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Abstract

In Chapter 1, I examine if the sparse trade patterns between affiliates and parents of multinational firms are a puzzle for a quantitative model of global sourcing. I find that recently developed models of global sourcing broadly reproduce the the skewed distributions of trade flows between parents and affiliates within multinational firms. Distributions of affiliate-to-parent sales from a simulated global sourcing model are consistent with the patterns reported from the data on multinationals.

In Chapter 2, I examine to what extent trade liberalization contributed to changes in skill premia and quantify the impact of trade liberalization against other quantitatively important channels such as technological growth and rising demand for skill intensive services. Skill premia increased in multiple countries in the world in recent decades but potentially for different reasons. This chapter is a quantitative estimation of how falling sectoral trade frictions, technological growth and reallocation of valued added to skill-intensive industries contribute to the growth of skill premia. In a baseline calibration for 29 countries over years 1995 - 2007 I find that shocks to technology account for 88% of growth in skill-premia for an average country. Among sectoral shocks to trade frictions, shocks in capital equipment sector account for 82% on average. In contrast, capital equipment sector accounts for less than a third of total effect in terms of technology shocks for most countries. Growth of relative demand for

services driven by differential sectoral income elasticities in preferences exacerbates the response of skill premia to technology and trade frictions shocks by up to 20%. In Chapter 3, I study international trade of digital goods. Using product-level sales data of PC games on digital distribution platform STEAM, I estimate the effects of geographical and cultural barriers on digital international trade. I find that even in this extreme case when trade does not involve any physical delivery and information frictions are small and not related to geography, the effect of distance on trade volumes is still statistically significant yet an order of magnitude smaller than for trade in physical goods. Translating the content of a digital good into the language of the destination market increase sales by around 20%. This suggests that firms take language support into serious consideration when selling in culturally differentiated markets.

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Chapter 1

Can Ricardian Trade Model Account for Sparse Trade between Affiliates of Multinational Firms?

1.1 Introduction

Offshoring parts of the production chain has been one of the main components of multinational activity. Recent literature documents that multinational corporations (MNCs) own as much as 50% of their foreign affiliates in industries vertically related to the industry of a parent establishment [1]. However, the vast majority of affiliates do not trade with their parents. According to [1] [2] , a median affiliate of a U.S. multinational ships nothing to and imports nothing from its parent. Trade with

[1] [2] report this figure in their study of more than 650 000 affiliates in 400 different industries and 90 countries.

[2] [1]'s sample consists of the majority-owned foreign affiliates (MOFAs: affiliates with parents that own more than $50 % of the affiliate's voting stock or equivalent), that have sales, assets, or net income (loss) of more than $25 million, and that operate — and are owned by a parent that operates — in a manufacturing industry.

parents is heavily concentrated among a small share of foreign subsidiaries. [3]. Absence of input shipments from affiliates is hard to explain with the basic model of vertical foreign direct investment (FDI), acccording to which relocating parts of supply chain into cost effective locations is the rationale for FDI. However, multinationals are engaged in much more complex supply chains and own multiple subsidiaries abroad[4]. Is lack of shipments from vertically related affiliates a puzzle given complex production chains of multinationals?

To shed light on the question, I study whether recent theoretical models of complex FDI can be reconciled with the absence of trade between parents and affiliates . What patterns of intra-firm trade does a simple model of multinational production chain predict? And specifically, how many zero trade flows between vertical affiliates and parents does a model generate? I apply a simple framework of multinational activity with supply chain considerations. In the framework multinationals own assembling plants in different countries and source intermediate inputs *only* within the boundaries of a firm. Multinationals choose where to set up input production given trade costs between a potential location and assembly plants, fixed costs of establishing production and expected unit costs at a location. As a network of input factories is determined, an assembly plant sources each input from the cheapest location.

The description of the problem is reminiscent of the model of global sourcing in [3]. While in [3] benefit of sourcing from a new market depends on where a firm sources from already, here benefit of opening a new input producing plant depends

[3]A considerable share of the affiliates might be horizontal in nature that is established to serve foreign markets. For such kind of affiliates, the lack of shipments to headquarters does not seem to be surprising. However, [1] control for input-output proximity between parent's and affiliate's industries and input-output linkages do not predict the share of shipments to parents in total sales of an affiliate.

[4]Volkswagen Group owns 68 factories, 52 of them outside Germany and 39 outside EU

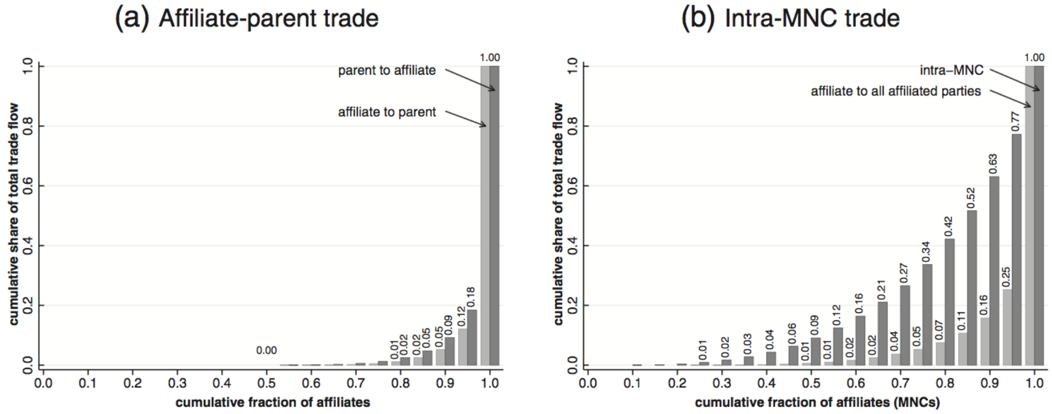


Fig. 2. Distribution of intra-MNC trade across affiliates and MNCs. Notes: In panel a, observations are at the affiliate level. In panel b, intra-MNC shipments are the sum over all of the foreign affiliates and the parent of the MNC, and shipments to all affiliated parties are total shipments from an affiliate to other parties in the MNC. In panel (a), the 55th percentile is the first non-zero entry for both parent-to-affiliate and affiliate-to-parent trade. In panel (b), the 25th (10th) percentile is the first non-zero entry for affiliate–affiliated-party (intra-MNC) trade.

Figure 1.1. Distribution of intra-MNE trade across affiliates and MNEs from [1]

on the set of other affiliates, which provide inputs. This interdependency leads to a potentially complicated computational problem. Using algorithm in [4], [3] can still solve the problem in a feasible time under some restrictions on parameter values. For this reason I want to build a benchmark model on [3] setting.

Zero trade flows between parent firms and integrated input producers is a part of a bigger picture, which is small volumes of intra-MNC trade. [1] report that a median affiliate in their sample sells only 9% within the boundaries of a multinational firm. Five percent of affiliates are responsible for 88% of affiliate-to-parent trade, 82% of parent-to-affiliate trade, and 75% of affiliate trade to other affiliates. All these sales distributions are very skewed and the numbers on the other tail are zeros. To explain this skewness and lack of trade, papers in the literature generally conjecture alternative (to production fragmentation) rationales for firm ownership. A prevalent conclusion is that ownership facilitates sharing or transfer of intangible inputs, knowledge and expertise [5] [6]. As far as firms in I-O related industries are close in terms of their expertise and capabilities, the I-O links can predict the ownership but not necessarily the intra-MNC trade flows of tangible goods. An alternative explanation for ownership is value of trading network of potential subsidiaries. Using data on french firms, [8] show that french enterprises with large export networks are relatively more attractive targets for M&A by foreigners.

My approach is rather orthogonal to the discussed explanations for lack of intra-MNC shipments. Since multinationals own subsidiaries in different locations around the world, supply chain considerations might be important to account for the volumes and directions of trade flows within a multinational firm. How close is a model of a multinational firm with supply chain structure to predicting the observed patterns of intra-MNC sales? This is the question I approach in this paper.

1.2 The Model

There are two types of goods in the economy: final and intermediate. Final goods are not traded internationally, while intermediates can be potentially sourced from each country $i \in 1, .., N$. In country i households derive utility from consumption of differentiated varieties of final goods:

$$U = \left(\int_{\omega \in \Omega_i} q(w)^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}}, \sigma > 1 \tag{1.1}$$

[5] [5] and [1] provide such conjecture. [5] observe lack of intra-firm trade between establishments within U.S. firms.

[6] As for the literature on knowledge transfer, [6] is a perfect example. While [7] provides a review of this literature.

where Ω_i is the set of varieties available in country i, σ is the elasticity of substitution between individual varieties. Demand for individual variety is given by:

$$q_i(w) = E_i P_i^{\sigma-1} p_i(w)^{-\sigma} \tag{1.2}$$

where E_i is total spending on differentiated goods in country i and P_i is the price index associated with CES preferences in (1.1). For succeeding description, it will be convenient to introduce market demand term in a following way:

$$B_i = \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} E_i P_i^{\sigma-1} \tag{1.3}$$

Labor is the only production factor in the economy and it is paid wage w_i in a respective country. Country i is endowed with L_i units of labor. To close the model in general equilibrium I introduce the outside good, one unit of which takes one unit of labor to produce. Labor is mobile between the sector of differentiated goods and outside good sector. Outside good can be costlessly traded across borders. A fixed share $(1-\eta)$ of household's income is spent on the good in every country and this share is large enough to equalize wages across countries. I imply this assumption to abstract from wage differences in a simple framework of multinational production. Although, it can be dropped and cost differences will have an effect on firm's decisions and equilibrium outcomes.

1.2.1 Firm's Technology

A firm can serve a market B_i by establishing an assembly plant in country i [7]. A firm has an efficiency φ in assembling a final good and can be indexed by this parameter. To assemble a final good in country i, a firm needs to source a number N_v of inputs [8]. Each input v can be produced in one of countries from the set J, where a firm has established vertical affiliates. Intermediate v can be produced in country $j \in J$ with firm-specific labor requirement $a_j(v, \phi)$. If a φ-firm sources input $v \in [0, 1]$ from its factory in country $j(v)$, unit costs of production in i are given by:

$$c_i\Big(\{j(v)\}_{v=1}^{N_v}, \varphi\Big) = \frac{1}{\varphi}\left(\sum_{v=1}^{N_v}\Big(\tau_{ij} a_{j(v)}(v, \phi) w_{j(v)}\Big)^{1-\rho}\right)^{\frac{1}{1-\rho}} \tag{1.4}$$

Following models of heterogeneous firms such as [10] and [11], I assume that a firm originating in country i draws core productivity parameter φ from an exogenous distribution $G_i(\varphi)$. Unit labor requirements associated with input production $\{a_j(v, \varphi)\}_{j \in J}$ are draws independent across locations and inputs. Building on [12], I assume that $1/a_j(v, \varphi)$ follows Frechet distribution, that is:

$$\Pr[a_j(v, \varphi) \geq a] = e^{-T_j a^{\theta}}, \quad T_j > 0 \tag{1.5}$$

Here parameter T_j can be interpreted as state of technology in the country and drives absolute advantage of a source. While θ governs the variability of productivity draws with lower θ resulting in greater variability and hence comparative advantage within an input industry. Note that the distribution of draws in input productivity

[7] It follows naturally from the assumption that final good is not traded across borders. Thus I exclude possibility of export platforms in the model. While the problem of export platforms is interesting and can be solved (see [9]), it would add yet another layer of complexity to the model.

[8] I abstract from the firm's decision of how many inputs to source, so that N_v is exogenous

$a_j(v,\varphi)$ does not depend on the core efficiency φ. However, according to cost structure a firm with higher core efficiency φ can take greater advantage of favorable $a_j(v,\varphi)$ draws.

While a firm can potentially establish input production in every county $j \in N$, I assume that a firm from country i can draw a vector $\{a_j(v,\varphi)\}_{v=1}^{N_v}$ only after paying fixed costs equal to $w_i f_{ij}$. Fixed costs are not input specific and paid once, no matter how many different inputs a firm will produce at a location. I denote by $J_i(\varphi) \in N$ a set of countries where a firm has decided to pay fixed costs $w_i f_{ij}$ to start input factories and subsequently has a chance to source from.

1.2.2 Equilibrium of the Model

Solving for the equilibrium of the model takes the following steps. First, given the set of markets where to sell final goods, a firm decides on the optimal set of countries $J(\varphi)$ where to locate input production. Second, aggregating firm's decisions about input production, prices and quantities of final goods yields market-level outcomes, which clear markets and are consistent with firms' decisions in the equilibrium.

1.2.3 Location of Input Production

Suppose a multinational φ-firm originating in country i sells final goods in M countries characterized by their demand terms $\{B_m\}_{m=1}^{M}$, where m stands for market. Given factories for input production in countries $J_i(\phi)$ and draws $\{a_j(v,\varphi)\}_{v=1, j\in J_i(\varphi)}^{N_v}$ of inverse efficiencies, for each intermediate $v \in 1,..,N_v$ a vertical affiliate will serve market m, that delivers minimal costs of input production and shipping $j(m,v) =_{j\in J_i(\varphi)} \{\tau_{mj} a_j(v,\varphi) w_j\}$. Since the draws $a(j,v)$ are independent across inputs, country j does not have to be the cheapest source for a final good factory in market m for *all* the inputs.

As efficiencies $a_j(v, \varphi)$ are distributed Fréchet (see (1.5)), the probability that, within an MNE originated in i, an assembling plant in m sources an input from a vertical affiliate in j is given by:

$$\psi_{ijm} = \frac{T_j(\tau_{mj} w_j)^{-\theta}}{\Theta_{im}(\varphi)}, \quad j \in J_i(\varphi) \tag{1.6}$$

and $\psi_{ijm} = 0$ for the countries j, where an MNE does not have input factories. Here

$$\Theta_{im}(\varphi) = \sum_{k \in J_i(\varphi)} T_k(\tau_{km} w_k)^{-\theta} \tag{1.7}$$

Following the terminology of [3], I refer to $T_j(\tau_{mj} w_j)^{-\theta}$ as the *sourcing potential* of country j and $\Theta_{im}(\varphi)$ as the *sourcing capability* of market m. Affiliates in countries $j \in J_i(\phi)$ with a high state of technology T_j, low wages w_j and close to final good market (low iceberg costs τ_{mj}) are more likely to provide inputs for an assembly plant. Note that firm-specific sourcing potential of an m-market $\Theta_{im}(\varphi)$ depends on i — the origin country of an MNE — implicitly through the set of countries $J_i(\varphi)$ where an MNE had established affiliated input plants. The origin i of an MNE drives the fixed costs $w_i f_{ij}$ of establishing a plant in country j. Therefore the origin affects the choice of $J_i(\varphi)$ and the capability of every market where a firm sells final goods. Suppose, it's cheap for a U.S. multinational to open an input plant in Mexico, for a German multinational — to open an input plant in Poland. Then the Brazilian market might have a greater capability for the U.S. firm than for the German due to its proximity to Mexico relative to Poland. So far in the simple setup, this is the only way how the origin of a multinational affects the costs of goods sold in different markets.

Consider a sourcing strategy of an MNE, that sells final goods in markets $\{B_m\}_{m=1}^{M}$.

