible structure on the supply side and controlling for any pattern of Ricardian comparative advantage forces at the sector level.

**Endowments** Each country  $i$  is populated by a number  $L_i$  of individuals. The total supply of factor  $f$  is fixed in each country and denoted by  $V_{if}$ . Each person is endowed by  $V_{if}/L_i$  units of factor  $V_{if}$  implying no within-country income inequality.<sup>16</sup>

<sup>15</sup>Note that we also assume  $\theta_k > \xi_k - 1$  for all  $k$  to ensure a well-defined CES price index for each industry.

<sup>16</sup>We show in Caron et al (2014) that we obtain very similar preference estimates when account for the distribution of income across quintiles for a subset of countries.

## 2.2 Equilibrium

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

$$D_{nk} = L_n (\lambda_n)^{-\sigma_k} \alpha_{2,k} (P_{nk})^{1-\sigma_k} \quad (5)$$

where  $\lambda_n$  is the Lagrange multiplier associated with the budget constraint:

$$L_n e_n = \sum_k D_{nk} \quad (6)$$

where  $e_n$  denotes per-capita income. Total demand  $X_{nk}$  for goods  $k$  in country  $n$  is the sum of the demand for final consumption  $D_{nk}$  and intermediate use:

$$X_{nk} = D_{nk} + \sum_h \gamma_{hk} Y_{nh} \quad (7)$$

where  $Y_{nh}$  refers to total production in sector  $h$ .

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

$$\pi_{nik} \equiv \frac{X_{nik}}{X_{nk}} = \frac{S_{ik} (d_{nik})^{-\theta_k}}{\Phi_{nk}} \quad (8)$$

where  $S_{ik}$  and  $\Phi_{nk}$  are defined as follows. The ‘‘supplier effect’’,  $S_{ik}$ , is inversely related to the cost of production in country  $i$  and industry  $k$ . It depends on the factor productivity parameter  $z_{ik}$ , intermediate goods and factor prices:

$$S_{ik} = z_{ik}^{\theta_k} (c_{ikLab})^{-\theta_k \gamma_{kLab}} \prod_{f \notin Lab} (w_{if})^{-\theta_k \gamma_{kf}} \prod_h (P_{ih})^{-\theta_k \gamma_{kh}} \quad (9)$$

with the cost of labor  $c_{ikLab} = \left[ \mu_{ikL} w_{iL}^{1-\rho} + \mu_{ikH} w_{iH}^{1-\rho} \right]^{\frac{1}{1-\rho}}$  as in Equation (4).

In turn, we define  $\Phi_{nk}$  as the sum of exporter fixed effects deflated by trade costs.  $\Phi_{nk}$  plays the same role as the ‘‘inward multilateral trade resistance index’’ as in Anderson and van Wincoop (2003):

$$\Phi_{nk} = \sum_i S_{ik} (d_{nik})^{-\theta_k} \quad (10)$$

This  $\Phi_{nk}$  is actually closely related to the price index, as in Eaton and Kortum (2002):

$$P_{nk} = \alpha_{3,k} (\Phi_{nk})^{-\frac{1}{\theta_k}} \quad (11)$$

with  $\alpha_{3,k} = \left[ \Gamma \left( \frac{\theta_k + 1 - \xi_k}{\theta_k} \right) \right]^{\frac{1}{\xi_k - 1}}$  where  $\Gamma$  denotes the gamma function.<sup>17</sup>

Finally, two other market clearing conditions are required to determine factor prices and income in general equilibrium. Income for each factor equals the sum of total production weighted respectively by factor intensity. With factor supply  $V_{if}$  and factor price  $w_{if}$  for factor  $f$  in country  $i$ , market clearing for factors other than labor implies:

$$V_{if}w_{if} = \sum_k \gamma_{kf}Y_{ik} = \sum_{n,k} \gamma_{kf}X_{nik} \quad (12)$$

For each type of labor  $l \in \{L, H\}$ , factor intensity is given by:

$$\beta_{ikl} = \frac{\mu_{ikl} w_{il}^{1-\rho}}{\mu_{ikL} w_{iL}^{1-\rho} + \mu_{ikH} w_{iH}^{1-\rho}} = \mu_{kl} w_{il}^{1-\rho} c_{ikLab}^{\rho-1} \quad (13)$$

and labor market clearing imposes:

$$V_{il}w_{il} = \sum_k \beta_{ikl} \gamma_{kLab} Y_{ik} = \sum_{n,k} \beta_{ikl} \gamma_{kLab} X_{nik}. \quad (14)$$

In turn, per-capita income is determined by average income across all factors:

$$e_i = \frac{1}{L_i} \sum_f V_{if} w_{if} \quad (15)$$

By Walras' Law, trade is balanced at equilibrium.

### 2.3 Counterfactual equilibria

Following Dekle et al. (2007) and Caliendo and Parro (2014), the model lends itself naturally to counterfactual simulations in general equilibrium. By reformulating the above equilibrium conditions in terms of changes relative to the baseline observed equilibrium, counterfactuals can be obtained using a set of observed variables and only a few parameters to estimate. We do so with the help of hat notation, where  $\widehat{Z} = Z'/Z$  denotes the relative change for variable  $Z$  ( $Z'$  referring to the value in the new equilibrium).

In our counterfactual simulations, we will examine the impact of the changes in productivity  $\widehat{z}_{ik} = \frac{z'_{ik}}{z_{ik}}$  that explain recent changes in GDP per capita. Jointly or separately, we will also simulate changes in trade costs  $\widehat{d}_{nik} = \frac{d'_{nik}}{d_{nik}}$  in order to match changes in openness to trade.

The model yields the following set of equilibrium conditions:

$$\widehat{D}_{nk} = \widehat{\lambda}_n^{-\sigma_k} \widehat{P}_{nk}^{1-\sigma_k} \quad (16)$$

<sup>17</sup>Alternatively, we can generalize this model and assume that the elasticity of substitution for intermediate use differs from the elasticity of substitution for final use, and depends on the parent industry. This does not affect the elasticity of the price index w.r.t.  $\Phi_k$ . Differences in elasticities of substitution would be captured by the industry fixed effect that we include in our estimation strategy and would not affect our estimates.

$$\widehat{e}_n = \frac{\sum_k \widehat{D}_{nk} D_{nk}}{\sum_k D_{nk}} \quad (17)$$

$$\widehat{X}_{nk} = \frac{1}{X_{nk}} \left[ D_{nk} \widehat{D}_{nk} + \sum_h \gamma_{hk} Y_{nh} \widehat{Y}_{nh} \right] \quad (18)$$

$$\widehat{X}_{nik} = \widehat{S}_{ik} \widehat{d}_{nik}^{-\theta_k} \widehat{P}_{nk}^{\theta_k} \widehat{X}_{nk} \quad (19)$$

$$\widehat{Y}_{ik} = \frac{\sum_n X_{nik} \widehat{X}_{nik}}{\sum_n X_{nik}} \quad (20)$$

$$\widehat{S}_{ik} = \widehat{z}_{ik}^{\theta_k} (c_{ikLab})^{-\theta_k \gamma_{kL}} \prod_{f \neq L} (\widehat{w}_{if})^{-\theta_k \gamma_{kf}} \prod_h (\widehat{P}_{ih})^{-\theta_k \gamma_{kh}} \quad (21)$$

$$\widehat{P}_{nk} = \left[ \frac{1}{X_{nk}} \sum_i X_{nik} \widehat{S}_{ik} \widehat{d}_{nik}^{-\theta_k} \right]^{-\frac{1}{\theta_k}} \quad (22)$$

$$c_{ikLab} = \left[ \beta_{ikL} \widehat{w}_{iL}^{1-\rho} + \beta_{ikH} \widehat{w}_{iH}^{1-\rho} \right]^{\frac{1}{1-\rho}} \quad (23)$$

$$\widehat{w}_{if} = \left[ \sum_k sh_{ikf} c_{ikLab}^{\rho-1} \widehat{Y}_{ik} \right]^{\frac{1}{\rho}} \quad \text{for } f \in \{L, H\} \quad (24)$$

$$\widehat{w}_{if} = \sum_k sh_{ikf} \widehat{Y}_{ik} \quad \text{for } f \notin \{L, H\} \quad (25)$$

$$\widehat{e}_i = \frac{\sum_f V_{if} w_{if} \widehat{w}_{if}}{\sum_f V_{if} w_{if}} \quad (26)$$

where, in Equations (24) and (25),  $sh_{ikf} = \frac{\beta_{ikf} Y_{ik}}{\sum_{k'} \beta_{ik'f} Y_{ik'}}$  is the share of sector  $k$  in the total returns to factor  $f$ , and  $\beta_{ikf}$  is factor intensity described in Equation (13) for labor and equal to  $\gamma_{kf}$  for other factors.

Knowing the values of variables  $D_{nk}$ ,  $e_n$ ,  $X_{nk}$ ,  $X_{nik}$  and  $V_{if} w_{if}$  in the baseline equilibrium as well as parameters  $\sigma_k$ ,  $\theta_k$ ,  $\gamma_{kh}$  and  $\beta_{ikf}$ , we can solve for all changes  $\widehat{D}_{nk}$ ,  $\widehat{\lambda}_n$ ,  $\widehat{e}_n$ ,  $\widehat{P}_{nk}$ ,  $\widehat{S}_{nk}$  and  $\widehat{w}_{nf}$  driven by given changes in productivity  $\widehat{z}_{ik}$  and/or trade costs  $\widehat{d}_{nik}$ .<sup>18</sup>

## 2.4 Implications for the skill premium

In this section, we illustrate how productivity growth and trade can affect the relative returns to factors if demand is non-homothetic and there is a systematic relationship between preference parameters and factor intensities.

### 2.4.1 Productivity growth and the skill premium

When skill intensity and income elasticity are correlated across industries, productivity (TFP) growth has a positive effect on the skill premium through the composition of consumption. The intuition is

<sup>18</sup>We solve this system in three iterative steps. In a first step, taking income and factor prices as given, we use Equations (21), (22) and (23) to solve for prices. Then, in a second step, given the change in prices from step 1, we use Equations (16) to (20) to solve for demand, trade and production. In a third step, we adjust for changes in factor prices and income using (24) to (26). We iterate these three steps until convergence is achieved.

simple. As productivity increases, people become richer and consume more goods from income-elastic industries which are, as we show, more intensive in skilled labor.<sup>19</sup> This increases the demand for skilled labor relative to less skilled labor and increases the relative wage of skilled workers. On the contrary, with homothetic preferences, uniform productivity growth is neutral for the skill premium.

To develop intuition, we derive first-order approximations of the response of the skill premium to changes in productivity, assuming uniform growth in all countries and all sectors. In the quantitative section, we will show how these approximations compare with estimates of changes in the skill premium obtained from general equilibrium simulations. The complete derivation of these approximations can be found in Appendix B.

**Autarky without intermediate goods** If countries are in autarky and intermediate goods are ignored, all changes in production can be traced back to changes in domestic consumer demand. Holding nominal GDP constant (normalization), a homogeneous productivity increase  $\hat{z}$  leads, as a first approximation, to a homogeneous change in prices  $\widehat{P}_{nk} \approx \hat{z}^{-1}$ . Using Equations (16) and (26), we obtain that the changes in demand, and therefore production, in country  $n$  and sector  $k$  are simply given by the income elasticity  $\eta_{nk}$ :  $\log \widehat{D}_{nk} \approx (\eta_{nk} - 1) \log \hat{z}$ . We can then obtain a simple expression for the elasticity of the skill premium,  $\frac{w_{nH}}{w_{nL}}$ , to a TFP increase  $\hat{z}$ :

$$\log \left( \frac{\widehat{w_{nH}}}{w_{nL}} \right) \approx \frac{1}{\tilde{\rho}_n} \log \hat{z} \sum_k (sh_{nk}^H - sh_{nk}^L) \eta_{nk} \quad (27)$$

where  $sh_{nk}^H \equiv \frac{\beta_{nkH} Y_{nk}}{\sum_{k'} \beta_{nkH'} Y_{nk'}}$  is the share of sector  $k$  in the total skill labor employment in country  $n$  (and  $sh_{nk}^L$  refers to the share of unskilled workers in sector  $k$ ), and  $\eta_{nk}$  is the income elasticity in sector  $k$ , country  $n$ . In this expression, the effect on the skill premium is deflated by an adjusted elasticity of substitution between labor types  $\tilde{\rho}_i = \rho - (\rho - 1) \sum_k (sh_{ik}^H - sh_{ik}^L) \beta_{ikH}$ , which is very close to  $\rho$  for most countries (and always smaller than  $\rho$  given the positive correlation between skill intensity and income elasticity).

We can see that this term is positive if income elasticity  $\eta_{nk}$  is correlated with the demand for high vs. low-skilled labor (the term in  $sh_{nk}^H - sh_{nk}^L$ ) across sectors. In that case, growth in TFP generates an increase in the skill premium.

This first-order approximation neglects the feedback effect of the changes in the skill premium on relative prices across products. When the skill premium increases, the relative price of skill-intensive goods increases, decreasing the relative demand for these goods and thus the relative demand for skilled workers. Our general equilibrium simulations indicate that that this feedback effect is small and can be neglected in a first-order approximation. This equation provides a good approximation of the skill premium increase even if labor is not the only factor of production—we also consider capital, land and other natural resources in our simulations to confirm this. Finally, let us also point out that this relationship would hold with income elasticities derived from any other type of preferences as a

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<sup>19</sup>This assumes that the evolution of income is not driven by an accumulation of skills, which could of course mitigate the increase in the skill premium.

first-order approximation: the structure imposed on the model only matters for large changes and for the estimation of income elasticities.

Input-output linkages and trade can also affect the relationship between income elasticity and the demand for skills, and can be approximated as described just below.

**With trade in final and intermediate goods:** Under the assumption that the productivity increase  $\widehat{z}$  augments all factors of production in all countries,<sup>20</sup> the change in price  $\widehat{P}_{nk}$  still corresponds to  $\widehat{z}^{-1}$  when we neglect the feedback effect of wages on prices.<sup>21</sup> Similarly, we obtain that  $\widehat{S}_{ik} \approx \widehat{z}^{\theta_k}$  for each exporter  $i$  in industry  $k$ , which implies that trade shares  $\pi_{nik} = \frac{X_{nik}}{X_{nk}}$  remain constant. Combining Equations (18), (19) and (20), we can now account for trade and international production chains. The changes in production and demand satisfy:

$$Y_{ik}\widehat{Y}_{ik} = \sum_n \pi_{nik} D_{nk} \widehat{D}_{nk} + \sum_h \sum_n \pi_{nik} \gamma_{hk} Y_{nh} \widehat{Y}_{nh} \quad (28)$$

Coefficients  $\pi_{nik}\gamma_{hk}$  (direct requirement coefficients) reflect the value of inputs from industry  $k$  and country  $i$  required for the production of one unit of output in sector  $h$  and country  $n$ . The matrix containing these coefficients is a standard modeling tool to account for input-output linkages (Miller and Blair, 2009; Johnson, 2014). If we denote this matrix by  $G$ , the coefficients of the matrix  $(I-G)^{-1}$ , also called Leontief total requirement coefficients, can then be used to link changes in output to changes in final demand (see appendix for additional details):

$$\widehat{Y}_{ik} = \frac{1}{Y_{ik}} \sum_{n,h} \gamma_{nihk}^{tot} D_{nh} \widehat{D}_{nh} \quad (29)$$

where  $\gamma_{nihk}^{tot}$  is the value of inputs from  $i$  in sector  $k$  needed for each dollar of final good  $h$  consumed in country  $n$ . Using this result and  $Y_{ik} = \sum_{n,h} \gamma_{nihk}^{tot} D_{nh}$ , we can then express the difference in the changes in wages between skilled and unskilled workers as a function of the changes in final demand, and therefore as a function of income elasticities in downstream sectors, following the same first-order approximation as above:

$$\begin{aligned} \log\left(\frac{\widehat{w}_{iH}}{\widehat{w}_{iL}}\right) &\approx \frac{1}{\bar{\rho}_i} \sum_{k,h,n} (sh_{ik}^H - sh_{ik}^L) \frac{\gamma_{nihk}^{tot} D_{nh}}{Y_{ik}} \log \widehat{D}_{nh} \\ &\approx \frac{1}{\bar{\rho}_i} \log \widehat{z} \sum_{k,h,n} (sh_{ik}^H - sh_{ik}^L) \frac{\gamma_{nihk}^{tot} D_{nh}}{Y_{ik}} \eta_{nh} \end{aligned} \quad (30)$$

This generalizes Equation (27) to account for international trade and intermediate goods: a country's skill premium will increase if a sector's demand for high vs. low-skilled labor (the term in  $sh_{nk}^H - sh_{nk}^L$ ) is correlated with the average income elasticity of all its downstream sectors, in all countries.

<sup>20</sup>Note that in our simulations, we will allow for productivity increase to vary across countries.

<sup>21</sup>Holding world nominal GDP constant as our normalization.

### 2.4.2 Trade cost reductions and the skill premium with non-homothetic preferences

How does a reduction in trade costs affect the skill premium? Standard models of trade such as the Heckscher-Ohlin model have focused on the supply side and ignored any role for the demand side in explaining the changes in the skill premium. Here we discuss how the structure of preferences may affect these results relative to a similar structure where we impose homothetic preferences.

In a similar fashion as above for productivity and the skill premium, we can provide a first-order approximation of the effect of trade cost reductions  $\hat{d}$  on the skill premium (additional details are provided in the appendix) by neglecting second-order terms in  $(\log \hat{d})^2$ . The decomposition isolates the direct effect of changes in trade costs and the direct effect of changing consumption patterns from the remaining general equilibrium effects. Combining Equations (25) for factor prices, (20) for production and (19) for bilateral trade, we obtain:

$$\log \left( \frac{\widehat{w}_{iH}}{\widehat{w}_{iL}} \right) \approx -\frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \underbrace{\theta_k \frac{NX_{ik}}{Y_{ik}} \log \hat{d}}_{\text{Direct effects}} \quad (31)$$

$$+ \frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \underbrace{\left[ \sum_n \frac{\pi_{nik} D_{nk}}{Y_{ik}} \log \left( \widehat{\lambda}_n^{-\sigma_k} \widehat{P}_{nk}^{1-\sigma_k} \right) \right]}_{\text{Effects on final demand}} \quad (32)$$

$$+ \frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \underbrace{\left[ \sum_{n,h} \frac{\pi_{nik} \gamma_{hk} Y_{nh}}{Y_{ik}} \log \widehat{Y}_{nh} \right]}_{\text{IO linkage effects}} \quad (33)$$

$$+ \frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \underbrace{\left[ \sum_n \frac{X_{nk} \pi_{nik}}{Y_{ik}} \log(\widehat{S}_{ik} \widehat{P}_{nk}^{\theta_k}) - \sum_j \frac{X_{ik} \pi_{ijk}}{Y_{ik}} \log(\widehat{S}_{jk} \widehat{P}_{ik}^{\theta_k}) \right]}_{\text{Effects on multilateral resistance}} \quad (34)$$

where  $NX_{ik}$  denotes net exports in sector  $k$  from country  $i$ , and where we recall that  $\pi_{nik}$  denotes the share of demand in country  $n$  in sector  $k$  that is imported from country  $i$ . In these expressions,  $X_{ik}$  and  $Y_{ik}$  are fitted expenditures and production which are constructed based on consumption patterns derived from either homothetic or non-homothetic preferences.