Once it has input producers in $J_i(\varphi)$, expected marginal costs for market m are given by:

$$c_{im}(\varphi) = \frac{1}{\varphi}\Big(\gamma\Theta_{im}(\varphi)\Big)^{-\frac{1}{\theta}} N_v^{\frac{1}{1-\rho}} \tag{1.8}$$

where N_v is the number of different inputs used in production and $\gamma = \left[\Gamma\left(\frac{\theta+1-\rho}{\theta}\right)\right]^{\frac{\theta}{1-\rho}}$ for $N_v > 1$, or $\gamma = \left[\Gamma\left(\frac{\theta+1}{\theta}\right)\right]^{\theta}$, if there is a unique input [9]. With expected marginal costs at hand, one can describe the decision of a multinational from i to place input factories in foreign countries. Opening a factory in a country j lowers expected marginal costs of final goods production in every market B_m. Opening an affiliate in country j costs f_{ij} units of country i labor. Therefore, taking into account constant markup pricing for a final good (1.2) and definition of demand term (1.3), a problem of an MNE to set up vertical affiliates can be formulated as:

$$\max_{I_{ij}\in\{0,1\}_{j=1}^{N}} \pi_i(\varphi, I_{i1}, .., I_{iN}) = \varphi^{\sigma-1}\gamma^{\frac{\sigma-1}{\theta}} N_v^{\frac{\sigma-1}{\rho-1}} \sum_{m=1}^{M}\left(\sum_{j=1}^{N} I_{ij}T_j(\tau_{jm}w_j)^{-\theta}\right)^{\frac{\sigma-1}{\theta}} B_m - w_i \sum_{j\in J_i(\varphi)} I_{ij}f_{ij} \tag{1.9}$$

where I_{ij} are indicator variables and hence take values 0 or 1. Brute force approach to solve the problem would require estimation of 2^N plausible choices of a firm, since having a vertical affiliate in one location affects the marginal gain of opening an affiliate in other locations. However, under some assumptions on parameter values the problem can be solved in feasible time. First, for illustrative purposes consider a knife-edge case, when $\sigma - 1 = \theta$. In this case marginal cost index and the whole profit function of a firm is additive across potential sources, and the decisions to open

[9] $\Gamma(.)$ stands for gamma function. The deviations of the expected unit costs are analogous to [12]. However, here the derived cost-index reflects *expected* marginal costs, since number of inputs is finite. To ensure well-defined marginal costs, I assume $\theta > \rho - 1$. In the case of a unique input elasticity of substitution between inputs ρ is irrelevant, which is reflected in γ.

a vertical affiliate in a country is independent of a set of active affiliates:

$$I_{ij} = 1 \iff \varphi^{\sigma-1}\gamma^{\frac{\sigma-1}{\theta}} N_v^{\frac{\sigma-1}{\rho-1}} \left(T_j w_j^{-\theta}\right)^{\frac{\sigma-1}{\theta}} \sum_{m=1}^{M} \tau_{jm}^{1-\sigma} B_m \geq w_i f_{ij} \tag{1.10}$$

A firm will be more likely to open an affiliate in a country with a high state of technology and low wages. Geography plays a role. Vertical affiliates are more likely to emerge in locations close to final good markets served by an MNE. Being close to large markets rather than small ones increases the chances of input production at a location. Locations with high fixed costs f_{ij} are difficult to establish a plant at. For simpicity, I assume here and later on that $f_{ii} = 0$, that is an MNE always can source inputs from factories in home country and therefore $i \in J_i(\varphi)$ always. As for the firm-specific factors behind the decision to set up input production, more productive firms are more likely to open more vertical affiliates.

The intuition of a knife-edge example above holds under general assumptions on value of $\frac{\sigma-1}{\theta}$. But the decisions over locations are interdependent. When $\frac{\sigma-1}{\theta} > 1$, profit function of a firm features increasing differences in (I_{ij}, I_{ik}), so that the marginal gain of opening an input plant abroad increases in firm's *sourcing capability*. In other words, potential locations are *complements*. In the *complements case*, problem of a firm can be solved in a feasible time for large sets of potential locations. To the best of my knowledge, the solution algorithm was introduced in [4]. [10] In what follows, I assume the *complements case* so that I am able to implement the algorithm. [11]

[10] Among the papers that rely on this algorithm are [3] and [9].

[11] [3] estimates of θ and σ provide some evidence that the assumption $\frac{\sigma-1}{\theta} > 1$ holds for american firms sourcing inputs from unaffiliated suppliers.

1.2.4 Market-Level Equilibrium Outcomes

To keep the model simple, I abstract from a firm's decision about establishing assembly plants in foreign countries. As a result, in the simplest framework each active firm is multinational , that assembles and sells final goods in all countries, so that $\{B_m\} = \{B_1, .., B_N\}$. Still a firm pays a fixed cost of entry f_{ei} in terms of home-country labor before drawing its core productivity φ from $G_i(.)$. In what follows, I assume that firms draw core productivities φ from Pareto distribution $G(\varphi) = 1 - \left(\frac{\varphi}{\underline{\varphi}}\right)^{-\kappa}$. In the equilibrium, only lucky firms with a draw higher than the cutoff level $\bar{\varphi}_i$ are active. Firms with draws lower than $\bar{\varphi}_i$ are not profitable enough to repay the sunk costs of entry. A firm with the cutoff productivity $\bar{\varphi}_i$ breaks even:

$$\bar{\varphi}_i^{\sigma-1}\gamma^{\frac{\sigma-1}{\theta}} N_v^{\frac{\sigma-1}{\rho-1}} \sum_{m=1}^{M} \Big(\Theta_{im}(\bar{\varphi}_i)\Big)^{\frac{\sigma-1}{\theta}} B_m - w_i \sum_{j\in J_i(\bar{\varphi}_i)} f_{ij} = w_i f_{ei} \tag{1.11}$$

Free entry conditions state that the expected profits of active firms (those with productivity higher than the cutoff $\bar{\varphi}_i$) equate entry costs of all entrants:

$$\int_{\bar{\varphi}_i}^{\infty} \left[\varphi^{\sigma-1}\gamma^{\frac{\sigma-1}{\theta}} N_v^{\frac{\sigma-1}{\rho-1}} \sum_{m=1}^{M} \Big(\Theta_{im}(\varphi)\Big)^{\frac{\sigma-1}{\theta}} B_m - w_i \sum_{j\in J_i(\varphi)} f_{ij}\right] dG_i(\varphi) = w_i f_{ei}, \quad i \in \{1, .., N\} \tag{1.12}$$

Given the wage equalization across countries (which follows from the unimpeded trade in outside good), free entry conditions represent the system of nonlinear equations to determine $\{B_m\}_{m=1}^N$. Nonlinearity emerges through the dependence of $\{\bar{\varphi}_i\}_{i=1}^N$, market potentials $\Theta(\cdot)$ and sourcing strategies $J(\cdot)$ on market sizes. This system does not have a closed form solution. I solve it numerically by iterating over $\{B_m\}_{m=1}^N$. Note that for each iteration over $\{B_m\}_{m=1}^N$, one needs to solve for sets of input sources $J_i(\varphi)$ for firms in the whole world economy.

Since a share η of household income in market m is spent on differentiated final goods, equilibrium masses of firms $\{N_i\}_{i=1}^N$ can be determined from the system of equations:

$$\eta L_m w_m = \sigma \left[\sum_{i=1}^{N} N_i \int_{\varphi_i}^{\infty} \varphi^{\sigma-1} \gamma^{\frac{\sigma-1}{\theta}} N_v^{\frac{\sigma-1}{\rho-1}} \Big(\Theta_{im}(\varphi)\Big)^{\frac{\sigma-1}{\theta}} dG_i(\varphi) \right] B_m, \quad m = 1,..,N \tag{1.13}$$

I exploit the facts that sales of a firm are σ-multiple of its variable profits and that variable profits are separable across markets. For convergence of the integrals on the right hand side $\kappa + 1 - \sigma > 0$ is a necessary condition, where κ is the shape parameter of Pareto distribution. The same condition has to hold to define price indices for final goods. I define the price indices in the next section and explain in detail why the condition is necessary.

1.2.5 Price Indices

To conduct welfare analysis, one needs to solve for price indices for final goods. For a market m, price index is formed by multinationals originating in different countries i and selling their goods in market m:

$$P_m = \left[\sum_i N_{im} P_{im}^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \tag{1.14}$$

Here N_{im} is the mass of firms originated in i, that sell to the market m. In the simple model above, every active firm from i sells final goods to all markets m, so that $N_{im} = N_i \quad \forall i, m$. After recalling that prices of final goods are constant markups over marginal costs and expression (1.8) for marginal cost index, bilateral price indices are given then by:

$$P_{im}^{1-\sigma} = \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \gamma^{\frac{\sigma-1}{\theta}} N_v^{\frac{\sigma-1}{\rho-1}} \int_{\bar{\varphi}_i}^{\infty} \varphi^{\sigma-1} \Big(\Theta_{im}(\varphi)\Big)^{\frac{\sigma-1}{\theta}} dG_i(\varphi) \tag{1.15}$$

Recall that sourcing capability $\Theta_{im}(\varphi)$ is defined by:

$$\Theta_{im}(\varphi) = \sum_{k \in J_i(\varphi)} T_k(\tau_{km} w_k)^{-\theta}$$

In the complements case, for two firms from the same country i, $\varphi_1 < \varphi_2$ implies $J_i(\varphi_1) \in J_i(\varphi_2)$, so that more productive firms source from bigger or at least the same set locations and there is a hierarchy of the sourcing sets. Then the interval $[\bar{\varphi}_i, \infty)$ can be partitioned into $\bar{\varphi}_i < \varphi_2 < \varphi_3 < ... < \varphi_N < \infty$, where φ_n stands for the least productive firm that sources from n locations. On every interval $[\varphi_{n-1}, \varphi_n)$ the term $\Theta_{im}(\varphi)$ is costant, so that one need to integrate $\varphi^{\sigma-1}$ over the distribution $G_i(\varphi)$. While φ_n are finite and positve, one needs to care about convergence for the integral over $[\varphi_N, \infty)$. For Pareto distribution with parameter κ, the convergence is guaranteed by $\kappa + 1 - \sigma > 0$.

1.3 Simulation of the Model

To compare model predictions with the data, I perform simple simulations. In all of them, I borrow values of structural parameters from the literature [12].

To start, I simulate the economy for a small number of countries N in a symmetric case. Fixed costs of establishing a vertical affiliate in a foreign country are $f_{ij} = f > 0 \quad \forall i \neq j$ and market entry costs are the same across countries $f_{ei} = F > 0$. States of technology are the same across all countries, and only one intermediate input is

[12] The condition $\kappa + 1 - \sigma > 0$ holds for parameter values taken from the literature

Table 1.1. Structural parameters used in simulations

σ	3.85	elasticity of substitution for final goods	[3] baseline
κ	4.5	shape parameter for Pareto distribution	[13]
$\bar{\varphi}$	1	lower bound for Pareto distribution	[13]
θ	1.71	Fréchet parameter	[3] baseline
ρ	2	elasticity of substitution between inputs	does not matter as long as $\theta > \rho - 1$

needed for production.

1.3.1 Shares of Affiliate Sales to a Parent

Zero trade flows between parents and affiliated parties is one of the puzzles in the literature and motivating facts for this paper. In the first exercise, I want to explore how much parent-affiliate trade the model generates. Below is the original table from [1] to illustrate the distribution quantiles in the data. For current exercise my attention is on the "share of affiliate sales to parent" row of the table.

Figure 1.2. Summary statistics on intra-MNE trade from [1]

Table 1
Intra-MNC trade, summary.

	Mean (1)	Std (2)	p50 (3)	p75 (4)	p95 (5)	Emp > p50 (6)	Emp > p75 (7)	Emp > p95 (8)
Panel 1: Share of affiliate sales								
To any unaffiliated parties	0.73	0.34	0.91	1.00	1.00	0.70	0.68	0.64
To local unaffiliated parties	0.57	0.39	0.66	0.97	1.00	0.55	0.54	0.51
To non-local unaffiliated	0.17	0.27	0.00	0.24	0.84	0.15	0.13	0.12
To any affiliated party	0.27	0.34	0.09	0.41	1.00	0.30	0.32	0.36
To parent	0.07	0.19	0.00	0.02	0.49	0.09	0.11	0.14
Panel 2: Share of affiliate cogs								
From parent	0.06	0.15	0.00	0.04	0.38	0.05	0.05	0.06
Panel 3: Share of total MNC sales								
To any unaffiliated party	0.89	0.13	0.93	0.98	1.00	0.89	0.88	0.86
To any affiliated party	0.10	0.11	0.06	0.15	0.31	0.11	0.12	0.16

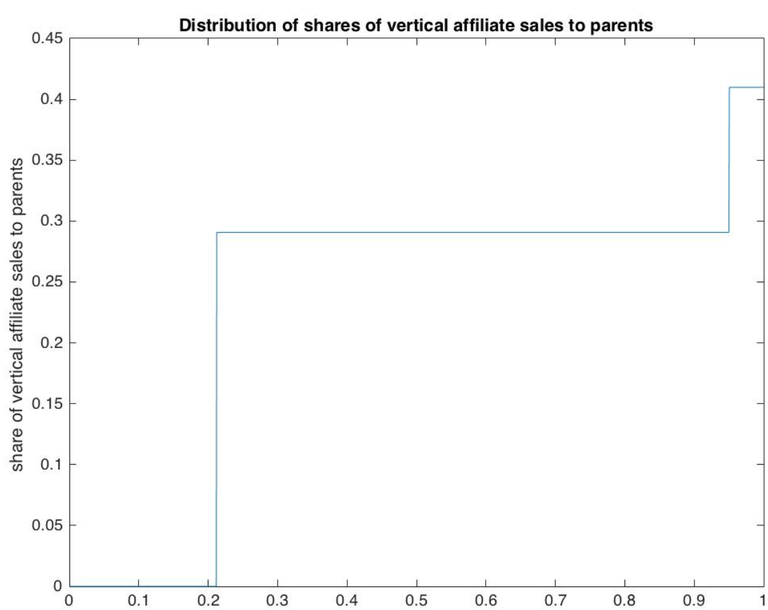
Notes: Columns 3–5 report the average of the 11 firms around the indicated percentile. Columns 6–8 report the average values for the firms (or MNCs) with employment greater than the indicated percentile employment. In panel 3, statistics correspond to the aggregate at the corporate level, which includes the parent and its reporting foreign affiliates.

I simulate the economy with $N = 3$ countries, so that a multinational can potentially own vertical affiliates in 2 countries. I draw 100 φ-levels for each country and 100 vectors of Fréchet draws for each level of φ and origin of an MNE i. The matrix of iceberg trade costs for my simulation is given by:

$$||\tau_{ij}|| = \begin{bmatrix} 1 & 1.2 & 1.2 \\ 1.2 & 1 & 1.2 \\ 1.2 & 1.2 & 1 \end{bmatrix}$$

Figure 1.3 depicts the distribution of shares of affiliate sales to a parent firm in the model. Recall, that in the model a multinational firm originated in country i has subsidiaries that sell final goods in different countries and vertical affiliates that ship inputs to the final good subsidiaries. A vertical affiliate in country j can potentially ship inputs to all the markets m, a firm serves. After the realization of a Fréchet draw it will serve only some of these markets and probably will ship back to home country i. This shipment is interpreted as sales to a parent firm. The graph below is the distribution over vertical affiliates for a given country in the simulation.

Figure 1.3. Distribution of affiliate sales to parents. Part 1

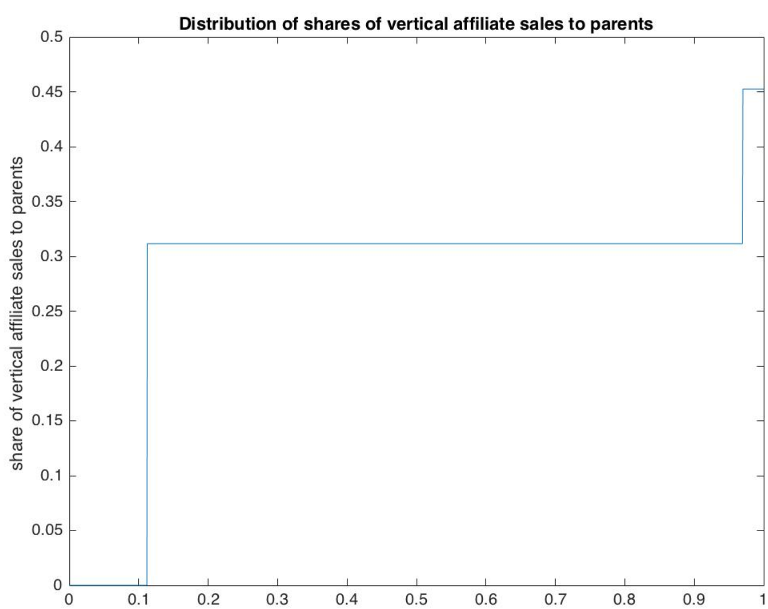


Approximately 20% of vertical affiliates ship nothing to their parent. As I change the marginal trade barriers τ_{ij}, the distribution of affiliate sales changes as well. I decrease the trade barriers between countries. So that now a vertical affiliate in country j is supposed to sell relatively more to a parent (country i), than to assembly plant in its own country. Consider an altered matrix of trade costs:

$$||\tau_{ij}|| = \begin{bmatrix} 1 & 1.1 & 1.1 \\ 1.1 & 1 & 1.1 \\ 1.1 & 1.1 & 1 \end{bmatrix}$$

Now only 12% of input producers ship nothing to home country. The distribution is depicted in figure 1.4.

Figure 1.4. Distribution of affiliate sales to parents. Part 2



Now consider what happens to the distribution in intterest as the number of world countries becomes larger. Suppose a φ-firm originated in country i and established a vertical affiliate in country j, which potentially serves firm's final good factories in different markets. Expected sales of this affiliate to a given market m are given by:

$$s_{ijm} = \frac{T_j(\tau_{mj}w_j)^{-\theta}}{\sum_{k \in J_i(\varphi)} T_k(\tau_{mk}w_k)^{-\theta}} \frac{\sigma - 1}{\sigma} \varphi^{\sigma-1} (\gamma \Theta_{im}(\varphi))^{\frac{\sigma-1}{\theta}} B_m \tag{1.16}$$

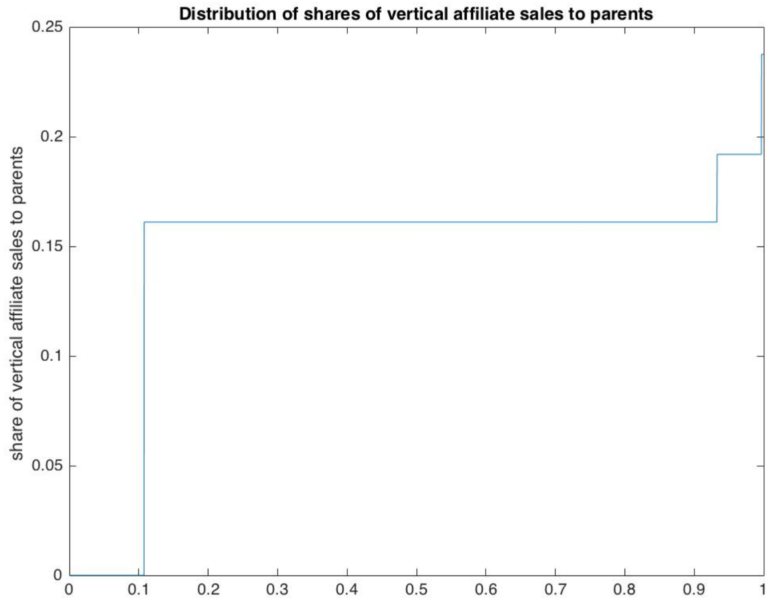
A share of its total sales that a vertical affiliate sends to market m are given by:

$$\frac{s_{ijm}}{\sum_{m'} s_{ijm'}} = \frac{\Big(\Theta_{im}(\varphi)\Big)^{\frac{\sigma-1}{\theta}} B_m \tau_{mj}^{-\theta}}{\sum_{m'} \Big(\Theta_{im'}(\varphi)\Big)^{\frac{\sigma-1}{\theta}} B_{m'} \tau_{m'j}^{-\theta}} \tag{1.17}$$

The denominator as well as all the terms in the numerator in the expression for shares (1.17) comprise of the geography term $\tau_{mj}^{-\theta}$ as well as market potential term $\Big(\Theta_{im}(\varphi)\Big)^{\frac{\sigma-1}{\theta}} B_m$, so that a vertical affiliate will sell more to close and big markets (relative to the other markets where a multinational sells final goods). Since in the simple framework presented, every active firm sells final good in all the world markets, number of terms in the denominator eqauls N. So for the symmetric case the average share is close to $1/N$. As the number of countries expands, expected share of input shipments to any market falls. Shipments to home market, which are interpreted as shipments back to parent, are not an exclusion. Figure 1.5 depicts the result of a simulation for $N = 6$ countries and the latest matrix of trade costs and it illustrates $1/N$ pattern. As for the share of zeros, it is virtually unchanged.

Symmetric examples with small number of countries provided above do not allow for curvature in the distribution function of shares of sales to a parent, though they might be useful for illustrative purposes. To obtain more realistic picture, one has to impose richer geography and technology differences across countries.

Figure 1.5. Distribution of affiliate sales to parents. Part 3



1.3.2 Cumulative Distribution of Affiliate-to-Parent Sales

Alternatively I plot the cumulative distribution of shipments from vertical affiliates to their parents. For the matrix of trade costs given below:

$$||\tau_{ij}|| = \begin{bmatrix} 1 & 1.1 & 1.1 \\ 1.1 & 1 & 1.1 \\ 1.1 & 1.1 & 1 \end{bmatrix}$$

The distribution is similar to the one from [1] in the introduction. The shape of the distribution is sensitive to the Fréchet parameter θ and to the elasticity of substitution σ, which I take from [3]. Recall that shipment of inputs of an affiliate from country j to its parent in country i is given by:

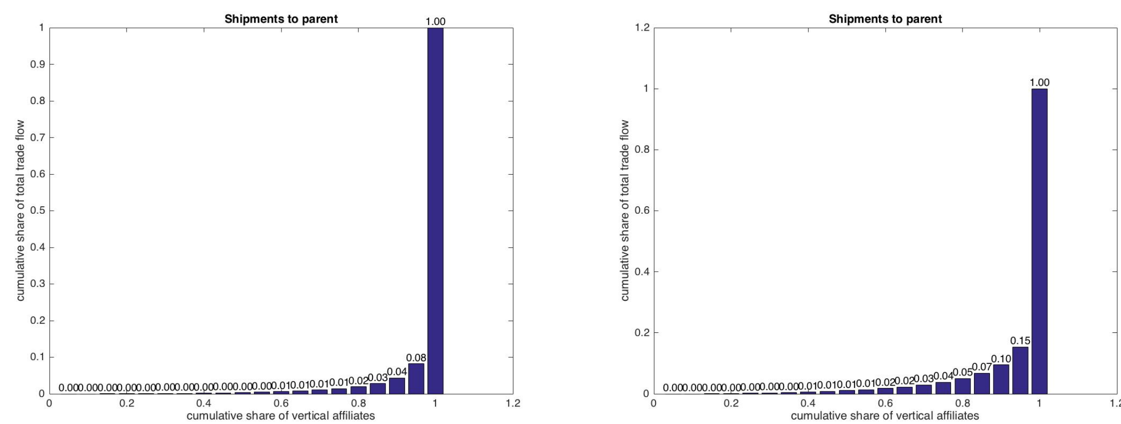
$$s_{iji} = T_j \tau_{ij}^{-\theta} \frac{\sigma - 1}{\sigma} \varphi^{\sigma-1} \gamma^{\frac{\sigma-1}{\theta}} \Theta_{ii}(\varphi)^{\frac{\sigma-1}{\theta}-1} B_i \tag{1.18}$$

where $\Theta_{ii}(\varphi)$ is a sourcing capability of a home country:

$$\Theta_{ii}(\varphi) = \sum_{k \in J_i(\varphi)} T_k(\tau_{ki} w_k)^{-\theta} \tag{1.19}$$

This equation suggests that the shape of sales distribution depends on the geography, as affiliates from different sources j will have different shipments because of τ_{ij}. Also it will depend on how different the sourcing strategies are for different firms. Recall that $J_i(\varphi)$ is the set of countries, where an MNE from i with a particular core productivity establishes vertical affiliates. In the *complements* case $\frac{\sigma-1}{\theta} > 1$ and affiliates of more productive firms (higher φ) have extra sales, since more productive firms have bigger sourcing sets $J_i(\cdot)$. Also expression (1.18) justifies the *complements* terminology. Note that in this case there is NO cannibalization effect from vertical affiliates in other countries, in a sense that having more affiliates (larger set J) boosts expected sales of any vertical affiliate to any market, served by a firm.

Figure 1.6. Cumulative distribution of affiliate shipments to a parent. Varying θ.



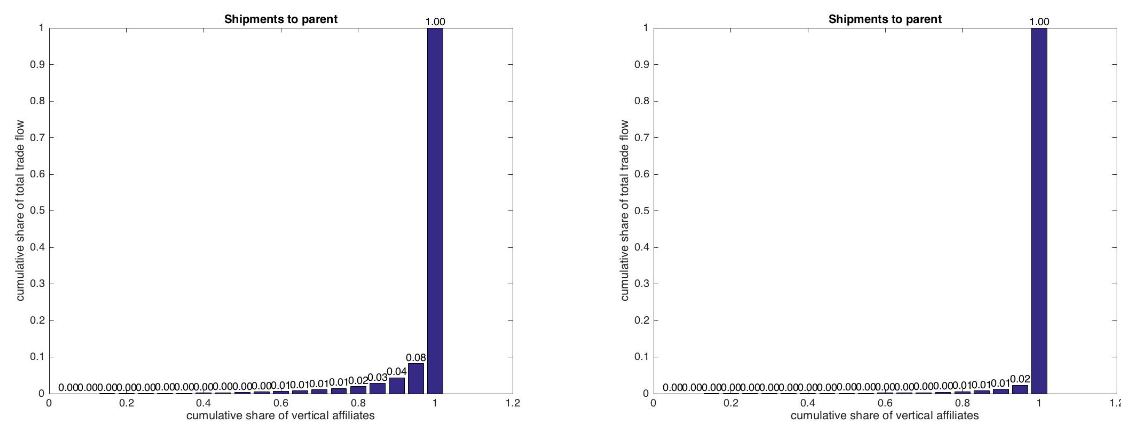
Effect of the value of Θ on the distribution of affiliate shipments to a parent. Left graph depicts simulated distribution for baseline value $\Theta = 1.71$. Right Graph depicts simulated distribution for $\Theta = 2$

Expression (1.18) suggests that the distribution of input shipments is sensitive to parameters θ and σ. Besides the obvious reason, that θ determines the variation of

Fréchet draws, that is *realized* efficiencies of vertical affiliates, its value affects the shipments in *expectation* via the sensitivity of sales to $\Theta_{ii}(\varphi)$. Finally θ is the elasticity of sales with respect to geography within a given multinational firm. Through all three channels, larger value of θ implies less variation in the sales across affiliates. In the equilibrium with $\theta = 2$ instead of baseline $\theta = 1.71$, the variation in the efficiency draws is smaller and as a result variation in affiliates sales to parents is smaller (see figure 1.6). Now 5% of the top sellers are responsible for 85% of sales, while at baseline 5% of top selling firms generate 92% of affiliate-to-parent sales.

1.3.3 Fixed Costs of Establishing Vertical Affiliates

Figure 1.7. Fixed costs and distribution of affiliate shipments to a parent



Left graph depicts distribution of affiliate sales to parent with baseline values of fixed costs of establishing an affiliate. Right graph depicts the distribution when fixed costs are set to zero.

Now I want to illustrate the effect of fixed costs on the equilibrium sales distributions. In the symmetric case with $N = 3$ countries, I first set the fixed costs of establishing the vertical affiliates so that 35% of active multinationals from every country establish input factories abroad. This is the baseline. The distribution is skewed and 5% of the affiliates ship 92% of total volume (left graph in figure 1.7).

As I allow all the firms to source from everywhere by setting $f_{ij} = 0$, the cumulative distribution of sales is even more skewed and now top 5% of the vertical affiliates ship 98% of total shipments to parents (right graph in figure 1.7).

1.4 Conclusion

In this chapter I explored whether an absence of trade between parents and affiliates of multinational enterprises is consistent with quantitative models of supply chains. My finding is that observed lack of trade is consistent with a basic model of MNE supply chain in the spirit of [3]. The literature has explained zero or low volumes of trade within MNEs by assuming that transfer of technology and intangible inputs or access to trading network of potential subsidiaries as rationales for existence of MNEs. I complement the literature by providing the evidence that low trade volumes observed within MNEs are broadly consistent with the Ricardian model of multinational production, where differences in technology, factor costs and closeness to potential markets determine the shape of supply chains for MNEs.

Chapter 2

Trade, Technology and Skill Premia: a Quantitative Investigation

2.1 Introduction

Wage inequailty has grown across multiple countries in the world in recent decades and different explanations were suggested which can potentially account for this phenomenon. The popular potential suspects include trade liberalization and technological growth. Both falling trade barriers and improving technology can lead to shifts in relative demand for skilled workers. How strong are the effects of trade versus technology on wage inequality? Do relative contributions of these two culprits exhibit similarity across countries or some countries are more exposed to the effects of trade liberalization and others to the effects of technological progress? Shocks to which sectors contribute the most to the changes in wage inequality? Such kind of questions motivate a quantitative investigation. In this paper I dissect the changes in a measure of wage inequality, namely skill premium [1] and ask how much falling sectoral trade barriers and growth of sectoral technology levels contribute to the changes in skill premia.

Decreasing trade barriers affect skill premia for two reasons. First, reduction in trade barriers leads to lower prices of imported goods. If tradable sectors are intensive in unskilled labor and tradables complement non-traded sectors in consumption, falling trade barriers lower prices of tradables, the share of tradables in consumption and relative demand for unskilled workers. This mechanism is proposed in [14] and my quantification accounts for it. In addition, my framework allows to assess the strength of this channel against other mechanisms, which I describe further.

Among tradables *equipment* or capital goods sector plays a special role. [2] If capital goods substitute for unskilled labor in production, falling prices of capital goods shift relative demand for unskilled workers and lead to growth in skill premia. [15] studies the effect of decreasing trade barriers for capital goods sector as well as technological growth in capital goods sector on skill premia in a multi-country quantitative trade model. The quantitative model in this paper accounts for the mechanisms established in [15] and assesses the relative contribution of capital goods sectoral shocks to changeis in skill premia. Empirically, capital goods sector experienced sharper declines in trade frictions relative to other tradables. This fact motivates me to have distinct capital goods sector in the model.

A different motivation for a separate capital goods sector is evidence on capital-skill complementarity in production and its contribution to the rise of skill premium. [16] is a prominent studies in this well established literature. If capital goods substitute

[1] In this study skill premium is defined as an hourly wage of a worker with at least a bachelor's degree relative to a wage of a worker without a bachelor degree.

[2] Examples of capital goods are machninery, computer equipment, other electrical and optial equipment, transport equipment.

differently for unskilled and skilled labor in production, decreasing prices of capital goods affect levels skill premia. I folllow [16] and as well as quantitative trade papers [3] focusing on wage inequality by using the production function which features capital-skill complementarity. In the framework, capital-skill complementarity in production governs the response of skill premia to technological shocks and changing relative prices of capital goods. I add to the quantitative trade literature on skill-premia by assessing the contribution to the rise in skill-premia of technology shocks emerging in *all* sectors, not only in capital goods sector.

Finally, this quantitative paper addresses the emerging literature on *skill-biased* reallocation of economic activity between broad sectors. For a set of advanced economies, [18] document the growing shares of skill-intensive sevices in value added over recent decades. [18] propose a simple accounting framework to estimate contribution of such relocation to the growth of skill premia in the US. I test the contribution of this channel to skill-premia against other mechanisms for a broad set of both developing and advanced countries while also allowing for realistic trade and input-output linkages. I do so by borrowing non-homothetic preferences from in [19], which accounts for shifts of value added between broad sectors of the economy. Share of skilled services in demand grows when consumers increase real purchasing power (*income effect*) and if when relative prices of skilled services increase (*price effect*).

In this paper I use wedge accounting approach to estimate contributions of trade and technology shocks as well as non-homotheticities in demand to changes in skill premia. I calibrate a quantitative trade model with input-output linkages for 29 countries and the rest of the world. Under a baseline calibration technology shocks have considerably greater effect on skill-premia than shocks to trade frictions. For an average country, marginal contribution of technology shocks is six times greater

[3] [15], [14] and [17] are good examples of such studies.

than marginal contribution of trade shocks. When limited to shocks in capital goods sector, technology shocks have five times greater contribution than shocks to trade frictions for an average country. For most of the countries technology shocks in equipment sector explain 20% to 35% of the total effect of technological change on skill premia. This is in contrast with shocks to trade frictions where capital goods account for around 80% of the effect on skill-premia in an average country. As for the role of shifts in relative demand for skilled services, under a baseline calibration income effects can explain about a fifth of response of skill premia to both trade and technology shocks. And price effects are negligible.

The rest of the paper is designed as follows. Section 2.2 characterizes the quantitative model, equilibrium and the concept of the solution. In section 2.3 I describe the data and wedge accounting procedure. Section 2.4 explains the contributions of different shocks to the changes in skill premia. It is followed by the conclusion.

2.2 Model

2.2.1 Overview

The world economy comprises I countries indexed by i and J sectors indexed by j. The sectors are equipment (k), other goods (g), high-skilled (hs) and low-skilled (ls) services. Sectoral output is used either for final consumption or as an input in production in every sector. The other inputs in production are skilled and unskilled labor. Each country is endowed with H_i and L_i units of skilled and unskilled labor respectively. There is a set of heterogeneous producers defined by their efficiency and sector in every country. All goods and factor markets are perfectly competitive.