The decomposition described by Equations (31) through (34) can be used to illustrate several mechanisms through which consumption patterns and trade costs affect the demand for skills. The first term captures the direct incidence of trade costs on production, ignoring changes in consumption patterns and other general-equilibrium effects, while the remaining terms capture indirect effects. The second term captures the effect of changes in the composition of final demand caused by changes in income and prices. The third term captures the effect of changes in intermediate demand through input-output linkages. The fourth term captures changes in multilateral-resistance terms, e.g. adjustment in factor costs (in origin countries) and competition (in destination countries). As we will show, the quantification of all of these terms depends on preferences being homothetic or non-homothetic.

The first term, which we could call the Stolper-Samuelson effect, reflects the most direct effect of trade costs on production, and depends crucially on net export  $NX_{ik}$  relative to production. In particular, it reveals that trade cost reductions will lead to a larger increase in the skill premium in countries in which the sectors that employ the largest shares of skilled workers (with high  $sh_{ik}^H - sh_{ik}^L$ ) have the highest net export ratios  $NX_{ik}/Y_{ik}$ . As we will illustrate, net export ratios, which depend on fitted export shares, depend not only on the supply side (comparative advantage) but also differ substantially across specifications on the demand side. With non-homothetic preferences, poor countries consume relatively less skill-intensive and income-elastic goods than other countries, and thus have higher net exports for these goods. Conversely, they have relatively lower net exports in income-inelastic and less skill-intensive goods. A consequence is that a reduction in trade leads to proportionally larger increases in the production of skill-intensive goods relative to the homothetic case in poor countries. In rich countries, the opposite should hold.

In the case where the trade elasticity  $\theta_k = \theta$  is homogeneous across sectors, one can further rewrite the direct effect as a function of the net factor content in unskilled vs. skilled workers. The first term becomes:

$$\text{Direct effects} \approx -\frac{\theta}{\bar{\rho}_i} \left( \frac{NCT_i^H}{V_{iH}} - \frac{NCT_i^L}{V_{iL}} \right) \log \hat{d} \quad (35)$$

where  $\frac{NCT_i^f}{V_{if}}$  denotes the net factor content of trade of country  $i$  in factor  $f \in \{H, L\}$  (skilled or unskilled labor) relative to its factor supply. As shown in Caron et al (2014), non-homothetic preferences lead to a smaller content of trade in skilled labor for high-income countries and a smaller content of trade in unskilled labor in low-income countries. This implies that the Stolper-Samuelson effect is weaker.

Another direct impact of trade cost reductions on the skill premium can potentially stem from differences in tradability and trade elasticities across sectors. If skill-intensive sectors have higher elasticity of trade to trade costs  $\theta_k$  or higher export shares, they would expand relatively more with a reduction in trade costs, and the demand for skills would increase with trade openness. Hence, we will later examine whether trade shares  $1 - \pi_{iik}$  or  $\theta_k$  are correlated with skill intensity and income elasticities (Section 3.4).

The remaining channels in the decomposition relate to different ways in which the model's endogenous variables react to the reduction in trade costs. The second channel identifies the role of trade-induced income and price effects in final demand described in (32), leading to changes in consumption patterns across industries. We use it to identify the role of changes in real income. As a country and its neighbors open to trade, their income increases,  $\lambda_n$  decreases, and consumption shifts towards income-elastic and skill-intensive goods. This mechanism is the same as was highlighted in the previous section on the effect of productivity growth. While price effects remain present under homothetic preferences, income effects disappear.

The third term in (33) captures the relationship between the skill premium and changes in the demand for intermediate goods. Skill-intensive sectors tend to require inputs that are skill-intensive as well (albeit less so, on average), so differences in demand patterns caused by non-homothetic



preferences can potentially magnify both the direct effect and the final demand effect through input-output linkages.<sup>22</sup>

Finally, the fourth “multilateral-resistance” term (34) reflects changes in the supplier term  $S_{jk}$  (outward multilateral resistance index) and buyer term  $P_{jk}^{\theta_k}$  (inward multilateral resistance index), and captures general-equilibrium feedback on wages and other prices. This feedback effect generally dampens the effect of trade. For instance, a higher skill premium leads to relatively higher costs in skill-intensive industries, as well as lower exports in these industries, which mitigate the skill premium increase.

### 3 Estimation

We now discuss the data and the estimation of the key parameters in the model. The estimation here closely follows Caron, Fally and Markusen (2014), although with different datasets and a number of additional robustness checks.

#### 3.1 Data

Our empirical analysis is mostly based on Global Trade Analysis Project (GTAP) data. Unless otherwise indicated, model estimation and simulations rely on version 5 (GTAP 5) of the dataset (Dimaranan and McDougall, 2002), which describes 1997 data<sup>23</sup>. As noted earlier, we also test the robustness of our results by re-estimating all parameters using version 8 of the dataset (Narayanan et al., 2012), which is based on 2007.<sup>24</sup>

Both versions of the dataset contain consistent and harmonized production, consumption, endowment, trade and input-output tables for 57 sectors of the economy,<sup>25</sup> 5 production factors, and 66 countries (109 countries in version 8). The set of sectors covers both manufacturing and services and the set of countries covers a wide range of per-capita income levels. Demand systems are estimated over all available countries using final demand values based on the aggregation of private and public expenditures in each sector.

The GTAP dataset provides country-specific input requirement coefficients, including intermediate demand and demand for capital, high- and low-skilled labor, land and other natural resources. To limit cross-country variations in results, we use average input shares to calibrate our benchmark simulation

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<sup>22</sup>Note that we assume Cobb-Douglas production functions, which implies constant input-output requirement coefficients. Additional effects on the skill premium can be obtained by assuming strong complementarity between manufacturing goods and services, as described in Cravino and Sotelo (2018).

<sup>23</sup>This is the earliest version of the dataset that includes a disaggregation of skilled and unskilled labor.

<sup>24</sup>The latest available iteration of GTAP data (version 9, 2011 data) includes a different (redefined) disaggregation of labor types, making it difficult to map onto skilled and unskilled labor to directly compare with previous datasets.

<sup>25</sup>Some sectors in GTAP are used primarily as intermediates and correspond to extremely low consumption shares of final demand. Six sectors for which less than 10% of output goes to final demand (coal, oil, gas, ferrous metals, metals n.e.c. and minerals n.e.c.) are assumed to be used exclusively as intermediates and are dropped from the final demand estimations. We also drop “dwellings” from our analysis, as this sector is associated with no trade and large measurement errors in consumption and factor intensities.

model (average weighted by each country’s share of global factor demand), but our results are similar (slightly stronger) when we use country-specific input shares (see Section 4.6).

In addition to the GTAP trade data, estimating the gravity equations requires a set of bilateral variables describing physical distance, common language, access to sea, colonial link and contiguity which we obtained from CEPII ([www.cepii.fr](http://www.cepii.fr)).<sup>26</sup> Dummies for regional trade agreement and common currency are from de Sousa (2012).

Among other model parameters, all but one will be estimated. The elasticity of substitution between skilled and unskilled labor,  $\rho$ , is instead calibrated at a value of 1.4, as estimated by Katz and Murphy (1994). We discuss the role of this parameter and robustness of results in Section 4.6.

Finally, Section 4.5 compares our simulation results with observed changes in the skill premium. While a number of data sources and papers provide scattered estimates, a systematic comparison requires a harmonized panel data of skilled and unskilled wages. We use the WIOD dataset (see Timmer et al., 2015 and Timmer et al., 2016), which, to our knowledge, provides the longest and widest consistent panel for this purpose. It comprises 40 countries, all of which are also in the GTAP5 dataset, allowing for an easy match for our analysis.<sup>27</sup> These data have been used, for instance, by Costinot and Rodríguez-Clare (2014), Cravino and Sotelo (2018).

### 3.2 Estimation strategy

The value of final demand in an industry is determined as in Equation (5) or equivalently Equation (1) for individual expenditures  $x_{nk} = \frac{D_{nk}}{L_n}$ . In log, the model provides:

$$\log x_{nk} = -\sigma_k \cdot \log \lambda_n + \log \alpha_{2,k} + (1 - \sigma_k) \cdot \log P_{nk} \quad (36)$$

where  $\alpha_{2,k}$  is a preference parameter which varies across industries only. In addition, final demand should satisfy the budget constraint which determines  $\lambda_n$ : a higher income per capita is associated with a smaller Lagrange multiplier  $\lambda_n$ .

If there were no trade costs, the price index  $P_{nk}$  would be the same across countries and could not be distinguished from an industry fixed effect. If, in richer countries, consumption were larger in a particular sector relative to other sectors, the estimated  $\hat{\sigma}_k$  would be larger for this sector. Since trade is not costless, estimated income elasticities would be biased if we did not control for the price index  $P_{nk}$  (to capture supply-side characteristics). As richer countries have a comparative advantage in skill-intensive industries, the price index is relatively lower in these industries. Conversely, poor countries have a comparative advantage in unskilled-labor-intensive industries and thus have a lower price index in these industries relative to other industries. When the elasticity of substitution between

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<sup>26</sup>Distance between two countries is measured as the average distance between the 25 largest cities in each country weighted by population. Similarly, internal distance within a country is measured as the weighted average of distance across each combination of city pairs. See Mayer and Zignago (2011).

<sup>27</sup>Note that the GTAP5 dataset has labor shares for skilled vs unskilled workers in terms of total wage bill but does not provide average wages. WIOD provides disaggregated skilled and unskilled average labor wages up to 2009. Note also that the WIOD provides three levels of skills. We aggregate medium and high-skill together in order to better match the definition of skilled labor in GTAP.

industries is larger than one, these differences in price indices affect the patterns of consumption. If we were not controlling for  $P_{nk}$ , we would overestimate the income elasticity in skill-intensive sectors.

We thus proceed in two steps. The main goal of the first step is to obtain a proxy for the price index  $\log P_{nk}$ . According to equilibrium condition (11),  $\log P_{nk}$  depends linearly on  $\log \Phi_{nk}$  which itself can be identified using gravity equations. Gravity equations by sector are derived from Equation (8). Specifying trade costs  $\log d_{nik}$  as a linear combination of trade proxies, we obtain our first-step estimation equation:

$$X_{nik} = \exp \left[ FX_{ik} + FM_{nk} - \sum_{var} \beta_{var,k} TC_{var,ni} - \beta_{border,ik} \delta_{n \neq i} + \varepsilon_{nik}^G \right] \quad (37)$$

where the set of variables  $TC_{var,ni}$  refers to trade costs proxies: log physical distance between countries  $n$  and  $i$ , dummies for common language, colonial links, contiguity (equal to one if countries  $i$  and  $n$  share a common border), free-trade agreements, common currency and common legal origin (additional details are provided in Appendix). Following Waugh (2010), we also include a dummy  $\delta_{n \neq i}$  for international transactions allowing for an exporter-specific border effect denoted by  $\beta_{border,ik}$ .

Following the model structure and using our estimates, we can then construct:

$$\widehat{\Phi}_{nk} = \sum_i \exp \left( \widehat{FX}_{ik} - \sum_{var} \widehat{\beta}_{var,k} TC_{var,ni} - \widehat{\beta}_{border,ik} \delta_{n \neq i} \right) \quad (38)$$

Notice that, if country  $n$  is close to an exporter that has a comparative advantage in industry  $k$ , i.e. an exporter associated with a large exporter fixed effect  $FX_{ik}$  (large  $S_{ik}$ ), our constructed  $\widehat{\Phi}_{nk}$  will be relatively larger for this country, reflecting a lower price index of goods from industry  $k$  in country  $n$ .

In a second step, we estimate the final demand Equation (36) using  $\widehat{\Phi}_{nk}$ , which is rewritten as:

$$\log x_{nk} = -\sigma_k \cdot \log \lambda_n + \alpha_{3,k} + \frac{(\sigma_k - 1)}{\theta_k} \log \widehat{\Phi}_{nk} + \varepsilon_{nk}^D \quad (39)$$

where  $\alpha_{3,k}$  is an industry fixed effect and  $\lambda_n$  is the Lagrange multiplier associated with the budget constraint which must hold, i.e. such that  $\sum_k x_{nk} = e_n$  (using observed per capita income  $e_n$ ). While the coefficient for  $\log \widehat{\Phi}_{nk}$  helps identify the ratio  $\frac{(\sigma_k - 1)}{\theta_k}$ , the level of each term is not identified. We therefore allow  $\theta_k$  to vary across sectors but we impose its average to equal 4, a standard calibration value in the trade literature (Simonovska and Waugh, 2014).<sup>28</sup> We estimate Equation (39) by constrained non-linear least squares.

Using our estimates of  $\sigma_k$ , income elasticities can then be retrieved as:

$$\widehat{\eta}_{nk} = \widehat{\sigma}_k \cdot \frac{\sum_{k'} \widehat{x}_{nk'}}{\sum_{k'} \widehat{\sigma}_{k'} \widehat{x}_{nk'}} \quad (40)$$

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<sup>28</sup>In our estimation, the coefficients for  $\log \widehat{\Phi}_{nk}$  equal 0.4 on average. This implies that  $\sigma_k$  lies around 2 for most sectors. Note that the level of sigmas does not affect the computation of income elasticities, as described in Equation (40). Note that while CRIE preferences imply an explicit link between price and income elasticities, in Section 4.6 we examine the robustness of our results by using Comin et al. (2015) preferences, which results in an estimated elasticity of substitution of 0.76 across sectors.

given that the weighted average of income elasticities must equal one (Engel aggregation).

We describe our procedure in the appendix in more detail, along with alternative specifications to examine the robustness of our estimates. Firstly, an alternative specification disregards the budget constraint in our estimation, i.e. estimates Equation (39) without imposing the sum of fitted expenditures to equal the sum of actual expenditures. Secondly, we instrument  $\log \widehat{\Phi}_{nk}$  by an alternative measure based only on foreign markets, i.e.:  $\widehat{\Phi}_{nk}^{IV} = \sum_{i \neq n} \exp \left( \widehat{F}X_{ik} - \sum_{var} \widehat{\beta}_{var,k} TC_{var,ni} - \widehat{\beta}_{border,ik} \right)$  summing across  $i \neq n$ . This leaves out each country’s own exporter fixed effect  $\widehat{F}X_{nk}$ , which may be endogenously related to final expenditures  $x_{nk}$ . Thirdly, we examine an alternative specification approximating the log of the Lagrange multiplier by a linear function of the log of income per capita:  $\log \lambda_n \approx -\nu \log e_n$ . This approach allows us to identify  $\widehat{\sigma}_k \nu$  up to a constant term  $\nu$ , but one can see that this constant term drops out of Equation (40): the implied income elasticities estimates are scale invariant. Finally, we have also re-estimated (39) by calibrating  $\theta_k = 4$  across all sectors, thereby imposing an additional constraint on the coefficient of  $\log \widehat{\Phi}_{nk}$  in Equation (39).

### 3.3 Parameter estimates

**Gravity:** Parameters estimated from Equation 37 are in line with the gravity literature and described in Section C of the Appendix (Table A.1 presents summary statistics). Coefficients on distance and the other bilateral determinants are of the expected sign and magnitude and significant in most industries. The estimates imply an important role for geography in explaining relative prices. Proximity to countries with a comparative advantage in certain industries leads to significantly lower relative prices in these industries. These effects are captured in the  $\widehat{\Phi}_{nk}$  terms, which vary greatly across countries and sectors.<sup>29</sup>

**Preferences:** Table 1 describes our income elasticity estimates by sector (evaluated at mean income), as well as differences in skill intensity across sectors. Estimates range from nearly zero for cereal and grains to 1.412 for insurance, with a clear dominance of agricultural sectors at the low end and service sectors at the high end. Half of the estimates are significantly different from unity (P-value  $< 0.05$ ), with standard errors between 0.05 and 0.2 for most sectors.<sup>30</sup> We confirm the results from Caron, Fally and Markusen (2014): non-homotheticity is economically and statistically significant. It reduces by 24.2% the variance left unexplained with a homothetic preference specification with  $\sigma_k = \sigma$ , and the F-stats associated with imposing common  $\sigma_k$ ’s across industries clearly reject homotheticity (F-stat equal to 11.74, all P-values  $< 0.001$ ).<sup>31</sup>

We also examine several alternative specifications, all described in detail in Appendix D and illustrated in Figure A.1. We find our benchmark estimates to be robust to: removing the budget constraint as a constraint in our estimation (given the large variations in per capita income, introducing

<sup>29</sup>The standard deviation of demeaned  $\log \widehat{\Phi}_{nk}$  is 1.22, taking the residual of a regression of  $\log \widehat{\Phi}_{nk}$  on country and sector fixed effects.

<sup>30</sup>Two sectors have standard deviations between 0.2 and 0.3: gas and wheat.

<sup>31</sup>The Akaike (AIC) and Bayesian (BIC) information criteria also favor the specification allowing for non-homotheticity.

error terms in the budget constraint does not affect results); estimating demand in reduced-form, approximating  $\log \lambda_n$  by a linear function of (log) per capita income (in our benchmark specification, Lagrange multipliers and per capita income are highly correlated); imposing  $\theta_k = 4$  in all sectors, instead of treating it as parameter to be estimated. We also address potential endogeneity in  $\log \hat{\Phi}_{nk}$ , instrumenting by an alternative measure based only on foreign markets, taking the sum of exporter fixed effects across all other countries but excluding its own market (Appendix Figure A.2).

Aside from these alternative estimations of Constant Relative Income Elasticities (CRIE) preferences, we have also estimated preferences as in Comin, Lashkari and Mestieri (2017), which impose a common price elasticity  $\sigma$  across sectors while allowing for different income elasticities of demand. Again, income elasticity estimates remain similar (Appendix Figure A.3). We also refer to Caron et al (2014) for a comparison between CRIE, LES (Stone Geary) and AIDS (Deaton and Muellbauer, 1980) preferences. While LES yields much smaller differences in income elasticities across sectors, estimates based on AIDS are fairly similar to CRIE (the rank correlation is higher than 85% between any two of these specifications).