2.2.2 Demand

A representative household gains utility from aggregate consumption C_i implicitly defined by

$$\sum_j \Omega_{i,j}^{\frac{1}{\sigma}} C_i^{\frac{\epsilon_j-\sigma}{\sigma}} C_{i,j}^{\frac{\sigma-1}{\sigma}} = 1 \tag{2.1}$$

where $C_{i,j}$ is sectoral consumption and $\Omega_{i,j}$ controls the share of each sector $j \in \{g, k, ls, hs\}$ in aggregate consumption bundle. Introduced preferences structure is a non-homothetic generalization of CES (constant elasticity of substitution) preferences. When $\epsilon_j = 1$ for every sector j, the preference system collapses to standard homothetic CES with the elasticity of substitution $\sigma > 0$. In a baseline case of the model $\epsilon_j \geq 1$ for any sector j. [4] A representative household maximizes aggregate consumption C_i facing the budget constraint:

$$I_i \equiv w_{h,i} H_i + w_{l,i} L_i = \sum_j P_{i,j} C_{i,j} \tag{2.2}$$

The sources of income I_i are total wage bills of skilled and unskilled workers. The household allocates consumption to sectoral goods according to the following optimal rule:

$$C_{i,j} = \Omega_{i,j} \left(\frac{P_{i,j}}{P_i} \right)^{-\sigma} C_i^{\epsilon_j} \tag{2.3}$$

[4]This paper focuses on the case when $\sigma \in (0, 1)$. In this case the utitlity level C_i implicitly defined in (2.1) is a monotonically increasing and quasi-concave function of the bundle $(C_{i,j})_{j \in J}$ if $\epsilon_j > \sigma$ for every sector j. Moreover, when $\epsilon_j \geq 1$ for every j, C_i is a concave function. Since only differences $\epsilon_j - \epsilon_{j'}$ can be identified from the data, I will normalize the lowest value of ϵ_j's to unity so that C_i is a concave function. Concavity of the implicitly defined function C_i is useful as it implies a unique solution to the consumer's problem. For a more detailed discussion of the preference system see [20] and [19]

where P_i is the aggregate price index:

$$P_i = \frac{1}{C_i}\left[\sum_j \Omega_{i,j} C_i^{\epsilon_j - \sigma} P_{i,j}^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{2.4}$$

The price index is a modification of a CES price index in the non-homothetic case. [5]

Sectoral budget shares are:

$$\omega_i^j = \frac{P_I^j C_i^j}{P_i C_i} = \Omega_{i,j}\left(\frac{P_{i,j}}{P_i}\right)^{1-\sigma} C_i^{\epsilon_j - 1} \tag{2.5}$$

Two properties of the introduced demand system are crucial for understanding how consumers allocate their consumption.

1. Elasticity of substitution between different sectors is constant and is governed by σ:

$$\frac{\partial \log(C_{i,j}/C_{i,k})}{\partial \log(P_{i,j}/P_{i,k})} = -\sigma \tag{2.6}$$

2. Allocation of consumption between different sectors depends on the level of real income:

$$\frac{\partial \log(C_{i,j}/C_{i,k})}{\partial \log C_i} = \epsilon_j - \epsilon_k \tag{2.7}$$

According to the first property substitution patterns between any pair of sectors are determined by $\sigma > 0$. When the relative price of sectoral output decreases, consumers allocate higher *real* share to the good's consumption. However, allocation of budget shares in response to changing relative prices is ambiguous without further restrictions on σ:

$$\frac{\partial \log([P_{i,j}C_{i,j}]/[P_{i,k}C_{i,k}])}{\partial \log(P_{i,j}/P_{i,k})} = 1 - \sigma \tag{2.8}$$

[5] When $\epsilon_j = 1$ for every sector, the price index would collapse to a standard CES price index.

When $0 < \sigma < 1$, there is a countermovement between nominal and real sectoral shares. Demand is not elastic enough, so that a good that faces decrease in its relative price is consumed relatively more in real terms, but not to a degree to compensate the reduction in the relative prices. Nominal consumption share of the good falls. This line of argument is inherent in the structural change literature and goes back at least to [21]. The *price effects*, i.e. response of real and nominal shares to a change in relative prices, can qualitatively explain how manufacturing share of GDP decreased while manufacturing share of real output grew at the same time over the development path of many economies. This pattern of structural change is relevant for the study of skill premium since manufacturing sector is intensive in unskilled labor. The prices of unskilled manufacturing have decreased relative to the prices of skilled services.

The second property illustrates *income effect*. Growth of real income C_i is associated with the shift of consumption to sectors with high income elasticity ϵ_j and away from sectors with low income elasticity: $\epsilon_k < \epsilon_j$. It is the difference between sectoral values of ϵ that is important for *income effect*. If $\epsilon_{hs} > \epsilon_g$, the income effect shifts demand to skilled services and away from unskilled goods. Alongside price effect, the income effect is empirically relevant for capturing observed growth of skilled services sector when economies become reacher ([19]). For this reason accounting for growth of skilled services through the income effect can help explain the changes in skill premia over time and in different countries.

2.2.3 Production and Trade

Production:

Each sector combines a continuum of intermediate varietes, indexed by $\nu \in [0, 1]$

according to CES production function:

$$Q_i^j = \left[\int_0^1 q_i^j(\nu)^{1-1/\eta} d\nu \right]^{\frac{\eta}{\eta-1}} \tag{2.9}$$

Each intermediate variety can be produced in any country potentially, and the aggregate sectoral ouptut Q_i^j is not traded. [6] Variety ν can be produced according to the production function:

$$q_i^j(\nu) = z_i^j(\nu) \left[(1-\alpha_{i,j})^{\frac{1}{\rho}} h_{i,j}(\nu)^{\frac{\rho-1}{\rho}} + \alpha_{i,j}{}^{\frac{1}{\rho}} k_{i,j}(\nu)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}\gamma_{i,j}} l_{i,j}(\nu)^{\gamma_{i,j}^l} \prod_{j' \neq k} m_{i,jj'}(\nu)^{\gamma_i^{jj'}} \tag{2.10}$$

In any industry $j \in J$ firms combine both skilled $h_{i,j}(\nu)$ and unskilled $l_{i,j}(\nu)$ workers, equipment $k_{i,j}(\nu)$, and $m_{i,jj'}(\nu)$ — inputs from all sectors j' other than equipment. Note that production function has the same functional form for every sector and country, but Cobb-Douglas shares of unskilled labor $\gamma_{i,j}^l$, inputs in production $\gamma_i^{jj'}$ and the bundle of skilled labor and equipment $\gamma_{i,j}$ are country-sector specific. These shares sum up to one so that production exhibits constant returns to scale. Skilled labor and equipment are bundled together in a CES aggregate with country-sector specific weights determined by $\alpha_{i,j}$.

Common across sectors and countries, elasticity ρ governs *capital-skill complementarity* in production. Equipment complements skilled labor in production and substitute for unskilled labor when $\rho < 1$. When prices of equipment decline because of technological advancement or because of falling costs of imported capital, unskilled labor is substituted for equipment in production. Country-sector-variety specific efficiency of production $z_i^j(\nu)$ is drawn from country-sector specific distribution $F_{i,j}(z) = \exp\left[-T_i^j z^{-\theta_j} \right]$. This is Frechet distribution. High value of $T_i^j > 0$

[6] I follow a big body of quantitative trade literature and assume there is no value added created by aggregating varieties in the sectoral output.

reflect high average of productivity draws and low $\theta_j > 1$ imply high dispersion of productivities in a sector.

There is free entry so that firms price at unit cost of production $p_i^j(\nu) = \frac{c_i^j}{z_i^j(\nu)}$. Term c_i^j is sector-country specific cost which does not depend on productivity draw. It depends on wages of skilled and unskilled workers $w_{i,h}$ and $w_{i,l}$, sectoral prices $p_{i,j}$ including the price of equipment ($j = k$):

$$c_i^j = B_i^j \left[(1 - \alpha_{i,j}) w_{i,h}^{1-\rho} + \alpha_{i,j} p_{i,k}^{1-\rho} \right]^{\frac{\gamma_{i,j}}{1-\rho}} w_{i,l}^{\gamma_{i,j}^l} \prod_{j' \neq k} p_{i,j'}^{\gamma_i^{jj'}} \tag{2.11}$$

and B_i^j is a constant term. [7]

Trade:

each intermediate variety bought in destination n is sourced from the cheapest origin:

$$p_n^j(\nu) = \min_i \{ p_{ni}^j(\nu) \} \tag{2.12}$$

where $p_{ni}^j(\nu) = \frac{c_i^j}{z_i^j(\nu)} \cdot \tau_{ni}^j$ reflects the price of producing good in origin i and bilateral trade costs $\tau_{ni}^j \geq 1$. [8] I assume that triangular inequality holds for trade barriers: $\tau_{ni}^j \tau_{im}^j \geq \tau_{nm}^j$ for any country triple $n, i, m \in I$ and sector $j \in J$. In the model skilled and unskilled services are non-tradable, which corresponds to $\tau_{ni}^j = \infty, i \neq n$ for $j \in \{hs, ls\}$

[7] $B_i^j = [\gamma_{i,j}]^{-\gamma_{i,j}} [\gamma_{i,j}^l]^{-\gamma_{i,j}^l} \prod_{j' \neq k} [\gamma_i^{jj'}]^{-\gamma_i^{jj'}}$

[8] $\tau_{ii}^j = 1$ by definition

2.2.4 Equilibrium

Given CES aggregation of intermediate varieties (2.9), the sectoral price index is introduced:

$$P_n^j = \left[\int_0^1 p_n^j(\nu)^{1-\eta} d\nu \right]^{\frac{1}{1-\eta}} \tag{2.13}$$

Recall, that each variety is delivered from the cheapest source $p_n^j(\nu) = \min_i\{\frac{c_i^j}{z_i^j(\nu)} \cdot \tau_{ni}^j\}$ and $z_i^j(\nu)$ is a random draw. Followng the seminal paper [12], one can integrate over productivity draws and use properties of Frechet distribution to find a closed form for the sectoral price index:

$$P_n^j = \Upsilon^j \left[\sum_{i \in I} T_i^j [\tau_{ni}^j c_i^j]^{-\theta_j} \right]^{-1/\theta_j} \tag{2.14}$$

The price depends on technology levels of trade partners [9] T_i^j and bilateral trade frictions τ_{ni}^j as well as unit production costs of trade partners c_i^j. [10] Technological advancement in a trade partner (high value of T_i^j) make a sectoral good cheaper in importer n. Similarly low trade barriers τ_{ni^j} allow importer n to buy a good at lower price. Unit costs of production in trading partners reflect cost of labor and prices of inputs from other sectors. And once the importer n trades with a country i with low factor costs, the sectoral price level goes down.

To clearly see what determines how much of the good a country actually buys from its trading partners, it will be useful to introduce bilateral trade shares π_{ni}^j. If X_n^j is total absorption of sector j ouptut in country n and X_{ni}^j is sectoral imports from trading partner i, then by definition $\pi_{ni}^j = X_{ni}^j / X_n^j$. Since there is a continuum of varieties and each variety can be bought from i with some probability, π_{ni}^j is

[9] One of the trade partners is the importer country itself.

[10] $\Upsilon^j = \Gamma\left[\frac{\theta_j+1-\eta}{\theta}\right]^{1/1-\eta}$ is a constant of integration. The integral is well-defined if $\theta_j + 1 - \eta > 0$. I assume that $\eta = 2$, then this restricion will hold given calibrated values of θ_j.

essentially this probability integrated over the set of varieties and it has the following form: [11]

$$\pi_{ni}^j = \frac{T_i^j[\tau_{ni}^j c_i^j]^{-\theta_j}}{\sum_{m\in I} T_m^j[\tau_{nm}^j c_m^j]^{-\theta_j}} \tag{2.15}$$

A greater share of imports will be sourced from countries with high production efficiency T_i^j, low costs of production c_i^j or trade barriers τ_{ni}^j.

A competitive equilibrium is a set of quantities, prices and wages such that:

- households and firms make optimal decisions about consumption and production respectively
- goods and labor markets clear
- trade is balanced.

I assume that labor is perfectly mobile within a country. Labor market clearing conditions are:

$$w_{i,l}L_i = \sum_j \gamma_{i,j}^l Y_i^j \tag{2.16}$$

$$w_{i,h}H_i = \sum_j \gamma_{i,j}^h Y_i^j \tag{2.17}$$

where $Y_i^j \equiv Q_i^j P_i^j$ is the value of sectoral output and $\gamma_{i,j}^l, \gamma_{i,j}^h$ are cost shares [12] of unskilled and skilled labor.

Sectoral output is absorbed by country's trading partners to a degree determined by trade shares:

$$Y_i^j = \sum_n \pi_{ni}^j X_n^j \tag{2.18}$$

[11] [12] provide a clear and detailed derivation.

[12] Shares of skilled-labor $\gamma_{i,j}^h = \gamma_{i,j}\frac{(1-\alpha_{i,j})w_{i,h}^{1-\rho}}{(1-\alpha_{i,j})w_{i,h}^{1-\rho}+\alpha_{i,j}p_{i,k}^{1-\rho}}$ are endogenous, unlike the shares of unskilled labor

And sectoral absorption is divided between households' consumption and inputs in production by all sectors

$$X_n^j = \omega_{i,j} I_i + \sum_{j'} \gamma_n^{j'j} Y_n^{j'} \tag{2.19}$$

Trade is balanced so that total exports $\sum_j \sum_n \pi_{ni}^j X_n^j$ equalize total imports $\sum_j \sum_n \pi_{in}^j X_i^j$:

$$\sum_j \sum_n \pi_{ni}^j X_n^j = \sum_j \sum_n \pi_{in}^j X_i^j \tag{2.20}$$

Given country-sector specific parameters defining production and consumption $\{\gamma_{i,j}, \gamma_{i,j}^l, \gamma_i^{jj'}, \alpha_{i,j}, \Omega_{i,j}\}$, structural parameters $\{\sigma, \eta, \rho, \epsilon_j, \theta_j\}$, country-sector specific efficiency parameters $\{T_i^j\}$, bilateral trade frictions $\{\tau_{ni}^j\}$ and labor endowments $\{H_i, L_i\}$, a competitive equilibrium is a set of wages $\{w_{i,l}, w_{i,h}\}$ and prices $P_{i,j}$ that solve (2.2),(2.4), (2.2.2), (2.14) - (2.20).

2.2.5 Solving the Model in Relative Changes

I use the technique developed in [22] to solve for the equilibrium in relative changes. Consider a static equilibrium at two moments in time. Then a relative change can be defined as $\hat{x} \equiv \frac{x'}{x}$, where x' is a value of a variable in the new static equilibrium and x is a value in the initial equilbrium.

Using expressions 2.14 and 2.15, relative changes in sectoral prices are:

$$\hat{P}_n^j = \left[\sum_i \pi_{ni}^j \hat{T}_i^j [\hat{\tau}_{ni}^j \hat{c}_i^j]^{-\theta_j} \right]^{-1/\theta_j} \tag{2.21}$$

where π_{ni}^j are trade shares in the initial equilibrium, $\hat{T}_i^j$ and $\hat{\tau}_{ni}^j$ are shocks to technology levels and trade barriers. Changes to unit costs $\hat{c}_i^j$ are the functions of relative changes in prices and wages:

$$\hat{c}_i^j = \left[\frac{\gamma_i^{jk}}{\gamma_{i,j}}\hat{p}_{i,k}^{1-\rho} + \frac{\gamma_{i,j}^h}{\gamma_{i,j}}\hat{w}_{i,h}^{1-\rho}\right]^{\frac{\gamma_{i,j}}{1-\rho}} \hat{w}_{i,l}^{\gamma_{i,j}^l} \prod_{j' \neq k} \hat{p}_{i,j'}^{\gamma_i^{jj'}} \tag{2.22}$$

here $\gamma_{i,j}^k, \gamma_{i,j}^h$ are cost shares [13] of capital equipment and skilled labor in the initial equilibrium. Relative changes in trade shares can be expressed as:

$$\hat{\pi}_{ni}^j = \frac{\hat{T}_i^j(\hat{\tau}_{ni}^j \hat{c}_i^j)^{-\theta_j}}{\hat{P}_n^{j-\theta_j}} \tag{2.24}$$

Goods market clearing and trade balance in the new equilibrium are:

$$X'^j_n = \omega'_{i,j} I'_i + \sum_{j'} \gamma_n^{j'j} Y'^{j'}_n \tag{2.25}$$

$$\sum_j \sum_n \pi'^j_{ni} X'^j_n = \sum_j \sum_n \pi'^j_{in} X'^j_i \tag{2.26}$$

Labor market clearing is:

$$\hat{w}_{i,l}\hat{L}_i \cdot w_{i,l} L_i = \sum_j \gamma_{i,j}^l Y'^j_i \tag{2.27}$$

$$\hat{w}_{i,h}\hat{H}_i \cdot w_{i,h} H_i = \sum_j \gamma'^h_{i,j} Y'^j_i \tag{2.28}$$

Capital-skill complementarity in the production function implies that the cost shares of skilled labor $\gamma'^h_{i,j}$ and capital equipment γ'^{jk}_i in the new equilibrium are different

[13] These shares are endogenous in the initial equilibrium

$$\frac{\gamma_{i,j}^h}{\gamma_{i,j}} = \frac{(1-\alpha_{i,j})w_{i,h}^{1-\rho}}{\alpha_{i,j}p_{i,k}^{1-\rho} + (1-\alpha_{i,j})w_{i,h}^{1-\rho}}, \quad \frac{\gamma_i^{jk}}{\gamma_{i,j}} = 1 - \frac{\gamma_{i,j}^h}{\gamma_{i,j}} \tag{2.23}$$

from the initial shares:

$$\gamma'^{h}_{i,j} = \frac{\gamma_{i,j}}{1 + \frac{\gamma^{k}_{i,j}}{\gamma^{h}_{i,j}} \left[\frac{\hat{p}_{i,k}}{\hat{w}_{i,h}}\right]^{1-\rho}} \quad \text{and} \quad \gamma'^{jk}_{i} = \frac{\gamma_{i,j}}{1 + \frac{\gamma^{h}_{i,j}}{\gamma^{jk}_{i}} \left[\frac{\hat{w}_{i,h}}{\hat{p}_{i,e}}\right]^{1-\rho}} \tag{2.29}$$

New level of total income depends on shocks to labor endowments and changes in wages:

$$I'_i = \hat{w}_{h,i}\hat{H}_i \cdot w_{h,i}H_i + \hat{w}_{l,i}\hat{L}_i \cdot w_{l,i}L_i \tag{2.30}$$

New consumption shares are determined simultaneously with relative changes in real consumption level $\hat{C}_i$:

$$\omega'^{j}_{i} = \omega^{j}_{i} \cdot \frac{\hat{P}^{j\,1-\sigma}_{i} \hat{C}_{i}^{\epsilon_j - \sigma}}{\hat{I}^{1-\sigma}_{i}} \quad \text{and} \quad \hat{I}_i = \left[\sum_j \omega^{j}_{i} \hat{P}^{j\,1-\sigma}_{i} \hat{C}_{i}^{\epsilon_j - \sigma}\right]^{\frac{1}{1-\sigma}} \tag{2.31}$$

The equilibrium in relative changes is defined as the set of relative changes in prices and wages $\{\hat{P}^j_n, \hat{w}_{n,l}, \hat{w}_{n,h}\}$ that solve equations (2.21) - (2.31), given production and consumption shares $\{\gamma_{i,j}, \gamma^{l}_{i,j}, \gamma^{jj'}_{i}, \alpha_{i,j}, \omega_{i,j}\}$, sectoral trade shares $\{\pi^j_{ni}\}$, and wage bills $\{w_{i,l}L_i, w_{i,h}H_i\}$ in the initial period, and a set of shocks $\Psi = \{\hat{T}^j_i, \hat{\tau}^j_{ni}, \hat{H}_i, \hat{L}_i\}$ consisting of shocks to: (i) country-sector technological levels $\hat{T}^j_i$; (ii) bilateral trade frictions $\hat{\tau}^j_{ni}$; (iii) labor endowments $\hat{H}_i, \hat{L}_i$.

2.3 Matching the Model to the Data

2.3.1 Data

Data on sectoral production and skill premia country by country is extracted from the July 2014 Release of WIOD SEA (World Input Output Dataset Socio Economic Accounts) dataset. The dataset allows to construct data on production, price levels, production shares of intermediate inputs, skilled and unskilled labor as well as various forms of capital. [14] The variables are available on the level of 35 industries for each country for years 1995 - 2009. The industries are then aggregated into 4 broad sectors used in the paper.[15] I limit the study to years up to 2007, to abstract from the trade collapse accompanying the Great Recession and focus on the long term trend of trade expansion, that in theory leads to growth in skill premia around the world. The data on trade in goods and capital equipment for years 1995 - 2007 comes from WIOT (World Input Output Table). Trade data is denominated in US dollars and the data on production from WIOD SEA is transformed to US dollars using historical exchange rates from OECD website.

2.3.2 Calibration

Before going to the discussion of the set of shocks , it is important to notice that a complete set of shocks is extracted through the equilibrium structure of the model and therefore values of shocks are conditional on calibrated country-sector level parameters $\{\gamma_{i,j}, \gamma_{i,j}^{l}, \gamma_i^{jj'}, \alpha_{i,j}, \omega_{i,j}\}$ as well as values of structural parameters $\{\sigma, \eta, \rho, \epsilon_j, \theta_j\}$. For a baseline calibration I borrow values of structural parameters from the literature.

[14] Data Appendix describes the mapping between the original variables in WIOD SEA and parameter and variable values in the model.

[15] The mapping table can be found in Data Appendix.

Table 2.1. Baseline Calibration

parameter	value	source
θ_k	4.55	Caliendo Parro [23]
θ_g	5.26	Caliendo Parro [23]
ρ	.67	Krussell et al (2000) [16]
σ	.7	Comin Lashkari Mestieri [19]
ϵ_{hs}	1.69	Comin Lashkari Mestieri [19]
ϵ_{ls}	1.22	Comin Lashkari Mestieri [19]

Table 2.1 summarizes their values. With the calibrated model and data at hand, the set of shocks can be extracted.

2.3.3 Shocks and Outcomes

Data on production, trade and skill premia for years 1995-2007 allows to identify a set of shocks $\Psi = \{\hat{T}_i^j, \hat{\tau}_{ni}^j, \hat{H}_i, \hat{L}_i\}$ consisting of shocks to: (i) country-sector technological levels $\hat{T}_i^j$; (ii) bilateral trade frictions $\hat{\tau}_{ni}^j$; (iii) labor endowments $\hat{H}_i, \hat{L}_i$. The shocks are identified under a restriction that a complete set of shocks fed into the model in changes *exactly* reproduces the observed changes in skill premia. In the counterfactual exercises, the magnitudes of the shocks will govern the associated counterfactual changes to skill premia. Therefore it is useful to mention how exactly the shocks are constructed using data as well as to take a look on the magnitude of shocks for different countries.

2.3.3.1 Shocks to Trade Frictions

Shocks to bilateral trade frictions $\hat{\tau}_{ni}^j$ are extracted using the expressions for bilateral trade shares and data on bilateral trade volumes from WIOD. For each tradable sector $j \in \{g, k\}$ we have from 2.24: [16]

$$\frac{\hat{\pi}_{ni}^j \hat{\pi}_{in}^j}{\hat{\pi}_{nn}^j \hat{\pi}_{ii}^j} = (\hat{\tau}_{ni}^j \hat{\tau}_{in}^j)^{-\theta_j} \tag{2.32}$$

I assume the symmetry ($\hat{\tau}_{ni}^j = \hat{\tau}_{in}^j$) and recover the shocks to bilateral trade barriers:

$$\hat{\tau}_{ni}^j = \left(\frac{\hat{\pi}_{ni}^j \hat{\pi}_{in}^j}{\hat{\pi}_{nn}^j \hat{\pi}_{ii}^j} \right)^{-\frac{1}{2\theta_j}} \tag{2.33}$$

[16] An assumption that trade is frictionless within a country $\tau_{ii}^j = \tau'^j_{ii} = 1$ is also used.

The data on changes to bilateral trade shares from 1995 to 2007 along with the sectoral value of trade elasticity θ_j is sufficient to identify the values of trade shocks in a sector.

Table 2.2 illustrates magnitudes of the changes in trade frictions. It contains median values (across trading partners) for trade frictions shocks in tradable sectors: equipment and goods. Except for a few countries [17] , trade frictions decreased to a larger degree in equipment sector than in goods sector. This regularity is similar to [15], who extracts trade shocks from the data on trade tariffs, while I use the structure of the model and data on bilateral trade shares to infer the shocks to trade frictions of any nature. A greater decrease of trade frictions in capital equipment is important regularity and, together with evidence from the literature on capital-skill complementarity in production, it motivated the split of the tradable goods in capital equipment and other goods.

2.3.3.2 Shocks to Technology

Productivity shocks are extracted following the method of [24] and [25]. Expression for own trade share can be inverted so that:

$$\hat{T}_n^j = \hat{\pi}_{nn}^j \left(\frac{\hat{c}_n^j}{\hat{P}_n^j} \right)^{\theta_j} \tag{2.34}$$

Technology shock is a shock to total factor productivity $\widehat{TFP}_n^j = \frac{\hat{c}_n^j}{\hat{P}_n^j}$, scaled by the shape parameter of Frechet distribution θ_j and adjusted for selection by the change in own trade share $\hat{\pi}_{nn}^j$. Indeed when the economy opens up to trade, varieties with the least productive draws can not compete with imports and are not produced. Therefore estimating the change to technology level using only data on produced

[17] Denmark, Ireland and the Netherlands

varieties ($\widehat{TFP}_n^j$) would lead to a bias.

According to (2.22), to constuct $\hat{c}_n^j$ one needs data for sectoral prices $\hat{P}_n^j$ and wages for skilled and unsklled workers for initial and final year country by country. Values of these varialbles are constructed using WIOD SEA dataset. Factor shares in production vary by country and by sector and their values come from WIOT for the initial year 1995. Changes in trade shares $\hat{\pi}_{nn}^j$ are obtained from WIOT.

Table 2.2 contains magnitudes of sectoral TFP shocks. Several regularities are worth mentioning. First, for most countries TFP shocks are larger in equipment sector than in goods sector. Through capital-skill complementarity in production this difference should theoretically lead to the growth in skill premia in respective countries. Second, a classic mechanism in [21] may not shift relative demand for skilled vs unskilled labor. *Goods* and *unskilled services* sectors are intensive in unskilled labor unlike *equipment* and *skilled services* sector. For Baumol effect to contribute to the growth of skill premia goods and unskilled services should have experienced have grown faster and as a consequence, by Baumol's logic, shrunk in terms of wagebill. Table 2.2 illustrates that productivity in *unskilled* goods sector increased at lower rate than in *skilled* services and equipment sector in majority of the countries. Unskilled services experienced growth in productivity similar to skilled sectors in most of the countries. It is worth mentioning that sectors use intermediate inputs from one another so that both Baumol mechanism and capital-skill complementarity have to operate through the input-output structure of the world economy. This fact will be quantitatively important for assessing the effects of shocks on skill premia.

2.3.3.3 Labor Shocks

The shocks are designed in a way that the model in relative changes saturated with the the full set of shocks $\Psi = \{\hat{T}_i^j, \hat{\tau}_{ni}^j, \hat{H}_i, \hat{L}_i\}$ *exactly* matches relative changes in skill premia in the data $\left(\frac{\hat{w}_{i,h}}{\hat{w}_{i,l}}\right)_{data}$. The shocks to high-skill labor supply $\hat{H}_i$ are residual in a sense that they are not taken directly from WIOD SEA data but extracted using the equilibrium of the model, conditional on values of other shocks $\{\hat{T}_i^j, \hat{\tau}_{ni}^j, \hat{L}_i\}$ and changes to skill premia observed in the data $\left(\frac{\hat{w}_{i,h}}{\hat{w}_{i,l}}\right)_{data}$. The algorithm to extract $\hat{H}_i$ starts with feeding all the other shocks and initial values $\hat{H}_{i,0} = 1$ to the equilibrium in changes and then updating the values for $\hat{H}_{i,t>0}$ until at some step T the equilibrium of the model with $\Psi = \{\hat{T}_i^j, \hat{\tau}_{ni}^j, \hat{H}_{i,T}, \hat{L}_i\}$ produces changes in skill premia equal to those in the data. $\widehat{H_{i,T}}$ are treated as shocks to supply of skilled labor. The iteration takes more than one step because the countries trade with each other and changes to supply of skilled labor in one country have a feedback to skill premia in trading partners.

2.4 Basic Counterfactuals

Once all sets of shocks are backed out from the data, we can study how much various types of shocks contributed to the changes in skill premia. To do so, we calculate changes to skill premia in a counterfactual equilibrium where only a set of shocks under investigation is not fed into the model. Since the model exactly reproduces observed skill premia, when all sets of shocks are fed into it, eliminating a single set of shocks in a counterfactual allows to quantify the contribution of the respective set of shocks to changes in skill premia. We examine the contributions of shocks to trade frictions in general and of shocks to trade frictions in equipment sector. Then we study the contribution of shocks to technology levels and compare the magnitude of the effects of technology and trade on skill premia. Finally, we demonstrate how accounting for non-homotheticicities in demand and through that the growth of relative demand for skilled services contributes to the rise in skill premia around the world.

2.4.1 Shocks to Trade Frictions and Skill Premia

Contribution of the shocks to trade frictions in equipment sector to the changes in skill premia is illustrated in figure 2.1. Y-coordinates are changes to skill premia in a counterfactual equilibrium of the world economy where all the shocks except trade shocks in equipment sector are fed into the model. X-coordinates are changes to skill premia in data. For all the countries except the Netherlands, Ireland and Denmark [18] the points lie below the 45-degree line which implies that decline in trade frictions contributed to the growth of skill premia. The sign of the effect is independent of whether a country specializes in equipment production or not, which is at odds with

[18] For Netherlands and Denmark trade frictions in equipment increased on average (see Table 2.2), which makes the negative effect not surprising and in line with positive effects of other countries.

Stolper-Samuelson effect. This is not a particular surprise but rather a reassuring result consistent with investigations of trade liberalization and wage inequality in quantitative trade models such as [15] and [14]. Lower trade frictions imply lower prices of capital equipment which substitute for unskilled labor in production driving its relative demand down and skill premia up. For a complete set of numbers one can refer to table 2.3.

Decline of trade frictions in equipment (capital goods) sector leads to growth in skill premia because of capital-skill complementarity and is a well-documented channel in quantitative trade literature and consistent with the counterfactual outcomes in this paper. However, from quantitative standpoint it is also interesting to know how trade liberalization as a whole (not only in equipment) affected wage inequality. The countries that specialize in low-skill intensive industries that do not require much equipment can, in principle, experience decline in skill premia because of trade liberalization. Figure 2.2 illustrates that the whole set of trade shocks, i.e. shocks to tradable equipment and goods sectors, contributes to greater growth of skill premia than trade shocks in equipment sector alone for most countries. Exceptions are Australia and Korea, the countries for which trade frictions in goods sector slighlty increased on average (see table 2.2). For a median country trade shocks in equipment sector contribute 83% of total effect of trade shocks on skill premia. Growth of skill premia due to decline in trade frictions is highest in countries that liberalized a lot during the period of interest, such as China and relatively small economies Hungary, Poland, Romania and Czech Republic, which opened up to trade after joining EU. Table 2.3 contains results of the counterfactual where all trade frictions shocks are removed from the model.

2.4.2 Shocks to Technology and Skill Premia

Growth in productitvity in equipment sector lowers the prices of equipment similar to falling sectoral trade barriers. Cheaper equipment substitutes for unskilled labor in production and induces growth in skill premia. Figure 2.3 illustrates changes to skill premia in the counterfactual equilibrium where productivity shocks in equipment sector are removed from the model. Counterfactual changes are plotted against changes to skill premia in the data on the horizontal axis. Hungary and Japan are the only countries which experienced decrease in productivity of the equipment sector and also have negative contribution of productivity in equipment sector to skill premia. For other countries growing productivity of equipment sector contributed positively to changes in skill premia. [19] A postive relationship between the sign of the technology shock and the change in skill premia should not be taken for granted in such a counterfactual as countries trade with each other and a positive technology shock of a trading partner lowers the price of equipment and influences the skill premium in the importer.