### 3.4 Empirical regularities

**Correlation between income elasticity and skill intensity across sectors** As discussed in the theory section, this correlation plays a crucial role in determining the impact of productivity growth and trade on the relative demand for skilled labor. It is illustrated in Figure 1 with additional regression statistics reported in Appendix Table A.4.

Our measures of skill intensity correspond to the ratio of skilled labor to total labor input, excluding ('direct') or including ('total') labor required to produce intermediate inputs to each final good. As in Caron, Fally and Markusen (2014), the correlation between income elasticity and 'direct' skill intensity is found to be strong and significant at 77.9 % (p-value < 0.001). Tracking input-output linkages to compute 'total' skill intensity coefficients which include the 'indirect' factor usage yields a similarly large correlation with income elasticity of 77.3%. This is consistent with the fact that skill-intensive final products tend to rely on intermediate goods that are skilled-labor intensive themselves, as also documented in Voigtländer (2014). However the figure also shows slightly less cross-sector variation in total than in direct skill intensity (standard deviation of 0.13 instead of 0.17): on average, intermediates are somewhat less skill-intensive than their downstream sector, while goods intensive in unskilled labor demand intermediates which are somewhat more skill-intensive.

Part of the large correlation between income elasticity and total skill intensity is explained by the composition of consumption into services vs. manufacturing industries, with services being generally associated with a larger income elasticity. However, the correlation remains high (72.3%) even after excluding service industries. The correlation also remains large (higher than 40%) and highly significant once we control for capital and natural resource intensity (Table A.4). Finally, the correlation remains above 50% when using alternative specifications for the estimation of CRIE preferences (imposing  $\theta_k = 4$ , instrumenting  $\log \hat{\Phi}_{nk}$ , using a reduced-form approximation, etc.) as well as when using alternative preferences such as AIDS, LES or implicitly-additive preferences as in Comin et al (2017).

**Correlation between income elasticity and other factor intensities** It is interesting to note that capital intensity is positively correlated with income elasticity, as found by Reimer and Hertel (2010), but this correlation is much weaker than with skill intensity (less than 10% in most specifications) and not robust to controlling for skill intensity (see columns (2) and (4) of Appendix Table A.4). In our framework, this implies, for instance, that growth should not greatly affect the returns to capital relative to wages. Income elasticity, however, tends to be negatively correlated with intensity in natural resources (including land), which supports the Prebisch-Singer hypothesis and implies that a growth in income per capita would lower the relative price of natural resources.

**Correlation with trade shares** Another potential determinant of the incidence of trade costs on the skill premium is the correlation between trade shares and skill intensity across sectors. A decrease in trade costs leads to an increase in the relative price of traded products, and therefore a change in the relative employment share of sectors, depending on the elasticity of substitution among sectors. Here we examine the cross-sectoral correlations between skill intensity and average export shares ( $1 - X_{iik}/Y_{ik}$ ) (averaged across countries).

Burstein and Vogel (2017) document that skill-intensive sectors tend to be more traded, but do not consider service sectors. In our data, we find that the correlation depends crucially on the inclusion of service sectors. If ignored, the correlation is positive at +30%. Once we include services, however, the correlation is considerably reduced, weakly negative (-6%) and no longer significantly different from zero (see Appendix Figure A.7).

Similar patterns are observed for the correlation between average trade shares and income elasticities. Looking across all sectors, the correlation is positive but not significant (15% correlation). When we exclude services, it jumps to 35%.

## 4 Quantitative implications for the skill premium

As argued in Section 2.4, non-homothetic preferences may help explain why the skill premium has been increasing for a large number of countries. In this section, we use our general equilibrium model to quantitatively estimate the response of the skill premium to historical changes in real per capita income and openness to trade. Our primary objective is to explore the potential for non-homothetic preferences to affect this response. Separate counterfactuals then decompose results into the effect of growth and the effect of trade. In each case, we also use approximations provided in the theory section 2.4 to further decompose the role of preferences, intermediate goods and trade patterns.

### 4.1 Calibration

Our main counterfactual consists of adjusting total factor productivity (TFP) and trade costs simultaneously such that the model matches historical rates of real income growth and trade openness for the 1995-2010 period (a period which will allow us to compare our results with observed changes in the skill premium compiled from the WIOD dataset).

More specifically, we use the GTAP5 dataset to calibrate the model, then solve it<sup>32</sup> allowing all endogenous variables as well as two otherwise exogenous parameters,  $z_{ik}$  (TFP) and  $\beta_{border,ik}$  (exporter-specific border effects) to adjust until the counterfactual equilibrium matches targeted (observed) changes in real per capita GDP and exports/GDP.<sup>33</sup> Changes in both variables are taken from the Penn World Table version 9 (Feenstra et al., 2015). The adjustments in both  $z_{ik}$  and  $\beta_{border,ik}$  are allowed to vary across countries but not sectors, in order to avoid effects on sectoral composition that are not directly driven by demand.

Targeted changes in per capita GDP and export/GDP ratios, the implied shocks to productivity and trade costs, and the resulting changes in the skill premium are reported in Appendix Table A.3 for all countries. On average, real per capita GDP (our proxy for real income) increased by 69% in the 66 countries of our sample, with changes ranging from 6% (Japan) to 175% growth (China). Growth was strongly biased in favor of low-income countries.<sup>34</sup> There also have been substantial but heterogeneous changes in export/GDP ratios (largest in low-income countries, 66% on average, and a standard deviation of 71%).<sup>35</sup> Implied changes in productivity and reductions in trade costs are weakly correlated at 0.18 and are very similar when the model is calibrated with homothetic preferences instead (correlation of 0.99 and 0.97 respectively).

## 4.2 Combined effects of productivity growth and trade liberalization, 1995-2010

Figure 2 displays simulated general equilibrium changes in the skill premium as a function of each country's (log) per capita expenditures (which in most countries is very close to per capita income). A value of 0.1 in the figure implies that the ratio of skilled to unskilled wages increased by 10% during the 1995 to 2010 period because of simulated changes in real income and trade.

Focusing first on estimates obtained using non-homothetic preferences reveals an increase in the skill premium in almost all countries, but changes are very heterogeneous.<sup>36</sup> Low-income countries, including some of the largest countries in our dataset, see the largest increases in the skill premium: e.g. a 17.4% increase in China, 29.6% in India, 20.7% in Vietnam, and similarly high values for most African countries. Countries classified as low-income by the World Bank in 1997 (China and 10 other countries in our sample) see an average increase of 9.3%. Other countries see a much lower increase, 2.4% on average. Middle-income countries see moderate increases (e.g. 3.3% in Mexico, 1.7% Brazil,

<sup>32</sup>The model is formulated in GAMS and solved by the non-linear PATH solver.

<sup>33</sup>We chose to target export/GDP ratios because trade affects the skill premium primarily through its changes in the relative supply of goods.

<sup>34</sup>Implied changes in TFP ( $\hat{z}$ ) are strongly correlated with these changes in real GDP (0.87), but are slightly lower in level (average of 60%), as the observed increase in real income is partially caused by trade (i.e. generated by the reductions in trade costs).

<sup>35</sup>Implied reductions in trade costs (captured by the exporter-specific border effects  $\hat{\beta}_{border,ik}$ ) are also well correlated with changes in exports/GDP, at 81%. Trade cost reductions are smaller in magnitude than changes in trade flows, and average 30%, a difference driven by the estimated elasticity of trade to trade costs parameters,  $\theta_k$ . They also vary substantially between countries (standard deviation of 62%), and 18 countries have increasing implied trade costs.

<sup>36</sup>Zimbabwe, Uruguay and Malawi are the only three countries with a reduction among developing countries. Zimbabwe has followed a very unusual growth path over the time period. Its ratio of exports to GDP increased by a factor of 2.5, while its per capita real income decreased by 66%.

3.6% in Russia) and estimates are lowest for developed countries (e.g. 0.8% for the USA and around 1-2% for European countries).

In some countries, our model also predicts non-negligible changes in the skill premium with homothetic preferences. Indeed, international trade can affect the relative wage of skilled workers if income growth rates vary across countries, and more generally the standard Stolper-Samuelson effects of trade do not require non-homothetic preferences. However, estimates are considerably closer to zero and their relationship with per capita income flatter. The effect of allowing for non-homothetic preferences is unambiguous, with higher estimates in all countries but especially for developing countries.

**Relative importance of income growth and openness to trade** To decompose these results, we re-simulate the changes in the skill premium caused by the estimated changes in productivity described above, but not changes in trade costs. This 'growth-only' counterfactual is displayed in Figure 3(a). We then do the opposite and compute the effect of 1995-2010 changes in trade costs, holding productivity fixed. This 'trade-only' counterfactual is displayed in Figure 3(b).

Results indicate that the effect of productivity growth dominates as it tends to have a quantitatively larger influence on the skill premium than changes in trade, especially in low- and middle-income countries. Adding the effect of productivity growth and trade costs to recompose the total effect on the skill premium leads to estimates which are very similar to those obtained by simulating both simultaneously as in our main counterfactual (see Figure A.8 in the Appendix). This suggests only small interactions between the growth and trade channels, so we now discuss them individually.<sup>37</sup>

### 4.3 Productivity growth and the skill premium

When preferences are homothetic, an homogeneous increase in productivity in all sectors should not affect the relative demand for skilled labor (although if rates of productivity growth vary across countries, changing patterns of trade would still affect the skill premium). However, when preferences are non-homothetic and when the income elasticity of demand is positively correlated with the skill intensity of production, an increase in productivity makes consumers richer, which in turn induces a relative increase of consumption in skill-intensive industries (high-income elastic industries), and thus raises the relative demand for skilled labor. This demand-driven explanation contrasts with previous studies that have focused on the supply side, and we find it to be quantitatively important.

Comparing Figures 2 and 3(a) shows that the magnitude of the effect and its relationship with per capita income is similar to that obtained in the 'unified' growth and trade counterfactual: estimates vary considerably between countries but are again highest in low-income countries. Estimates can be large, including a 14.5% increase in the skill premium in China, 22.6% in India, 8.7% in Vietnam and in the 10-18% range for African countries. It is 9.6% on average for countries classified as low-income,

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<sup>37</sup>Changes in the skill premium from simulations of simultaneous shocks tend to be slightly lower, especially for low-income countries. The effect of trade costs on the skill premium depends on per capita income (as will be seen) and is thus weaker when evaluated simultaneously with the effect of productivity growth which makes countries richer; on the other hand, the effect of productivity growth on skill premium depends on trade costs. Changes in domestic consumption patterns (caused by income growth) have a smaller impact on the skill premium as countries open to trade.



and 2.4% for countries middle-income and above. As expected, the difference with estimates obtained with homothetic preferences is positive for all countries and again large for developing countries.

**The role of trade and input-output linkages.** As discussed in Section 2.4.1, the main argument for the role of non-homothetic preferences does not involve trade and also applies to closed economies. To first identify the role of trade, we compute the closed-economy approximation described by Equation (27), inserting our estimates for income elasticities ( $\eta_{nk}$ ) as well as labor shares ( $sh_{nk}^H$  and  $sh_{nk}^L$ ) which include demand for labor embodied in intermediates. Figure 4 shows that these closed-economy approximations of changes in the skill premium are a very good predictor of the simulated open-economy general equilibrium elasticities. In both cases, the figure plots the difference between non-homothetic and homothetic preferences to pinpoint the role of non-homotheticity (recall that in a closed economy, there is no change in the skill premium with homothetic preferences). The high (98%) correlation is partly due to production being mostly destined for local consumption, and partly because countries tend to trade with countries of similar per capita income, so that the change in the composition of consumption of their trading partners is similar to their own.

To investigate the importance of input-output linkages, Figure 4 also shows closed-economy approximations implied by Equation (27), this time using labor shares which only account for final good production (without IO linkages). While these approximated changes in the skill premium again provide a fairly good approximation of the open-economy general equilibrium estimates, they are consistently larger.<sup>38</sup> This upward bias is explained by the higher variance in skill intensity between sectors when intermediate demand is ignored: input-output linkages mitigate the effect of changes in the composition of demand on the skill premium. Ignoring them would therefore lead to largely overstated predictions.

**Why is the effect on the skill premium larger for low- and middle-income countries?** The rates of income growth underlying the results vary considerably between countries. To better visualize the relative strength of the non-homothetic consumption effect across countries, Figure 5 compares approximated changes in the skill premium to estimates based on uniform growth rates. These can be interpreted as *elasticities* to productivity growth: a value of 0.1 implies the skill premium increasing by 1% for every 10% increase in per capita income. The differences between rich and poor countries remain large, and are therefore not primarily driven by stronger productivity growth in the developing world over the 1995-2010 period.

As we have shown in Section 2.4.1, differences in the skill premium across countries depend on differences in the income elasticity of demand and skilled/unskilled employment shares across countries and sectors. CRIE preferences generate income elasticities which decrease according to a country's income, which could partially explain why the effect on the skill premium is smaller for richer countries. Second, a larger share of low-skilled employment in developing countries produces income-inelastic

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<sup>38</sup>Regressing the approximation without IO linkages on the approximation with IO linkages yields a coefficient equal to 1.62 with an R-squared of 92%.

goods while skilled workers produce income-elastic goods. In rich countries, there are smaller differences in income elasticity between the goods that skilled and low-skilled workers produce. To disentangle these effects, we also show in Figure 5 that replacing country-specific income elasticities by their mean across countries, per sector (such that all the variations across countries comes from differences in employment shares), still yields a strong negative relationship between skill premium changes and income. Hence, we conclude that it is mostly due to the differences in employment shares and not linked to specific properties of our demand system.

#### 4.4 Trade liberalization and the skill premium

We now examine the role of trade liberalization by focusing on the 'trade-only' counterfactual in which we simulate the 1995-2010 implied changes in trade costs, but hold productivity constant (Figure 3b).<sup>39</sup> With homothetic preferences, the effect of trade on the skill premium tends to be negative for developing countries and positive among the richest countries. This is in line with standard Stolper-Samuelson predictions: trade leads to a decrease in the relative demand for skilled labor in countries that are abundant in unskilled labor, and to an increase in the skill premium in more skilled-labor abundant countries.

This effect is mitigated, and often reversed, when we allow for non-homothetic preferences: trade cost reductions lead to a larger increase (less negative change for poor countries) in the skill premium in all but the highest-income countries. The correlation between the effect of trade on the skill premium and a country's per capita income disappears (becoming slightly negative). The difference is unambiguously largest for low-income countries, which have on average a 3.4% higher skill premium with non-homothetic than homothetic preferences. The difference is smaller in middle-income countries, 0.45% on average, and is negative (but very small) in high-income countries.

**Decomposition:** Table 2 decomposes the average effect of non-homothetic preferences into the channels described in Equations (31) through (34).

The "direct effects" of a trade cost reduction on the skill premium, also plotted on Figure 6(a), are derived from Equation (31) as an approximation which holds trade and demand patterns constant (for each specification of preferences) and neglects general-equilibrium feedback effects caused by changes in factor costs. As we described in Equations (31) and (35), this direct effect should be higher when countries have higher net exports in skill-intensive industries and a higher net content of trade in skilled labor relative to unskilled labor. Our findings confirm this to be true for developing countries when the model is fitted with non-homothetic preferences (relative to homothetic preferences): they are indeed predicted to consume relatively more of the unskilled-intensive goods for which they have a comparative advantage in production while their trade partners, predominantly richer countries, have a relatively higher demand for income-elastic and skill-intensive goods. As discussed after Equation (31),

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<sup>39</sup>Nine countries saw reductions in export/GDP ratios over the period (implying increases in trade costs). These naturally have different implications for the skill premium and are dropped from the figure for clarity.

this effect mitigates the standard Stolper-Samuelson effect which we find with homothetic demand. The reverse effect holds but is quantitatively much smaller for high-income countries.

Note that the direct effect of Trade costs on the skill premium (Equation 31) could also be affected by a systematic correlation between skill intensity and average tradability across sectors. If, in turn, tradability were correlated with income elasticity, the strength of this effect could differ between non-homothetic and homothetic preferences. In Section 3.4, however, we find that both of these correlations are weak once services are included. To confirm that the differences between non-homothetic and homothetic preferences are indeed driven by patterns of specialization (net exports) rather than by differences in tradability across sectors, we have re-evaluated the direct effect using average export shares at the sector level. The difference between non-homothetic and homothetic preferences in this case is very small.

The second “effects on final demand” term of the decomposition, plotted on Figure 6(b), captures changes in consumption patterns driven by changes in prices and income. With homothetic preferences, trade already generates changes in consumption patterns by changing relative prices, but the effect is larger with non-homothetic preferences:<sup>40</sup> trade liberalization generates an increase in real income which, similar to productivity growth, leads to a reallocation of consumption towards income-elastic goods which are also more skill intensive, and leads to an increase in the skill premium in all countries. This “demand” channel is quantitatively strong and explains a substantial share of the average difference between non-homothetic and homothetic preferences (see Table 2), though in low-income countries the “direct” impact of trade on the skill premium dominates. In rich countries, the direct and demand channels go in opposite directions, partially explaining the smaller role of non-homothetic preferences on the skill premium in those countries.

Since trade-driven income growth leads to a larger expansion in skill-intensive sectors with non-homothetic preferences, it also leads to a relatively larger demand for skill-intensive intermediate goods. While the role the input-output (“IO”) channel is to reinforce the final demand channel, the difference in the specifications tends to be quantitatively smaller relative to what is explained by the first two channels. Finally, general equilibrium effects captured by changes in “multilateral-resistance” (MR) terms mitigate the direct effect of trade costs (e.g. adjustment in factor prices), but also remain quantitatively smaller than the first two channels.

To summarize, a combination of the income-driven consumption composition effect (which drives the second and third terms) and the substantially reduced Stolper-Samuelson effect (identified through the first term) explains why, in our general equilibrium simulations, non-homothetic preferences imply a higher effect of trade on the skill premium in low-income countries.

## 4.5 Quantitative importance in explaining observed changes in the skill premium

Historical 1995-2010 changes in the skill premium in the 40 countries covered by WIOD vary greatly in sign and magnitude, with on average a larger increase in low-income countries (the correlation with

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<sup>40</sup>With lower price elasticities, as in Cravino and Sotelo (2018), we find larger effects on the skill premium, but the effects remain large with non-homothetic preferences, as documented in our robustness checks in Section 4.6.

log per capita income is -0.28), a pattern which is also evident in our simulation results. Observed changes are caused by a number of confounding and possibly interacting mechanisms including skill-biased technical change and skill accumulation which are not captured in our model. We therefore cannot precisely quantify the relative importance of non-homothetic preferences and the skill intensity-income elasticity correlation in explaining historical changes. Likewise, our simulation results cannot directly be used to make predictions of future changes in the skill premium. A simple correlation exercise, however, shows that our mechanisms may help explain historical changes.