When the whole set of technology shock is removed from the model, counterfactual changes in skill premia are much farther from values in the data. Figure 2.4 depicts counterfactual skill premia in this scenario together with the previous counterfactual. For a median country (Finland) the marginal effect of equipment shocks on skill premia is 26% of the marginal effect from the complete set of technology shocks. And for most of the countries the relative contribution of equipment shocks does not exceed a third (table 2.5 contains the complete set of figures).

[19] Recall that figure 2.3 plots the result of the counterfactual where a set of shocks is removed from equilibrium, so that points below the 45-degree line imply positive contribution of the removed set of shocks to changes in skill premia.

2.4.3 Effect of Trade vs Technology

Table 2.3 comprises the results for all counterfactuals discussed in two previous sections. Several regularities stand out.

The most important observation in quantitative terms is the fact that technology shocks as a whole contribute much more to the observed changes in skill premia than the fulll set of trade shocks. [20] Figure 2.5 plots actual changes in skill premia agains counterfactual outcomes where only trade shocks or only technology shocks are fed into the model. The coefficient in simple OLS regression of trade induced skill premia changes on actual changes in the data is not significantly different from zero, whereas the point estimate is 1.72 and statistically significant when regressin technology induces changes.

The fact that technology shocks play larger role is consistent with the quantitative trade literature. The difference of this paper from the previous studies is that I do not focus my attention on capital equipment or tradable sectors only in terms of technology shocks. [21] And it brings me to another observation: for most countries contribution of shocks in equipment sector ranges from a fifth to a third of the total effect of all technology shocks on skill premia (see table 2.5).

Finally, the relative contribution of shocks in equipment sector to the total effect of all sectoral shocks is much more modest in terms of technology than in terms of

[20]Relationship between trade and technology discussed here should be treated through the lens of the model only. At least for the reason that there is established evidence on association between trade and technology difusion. Falling trade barriers lead to technology adoption of new technologies. [26] investigate what implications impediments to trade in capital goods have for cross-country differences in productivities using growth framework. [27] is one of the recent studies that develops similar line of argument.

[21]I do limit trade shocks to goods and equipment sector only. While services sector experiences significant trade liberalization over the period of investigation, services are still much less traded than goods according to the data. And the trade volumes are sparse especially for 1995. I decide not to make them tradable in the model. When I include trade shocks in services into the model, the effect on skill premia is small relative to goods and equipment sector.

trade. Trade shocks in equipment sector contribute around 80% of the total effect of trade shocks for a median country (see table 2.4). This quantitative observation is partially due to the fact that trade barriers in equipment goods fell substantially more than in goods. [22]

2.4.4 Non-Homothetic Preferences

Growth in relative demand for skill-intensive services can potentially drive the growth in skill-premia. In the theoretical framework I follow main body of the literature and account for changes in demand for skilled-services with the help of non-homotheticities in preferences. Two mechanisms are at work: income and price effects. To what extent do income and price effects influence the response of skill premia to technology and trade shocks? Figure 2.6 illustrates the results when the set of technology shocks in all sectors is the only set of shocks fed into the model. The figure illustrates that the contribution of price effects is negligible relative to income effects: points for homothetic CES and Cobb-Douglas preferences are indistinguishable on the vertical axis. The fact that the contribution of price effects to changes in skill premia are quantitatively small is not surprising given that skill-intensive sectors experienced technical growth at comparable or even greater rate than unskilled sectors (see table 2.2). For price effects to cause growth in skill premia, sectors intensive in unskilled labor have to experience higher rate of technological growth. Then Baumol effect would have a bite.

Income effects exacerbate the response of skill-premia to technological shocks. The plots for other sets of shocks discussed earlier look very similar. How large are the effects quantitatively? Table 2.6 illustrates the results. The median contribution of

[22] A median ratio of decrease in equipment trade frictions to decrease in other goods trade frictions is 1.88

income effects across countries is 18% for Brazil. Contributions vary across countries and in absolute terms would mean the most for countries where tech shocks contributed a lot to skill premia like China, Czech Republic and Poland. For China and Czech Republic the contribution of income effect is around 10 percent, while for Poland it is closer to 20 percent of the total effect of technology shocks. Further eliminating price effects by moving from homothetic CES preferences to Cobb-Douglas preference structure barely affects the results. This results suggests that Baumol effect does not influence skill premia as it operates through price effects.

2.5 Conclusion

This paper studies the contributions of trade, technology and intersectoral shifts of economic activity on the changes in skill premia. It does so using wedge accounting procedure within a multicountry multisector trade model which features an established mechanism behind growth in skill premia, namely capital-skill complementarity in production. The model is calibrated for 29 countries and 4 broad sectors and spans years 1995-2007. The paper contributes to the quantitative trade literature by assessing the relative contributions of sectoral productivity and trade shocks to changes in skill-premia. Under a baseline calibration I find that shocks to technology are quantitatively much more important than shocks to trade frictions for changes in skill premia both in developed and developing countries. Among shocks to trade frictions, the ones in equipment sector play a major role. This is partially due to the fact that trade barriers fell to a greater extent in equipment sector. As for technology shocks, equipment sector does not stand out even though equipment inputs substitute for unskilled labor in production. I account for sectoral reallocation in demand and production by non-homotheticities in the preference structure. I find that income effects exacerbate the response of skill premia to trade and technology shocks, while price effects play negligible role.

Quantitative results of the paper are conditional on the magnitudes of wedges (shocks) extracted from the data and on the assumptions about production, trade and demand side of the economy. Capital-skill complementarity in production is quantitatively the most important channel through which shocks translate to changes in skill premia. Therefore further estimation of degree of capital-skill complementarity for different sectors would improve the reliability of the results.

Table 2.2. Shocks to Sectoral TFPs and Trade Frictions

	sectoral TFP shocks				trade frictions shocks	
	goods $\widehat{TFP}_n^g$	equipment $\widehat{TFP}_n^k$	skilled services $\widehat{TFP}_n^{hs}$	unskilled services $\widehat{TFP}_n^{ls}$	goods $\hat{\tau}_{n.}^g$	equipment $\hat{\tau}_{n.}^k$
Australia	1.032	1.056	1.077	1.059	1.012	0.851
Austria	1.101	1.193	1.189	1.193	0.922	0.843
Belgium	1.040	1.101	1.092	1.116	0.962	0.941
Brazil	1.073	1.193	1.155	1.206	1.022	0.865
Canada	1.167	1.395	1.408	1.406	0.990	0.936
China	1.111	1.238	1.349	1.262	0.891	0.789
Czech Republic	1.067	1.126	1.166	1.124	0.884	0.723
Germany	1.033	1.043	1.052	1.048	0.932	0.898
Denmark	1.154	1.310	1.337	1.329	0.978	1.002
Spain	1.050	1.175	1.106	1.151	0.908	0.885
Finland	1.152	1.380	1.377	1.337	0.965	0.870
France	1.196	1.474	1.444	1.435	0.986	0.932
United Kingdom	1.170	1.338	1.355	1.340	0.967	0.940
Greece	1.138	1.240	1.278	1.232	0.974	0.841
Hungary	0.928	0.855	0.842	0.846	0.871	0.618
Indonesia	0.997	1.041	1.003	1.018	0.945	0.934
India	1.070	1.159	1.301	1.242	0.949	0.734
Ireland	1.240	1.673	1.762	1.671	0.945	0.986
Italy	1.010	1.050	1.020	1.020	0.966	0.932
Japan	0.980	0.958	0.948	0.970	1.005	0.975
Korea	1.120	1.376	1.422	1.407	1.035	0.902
Mexico	1.003	1.035	1.018	1.025	0.910	0.762
Netherlands	1.079	1.199	1.204	1.168	0.964	1.029
Poland	1.188	1.727	1.672	1.730	0.838	0.713
Portugal	1.064	1.158	1.167	1.163	0.965	0.831
Romania	1.132	1.340	1.250	1.353	0.803	0.751
Slovenia	1.168	1.288	1.302	1.328	0.940	0.827
Sweden	1.166	1.406	1.397	1.398	0.937	0.937
United States	1.061	1.139	1.149	1.133	0.990	0.943

Notes: Values of sectoral TFP shocks and median values (across trading partners) of sectoral shocks to trade frictions over the period 1995-2007.

Table 2.3. Counterfactual Changes in Skill Premia

		Set of shocks removed in a counterfactual				
	all shocks (i.e. data)	trade frictions equipment $\hat{\tau}_{ni}^{k}$	trade frictions all sectors $\hat{\tau}_{ni}^{j}$	technology equipment $\hat{T}_n{}^k$	technology all sectors $\hat{T}_n{}^j$	relative labor supply $\frac{\hat{H_n}}{L_n}$
Australia	1.064	1.049	1.051	1.049	0.999	1.075
Austria	0.901	0.875	0.870	0.887	0.813	1.149
Belgium	0.968	0.963	0.957	0.949	0.894	1.087
Brazil	1.056	1.053	1.053	1.001	0.876	1.204
Canada	0.988	0.983	0.982	0.895	0.687	1.406
China	1.400	1.342	1.332	1.134	0.521	2.646
Czech Republic	0.984	0.870	0.843	0.950	0.750	1.511
Germany	1.144	1.127	1.124	1.137	1.114	1.039
Denmark	0.977	0.978	0.976	0.926	0.813	1.194
Spain	1.082	1.071	1.066	1.059	0.995	1.102
Finland	1.014	1.008	1.007	0.972	0.851	1.197
France	0.835	0.834	0.833	0.780	0.649	1.274
United Kingdom	1.020	1.018	1.017	0.979	0.861	1.188
Greece	0.976	0.958	0.956	0.927	0.748	1.317
Hungary	1.076	0.909	0.883	1.161	1.261	0.961
Indonesia	0.961	0.955	0.947	0.928	0.917	1.058
India	1.166	1.130	1.126	1.115	0.860	1.389
Ireland	1.155	1.159	1.156	1.079	0.813	1.392
Italy	1.042	1.035	1.032	1.038	1.017	1.033
Japan	0.960	0.958	0.958	0.984	1.011	0.951
Korea	0.934	0.932	0.933	0.896	0.824	1.134
Mexico	0.905	0.845	0.835	0.893	0.865	1.120
Netherlands	1.051	1.058	1.053	1.010	0.925	1.131
Poland	1.206	1.165	1.153	1.093	0.778	1.620
Portugal	1.123	1.098	1.091	1.102	0.987	1.170
Romania	1.063	0.993	0.979	0.976	0.676	1.685
Slovenia	0.927	0.906	0.900	0.905	0.817	1.175
Sweden	1.090	1.086	1.082	1.006	0.824	1.321
United States	1.031	1.028	1.028	1.004	0.933	1.108

Notes: First column shows the changes in skill premia in the data (ratios of the new value to the old value) which is the changes in the model with the complete set of shocks. Other columns show the counterfactual changes in skill premia. In each counterfactual a specified set of shocks is removed from the model.

Table 2.4. Relative Contributions of Trade Shocks

country	change in skill premia	Contribution of Trade Shocks		
country	change in skill premia	marginal effect	marginal effect	contribution of equipment shocks
country	data	$\hat{\tau}^k_{ni}$	$\hat{\tau}^j_{ni}$	column $\hat{\tau}^k_{ni}$ / column $\hat{\tau}^j_{ni}$
Australia	1.064	0.015	0.013	1.118
Austria	0.901	0.026	0.031	0.828
Belgium	0.968	0.005	0.011	0.455
Brazil	1.056	0.003	0.003	0.987
Canada	0.988	0.005	0.006	0.782
China	1.400	0.058	0.068	0.848
Czech Republic	0.984	0.115	0.141	0.812
Germany	1.144	0.017	0.020	0.823
Denmark	0.977	-0.001	0.001	-0.523
Spain	1.082	0.011	0.016	0.694
Finland	1.014	0.006	0.007	0.828
France	0.835	0.001	0.002	0.582
United Kingdom	1.020	0.002	0.003	0.572
Greece	0.976	0.018	0.020	0.900
Hungary	1.076	0.167	0.194	0.864
Indonesia	0.961	0.006	0.014	0.422
India	1.166	0.036	0.039	0.902
Ireland	1.155	-0.005	-0.001	5.919
Italy	1.042	0.007	0.010	0.709
Japan	0.960	0.002	0.002	0.979
Korea	0.934	0.002	0.001	1.847
Mexico	0.905	0.060	0.071	0.845
Netherlands	1.051	-0.006	-0.002	3.869
Poland	1.206	0.042	0.053	0.779
Portugal	1.123	0.025	0.032	0.773
Romania	1.063	0.070	0.084	0.839
Slovenia	0.927	0.021	0.027	0.774
Sweden	1.090	0.004	0.008	0.498
United States	1.031	0.003	0.003	0.946

Notes: Columns (2) and (3) show marginal contributions to the change in skill premia of shocks to trade frictions in equipment sector (column 2) and shocks to trade frictions in all sectors (column 3). Column (4) shows the contribution of equipment shocks to skill premia relative to the complete set of trade shocks and is the ratio of column 2 to column 3 values.

Table 2.5. Relative Contributions of Technology Shocks

		Contribution of Technology Shocks		
country	change in skill premia	marginal effect	marginal effect	contribution of equipment shocks
country	data	$\hat{T}_n^k$	$\hat{T}_n^j$	column $\hat{T}_n^k$ / column $\hat{T}_n^j$
Australia	1.064	0.015	0.065	0.231
Austria	0.901	0.014	0.088	0.161
Belgium	0.968	0.019	0.074	0.259
Brazil	1.056	0.055	0.180	0.307
Canada	0.988	0.093	0.301	0.309
China	1.400	0.266	0.879	0.303
Czech Republic	0.984	0.034	0.234	0.146
Germany	1.144	0.007	0.030	0.220
Denmark	0.977	0.051	0.164	0.311
Spain	1.082	0.023	0.087	0.264
Finland	1.014	0.042	0.163	0.261
France	0.835	0.055	0.186	0.294
United Kingdom	1.020	0.041	0.159	0.257
Greece	0.976	0.049	0.228	0.214
Hungary	1.076	-0.084	-0.184	0.458
Indonesia	0.961	0.033	0.045	0.750
India	1.166	0.051	0.306	0.166
Ireland	1.155	0.076	0.342	0.221
Italy	1.042	0.004	0.025	0.157
Japan	0.960	-0.024	-0.051	0.465
Korea	0.934	0.038	0.110	0.349
Mexico	0.905	0.012	0.040	0.305
Netherlands	1.051	0.042	0.126	0.331
Poland	1.206	0.113	0.428	0.264
Portugal	1.123	0.021	0.136	0.151
Romania	1.063	0.087	0.387	0.224
Slovenia	0.927	0.022	0.111	0.199
Sweden	1.090	0.084	0.266	0.315
United States	1.031	0.027	0.098	0.275

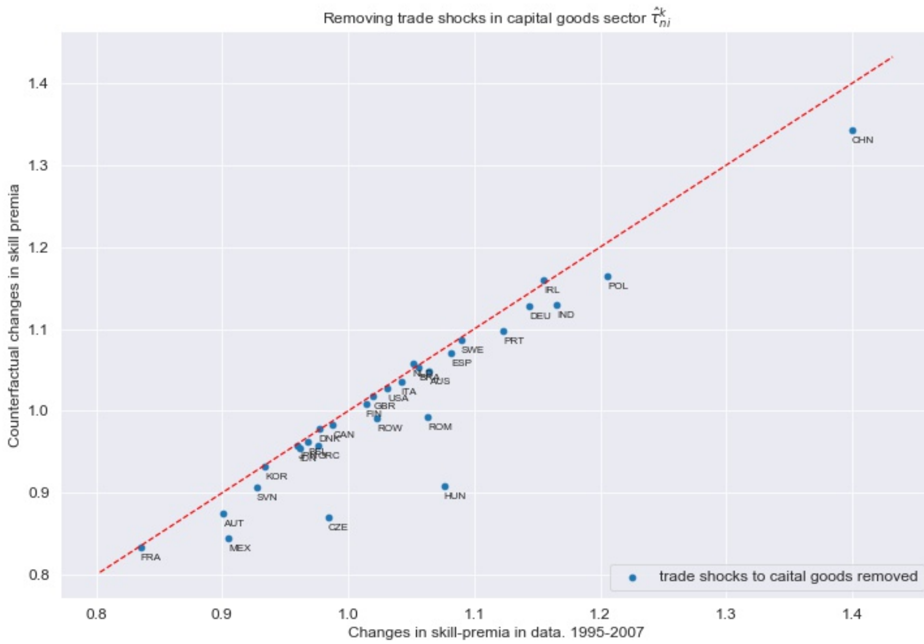
Notes: Columns (2) and (3) show marginal contributions to the change in skill premia of shocks to technology in equipment sector (column 2) and shocks to technology in all sectors (column 3). Column (4) shows the contribution of equipment shocks to skill premia relative to the complete set of technology shocks and is the ratio of column 2 to column 3 values.