Figure 7 plots observed changes (from WIOD) against simulated changes from our unified growth and trade counterfactual: the relationship is noisy and observed changes are on average larger in magnitude, but non-homothetic preferences significantly increase the correlation between model estimates and observed changes.<sup>41</sup> Note that the figure may understate the mechanisms' importance: contrary to GTAP, WIOD includes only a small number of low-income countries (China, Mexico, Brazil, India, Indonesia and Turkey) and thus lacks many of the countries that have experienced the highest rates of income growth and have the highest predicted increases in the skill premium.

Decomposing into channels, we find that while this increase in correlation is mostly driven by the 'growth channel' of income-driven shifts in consumption patterns, non-homothetic preferences also push our estimates of the effect of trade on the skill premium closer to observed changes.

(XX paragraph could be dropped -Jim says keep) The magnitude of growth and trade effects relative to observed changes varies country-by-country, but is sometimes substantial. For China, our 'unified' simulations suggest a 17.4% increase in the skill premium over the 1995-2010 period. Productivity growth alone would have led to a 14.5% increase (only 4.1% with homothetic preferences), and may thus have been an important mechanism behind the very large 51% increase reported in WIOD or the 40% increase between 1992 and 2006 reported by Ge and Yang (2009). We obtain a 22% increase for India (entirely due to productivity growth). WIOD shows very little change over the period, but Azam (2009) document an 11.9% increase between 1987 and 2004. For Thailand, our simulations lead to a 4.2% increase, to be contrasted to the 4.1% (WIOD) or 17.2% from 1990 to 2004 (DiGropello and Sakellariou, 2010). In Latin America, the mechanisms explain smaller but still significant shares of observed increases: our simulations lead to a 2.5% increase in Peru, contrasted to an observed increase of 23.9% from 1994 to 2000 (Mazumdar and Quispe-Agnoli, 2004); a 3.3% increase in Mexico, contrasted to 12.5% from 1990 to 2001 (Verhoogen, 2008); and a 1.7% increase in Colombia, contrasted to 26.4% between 1990 and 2000 (Gutierrez, 2009). Note also that many of our highest estimates are in African countries, about which little is known regarding skill premia. Among developed countries, the predicted increase in skill premium is small, but so are observed changes: about 0.8% for the US (0.6% from growth-driven re-allocation), contrasted to an observed 3.1% skill premium increase

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<sup>41</sup>Table A.5 in Appendix summarizes coefficients from regression of observed on simulated changes. Once controlling for changes in skill endowments, as measured by 1995-2010 log changes in years of schooling (using cross-country data from Barro and Lee, 2013.), we find the correlation increases from a statistically insignificant 0.182 with homothetic preferences to 0.317 (p-value 0.07) with non-homothetic preferences. The difference between the non-homothetic to homothetic difference is also significant (0.29; p-value 0.09), confirming that non-homothetic preferences significantly improve the model's capacity to explain changes in the skill premium.

(Parro, 2013) (11% in WIOD); 1% in Great Britain (0.5% from growth), contrasted with an observed 2% increase for 1990-2005 (Parro, 2013) or a 4% reduction in WIOD.

## 4.6 Robustness

As made evident in the analytical approximations provided in Section 2.4, the effects of productivity and trade are inversely proportional to  $\tilde{\rho}$  which is itself tightly linked to the elasticity of substitution  $\rho$  between skilled and unskilled labor. A higher  $\rho$  naturally leads to smaller effects. While this elasticity is difficult to estimate in practice, most estimates lie between 1.4 and 1.7 (Acemoglu, 2007). Within this range, we find that the difference in simulated general equilibrium estimates is almost exactly proportional to differences in  $\tilde{\rho}$ . Appendix E provides additional details for this and the following robustness checks.

We also tested the sensitivity of our results to differences in the  $\theta_k$  parameter which drives the response of trade flows to changes in trade costs. While this parameter affects our price index estimates and thus the estimation of income elasticities, we find similar results for the changes in the skill premium when  $\theta_k$  is calibrated to the same constant in all sectors instead of estimated.

The CRIE preferences assumed in our benchmark specification are separable. Separability is a natural and common assumption but an important disadvantage is that it imposes a strong link between price elasticities and income elasticities in consumption. Our results are not dependent on this property: they remain qualitatively and quantitatively similar when we integrate “implicitly-additive” preferences (as in Comin et al, 2016 and Matsuyama, 2019) into our general equilibrium model. These preferences impose no link between price and income elasticities.

In our benchmark analysis, we use a cross-country average of each sector’s input requirements, including skilled and unskilled labor intensity. Using country-specific measures of input requirements, we find that the correlation of income elasticity with skill intensity is strong in most countries, and our simulated skill premium estimates remain similar and indeed slightly stronger. Finally, while our benchmark empirical and simulation results are obtained using GTAP5, which is based on 1997 (the beginning of our 1995-2010 simulation period), we also find a strong correlation between income elasticity and skill intensity when using the more recent GTAP8 dataset based on 2007. Simulation results thus also remain very similar.

## 5 Summary and conclusions

Growing income inequality is a defining feature of our time, and many reasons for the increasing premium awarded to skilled workers have been identified and studied by the literature. We provide a quantitative assessment of a simple yet overlooked mechanism: when allowing for non-homothetic preferences, growth in income increasingly shifts consumption patterns towards goods and services that require relatively more skilled labor in their production.

We calibrate our model to match changes between 1995 and 2010, a period of moderate growth, increasing openness to trade, and increasing skill premiums. Simulations suggest that productivity

improvements underlying recent GDP growth had the potential to drive substantial increases in the skill premium, even if we assume uniform productivity growth across sectors. The predicted changes in the skill premium caused by the changing composition of consumption represent a sizable share of observed increases in many countries, particularly in the developing world.

We then show that income-driven changes in the composition of consumption can also be quantitatively important during an episode of trade liberalization. Like productivity, trade raises incomes and increases the return to skilled labor, once again with a strong effect in the developing world. The relationship between income and consumption patterns has further implications. The sector-level correlation between income elasticity and skill intensity implies a country-level correlation between relative specialization in consumption and relative specialization in production. This leads to a lower predicted net factor content of trade and therefore a weaker link between trade and relative wages. In many developing countries, this weakening of Stolper-Samuelson forces, combined with the effect of shifting consumption patterns, completely cancels out the decrease in the skill premium predicted by a standard homothetic-preference model.

We do not claim our demand-driven effects to be the main mechanisms behind increasing wage disparities. They are likely working alongside other forces, such as skill-biased technical change (Burstein and Vogel, 2017) and other sources of structural transformation (Cravino and Sotelo, 2018), with which they are not incompatible. Future research may want to integrate and contrast alternative mechanisms in a unified framework. We simply show that standard models ignoring non-homotheticity in demand would considerably underestimate effects on the skill premium, and that demand effects may be comparable in magnitude to other well-studied mechanisms in explaining why, despite accumulation of skills, inequality has been increasing.<sup>42</sup>

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<sup>42</sup>Our results are contingent on the cross-country approach which we have taken. While the broad cross-section of countries allows us to predict the range of per capita incomes in which the effect is likely to be strong, we cannot directly test whether preferences are indeed identical across countries, nor whether they are constant in time. Our approach also does not allow us to make out-of-sample predictions regarding the continuing evolution of income-driven consumption shifts in the richest countries. Instead, we rely on a robust empirical fact (the correlation between income elasticity and skill intensity) and a structural approach to illustrate the impact of trade and growth on the skill premium.

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## Tables and Figures

Table 1: Estimated income elasticity by sector. A \* adjacent the sector code denotes a service (non-manufacturing) sector.

GTAP code	Sector name	Skill intens.	Income elast.	Theta $\theta_k$	Export share
pdr	Paddy rice	0.063	0.370	1.534	0.015
v_f	Vegetables, fruit, nuts	0.088	0.562	1.528	0.124
c_b	Sugar cane, sugar beet	0.088	0.620	10.029	0.002
wol	Wool, silk-worm cocoons	0.093	0.265	0.993	0.119
wht	Wheat	0.104	0.246	3.130	0.228
ocr	Crops nec	0.106	0.864	1.318	0.270
osd	Oil seeds	0.111	0.561	1.674	0.231
pcr	Processed rice	0.120	0.549	0.993	0.054
oap	Animal products nec	0.124	0.223	1.069	0.058
rmk	Raw milk	0.131	0.596	0.993	0.001
fsk	Fishing	0.135	0.683	1.770	0.078
for	Forestry	0.141	0.363	1.252	0.099
gro	Cereal grains nec	0.141	0.000	0.993	0.155
pfb	Plant-based fibers	0.150	0.426	14.355	0.241
ctl	Cattle, sheep, goats, horses	0.176	0.189	1.069	0.039
sgr	Sugar	0.195	0.502	2.275	0.145
lea	Leather products	0.198	1.016	2.491	0.408
omt	Meat products nec	0.214	1.054	2.039	0.126
vol	Vegetable oils and fats	0.219	0.584	1.801	0.233
cmt	Bovine meat products	0.223	1.069	3.571	0.106
wap	Wearing apparel	0.230	1.024	3.204	0.309
tex	Textiles	0.230	0.814	1.069	0.296
mil	Dairy products	0.236	1.023	2.762	0.131
lum	Wood products	0.248	1.074	2.628	0.209
ofd	Food products nec	0.263	0.831	1.943	0.127
omf	Manufactures nec	0.274	1.022	2.864	0.269
b_t	Beverages and tobacco	0.283	0.761	4.364	0.097
otp*	Transport nec	0.294	1.061	1.710	0.083
cns*	Construction	0.302	0.832	16.036	0.009
atp*	Air transport	0.302	1.059	3.966	0.380
trd	Trade	0.304	1.090	4.916	0.021
wtp*	Water transport	0.315	1.055	1.292	0.353
mvh	Motor vehicles and parts	0.335	1.093	5.758	0.297
ppp	Paper products, publishing	0.337	1.072	4.629	0.125
otn	Transport equipment nec	0.344	1.027	1.069	0.378
p_c	Petroleum, coal products	0.346	0.780	16.036	0.114
crp	Chemical, rubber, plastic	0.355	0.909	1.624	0.252
ely*	Electricity	0.366	0.943	16.036	0.020
wtr*	Water	0.368	0.968	5.519	0.006
gdt*	Gas manufacture, distribution	0.369	1.057	16.036	0.025
ome	Machinery and equipment nec	0.374	0.931	3.552	0.408
ele	Electronic equipment	0.378	1.205	14.364	0.463
ros*	Recreational and other srv	0.482	1.171	1.807	0.029
obs*	Business services nec	0.491	1.209	7.430	0.065
cmn*	Communication	0.495	1.174	4.794	0.034
osg*	Public spending	0.499	0.994	1.368	0.017
isr*	Insurance	0.522	1.412	1.276	0.052
off*	Financial services nec	0.534	1.132	5.063	0.019

Notes: Estimates of income elasticities and theta  $\theta_k$  based on the benchmark specification; income elasticities evaluated using average country expenditure shares; skill intensity based on total requirements; export share is the sector average of the export share across countries.

Table 2: The effect of trade on the skill premium: average difference between non-homothetic and homothetic differences.

Channel:	Country groups (per capita income):		
	Low-income	Middle-income	High-income
Direct	4.10	0.10	-0.22
Demand	1.77	0.30	0.13
IO	0.08	0.08	-0.05
MR	-2.60	-0.03	0.07
Total	3.35	0.45	-0.06

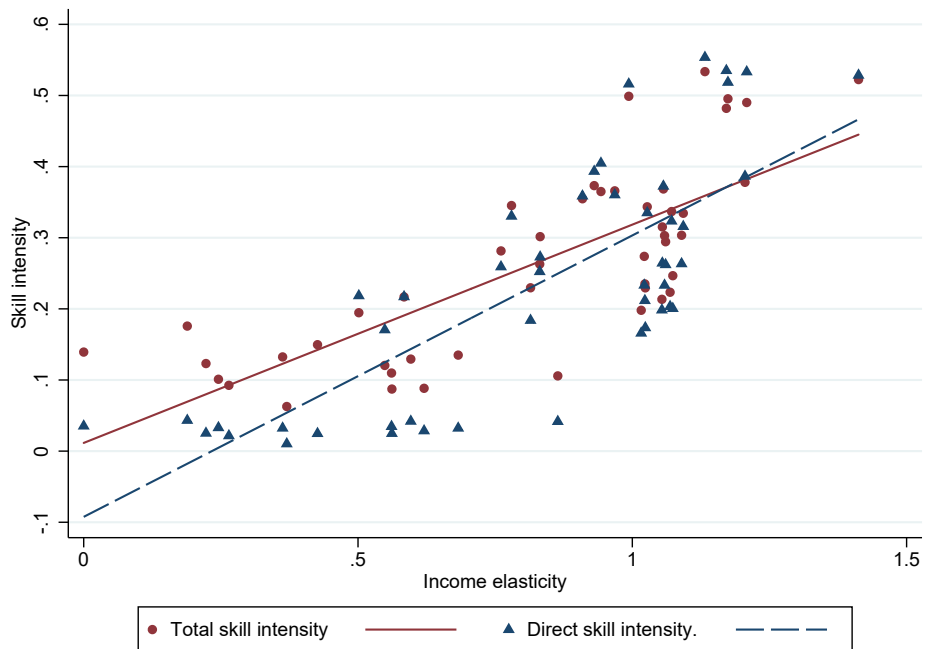


Figure 1: Correlation between income elasticity and skill intensity. Total skill intensity includes indirect demand for labor, direct does not. The standard deviation in total intensities is 0.13; the standard deviation in direct intensities is 0.17. The coefficient of correlation between income elasticity and total skill intensity is 0.773 with a robust standard error of 0.085 (p-value < 0.01, n = 49).

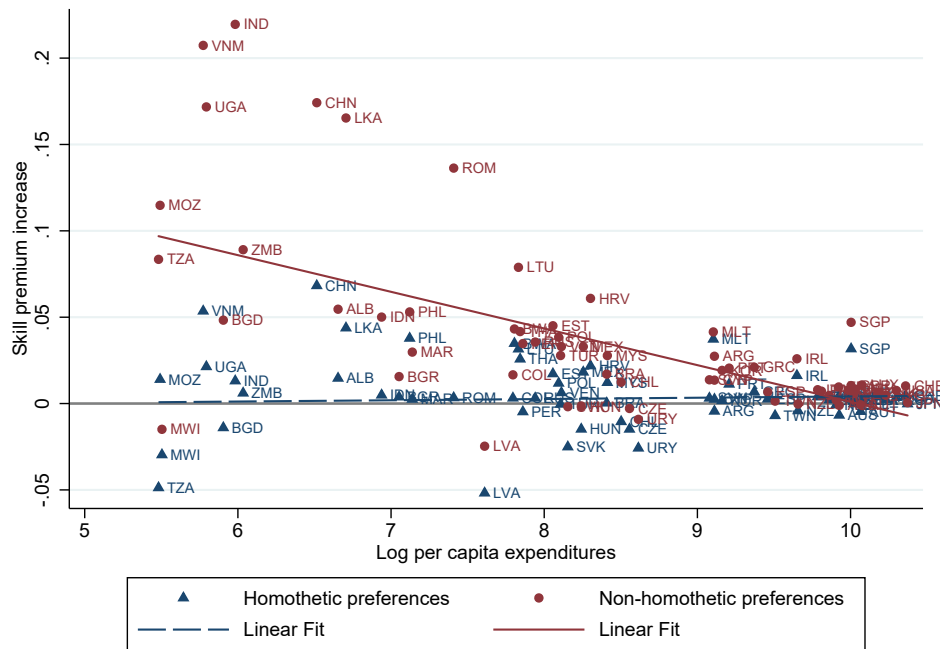
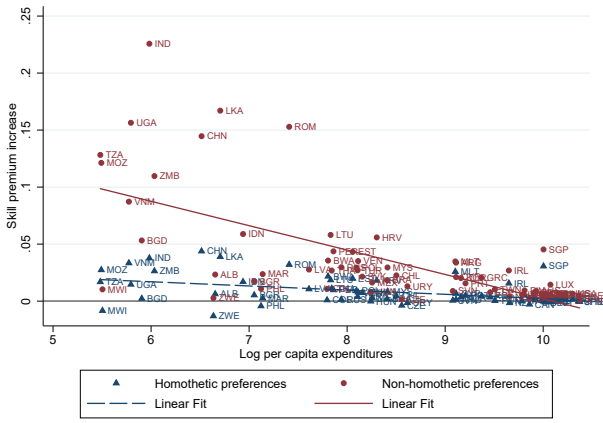
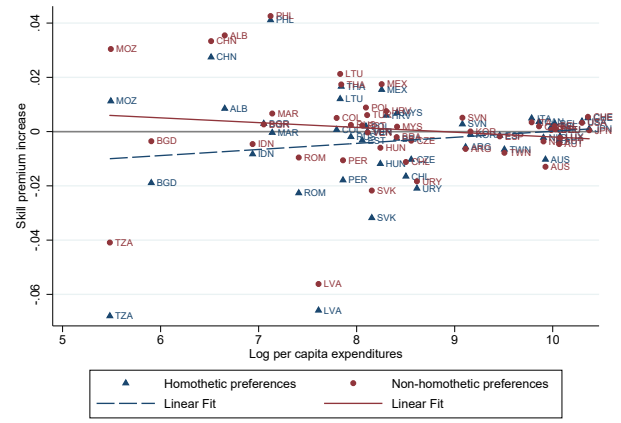


Figure 2: The effect of growth and trade on the skill premium. Simulated general equilibrium changes caused by 1995 to 2010 changes in real per capita income and openness to trade (unified counterfactual). Note: ZWE (Zimbabwe) dropped (values of -0.12 for non-homothetic preferences and -0.17 for homothetic preferences). See Appendix Table A.3 for the full set of estimates.



(a) Growth counterfactual



(b) Trade counterfactual

Figure 3: Decomposition into the growth and trade channels. Simulated general equilibrium changes in the skill premium caused by 1995 to 2010 changes in real per capita income (a) and openness to trade (b). For clarity, Figure b only displays countries which experienced a reduction in trade costs.



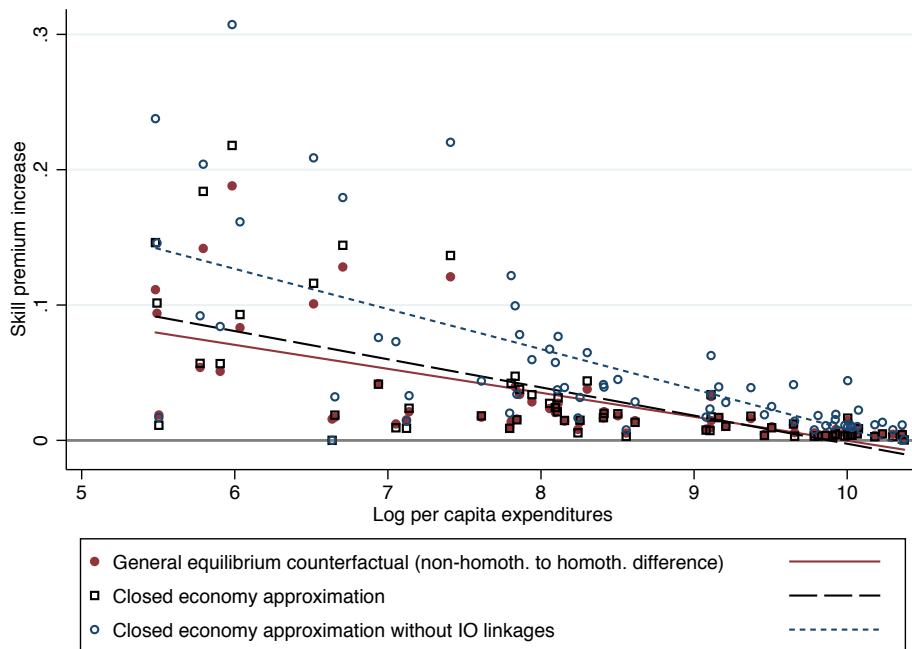


Figure 4: Growth channel. Closed-economy approximations with and without intermediate good (IO) linkages and comparison to general equilibrium estimates (showing the non-homothetic to homothetic difference – in closed economy approximations, there is no change in the skill premium under homothetic preferences).

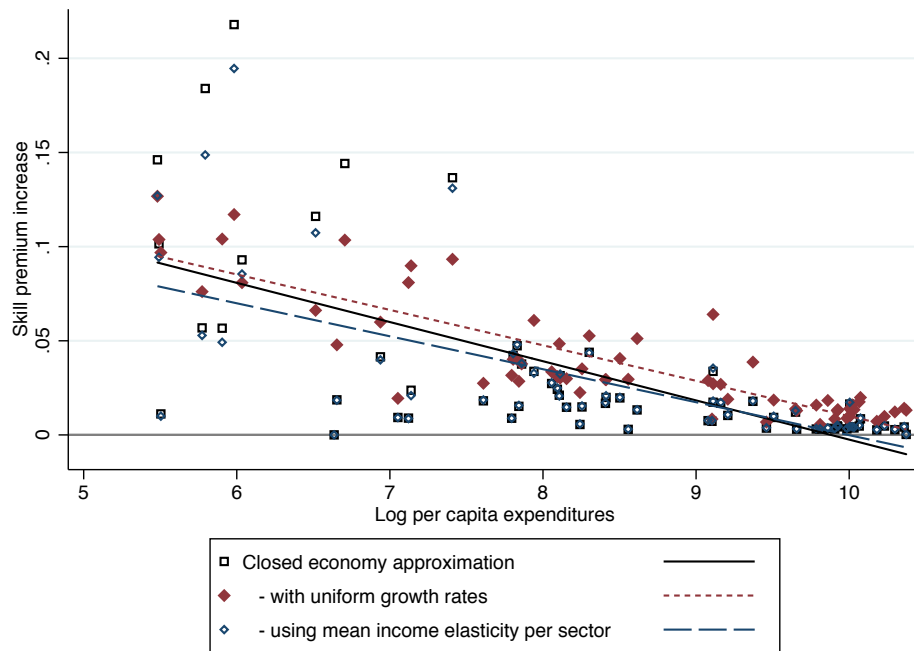
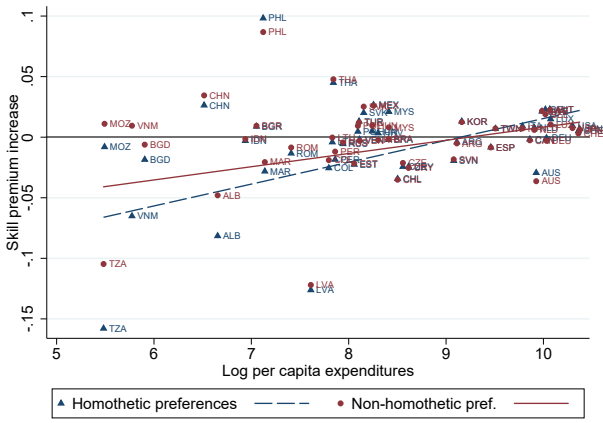
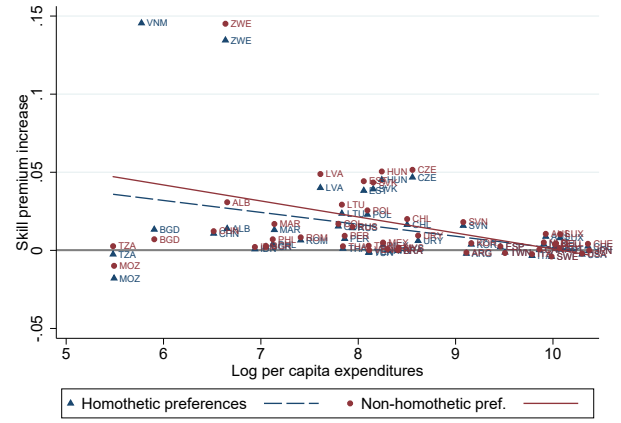


Figure 5: Growth channel. Closed-economy approximations. Effect of heterogenous growth rates and effect of cross-country variations in income elasticity within sectors.



(a) First term: Difference in direct effect



(b) Second term: Difference in final demand effects

Figure 6: Trade channel. Decomposition into the ‘direct’ and the ‘demand’ effects of trade cost reductions on the skill premium. For clarity, this figure only displays countries which experienced a reduction in trade costs.

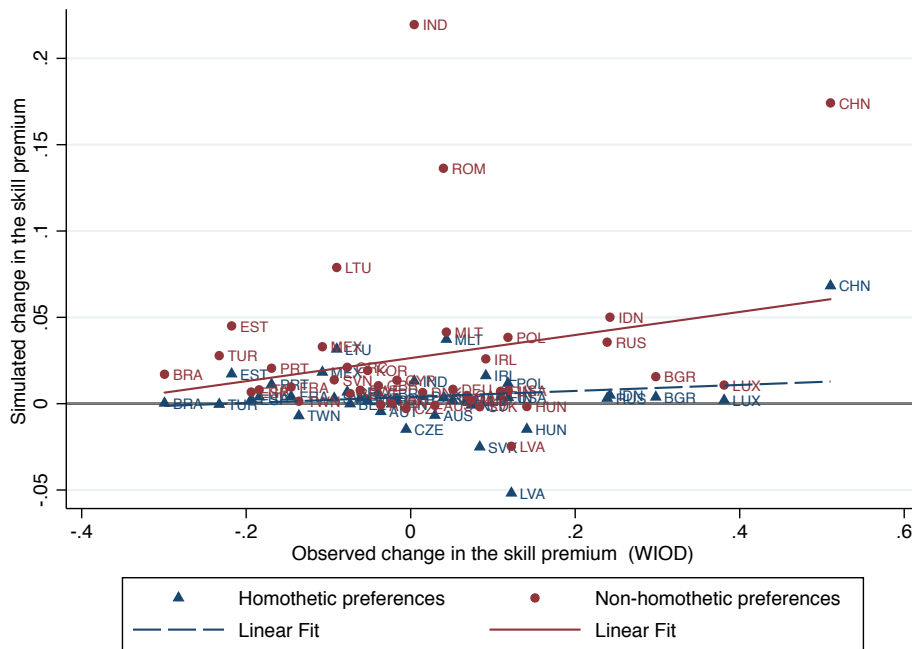


Figure 7: Comparison of observed changes in the skill premium with simulated estimates. 1995 to 2010 changes in the skill premium. Observed changes from WIOD. General equilibrium simulated changes caused by per capita income growth and openness to trade (unified counterfactual). See Table A.5 in Appendix for full set of regression statistics.

## Appendix – For online publication

**Notation: Summary list.** Subscripts  $n$  and  $i$  refer to countries,  $k$  and  $h$  refer to industries,  $f$  refers to factors of production (in particular,  $H$  and  $L$  are the two labor inputs).

### Endogenous variables (equilibrium outcomes):

$D_{nk}$	Final demand expenditures in country $n$ , industry $k$
$\eta_{nk}$	Income elasticity of consumption, country $n$ , industry $k$
$X_{nik}$	Value of trade from $i$ to $n$
$X_{nk}$	Total expenditures in country $n$ , $X_{nk} = \sum_i X_{nik}$
$Y_{ik}$	Production in country $i$ , $Y_{ik} = \sum_n X_{nik}$
$\pi_{nik}$	Share of exporter $i$ in country $n$ 's total expenditures, $\pi_{nik} = X_{nik}/X_{nk}$
$e_n$	per capita income in country $n$
$\lambda_n$	Budget constraint Lagrange multiplier
$P_{nk}$	CES Price index industry $k$ , country $n$
$\Phi_{nk}$	Inward multilateral-resistance term, industry $k$ importer $n$
$S_{ik}$	Outward multilateral-resistance term, capturing supplier costs
$w_{if}$	Cost of factor $f$ in country $i$
$c_{ikLab}$	Aggregate labor costs in industry $k$ , country $i$
$sh_{ikf}$	Share of industry $k$ in factor $f$ employment
$\beta_{ikf}$	Share of labor type $f \in \{L, H\}$ in total labor costs

### Parameters and exogenous variables:

$\sigma_k$	Parameter governing income elasticity
$\xi_k$	Elasticity of substitution within industry $k$
$\alpha_k$	Taste shifters
$z_{ik}$	Productivity shifters
$\theta_k$	Productivity dispersion and trade elasticity
$d_{nik}$	Iceberg trade cost from country $i$ to $n$ in industry $k$
$\gamma_{kh}$	Direct input-output coefficient, use of products $h$ by industry $k$
$\gamma_{kf}$	Direct factor use, use of non-labor factor $f$ by industry $k$
$\rho$	Elasticity of substitution between skilled and unskilled labor
$\mu_{kf}$	Industry-specific productivity shifter for labor type $f$
$L_i$	Population in country $i$
$V_{if}$	Endowments of country $i$ in factor $f$

## A) Simulation equations: baseline equilibrium and changes

From the demand equation (5):

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

It is easy to obtain the counterfactual change in demand as a function of the change in prices and Lagrange multiplier, which yields Equation (16) in the main text:

$$\widehat{D}_{nk} = \widehat{\lambda}_n^{-\sigma_k} \widehat{P}_{nk}^{1-\sigma_k}$$

The change in the Lagrange multiplier is such that total expenditures equal income (Equation 6). This yields Equation (26); the change in total expenditures also equals the change in income:

$$\widehat{e}_n = \frac{\sum_k \widehat{D}_{nk} D_{nk}}{\sum_k D_{nk}}$$

Total demand  $X_{nk}$  for goods  $k$  in country  $n$  is the sum of the demand for final consumption  $D_{nk}$  and intermediate use (Equation 7). This also holds in the counterfactual equilibrium, which yields:

$$X_{nk} \widehat{X}_{nk} = D_{nk} \widehat{D}_{nk} + \sum_h \gamma_{hk} Y_{nh} \widehat{Y}_{nh}$$

which can then be rewritten as in Equation (18).

Next, using gravity Equation (8) and (9), we directly obtain Equation (19) and Equation (21):

$$\begin{aligned} \widehat{X}_{nik} &= \widehat{S}_{ik} \widehat{d}_{nik}^{-\theta_k} \widehat{P}_{nk}^{\theta_k} \widehat{X}_{nk} \\ \widehat{S}_{ik} &= \widehat{z}_{ik}^{\theta_k} (\widehat{c}_{ikLab})^{-\theta_k \gamma_{kL}} \prod_{f \neq L} (\widehat{w}_{if})^{-\theta_k \gamma_{kf}} \prod_h (\widehat{P}_{ih})^{-\theta_k \gamma_{kh}} \end{aligned}$$

For the change in labor costs, we have:

$$\widehat{c}_{ikLab}^{1-\rho} \widehat{c}_{ikLab}^{1-\rho} = \mu_{ikL} \widehat{w}_{iL}^{1-\rho} w_{iL}^{1-\rho} + \mu_{ikH} \widehat{w}_{iH}^{1-\rho} w_{iH}^{1-\rho}$$

Hence:

$$\widehat{c}_{ikLab}^{1-\rho} = \beta_{ikL} \widehat{w}_{iL}^{1-\rho} + \beta_{ikH} \widehat{w}_{iH}^{1-\rho}$$

which gives Equation (23).

In turn, for price indices, we obtain from Equation (10):

$$\widehat{\Phi}_{nk} \Phi_{nk} = \sum_i \widehat{S}_{ik} S_{ik} (\widehat{d}_{nik})^{-\theta_k} (d_{nik})^{-\theta_k}$$

Hence:

$$\widehat{P}_{nk}^{-\theta_k} = \widehat{\Phi}_{nk} = \frac{\sum_i \widehat{S}_{ik} S_{ik} (\widehat{d}_{nik})^{-\theta_k} (d_{nik})^{-\theta_k}}{\widehat{\Phi}_{nk}} = \sum_i \pi_{nik} \widehat{S}_{ik} \widehat{d}_{nik}^{-\theta_k} \quad (\text{A.1})$$

which yields Equation (22) in the text ( $\pi_{nik}$  are import shares).

Given the change in trade flows, Equation (20) then follows from the equality between production and total outward trade for country  $i$  sector  $k$ :

$$\widehat{Y}_{ik} = \frac{\sum_n X_{nik} \widehat{X}_{nik}}{\sum_n X_{nik}}$$

We can now examine the changes in income and factor prices. From  $V_{if} w_{if} = \sum_k \gamma_{kf} Y_{ik}$  and thus  $V_{if} w_{if} \widehat{w}_{if} = \sum_k \gamma_{kf} Y_{ik} \widehat{Y}_{ik}$ , we obtain for factors other than labor:

$$\widehat{w}_{if} = \sum_k sh_{ifk} \widehat{Y}_{ik}$$

where  $sh_{ifk} = \frac{\gamma_{kf} Y_{ik}}{\sum_k \gamma_{kf} Y_{ik}}$  is the share of factor  $f$  used in sector  $k$ .

Finally, for labor, we have (Equation 13):

$$\beta_{ikl} = \mu_{kl} w_{il}^{1-\rho} c_{ikLab}^{\rho-1}$$

and thus:

$$\widehat{\beta}_{ikl} = \widehat{w}_{il}^{1-\rho} c_{ikLab}^{\rho-1}$$

For each type of labor  $f \in \{L, H\}$ , labor market clearing imposes:

$$V_{if} w_{if} = \sum_k \beta_{ikf} \gamma_{kL} Y_{ik}$$

and thus:

$$\widehat{w}_{if} = \sum_k sh_{ikf} \widehat{\beta}_{ikl} \widehat{Y}_{ik} = \sum_k sh_{ikf} \widehat{w}_{if}^{1-\rho} c_{ikLab}^{\rho-1} \widehat{Y}_{ik}$$

where  $sh_{ikf} = \frac{\beta_{ikf} \gamma_{kL} Y_{ik}}{V_{if} w_{if}}$  is the share of labor type  $f$  employed in sector  $k$ . Solving for  $\widehat{w}_{ikf}$  as a function of  $c_{ikLab}$  and  $\widehat{Y}_{ik}$ , we obtain Equation (24):

$$\widehat{w}_{if} = \left[ \sum_k sh_{ikf} c_{ikLab}^{\rho-1} \widehat{Y}_{ik} \right]^{\frac{1}{\rho}}$$

This equation can also be combined with the change in labor costs  $c_{ikLab}$ , to yield:

$$\widehat{w}_{if}^\rho = \sum_k sh_{ikf} \widehat{Y}_{ik} \left[ \beta_{ikL} \widehat{w}_{iL}^{1-\rho} + \beta_{ikH} \widehat{w}_{iH}^{1-\rho} \right]^{-1}$$

## B) Implications for the skill premium

First, we examine how the skill premium depends on changes in production patterns. A first-order approximation in log, for each  $f \in \{L, H\}$ , yields:

$$\begin{aligned} \log c_{ikLab} &\approx \beta_{ikL} \log \widehat{w}_{iL} + \beta_{ikH} \log \widehat{w}_{iH} \\ \rho \log \widehat{w}_{if} &\approx (\rho - 1) \sum_k sh_{ikf} \log c_{ikLab} + \sum_k sh_{ikf} \log \widehat{Y}_{ik} \\ &\approx (\rho - 1) \sum_k sh_{ikf} [\beta_{ikL} \log \widehat{w}_{iL} + \beta_{ikH} \log \widehat{w}_{iH}] + \sum_k sh_{ikf} \log \widehat{Y}_{ik} \end{aligned}$$

Taking the difference between high- and low-skilled workers, we get the change in the skill premium:

$$\begin{aligned} \rho \log \frac{\widehat{w}_{iH}}{\widehat{w}_{iL}} &\approx (\rho - 1) \sum_k (sh_{ik}^H - sh_{ik}^L) [\beta_{ikL} \log \widehat{w}_{iL} + \beta_{ikH} \log \widehat{w}_{iH}] + \sum_k (sh_{ik}^H - sh_{ik}^L) \log \widehat{Y}_{ik} \\ &\approx (\rho - 1) \sum_k (sh_{ik}^H - sh_{ik}^L) \left[ \log \widehat{w}_{iL} + \beta_{ikH} \log \frac{\widehat{w}_{iH}}{\widehat{w}_{iL}} \right] + \sum_k (sh_{ik}^H - sh_{ik}^L) \log \widehat{Y}_{ik} \\ &\approx (\rho - 1) \sum_k (sh_{ik}^H - sh_{ik}^L) \beta_{ikH} \log \frac{\widehat{w}_{iH}}{\widehat{w}_{iL}} + \sum_k (sh_{ik}^H - sh_{ik}^L) \log \widehat{Y}_{ik} \end{aligned}$$

Hence:

$$\log \frac{\widehat{w}_{iH}}{\widehat{w}_{iL}} \approx \frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \log \widehat{Y}_{ik} \quad (\text{A.2})$$

where  $\tilde{\rho}_i = \rho - (\rho - 1) \sum_k (sh_{ik}^H - sh_{ik}^L) \beta_{ikH}$ . This relationship between the skill premium and production can then be used in each counterfactual to link the changes in production patterns to changes in the skill premium.