Table 2.6. Margianal contributions of Technology Shocks to Skill Premia and Preferences Structure

	Marginal effects of technology shocks			income effects removed	price effects removed
country	baseline	CES	Cobb-Douglas	CES / baseline	Cobb-Douglas / CES
Australia	0.062	0.049	0.049	0.791	1.008
Austria	0.109	0.079	0.080	0.722	1.015
Belgium	0.076	0.065	0.065	0.857	1.003
Brazil	0.200	0.164	0.163	0.822	0.992
Canada	0.398	0.333	0.333	0.837	0.999
China	1.525	1.363	1.365	0.893	1.002
Czech Republic	0.305	0.273	0.275	0.896	1.007
Germany	0.022	0.020	0.020	0.895	1.030
Denmark	0.192	0.145	0.146	0.754	1.006
Spain	0.087	0.065	0.063	0.752	0.965
Finland	0.188	0.153	0.152	0.813	0.995
France	0.269	0.202	0.201	0.751	0.996
United Kingdom	0.184	0.134	0.134	0.733	0.998
Greece	0.290	0.209	0.213	0.720	1.020
Hungary	-0.213	-0.178	-0.178	0.836	0.996
Indonesia	0.043	0.043	0.043	0.998	1.021
India	0.343	0.293	0.293	0.854	0.998
Ireland	0.392	0.301	0.296	0.768	0.984
Italy	0.024	0.021	0.021	0.864	1.005
Japan	-0.051	-0.044	-0.044	0.862	1.003
Korea	0.132	0.094	0.094	0.716	0.994
Mexico	0.035	0.038	0.038	1.064	1.002
Netherlands	0.132	0.102	0.102	0.768	1.006
Poland	0.550	0.398	0.404	0.724	1.015
Portugal	0.138	0.096	0.098	0.697	1.015
Romania	0.559	0.475	0.481	0.849	1.012
Slovenia	0.141	0.087	0.089	0.616	1.022
Sweden	0.312	0.261	0.261	0.835	1.000
United States	0.105	0.088	0.089	0.839	1.011

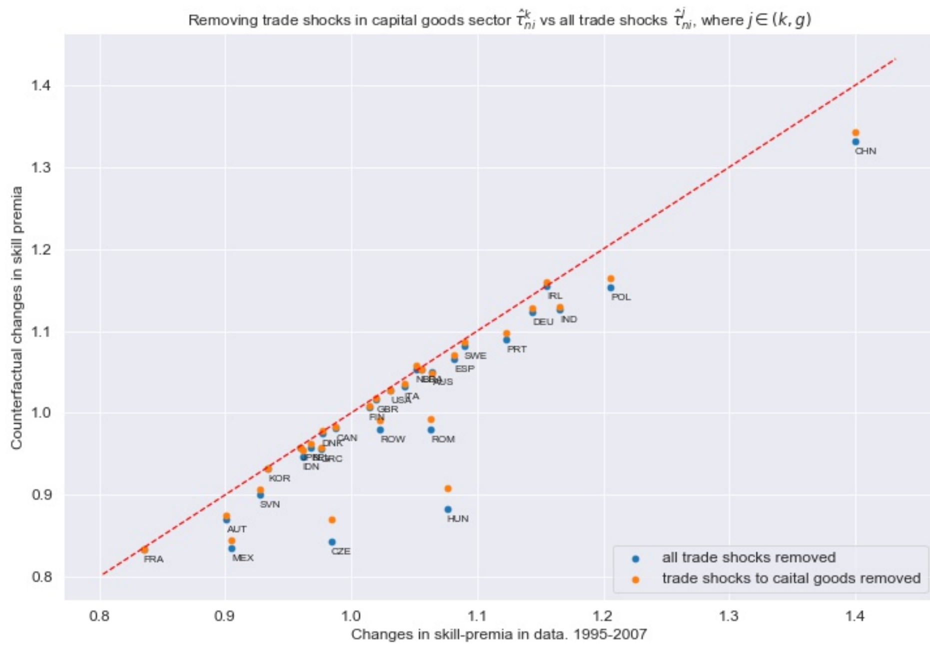
Notes: Table shows marginal effects $(\hat{\omega}_n - 1)$ of technology shocks on skill premia under different preference systems in coumnsl (1) - (3). Columns (4) and (5) illustrate the contribution of income and price effects on the response of skill premia to technology shocks.

Figure 2.1. Trade shocks in equipment removed



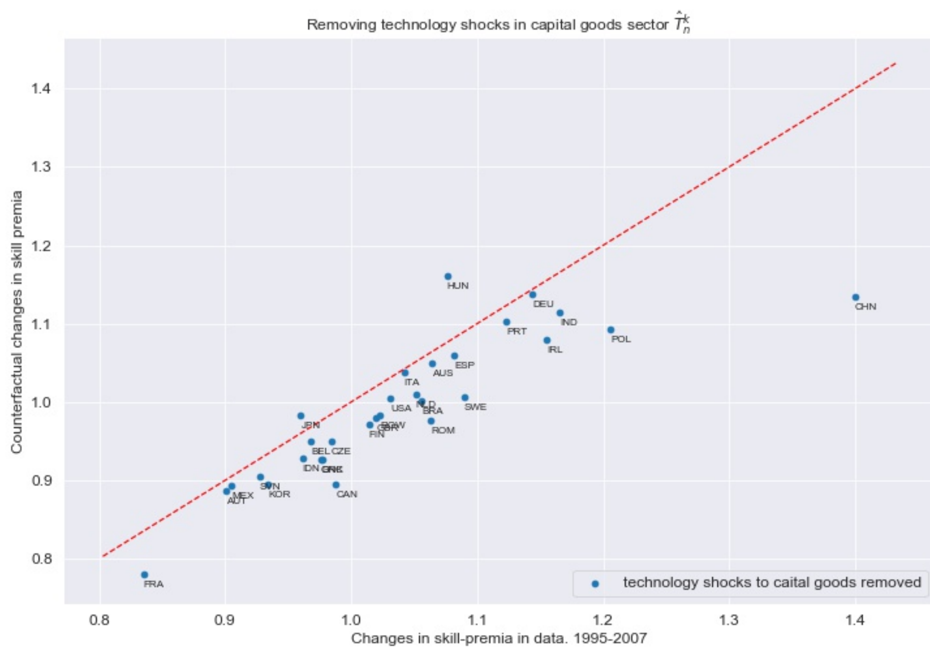
Notes: the figure plots the actual changes to skill-premia in data on horizontal axis against changes in a counterfactual where only an indicated set of shocks is removed.

Figure 2.2. All trade shocks removed vs trade shocks in equipment sector removed



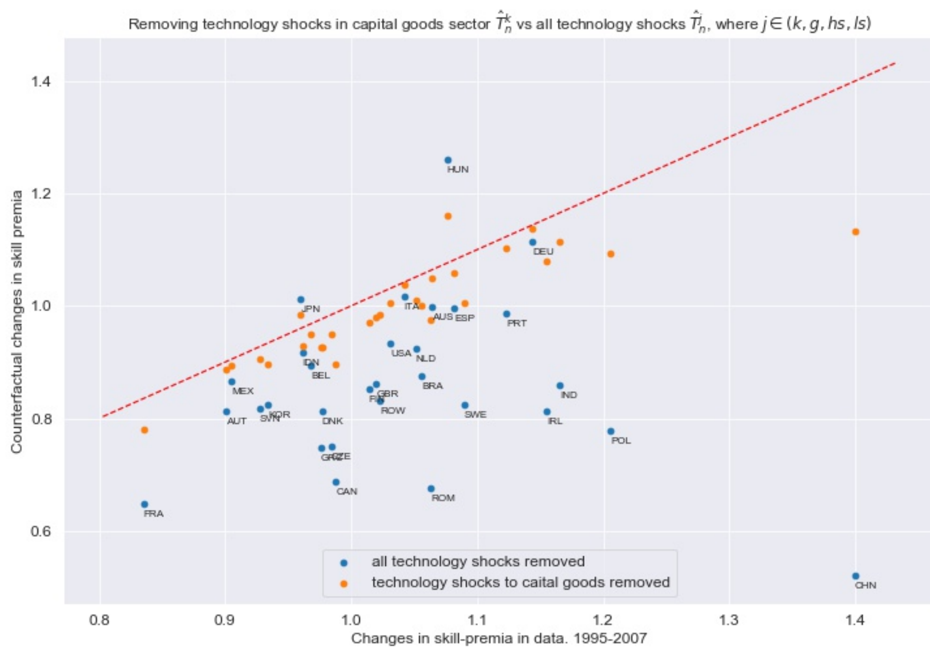
Notes: the figure plots the actual changes to skill-premia in data on horizontal axis against changes in two counterfactuals in order to illustrate the relative contributions of two different sets of shocks to changes in skill premia. In each counterfactual a set of shocks is removed.

Figure 2.3. Technology shocks in equipment sector removed



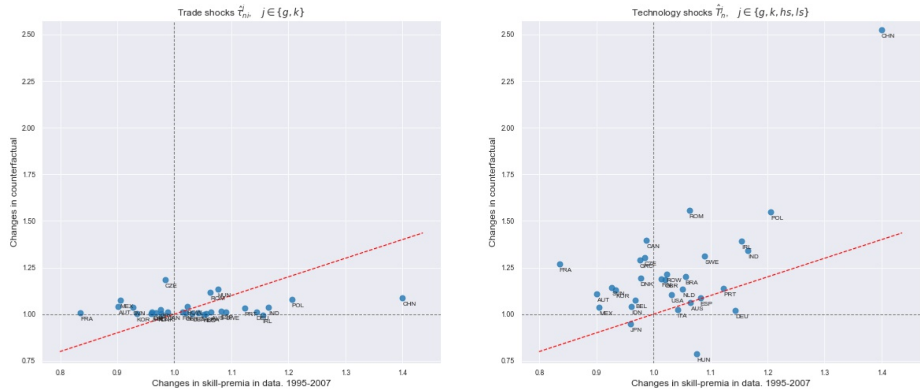
Notes: the figure plots the actual changes to skill-premia in data on horizontal axis against changes in a counterfactual where only an indicated set of shocks is removed.

Figure 2.4. All technology shocks removed vs technology shocks in equipment sector removed



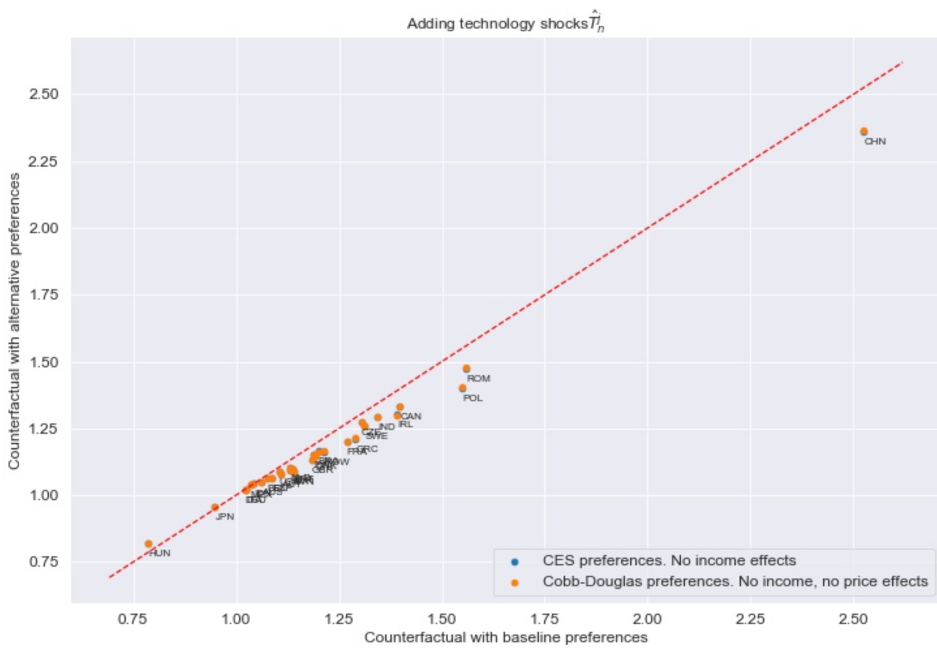
Notes: the figure plots the actual changes to skill-premia in data on horizontal axis against changes in two counterfactuals in order to illustrate the relative contributions of two different sets of shocks to changes in skill premia. In each counterfactual a set of shocks is removed.

Figure 2.5. Trade shocks vs Technology shocks



Notes: each figure plots the actual changes to skill-premia in data on horizontal axis against changes in a counterfactual exposed only to a specified set of shocks (trade shocks or technology shocks)

Figure 2.6. Income and Price effects and Technology shocks



Notes: Figure illustrates counterfactual skill-premia when only technology shocks are fed into the model. Results under baseline preferences are on the horizontal axis and Results under homothetic CES (no income effects) and Cobb-Douglas preferences (neither income nor price effects) are on the vertical axis.

Chapter 3

International Trade in the Digital Economy

3.1 Introduction

Over the past decade, the advancement of digital technology has become critical to the economic growth and production. Digital economy has penetrated all facets of modern life. Everyday transactions, internet browsing, streaming and social media consumption leave digital footprints beyond national borders. However, international trade in digital goods is relatively unstudied due to the lack of data. While trade in manufacturing goods is well tracked and documented, trade in bits and bytes is challenging to track.

Production and delivery of digital goods have features that are different from conventional manufacturing goods. In comparison to physical goods, transportation costs for digital goods are small in terms of time, weight, space and in monetary terms. These features go against the conventional explanation that distance systematically affects trade volumes because of costs associated with shipping. Negligible shipping costs could imply that trade in digital goods is less hindered by geography. In addition, online search costs are low and uncorrelated with distance for digital goods like computer games on a gaming platform or songs on a music platform. How much does geography matter for trade under this extreme circumstances? Consumption of digital goods such as reading ebooks, streaming TV shows and movies, and playing video games is usually content-oriented and involves lingual choice. Do cultural barriers and a choice of language play an integral part in shaping trade in digital goods?

Previous studies have consistently shown the importance of distance in international trade [[28]], and estimated reductions in trade frictions due to enabling digital technologies [[29] and [30]]. The analysis in the literature relies on trade flow data for physical goods. However, the magnitude of trade barriers has not yet been systematically estimated for transactions of digital goods. To the best of our knowledge, this paper is the first to offer estimates of geographic and cultural barriers for trade in digital goods using product-level sales. We observe sales across multiple markets for PC games on the video game digital distribution platform — STEAM. For this environment, we separate the geographic and language components of trade frictions.

Geographical distance has been deemed a crucial factor in trade between countries. [28] conduct a meta-analysis based on 1,000 gravity equations and establish the importance of distance in trade. In a public debate, however, there is a line argument that advent of personal computers and the internet should kill the effect of distance on trade flows. [31] argues that the global supply chain and more integrated business practices would imply a *flat world*. [32] suggests that internet facilitates the exchange of information, small firms and large firms would have equal opportunity to be integrated to the global economy; consumers from rural and urban areas would have the same access to variety of goods, which would eventual lead to the *death of distance*. However, empirical works find that, even in the context of digitization, the distance is still persistent and alive. [33] use corss-country website visits, and show that distance holds. [29] utilize cross-border sales on eBay, and demonstrates that distance matter maters for online trade flow, although it matters significantly less in contrast to offline trade flow. [30] use the cross-province trade flow in China to study the effect of distance under e-commerce. They also find a smaller but significant distance effect on trade flow. Overall, the above studies find that distance has a small but significant impact on trade under the digital economy, the effect of distance is around one-third of the effect from the gravity estimations using more traditional data sets. We shed light on the question since we can rigorously examine the role of distance on trade in digital goods by looking at computer games sold in the STEAM platform. This environment exmp an extreme case where buying and selling do not require any physical shipping. This setting not only allows us to examine international trade with complete absence of physical shipping costs, but also enables us to investigate trade where information and communication frictions are not engendered by geography. Prices, rankings and reviews of games, their detailed characteristics are available on the Steam platform. We estimate the distance elasticity with respect to bilateral trade volumes on country level as well as individual game sales in different markets. In addition, we investigate potential factors driving the trade patterns in digital goods, such as language and cultural barriers.