**Effect of uniform productivity growth** First, without intermediate goods and trade,  $\widehat{P}_{nk} \approx \widehat{z}^{-1}$  as a first approximation. Holding nominal income constant and using Equation (16), we obtain:

$$\log \widehat{D}_{nk} = -\sigma_k \log \widehat{\lambda}_n + (\sigma_k - 1) \log \widehat{z}$$

Given the constraint on total expenditures provided by (26), we need:

$$0 = \log \widehat{e}_n \approx \frac{\sum_k D_{nk} \log \widehat{D}_{nk}}{\sum_k D_{nk}} = \frac{\sum_k D_{nk} (-\sigma_k \log \widehat{\lambda}_n + (\sigma_k - 1) \log \widehat{z})}{\sum_k D_{nk}}$$

Solving for  $\log \widehat{\lambda}_n$  yields:

$$\log \widehat{\lambda}_n \approx \frac{\sum_k (\sigma_k - 1) D_{nk}}{\sum_k \sigma_k D_{nk}} \log \widehat{z}$$



Re-incorporating the solution for  $\log \widehat{\lambda}_n$  into the change in demand, we obtain the first-order approximation provided in the text:

$$\log \widehat{D}_{nk} \approx (\eta_{nk} - 1) \log \widehat{z}$$

$\eta_{nk} = \frac{\sigma_k \sum_{k'} D_{nk'}}{\sum_{k'} \sigma_{k'} D_{nk'}}$  is the income elasticity of demand in sector  $k$ , country  $n$ .

Using Equation (A.2) above, we can then obtain a simple expression for the response of the skill premium  $\frac{w_{nH}}{w_{nL}}$  to a productivity increase  $\widehat{z}$ :

$$\log \frac{\widehat{w}_{nH}}{\widehat{w}_{nL}} \approx \frac{1}{\widehat{\rho}_i} \log \widehat{z} \sum_k (sh_{nk}^H - sh_{nk}^L) \eta_{nk} \quad (\text{A.3})$$

Next, consider the situation with trade in final and intermediate goods. Under the assumption that the productivity increase  $\widehat{z}$  augments factors of production, the change in price  $\widehat{P}_{nk}$  still corresponds to  $\widehat{z}^{-1}$  when we neglect the feedback effect of wages on prices. One can check that  $\widehat{P}_{ik} = \widehat{z}^{-1}$  and  $\widehat{S}_{ik} = \widehat{z}^{\theta_k}$  are the solutions to the following system of equations:

$$\begin{aligned} \widehat{S}_{ik} &= (c_{ikLab}/\widehat{z})^{-\theta_k \gamma_{kL}} \prod_{f \neq L} (\widehat{w}_{if}/\widehat{z})^{-\theta_k \gamma_{kf}} \prod_h (\widehat{P}_{ih})^{-\theta_k \gamma_{kh}} \\ \widehat{P}_{nk} &= \left[ \frac{1}{\widehat{X}_{nk}} \sum_i X_{nik} \widehat{S}_{ik} \widehat{d}_{mik}^{-\theta_k} \right]^{-\frac{1}{\theta_k}} \end{aligned}$$

Hence relative prices and import shares remain constant (as a first-order approximation).

Equation (19) yields:

$$\widehat{X}_{nik} = \widehat{S}_{ik} \widehat{P}_{nk}^{\theta_k} \widehat{X}_{nk} = \widehat{X}_{nk}$$

For production, we get:

$$Y_{ik} \widehat{Y}_{ik} = \sum_n X_{nik} \widehat{X}_{nik} = \sum_n X_{nik} \widehat{X}_{nk}$$

Finally, using Equation (18), we obtain that the changes in production and demand satisfy:

$$Y_{ik} \widehat{Y}_{ik} = \sum_n \pi_{nik} D_{nk} \widehat{D}_{nk} + \sum_h \sum_n \pi_{nik} \gamma_{hk} Y_{nh} \widehat{Y}_{nh}$$

If we denote by  $G$  the matrix with coefficients  $\pi_{nik} \gamma_{hk}$ , by  $\Pi$  the matrix with coefficients  $\pi_{nik} 1_{k,h}$  (and where  $1_{k,h}$  is a dummy equal to one if  $h = k$ ), by  $Y \widehat{Y}$  the vector of production and  $D \widehat{D}$  the vector demand, we can write this equality as:  $Y \widehat{Y} = \Pi \cdot D \widehat{D} + G \cdot Y \widehat{Y}$ , which yields:

$$Y \widehat{Y} = (\text{I} - G)^{-1} \cdot \Pi \cdot D \widehat{D}$$

Denoting by  $\gamma_{inh}^{tot}$  the coefficients of the matrix  $(\text{I} - G)^{-1} \Pi$ , we can link changes in output to changes in final demand:

$$\widehat{Y}_{ik} = \frac{1}{Y_{ik}} \sum_{n,h} \gamma_{nih}^{tot} D_{nh} \widehat{D}_{nh}$$

Given that we have  $Y_{ik} = \sum_{n,h} \gamma_{nihk}^{tot} D_{nh}$ , we also have:

$$\widehat{Y}_{ik} - 1 = \frac{1}{\widehat{Y}_{ik}} \sum_{n,h} \gamma_{nihk}^{tot} D_{nh} (\widehat{D}_{nh} - 1)$$

Then, in log, a first-order approximation yields the two expressions in the text:

$$\begin{aligned} \log \widehat{w}_{iH} - \log \widehat{w}_{iL} &\approx \frac{1}{\tilde{\rho}_i} \sum_{k,h,n} (sh_{ik}^H - sh_{ik}^L) \frac{\gamma_{nihk}^{tot} D_{nh}}{Y_{ik}} \log \widehat{D}_{nh} \\ &\approx \frac{1}{\tilde{\rho}_i} \log \widehat{z} \sum_{k,h,n} (sh_{ik}^H - sh_{ik}^L) \frac{\gamma_{nihk}^{tot} D_{nh}}{Y_{ik}} \eta_{nh} \end{aligned}$$

**Effect of a reduction in trade costs.** Given Equation A.2, we need to examine how a reduction in trade costs leads to a change in production patterns. Using the following accounting equality (simply stating that production equals domestic demand plus exports minus imports):

$$Y_{ik} = X_{ik} + \left( \sum_{n \neq i} X_{nk} \pi_{nik} \right) - \left( X_{ik} \sum_{j \neq i} \pi_{ijk} \right)$$

we obtain, as a first-order approximation in terms of  $\log \widehat{\pi}$  and  $\log \widehat{X}$ :

$$\log \widehat{Y}_{ik} \approx \left[ \sum_{n \neq i} \frac{X_{nk} \pi_{nik}}{Y_{ik}} \log \widehat{\pi}_{nik} - \sum_{j \neq i} \frac{X_{ik} \pi_{ijk}}{Y_{ik}} \log \widehat{\pi}_{ijk} \right] + \left[ \sum_n \frac{X_{nk} \pi_{nik}}{Y_{ik}} \log \widehat{X}_{nk} \right]$$

The first term in brackets captures changes in trade shares  $\pi$  while the second term in brackets captures changes in demand. We will now split each of these two terms in two: i) the changes in trade shares is split as a function of the changes in bilateral trade costs (“direct effect”) and changes in multilateral-resistance terms (“MR effect”); ii) in turn, the changes in demand are split into changes in final demand and changes in demand for intermediate goods.

First, regarding trade shares, we can use Equation (19) for bilateral trade and obtain:  $\log \widehat{\pi}_{nik} = -\theta_k \log \widehat{d} + \log \widehat{S}_{ik} \widehat{P}_{nk}^{\theta_k}$ , assuming a uniform change in trade costs  $\log \widehat{d}$ . This provides the first two effects.

Second, regarding demand, we can combine Equations (16) and (18) to obtain:

$$\log \widehat{X}_{nk} \approx \frac{D_{nk}}{X_{nk}} \log(\widehat{\lambda}_n^{-\sigma_k} \widehat{P}_{nk}^{1-\sigma_k}) + \sum_h \frac{Y_{nh} \gamma_{hkn}}{X_{nk}} \log \widehat{Y}_{nh}$$

These provide the last two terms of the decomposition. Combining all terms, we get:

$$\log \widehat{Y}_{ik} \approx - \left[ \sum_{n \neq i} \frac{X_{nk} \pi_{nik}}{Y_{ik}} - \sum_{j \neq i} \frac{X_{ik} \pi_{ijk}}{Y_{ik}} \right] \theta_k \log \widehat{d} + \left[ \sum_{n \neq i} \frac{X_{nk} \pi_{nik}}{Y_{ik}} \log \widehat{S}_{ik} \widehat{P}_{nk}^{\theta_k} - \sum_{j \neq i} \frac{X_{ik} \pi_{ijk}}{Y_{ik}} \log \widehat{S}_{jk} \widehat{P}_{ik}^{\theta_k} \right]$$

$$+ \left[ \sum_n \frac{D_{nk}\pi_{nik}}{Y_{ik}} \log(\widehat{\lambda}_n^{-\sigma_k} \widehat{P}_{nk}^{1-\sigma_k}) \right] + \left[ \sum_{n,h} \frac{Y_{nh}\gamma_{hk}\pi_{nik}}{Y_{ik}} \log \widehat{Y}_{nh} \right]$$

Note that the first term in brackets coincides with net exports relative to production:

$$\sum_{n \neq i} \frac{X_{nk}\pi_{nik}}{Y_{ik}} - \sum_{j \neq i} \frac{X_{ik}\pi_{ijk}}{Y_{ik}} = \frac{NX_{ik}}{Y_{ik}}$$

Reordering, and plugging this four-term decomposition of output into Equation (A.2), we obtain the four-term decomposition proposed in the main text, Equations (31) to (34):

$$\begin{aligned} \log \left( \frac{\widehat{w}_{iH}}{\widehat{w}_{iL}} \right) &\approx -\frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \theta_k \frac{NX_{ik}}{Y_{ik}} \log \hat{d} \\ &+ \frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \sum_n \frac{D_{nk}\pi_{nik}}{Y_{ik}} \log \left( \widehat{\lambda}_n^{-\sigma_k} \widehat{P}_{nk}^{1-\sigma_k} \right) \\ &+ \frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \sum_{n,h} \frac{Y_{nh}\gamma_{hk}\pi_{nik}}{Y_{ik}} \log \widehat{Y}_{nh} \\ &+ \frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \left[ \sum_n \frac{X_{nk}\pi_{nik}}{Y_{ik}} \log(\widehat{S}_{ik}\widehat{P}_{nk}^{\theta_k}) - \sum_j \frac{X_{ik}\pi_{ijk}}{Y_{ik}} \log(\widehat{S}_{jk}\widehat{P}_{ik}^{\theta_k}) \right] \end{aligned}$$

These four terms are respectively what we call the direct effect, the effect on final demand, the effect of input-output linkages, and the adjustment in multilateral-resistance terms.

To obtain equation (35) in the case where  $\theta_k = \theta$  is homogeneous across industries, notice that the net content of trade  $NCT_f$  in labor type  $f \in \{H, L\}$  relative to its supply is given by:

$$\frac{NCT_{if}}{V_{if}} = \frac{1}{w_{if}V_{if}} \sum_k \beta_{ikf}\gamma_{kLab}(Y_{ik} - X_{ik}) = \sum_k sh_{ikf} \frac{NX_{ik}}{Y_{ik}}$$

Finally, consider a more general case where the change in bilateral trade cost is not uniform, but instead is given by the change in exporter-specific border effect  $\widehat{B}_{ik}$  as we impose in our simulations, such that we now have  $\log \widehat{\pi}_{nik} = \log \widehat{B}_{ik} + \log \widehat{S}_{ik}\widehat{P}_{nk}^{\theta_k}$ . The change in the skill premium is then:

$$\begin{aligned} \log \left( \frac{\widehat{w}_{iH}}{\widehat{w}_{iL}} \right) &\approx -\frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \left[ \sum_n \frac{X_{nk}\pi_{nik}}{Y_{ik}} \log \widehat{B}_{ik} - \sum_j \frac{X_{ik}\pi_{ijk}}{Y_{ik}} \log \widehat{B}_{jk} \right] \\ &+ \frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \sum_n \frac{D_{nk}\pi_{nik}}{Y_{ik}} \log \left( \widehat{\lambda}_n^{-\sigma_k} \widehat{P}_{nk}^{1-\sigma_k} \right) \\ &+ \frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \sum_{n,h} \frac{Y_{nh}\gamma_{hk}\pi_{nik}}{Y_{ik}} \log \widehat{Y}_{nh} \\ &+ \frac{1}{\tilde{\rho}_i} \sum_k (sh_{ik}^H - sh_{ik}^L) \left[ \sum_n \frac{X_{nk}\pi_{nik}}{Y_{ik}} \log(\widehat{S}_{ik}\widehat{P}_{nk}^{\theta_k}) - \sum_j \frac{X_{ik}\pi_{ijk}}{Y_{ik}} \log(\widehat{S}_{jk}\widehat{P}_{ik}^{\theta_k}) \right] \end{aligned}$$

## C) Estimation strategy

### Step 1: Gravity equation estimation and identification of $\Phi_{nk}$

As described in the text, the model yields Equation (37):

$$X_{nik} = \exp \left[ FX_{ik} + FM_{nk} - \sum_{var} \beta_{var,k} TC_{var,ni} - \beta_{border,ik} \delta_{n \neq i} + \varepsilon_{nik}^G \right] \quad (\text{A.4})$$

In this equation, importer fixed effects correspond to  $\log \frac{X_{nk}}{\Phi_{nk}}$  and exporter fixed effects correspond to  $\log S_{ik}$ . These terms are identified up to an industry constant (e.g.  $\alpha_k$  in preferences). We normalize the exporter fixed effect  $S_{US,k}$  to unity in each sector  $k$ .

$TC_{var,ni}$  refers to the variables (indexed by  $var$ ) included in the gravity equation to capture trade costs between  $n$  and  $i$ . Following the literature on gravity, we include the log of physical distance (including internal distance when  $i = n$ ), a common language dummy, a colonial link dummy, a border effect dummy (equal to one if  $i \neq n$ ), a contiguity dummy (equal to one if countries  $i$  and  $n$  share a common border), a free-trade-agreement dummy (equal to one if there is an agreement between countries  $i$  and  $n$ ), a common currency dummy and a common-legal-origin dummy (equal to one if  $i$  and  $n$  have the same legal origin: British, French, German, Scandinavian or socialist). Parameters  $\delta_{var,k}$  capture the elasticity of trade costs to each trade cost variable  $var$ , which may differ across industries. Since all coefficients to be estimated are sector specific, we estimate this gravity equation separately for each sector. Following Silva and Tenreyro (2006) and Fally (2015), we estimate gravity using the Poisson pseudo-maximum likelihood estimator (Poisson PML).

Table A.1: Coefficients from the gravity equation estimations.

Trade cost variable:	Mean across sectors	Standard Deviation across sectors
Distance (log)	-0.802	0.731
Contiguity	0.124	1.511
Common language	0.022	0.791
Colonial link	-0.016	0.845
Both access to sea	0.244	1.185
RTA	0.430	2.117
Common currency	0.641	3.920
Common legal origin	0.400	1.723
Exporter border effects	Yes	
Exporter FE	Yes	
Importer FE	Yes	
Nb. of industries	55	
Pseudo-R2 (incl. domestic)	0.999	
Pseudo-R2 (excl. domestic)	0.973	

*Notes:* Poisson regressions; dependent variable: trade flows. The coefficients above are estimated separately for each industry. Pseudo-R2 equal the square of the correlation coefficient between fitted and observed trade flows, including or excluding domestic flows.

We then use Equation (10),  $\Phi_{nk} = \sum_i S_{ik} (d_{nik})^{-\theta_k}$ , to construct  $\Phi_{nk}$ . The exporter fixed effects ( $\widehat{FX}_{ik}$ ) provide estimates for  $\log S_{ik}$  while  $\sum_{var} \widehat{\beta}_{var,k} TC_{var,ni}$  yields an estimate of trade cost  $d_{nik}$  multiplied by its elasticity for each sector and each country pair:  $\theta_k \log d_{nik}$ .

$$\widehat{\Phi}_{nk} = \sum_i \exp \left( \widehat{FX}_{ik} - \sum_{var} \widehat{\beta}_{var,k} TC_{var,ni} - \widehat{\beta}_{border,ik} \delta_{n \neq i} \right) \quad (\text{A.5})$$

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

## Step 2: Demand system estimation and identification of $\sigma_k$

The first step estimation gives us an estimate of  $\Phi_{nk}$ . From Equation (11), we know that the price index  $P_{nk}$  is a log-linear function of  $\Phi_{nk}$  which we can use as a proxy for  $P_{nk}$  on the right-hand side of Equation (36) describing final demand.<sup>43</sup>

<sup>43</sup>In Caron et al (2014), we show that this approach yields better and more conservative outcomes than using actual prices from the International Comparison Program. Using actual prices leads to a lower R-squared and a stronger correlation between income elasticity and skill intensity across sectors.

As described in the text, we estimate Equation (39) for final demand:

$$\log x_{nk} = -\sigma_k \cdot \log \lambda_n + \log \alpha_{3,k} + \frac{(\sigma_k - 1)}{\theta_k} \log \widehat{\Phi}_{nk} + \varepsilon_{nk}^D \quad (\text{A.6})$$

where  $\varepsilon_{nk}^D$  denotes the error term. In each country  $n$ , we further impose the sum of fitted expenditures across sectors to equal observed total per capita expenditures  $e_n$ , which leads to the following constraint:

$$\sum_k \exp \left[ -\sigma_k \cdot \log \lambda_n + \log \alpha_{3,k} + \frac{(\sigma_k - 1)}{\theta_k} \log \widehat{\Phi}_{nk} \right] = e_n \quad (\text{A.7})$$

We jointly estimate these equations using constrained non-linear least squares (we minimize the sum of squared errors  $(\varepsilon_{nk}^D)^2$  while imposing that both equations 39 and A.7 hold). Observed variables are: the price proxies  $\widehat{\Phi}_{nk}$ , individual expenditures  $x_{nk}$  per industry (net of intermediate goods) and total expenditures  $e_n$ . Free parameters to be estimated are the  $\sigma_k$ ,  $\theta_k$ ,  $\lambda_n$  and  $\alpha_{3,k}$ . This estimation procedure can be seen as a non-linear least squares estimation of Equation (39) in which  $\lambda_n$  is the implicit solution of the budget constraint, Equation (A.7), and thus a function of fitted coefficients and observed per capita expenditures  $e_n$ .

At least one normalization is required. Given the inclusion of industry fixed effects,  $\lambda_n$  can be identified only up to a constant.<sup>44</sup> We normalize  $\lambda_{USA} = 1$  for the US.

## D) Alternative specifications in the estimation of income elasticities

We explore several alternative specifications to illustrate the robustness of our income elasticity estimates:

**Specification without budget constraint** In our baseline estimation, we constrain our fitted per capita expenditures to sum up to observed per capita total expenditures  $e_n$  for each country. In other words, we assume that  $e_n$  is observed without measurement errors. However, we obtain similar estimates without this constraint, as illustrated in Figure A.1 below.

Given our good fit for final demand at the country-by-sector level, the fit of total expenditures for each country is then also very good. The difference is negligible if we compare it to the very large variations in per capita income across countries. Hence, imposing a perfect fit for  $e_n$  does not generate substantial differences in our estimates.

**Reduced-form estimation** While our estimation procedure is consistent with general equilibrium conditions and our specification of preferences, we show that similar estimates are found when estimating Equation (39) with a reduced-form approximation in which  $\log \lambda_n$  is replaced by a linear

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<sup>44</sup>To see this, we can multiply  $\lambda_n$  by a common multiplier  $\lambda'$  and multiply the industry fixed effect  $\alpha_k$  by  $(\lambda')^{\sigma_k}$ . Using  $\lambda_n \lambda'$  instead of  $\lambda_n$  and  $\alpha_k (\lambda')^{\sigma_k}$  instead of  $\alpha_k$  in the demand system generates the same expenditures by industry.

function of  $\log e_n$ . Assuming that  $\log \lambda_n \approx \nu \log e_n$ , we obtain:

$$\log x_{nk} = -\sigma_k \nu \log e_n + \log \alpha_{4,k} + \frac{1 - \sigma_k}{\theta_k} \cdot \log \Phi_{nk} + \epsilon_{nk} \quad (\text{A.8})$$

where  $\log \alpha_{4,k}$  and  $\nu$  are constant terms. Even if  $\nu$  is not separately identified from  $\sigma_k$ , we can obtain an estimate of income elasticities in each sector:

$$\eta_{mk} = \frac{\widehat{\sigma_k \nu} \sum_{k'} x_{nk'}}{\sum_{k'} \widehat{\sigma'_k \nu} x_{nk'}} \quad (\text{A.9})$$

We report our estimates in Figure A.1.

**Specification with  $\theta_k = 4$**  The benchmark specification described above identifies  $\sigma_k$  and income elasticities solely based on the coefficient associated with the Lagrange multiplier  $\lambda_n$ . The  $\sigma_k$  parameter also appears in the coefficient for  $\Phi_{nk}$  in Equation (39) but the benchmark specification does not impose any constraint on the coefficient for  $\Phi_{nk}$  since  $\theta_k$  is a free parameter. In an alternative estimation, we jointly identify  $\sigma_k$  from the coefficients on  $\lambda_n$  and  $\Phi_{nk}$  by constraining  $\theta_k$  to equal 4 in all sectors. This choice of  $\theta$  is close to the Simonovska and Waugh (2014) estimates of 4.12 and 4.03. Donaldson (2018), Eaton et al. (2011), Costinot et al. (2012) provide alternative estimates that range between 3.6 and 5.2. Figure A.1 reveals that the resulting income elasticity are well correlated (at 79.9%) with our benchmark estimates, though differences are significant for particular sectors. In the next section, we incorporate these estimates in the general equilibrium model to test the sensitivity of skill premium estimates.

Alternative values for  $\theta$  (e.g.  $\theta_k = 8$ ) yield similar results for income elasticities.

**Instrumenting or dropping  $\log \widehat{\Phi}_{nk}$**  Figure A.2 illustrates an alternative estimation of income elasticities where  $\log \widehat{\Phi}_{nk}$  is instrumented by an alternative measure constructed using foreign exporter fixed effects only. Instead of taking the sum of fixed effects across all countries as in the text (including own market), we construct as an instrument  $\widehat{\Phi}_{nk}^{IV}$  by taking the sum across foreign countries only:

$$\widehat{\Phi}_{nk}^{IV} = \sum_{i \neq n} \exp \left( \widehat{FX}_{ik} - \sum_{var} \widehat{\beta}_{var,k} TC_{var,ni} - \beta_{border,ik} \right)$$

Figure A.2 indicates that the two approaches yield very similar estimates with the exception of a few small sectors (“wol”: wool, “c\_b” cane and beet sugar, “pdr”: rice).

To illustrate how controlling for trade costs matters, we also estimate final demand by dropping  $\log \widehat{\Phi}_{nk}$  from the regression. This is equivalent to assuming that there are no trade costs and that all countries face the same prices. In this specification, we find even larger differences in estimated income elasticity, as illustrated in Figure A.1. These estimates are correlated at 94.6% with our baseline estimates.

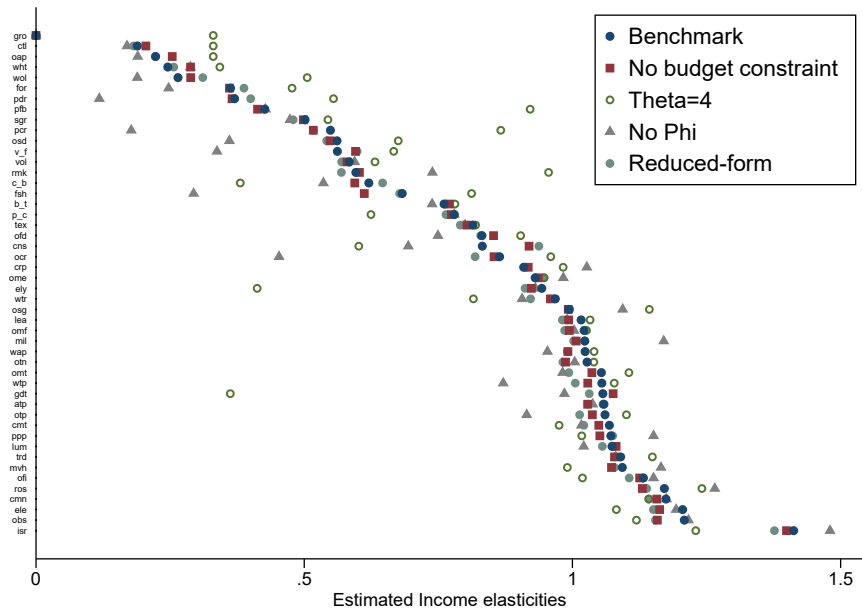


Figure A.1: Income elasticities across alternative specifications in the estimation of CRIE preferences.

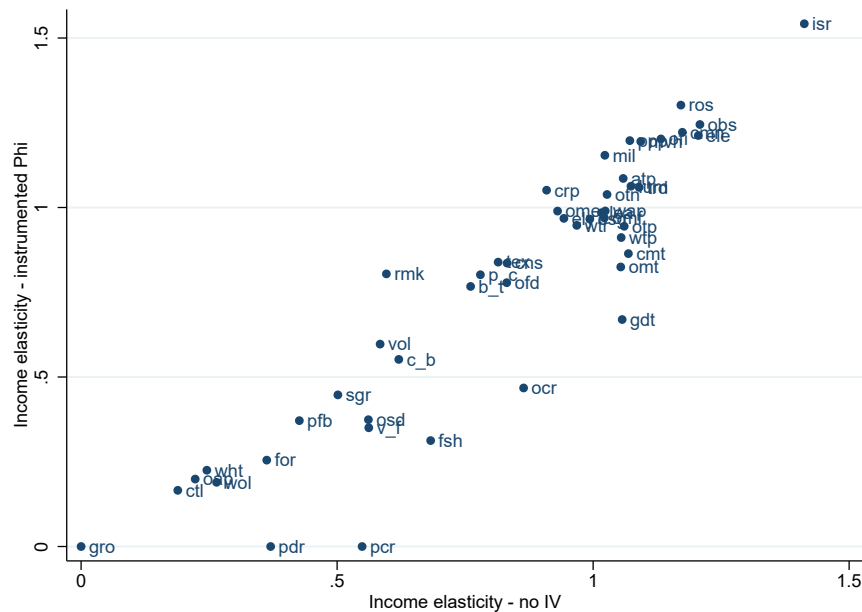


Figure A.2: Income elasticities estimated with and without instrumenting  $\Phi$  (with  $\Phi$ 's constructed ignoring domestic supplier effects). Correlation is 0.923.

**Preferences as in Comin, Lashkari and Mestieri (2016).** Following Comin, Lashkari and Mestieri (2016), we examine a specification where utility  $U_n$  for consumers in country  $n$  is implicitly defined by:



$$\sum_k \alpha_k^{\frac{1}{\sigma}} U_n^{\frac{\epsilon_k - \sigma}{\sigma}} Q_{nk}^{\frac{\sigma-1}{\sigma}} = 1$$

This leads to final demand:<sup>45</sup>

$$x_{nk} = \alpha_k e_n^\sigma U_n^{\epsilon_k - \sigma} P_{nk}^{1-\sigma} \quad (\text{A.10})$$

This implicit utility function does not impose any link between income elasticities (parameterized by  $\epsilon_k$ ) and price elasticities ( $\sigma$ ), unlike separable utility functions where income elasticities are proportional to price elasticities across sectors for any country.

We estimate Equation (A.10) by letting  $U_n$  be a free parameter. An alternative (as in Comin et al 2016) would be to construct a proxy for  $U_n$ , which would be roughly equivalent to the reduced-form approach discussed above (estimation Equation A.8).<sup>46</sup> We impose a value  $\theta_k = 4$  for this specification, and estimate the elasticity of substitution between sectors.

Using these estimates, the income elasticity can be retrieved as:

$$\eta_{nk} = 1 + (1 - \sigma) \frac{\epsilon_k - \bar{\epsilon}_n}{\bar{\epsilon}_n - \sigma}$$

where  $\bar{\epsilon}_n$  is an average of  $\epsilon_k$  weighted by consumption shares to ensure that the weighted average of income elasticities equals one for each country  $n$  (Engel aggregation).

Figure A.3 compares these estimates to our baseline specification, using average expenditures to compute  $\bar{\epsilon}_n$ . The two sets of estimates are very close and correlated at 88.7%. Moreover, the income elasticities estimated with Comin et al (2016) preferences remain highly correlated with skill intensity in production (78.1% correlation).

Our estimated elasticity of substitution is equal to 0.85, which is in line with Comin et al's (2016) own estimates (0.8 and 0.6 with cross-section and panel data respectively).

## E) Robustness checks for the general equilibrium estimates

**Elasticity of substitution between skilled and unskilled workers** Using our analytical approximations, it is fairly straightforward to predict the role of alternative elasticities on the effect of productivity and trade. Relative to the Cobb-Douglas specification ( $\rho = 1$ ), the change in the skill premium is scaled by a ratio of 1 over  $\tilde{\rho}_i = \rho - (\rho - 1) \sum_k (sh_{ik}^H - sh_{ik}^L) \beta_{ikH}$ . We find that this adjustment provides a very good approximation of actual simulation results with higher elasticities as long as the changes are not too large. It can therefore be used to quickly identify the sensitivity of results to  $\rho$ .

For instance, for the baseline counterfactual, we compare results with  $\rho = 1.4$  (as in our benchmark calibration) and  $\rho = 1.7$ , after multiplying the skill premium increase by  $\tilde{\rho}_i = \rho - (\rho - 1) \sum_k (sh_{ik}^H -$

<sup>45</sup>In this sum, each term is equal to the share of good  $k$  in expenditures:  $\frac{x_{nk}}{e_n} = \alpha_k^{\frac{1}{\sigma}} U_n^{\frac{\epsilon_k - \sigma}{\sigma}} Q_{nk}^{\frac{\sigma-1}{\sigma}}$ .

<sup>46</sup>One can see from the definition of  $U$  above that we can rescale with any exponent  $U' = U^a$ , hence  $(\epsilon_i - \sigma)$  is defined only up to a constant term. However, the income elasticity in CLM can still be identified as it is invariant to re-scaling utility by an exponent  $a$ .

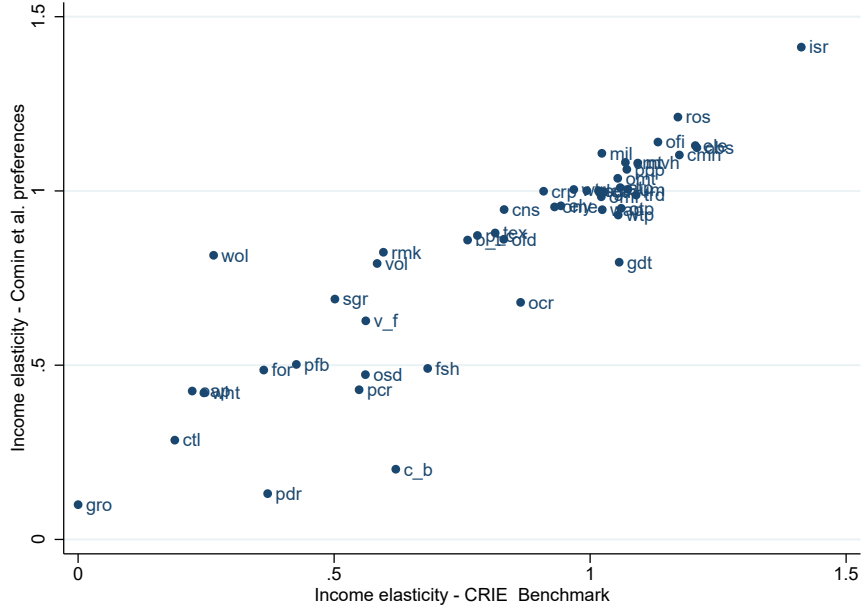


Figure A.3: Estimated income elasticities based Comin et al. (2016) preferences compared to benchmark CRIE preferences.

$sh_{ik}^L) \beta_{ikH}$ . Elasticities of substitution between 1.4 and 1.7 imply values of  $\tilde{\rho}_i$  between 1.3 and 1.6. We find there to be virtually no difference between simulations once we account for the  $\tilde{\rho}_i$  adjustment (correlation of 0.999, mean difference 3.4%). Also, the effects of growth and trade remain sizeable across this range of elasticities.

**Homogeneous trade elasticity  $\theta_k = 4$**  Our baseline simulations rely on sector-specific estimates of  $\theta_k$  which we recover from the estimation of preferences of Equation (39). As documented Appendix D above, imposing homogeneous trade elasticity  $\theta_k = 4$  yields income elasticity estimates which are at 79% correlated with our benchmarks estimates and remain well correlated with skill intensity. Figure A.4 replicates our main simulation and finds similar results for the changes in the skill premium with these alternative preference estimates.

Note also that our estimated  $\theta_k$  are slightly correlated with income elasticity (11% correlation), but this correlation is not crucial for our results.

**Alternative measures of skill and unskilled labor intensity** While the GTAP dataset provides skilled and unskilled labor usage for all countries, part of this information is extrapolated from a subset of European countries and six non-European countries (US, Canada, Australia, Japan, Taiwan and South Korea).<sup>47</sup> Also, skilled labor is defined on an occupational basis for a few of these countries (e.g. the US). In our baseline analysis, we thus use a cross-country average of skilled labor and

<sup>47</sup>See: <https://www.gtap.agecon.purdue.edu/resources/download/4183.pdf>

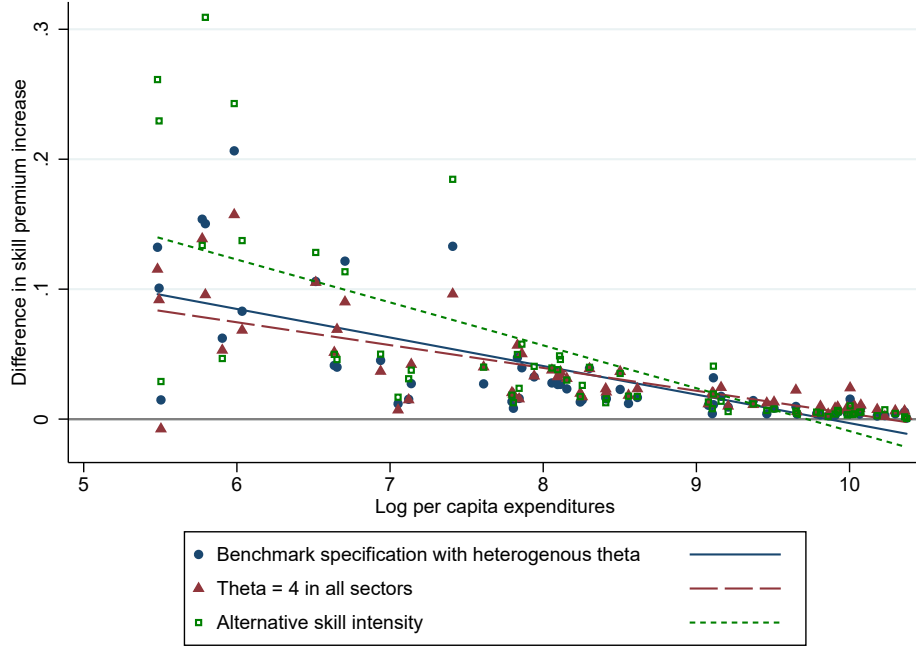


Figure A.4: Alternative specifications for the unified counterfactual (skill premium caused by 1995 to 2010 changes in real per capita income and openness to trade across); non-homothetic to homothetic difference. “Alternative skill intensity” corresponds to the use of country-specific skill intensity coefficients.

unskilled labor intensity ( $\bar{\beta}_{kL}$  and  $\bar{\beta}_{kH}$ ) in Equation (23) to solve for the counterfactual change in wages. Our results are however not very sensitive to this choice. Figure A.4 displays results from the unified growth and trade counterfactual obtained using the country-specific shares of skilled labor provided by GTAP ( $\beta_{ikL}$  and  $\beta_{ikH}$ ) in Equation 23. Resulting changes in the skill premium are higher in some low-income countries but overall similar. The robustness of results is due to the strong correlation of income elasticities with the country-specific measures of skill intensity of most countries, as documented in Caron et al (2014).

**Price elasticity and Comin et al (2016) implicitly-additive preferences** We integrate preferences as in Comin et al (2016) described above into the general equilibrium model. This yields the following counterfactual equilibrium conditions for final demand. Taking change ratios of final demand (Equation A.10), we obtain:

$$\hat{D}_{nk} = \hat{e}_n^\sigma \hat{U}_n^{\epsilon_k - \sigma} \hat{P}_{nk}^{1 - \sigma}$$

Like the Lagrange multiplier with CREI preferences, the change  $\widehat{U}_n$  is constrained by consumers' budget, which yields:

$$\widehat{e}_n = \frac{1}{L_n e_n} \sum_k D_{nk} \widehat{D}_{nk} = \frac{1}{L_n e_n} \sum_k D_{nk} \widehat{e}_n^\sigma \widehat{U}_n^{\epsilon_k - \sigma} \widehat{P}_{nk}^{1-\sigma}$$

These two equations allow us to determine  $\widehat{D}_{nk}$  and  $\widehat{U}_n$  depending on other outcome variables (changes in income  $\widehat{e}_n$  and prices  $\widehat{P}_{nk}$ ) and estimated parameters.

Simulation results for the unified counterfactual fitting changes in both productivity and trade are plotted in Figure A.5.

As argued by Cravino and Sotelo (2018), lower elasticity of substitution between sectors leads to larger skill premium increases with both types of preferences, yet the difference between non-homothetic and homothetic preferences remains large, if not larger with Comin et al's (2016) implicitly-additive specification.

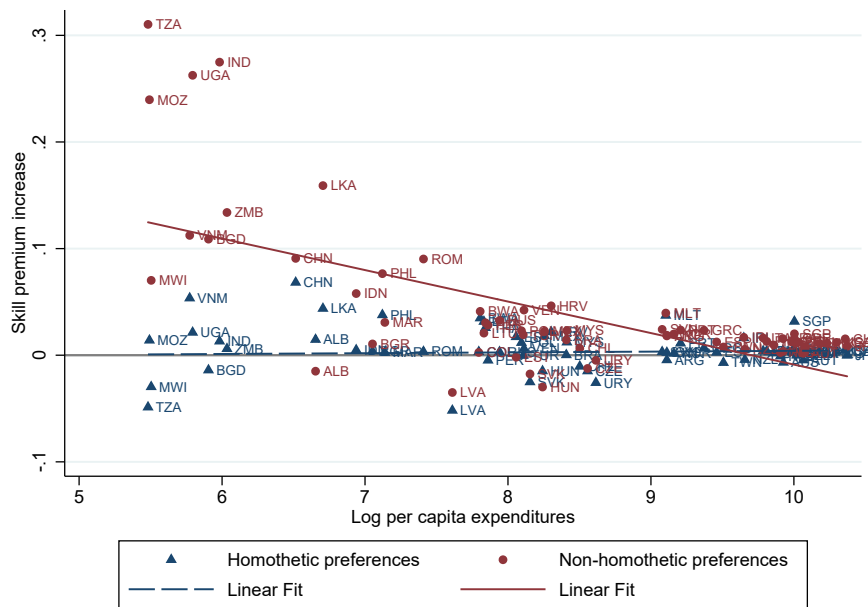


Figure A.5: Simulated estimates of changes in the skill premium caused by 1995 to 2010 changes in real per capita income and openness to trade – based on Comin et al (2016) preferences.

### F) Using a more recent version of the GTAP data (version 8 based on year 2007)

While our benchmark empirical and simulation results are obtained using GTAP5, which is based on 1997 data from the beginning of our 1995-2010 simulation period, we would obtain very similar results if using the more recent GTAP8 dataset based on year 2007.<sup>48</sup> We indeed find that skill intensity is also very strongly correlated with income elasticity in the GTAP8 data, as described in Table A.2.

<sup>48</sup>As noted earlier, comparisons to more recent GTAP version 9 data are difficult due to the change in labor types.

The correlation is also above 50% even if we control for capital intensity and natural resource intensity or if we exclude services.

We also confirm that the simulated responses of the skill premium to productivity growth and changes in trade costs yield similar patterns. In particular, Figure A.6 displays the simulated elasticity of the skill premium to productivity growth, using the GTAP8 data to calibrate the model. For the set of countries also included in GTAP5, these results are close to what we obtained in Figure 5. On average, results appear stronger with GTAP8 data mainly because it includes more low-income countries, for which our demand-driven mechanisms are the strongest (a number of African countries having elasticities above 20%, for instance).

Table A.2: Correlation between income elasticity and skill intensity, estimated using GTAP8 data (2007)

Dependent variable:	Income elasticity			
	(1) All sectors	(2) All sectors	(3) Excl. services	(4) Excl. services
Skill intensity	0.583 [0.108]**	0.546 [0.114]**	0.613 [0.126]**	0.660 [0.154]**
Capital intensity		0.177 [0.200]		-0.033 [0.274]
Natural resource Intensity		-0.045* [0.021]		0.138 [0.255]
Observations (sectors)	55	55	43	43

*Notes:* Dependent variable: income elasticity by sector evaluated using average expenditures; beta coefficients; robust standard errors in brackets; \* significant at 5%; \*\* significant at 1%.

## G) Additional tables and graphs

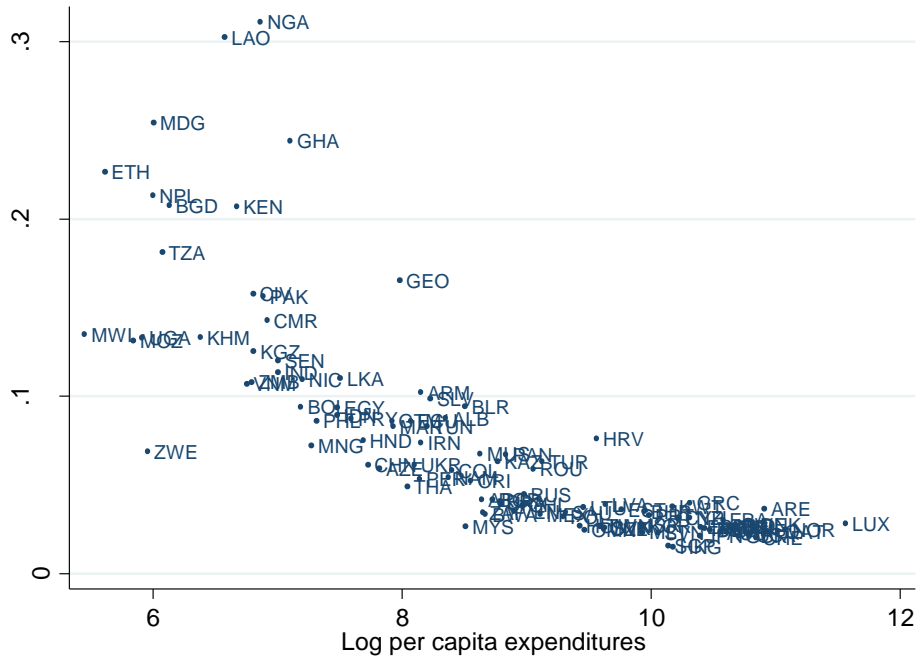


Figure A.6: Simulated elasticity of the skill premium to TFP, estimated using GTAP8 data (2007).

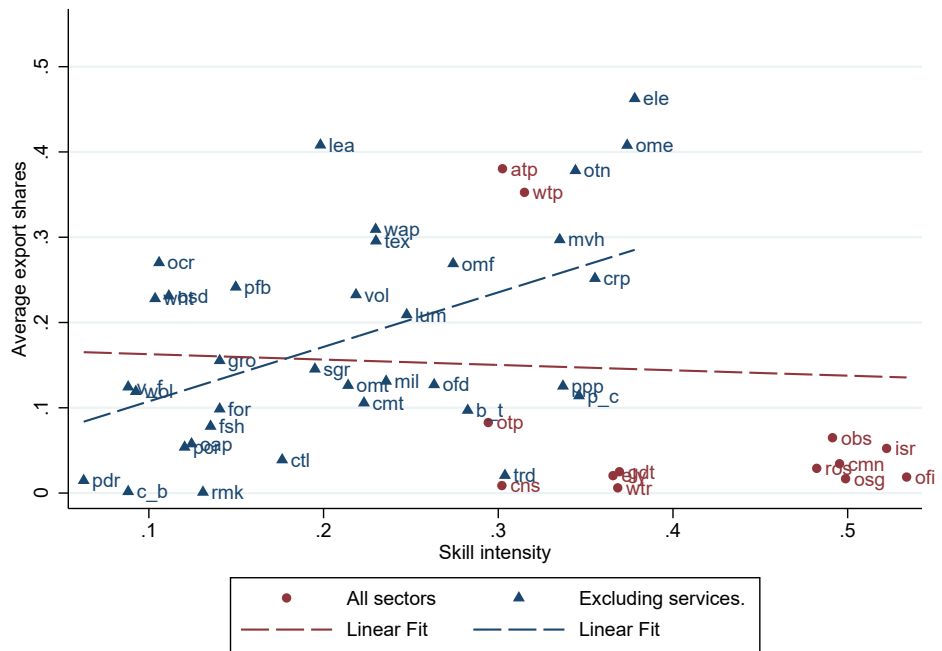


Figure A.7: Correlation between average export shares and skill intensity across sectors.

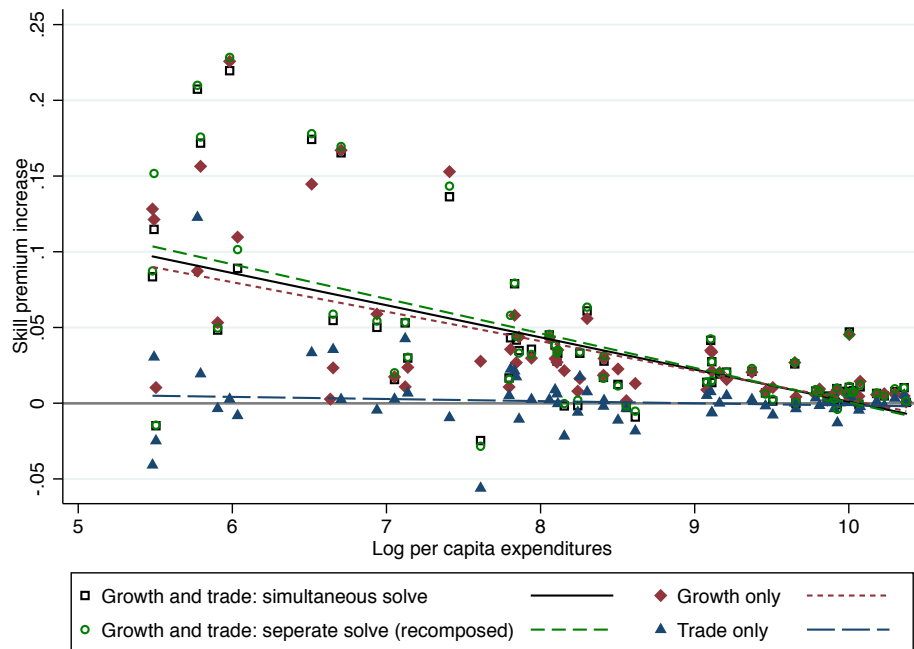


Figure A.8: 1995 to 2010 changes in the skill premium: simultaneous changes in productivity and trade, decomposition into growth and trade, comparison to recomposed growth + trade estimates. Results based on non-homothetic preferences. For clarity, Zimbabwe (ZWE) is dropped (values  $< -0.1$ ).



Table A.3: 1995-2010 percentage changes in productivity, trade cost shocks and implied changes in the simulated skill premium. General equilibrium unified counterfactual.

	Targeted changes		Calibrated changes		Simulated skill premium		
	Real income	Export/GDP	Productivity	Trade costs	Growth & trade	Growth	Trade
ALB	113.0	200.7	38.9	-197.3	5.5	2.3	3.5
ARG	54.5	44.0	52.7	-10.3	2.7	3.4	-0.6
AUS	41.6	81.6	31.7	-67.0	-0.1	0.9	-1.3
AUT	37.6	53.6	26.8	-9.2	-0.1	0.5	-0.5
BEL	38.9	25.2	26.0	-11.7	0.6	0.5	0.2
BGD	58.7	103.1	54.5	-48.8	4.8	5.3	-0.4
BGR	51.9	189.9	47.7	-48.1	1.6	1.7	0.3
BRA	58.3	69.9	56.9	-31.1	1.7	1.8	-0.2
BWA	78.9	-24.8	105.0	195.2	4.3	3.6	2.2
CAN	24.3	20.9	19.0	-12.9	0.5	0.2	0.2
CHE	39.4	35.3	29.6	-19.5	1.0	0.5	0.5
CHL	70.3	85.5	48.4	-105.9	1.2	2.3	-1.1
CHN	175.1	149.8	175.5	-85.7	17.4	14.5	3.3
COL	37.8	92.9	28.0	-68.2	1.7	1.1	0.5
CYP	51.7	-49.7	63.8	54.5	1.4	2.1	-0.6
CZE	41.2	221.4	9.9	-94.4	-0.3	0.2	-0.3
DEU	36.1	67.1	27.5	-27.7	0.8	0.7	0.1
DNK	39.9	10.0	36.9	3.8	0.6	0.6	0.1
ESP	58.4	31.7	52.8	-19.6	0.7	0.8	-0.2
EST	117.5	85.6	81.4	-62.1	4.5	4.3	0.2
FIN	55.5	-3.8	55.5	15.6	0.7	0.9	-0.2
FRA	38.9	5.7	37.2	9.1	1.0	0.8	0.2
GBR	32.9	13.5	29.5	0.7	1.0	0.5	0.6
GRC	47.4	30.0	46.1	6.2	2.1	2.0	0.2
HKG	52.9	22.4	48.2	12.7	0.5	0.6	-0.2
HRV	84.7	17.3	83.4	-3.0	6.1	5.6	0.8
HUN	62.6	197.5	24.5	-98.2	-0.2	0.8	-0.6
IDN	70.5	33.7	69.2	-22.5	5.0	5.9	-0.5
IND	167.9	47.0	186.2	29.6	22.0	22.6	0.3
IRL	84.7	-6.6	87.7	0.2	2.6	2.7	0.0
ITA	24.1	29.7	19.7	-3.4	0.8	0.6	0.3
JPN	5.7	52.8	1.9	-1.2	0.0	0.1	0.0
KOR	70.3	78.7	62.6	-24.7	1.9	2.0	0.0
LKA	99.9	-26.1	139.3	66.9	16.5	16.7	0.2
LTU	149.0	256.4	116.8	-65.0	7.9	5.8	2.1
LUX	57.8	27.6	42.9	-21.4	1.1	1.4	-0.2
LVA	120.8	163.4	65.9	-131.9	-2.5	2.8	-5.6
MAR	37.0	78.5	26.4	-57.1	3.0	2.4	0.7
MEX	48.7	64.1	42.3	-43.1	3.3	1.6	1.7
MLT	71.6	-17.3	85.6	14.7	4.1	3.5	0.8
MOZ	122.8	148.9	97.8	-70.2	11.5	12.1	3.0
MWI	19.5	28.4	11.5	7.1	-1.5	1.0	-2.5
MYS	70.1	9.6	67.9	-2.1	2.8	3.0	0.2
NLD	51.7	43.1	36.8	-21.0	0.2	0.6	-0.4
NZL	28.4	20.5	23.5	3.5	0.0	0.4	-0.4
PER	106.5	110.0	99.7	-88.2	3.5	4.4	-1.1
PHL	25.9	51.8	11.0	-19.8	5.3	1.1	4.3
POL	94.5	154.9	78.2	-79.5	3.8	2.9	0.9
PRT	56.4	7.1	54.5	2.0	2.1	1.6	0.5
ROM	147.9	102.3	146.4	-53.0	13.6	15.3	-1.0
RUS	64.1	89.9	55.5	-52.3	3.6	3.0	0.2
SGP	145.3	-29.9	166.4	32.0	4.7	4.5	0.0
SVK	81.2	222.1	49.2	-88.0	-0.2	2.1	-2.2
SVN	43.4	71.7	26.1	-41.6	1.4	0.9	0.5
SWE	41.2	21.4	36.6	-1.4	0.8	0.6	0.1
THA	64.2	61.8	53.3	-34.6	4.2	2.7	1.7
TUR	56.4	107.2	43.5	-57.0	2.8	2.7	0.6
TWN	54.2	24.3	50.1	-0.3	0.1	1.0	-0.8
TZA	121.6	53.2	115.3	-40.0	8.3	12.8	-4.1
UGA	64.5	-18.0	89.3	93.9	17.2	15.6	1.9
URY	43.2	76.8	25.9	-57.9	-0.9	1.3	-1.8
USA	25.1	37.7	22.7	-1.0	0.8	0.6	0.3
VEN	105.5	-0.5	104.2	-8.9	3.3	3.5	0.0
VNM	162.3	156.2	74.7	-218.6	20.7	8.7	12.3
ZMB	116.1	17.9	115.0	12.3	8.9	11.0	-0.8
ZWE	44.2	251.1	0.0	-209.1	-12.4	0.3	-13.1

Table A.4: Correlation between income elasticity and total skill intensity

Dependent variable:	Income elasticity			
	(1) All sectors	(2) All sectors	(3) Excl. services	(4) Excl. services
Skill intensity	0.773 [0.085]**	0.428 [0.133]**	0.723 [0.099]**	0.407 [0.172]*
Capital intensity		-0.015 [0.069]		-0.044 [0.094]
Natural resource intensity		-0.461 [0.157]**		-0.429 [0.207]*
Observations (sectors)	49	49	36	36

*Notes:* Dependent variable: income elasticity by sector evaluated using average expenditures; Factor intensities correspond to the ratio of each factor to total labor input including factors required to produce intermediate inputs to each final good; The table displays beta regression coefficients; Robust standard errors in brackets; \* significant at 5%; \*\* significant at 1%; In Caron et al (2014), we find that robust standard errors are very close to bootstrap standard errors constructed by resampling importers and sectors in all steps of the estimation in order to account for generated variable biases (income elasticities are estimated rather than observed).

Table A.5: Correlations between observed changes in the skill premium and simulated estimates

Dependent variable:	Observed change in skill premium				
	Preferences		Non-homothetic to homothetic difference		
	Homoth.	Non-homoth.			
Counterfactual:	Growth & trade	Growth & trade	Growth & trade	Growth only	Trade only
Simulated SP change	0.182 [0.161]	0.317 [0.167]*	0.296 [0.170]*	0.302 [0.171]*	0.167 [0.165]
Log schooling years	-0.225 [0.167]	-0.130 [0.162]	-0.224 [0.169]	-0.229 [0.171]	-0.148 [-0.165]

*Notes:* Dependent variable: Observed change in the skill premium over the 1995 to 2010 time period (WIOD); 40 observations, corresponding to the countries in the WIOD dataset; beta coefficients; robust standard errors in brackets; \* denotes 10% significance level.