The most distinctive feature of digital goods is low costs of replication. For software, the costs to replicate is near zero, the most important part in the production is the initial fixed costs that a studio must put into the development. Once the first copy of the software is completed, the software can be replicated without any additional costs. The second prominent feature is zero market entry costs. Recent heterogeneous firm literature in trade emphasizes the importance of fixed market penetration costs[1]. In the case of software developers, once the software is pushed to the platform, it becomes available in every country that the platform operates. We contribute to the empirical trade facts by observing that, even in the absence of market entry costs, sales distributions of computer games within and across geographically defined markets resemble the distributions for physycal goods extensively documented in [35] and [36].

Recent quantitative studies analyze the implication of digitization on trade and welfare. [37] build a general equilibrium trade model, and consider the distinctions between goods and services with tangible and intangible components. Intangible assets offer technologies for production of goods and services in the future. [30] use a quantitative multi-region trade model to study the effect of e-commerce. In their framework, a firm can choose to sell either via physical stores or E-commerce stores. To emphasize the special characteristic of e-commerce, they assume the market entry cost of e-commerce is zero. They find that e-commerce facilitates trade, and the accompanying welfare gains are 1.6% on average. Our data allows to build a quantitative model of the STEAM platform market and complement emerging quantitative literature on digital trade as the next step. The current study shows empirically that language adoption is an important factor behind sales of a game in a destination. Controlling for conventional gravity covariates, adoption of a language increases sales of an individual title in the market on 20% on average. This fact motivates us to build a model of firm's decision about whether to adopt a lnaguage for a given market. This is the avenue for our future work.

[1] See [34] for a comprehensive overview.

3.2 Data Description

Our analysis on digital platform relies on sales data from Steam. Steam is a PC game digital distributor developed by Valve Corporation, which is compatible with major operating systems including Microsoft Windows, Apple MacOS and Linux. Steam was first launched in 2002; it was originally developed to deliver updates or patches for Valve's own games, such as Counter-Strike and Half-Life series. In 2005 Valve started to negotiate with third party publishers to deliver their content on Steam. By May of 2007 there were only 150 games for sale on the platform, but 13 million accounts had been created. Steam is the largest PC game digital distributor. By 2017 it accounted for roughly 18% of global PC game sales, and the total sales was estimated to be roughly US $4.3 billion.

For sales data on games, we use the dataset produced by Steam Spy. Steam Spy is a website created by Sergey Galyonkin and launched in 2015. Steam Spy estimates the number of copies sold and average playtime for each title offered by Steam by using Steam's application programming interface(API), which allows programmers to pull information on user profiles, including titles in the inventory, location of users and total playtime for each title. Data from Steam Spy record monthly number of copies sold by country at title level. Steam Spy was deemed as the most reliable data source for PC gaming. PCGameN reports that Steam Spy is accurate to within 10% of actual sales for games. Many developers use data from Steam Spy to navigate their business decisions [2]

The dataset we construct using Steam Spy covers sales in 82 destination countries between February of 2017 to March of 2018. We observe over 9,000 unique games

[2] It has been reported that a developer from Berlin secured government funding by using data provided by Steam Spy.

across multiple genres, i.g. first-person shooter (FPS), role-playing games (RPG), fighting games, etc. To construct bilateral data on game sales, we utilize Steam's API to pull game-level information. Using Steam's API, we collect the prices of games across all destination countries, reviews by languages and all users, the names of developers/studios and detailed information about the characteristics of games, including genres, languages supported and tags. Our data includes titles developed by almost 6,000 developers. We use the name of the developer publishing on Steam to manually match each firm to the country where it is headquartered. After considering differential pricing across geography, our sample includes measured bilateral sales from 102 origin countries to 82 destination countries for each title and developer.

3.3 Empirical Facts

In this section I document patterns of trade in computer games on Steam platform. First look at the data supports gravity for sales on the country level. On the product level sales distributions for computer games are strikingly similar to those documented for physical goods in a seminal study [35] even though the features of computer games production and international distribution on the Steam platform are different from the trade in physical goods.

We first examine whether geography has effects on bilateral trade flow in digital goods, and check whether the implications of geography differ from the implications on physical goods. Trade in digital goods on digital platform reduces search costs and transportation costs significantly, hence we expect to see geography to have insignificant impacts. To resonate with the conventional gravity equation, we first aggregate our product-level sales data by exporting countries and destination markets to get bilateral trade flow in PC games. Following [38], we consider the role of geography by running the following regression:

$$\ln X_{i,n} = \gamma_i + \zeta_n + \mathbf{b}'\mathbf{z}_{i,n} + \varepsilon_{i,n}, \tag{3.1}$$

where $X_{i,n}$ is country i's total export in PC games to country n, γ_i and ζ_n are the dummies for exporter and importer, respectively. $z_{i,n}$ is a vector containing the geographical information between country i and n, including (1) log distance between country i and n, (2) whether they share border, $border_{i,n}$, (3) whether they share common colonizer, $colony_{i,n}$ (4) whether they share the same official language, $lang_{i,n}$. As discussed in [39], the information about geography are from the CEPII data set. The key variable is $b_{i,n}^{distance}$, which measure the elasticity of geographical distance on trade in digital goods. We run this regression using both ordinary least square and Poisson pseudo-maximum likelihood (PPML). The preliminary results are reported in Table 3.1.

Table 3.1. Gravity in Computer Games. First look

	OLS	PPML
Distance (logarithm)	-0.090*	-0.11*
	(-0.046)	(-0.047)
Contiguity	0.22**	-0.025
	(-0.096)	(-0.13)
Common language	0.77	-0.17
	(-0.20)	(-0.0994)
Common colonizer	0.18	0.11
	(-0.13)	(-0.11)
Origin fixed effect	Yes	Yes
Destination fixed effect	Yes	Yes
N	1385	1660

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The coefficients on distance for trade in digital goods is -0.09 when using OLS, is -0.11 when using PPML, which are around 90% smaller than the estimations on physical goods. [29] and [30] examine the role of distance under e-commerce, they find the effect of distance to be 50% to 65% smaller than the tradition estimation. However, their analysis are still restricted to trade in physical goods. We explore the role of geography in a more extreme case, and some interesting patterns emerge from our estimation. Since international trade in digital goods have near zero costs of transportation and replication, we expect insignificant and negligible effect of distance. Although the effect of distance from our estimation is the smallest in the literature, it is still significant. This preliminary finding motivates us to rigorously estimate the gravity relationship in sales of computer games using both country and game-level data.

A small effect of distance on trade in computer games raises a question naturally: what alternative factors potentially drive sales of computer games in geographically defined markets? In this paper we explore the language adoption factor. A studio can choose whether to translate contents of a game and user interface into the language of the destination market. On the product level, distributions of sales follow the same shape across markets. In order to investigate the effect of language adoption on trade, we utilize the product-level data. On product-level the distributions of sales have the same shape across different markets. Figure 3.1 plots distributions of sales for US produced games in the US, Canada, Japan and China. The shapes of distributions coincide with the pattern for physical goods in [35]. Figure 3.2 depicts the shape of positive relationship between the size of the firm and number of countries it penetrated. Again the pattern for computer games sold via Steam is similar to the relationship for physical goods.

Higher sales in a market are associated with the decision to translate a game into the language of a destination. According to figure 3.4, games translated into language of the destination market are systematically more likely to have more copies sold in the market. Figure 3.5 illustrates that games translated into more languages tend to have larger sales not only in a market to which translation was tailored but in other markets as well. These regularities motivate us to estimate the relationship between sales in the market and local language adoption.

3.4 The Role of Distance and Language

To examine the role of distance, firstly we run a regression using data aggregated on a country level. Define X_{in} as sales of the games developed in country i to country n. We use the following baseline specification for the gravity relationship:

$$\begin{split}\log X_{in} = \gamma_i + \zeta_n + \beta_{dist} * \log(Distance_{in}) + \beta_{Contiguity} * Contiguous_{in} + \\ \beta_{Colony} * Colony_{in} + \beta_{common\_lang} * Common\_Language_{in} + \epsilon_{in}\end{split} \tag{3.2}$$

Here γ_i and ζ_n are origin and destination fixed effects and the other variables were introduced in (3.1). Results are reported in the first column of Table 3.2. In other columns we include measures of cultural and language distance between origin and destination and find that the results for distance elasticity are stable across specifications. The coefficient on distance elasticity lies between -0.11 to -0.16 and is different from 0 at least at 5% significance level across the specifications. This is unexpected, given the environment where physical cost of shipment is absent, and search cost of a product is unrelated to physical distance between a buyer and a seller. The coefficients on contiguity, colony, common language and measures of cultural and language distance are unstable across specifications.

To disentangle the significant effect of distance, we run gravity-type regressions using product-level data. Table 3.3 reports results for OLS and PPML estimates

Table 3.2. Country-level gravity

	Sales Volume			
log of Distance	-0.11**	-0.12**	-0.15***	-0.16***
	(0.05)	(0.05)	(0.06)	(0.06)
Contiguity	-0.025	-0.057	0.022	0.024
	(0.13)	(0.13)	(0.12)	(0.11)
Colony	0.110	0.096	0.120	0.120
	(0.11)	(0.11)	(0.19)	(0.19)
Common Language	-0.17*	-0.13		
	(0.099)	(0.11)		
log of Cultural Distance		0.036		0.011
		(0.035)		(0.033)
log of Language DIstance			-0.019	-0.003
			(0.40)	(0.44)
Origin fixed effect	Yes	Yes	Yes	Yes
Destination fixed effect	Yes	Yes	Yes	Yes
N	1660	1446	829	730

Standard Errors in parenthesis.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

and various specifications. The coefficients on distance are negative and significant across all specifications. The magnitudes for PPML estimates are more credible since there are numerous zeros for product-desitnation trade pairs. The magnitudes of the distance elasticity is in the -0.17 to -0.18 interval and similar to country-level results. Adoption of the local language implies significant increase in sales of an individual game in the market but does not alter the effect of distance. The size of the coefficients in all specifications suggest that language adoption might be an important decision for firms and motivates for a theoretical model of firm's decision of language adoption. In addition, results on common language in a destination-origin pair and on the interaction term between an indicator of RPG, the most language intensive genre of computer games, and a language adoption decision stress the role of language for consumption of computer games. Even conservative OLS estimates imply that language adoption is associated with 14% - 20% increase in sales of a game in the market. PPML results imply twice as big an effect of 36% to 42%.

Table 3.3. Product-level gravity

	OLS				PPML		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
lndist	-0.0312***	-0.0293***	-0.0427***	-0.0280***	-0.174**	-0.175***	-0.174**
	(0.00476)	(0.00467)	(0.00733)	(0.00456)	(0.0731)	(0.0615)	(0.0732)
dest_lng		0.143***	0.200***	0.160***	0.376***	0.417***	0.364***
		(0.00998)	(0.0101)	(0.00983)	(0.0459)	(0.0359)	(0.0475)
home_mrkt				0.290***		-0.146	
				(0.0160)		(0.137)	
contig	0.0203	0.0156	0.0331**	-0.000318	-0.443**	-0.434***	-0.445**
	(0.0129)	(0.0128)	(0.0145)	(0.0124)	(0.184)	(0.151)	(0.184)
comlang_off	0.138***	0.133***	0.108***	0.170***	0.157***	0.205***	0.159***
	(0.0121)	(0.0122)	(0.0189)	(0.0111)	(0.0538)	(0.0373)	(0.0536)
dest_lng*rpg							0.0569**
							(0.0249)
Observations	80,700	80,624	59,488	86,066	238,169	262,953	238,169
R-squared	0.847	0.848	0.840	0.849			
appid FE	YES	YES	YES	YES	YES	YES	YES
dest FE	YES	YES	YES	YES	YES	YES	YES

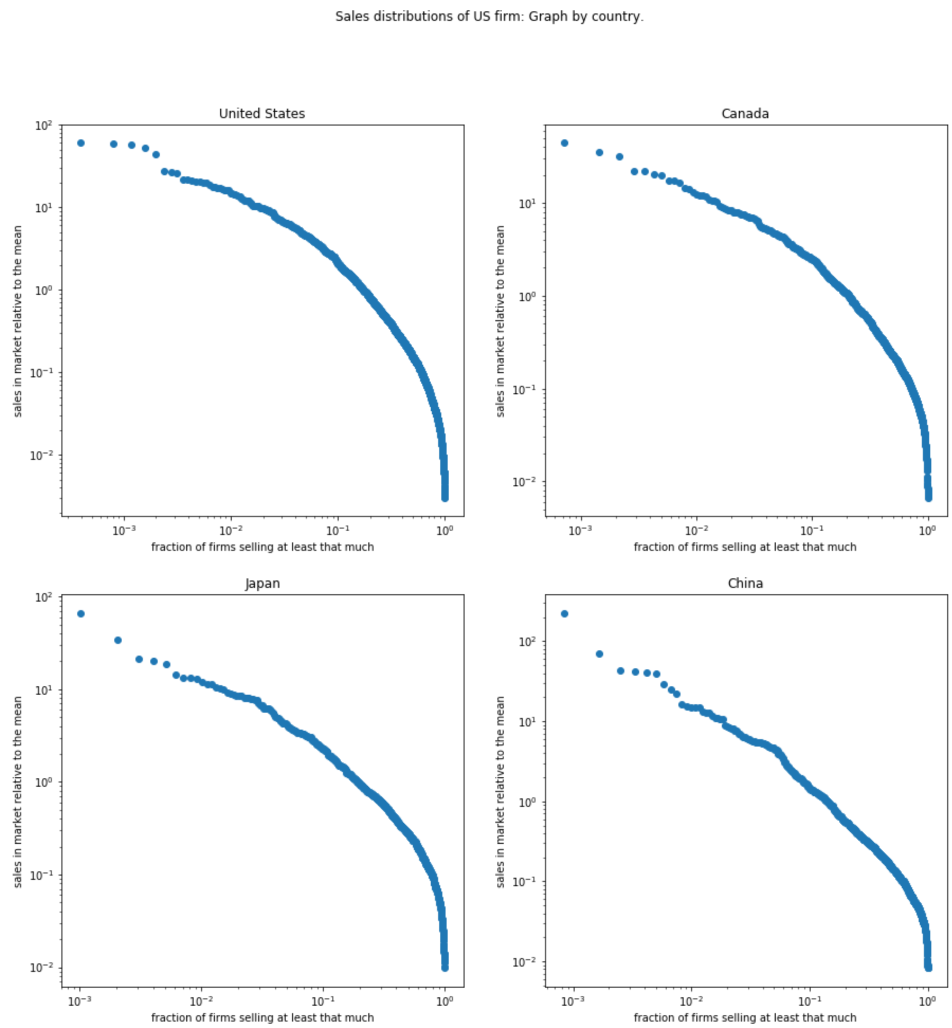
Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

3.5 Conclusion

In this paper we explore the effect of distance and language on international trade in digital goods in a very special environment of an online distribution platform for PC games – STEAM. In this specific case, the delivery of the goods comes at no cost in terms of money or time and the search and discovery of new products is unrelated to geography. We recover two main empirical regularities. First, the effect of distance between a producer and a consumer on sales volume is still significant and negative. The magnitude of the distance elasticity is around 10% of the distance elasticity estimates for offline trade in physical goods. We find this to be the smallest consistently significant elasticity estimate of the elasticity in the literature on international trade, both online and offline. The small size of the effect is not surprising given a specific environment of the STEAM distribution platform. A surprising observation is the consistent significance of the distance elasticity both on the country and on the product level. Second, we try to break down the effect of distance using the data on translation of games into a local language of a market. Accounting for language adoption does not erode the effect of distance on trade. More interestingly, local language adoption is associated with the sizeable increase in sales of a product in a given market. A conservative estimate of the increase in sales associated with language adoption is 14% - 20%. Our results suggest that a decision about language adoption is important for a producer of digital goods and call for a theoretical model and structural estimation of the effect of translation on sales of digital goods in a local market. By doing so we plan to extend an emerging quantitative literature on online trade and trade in services and goods where intangible assets are crucial for production of new varieties.

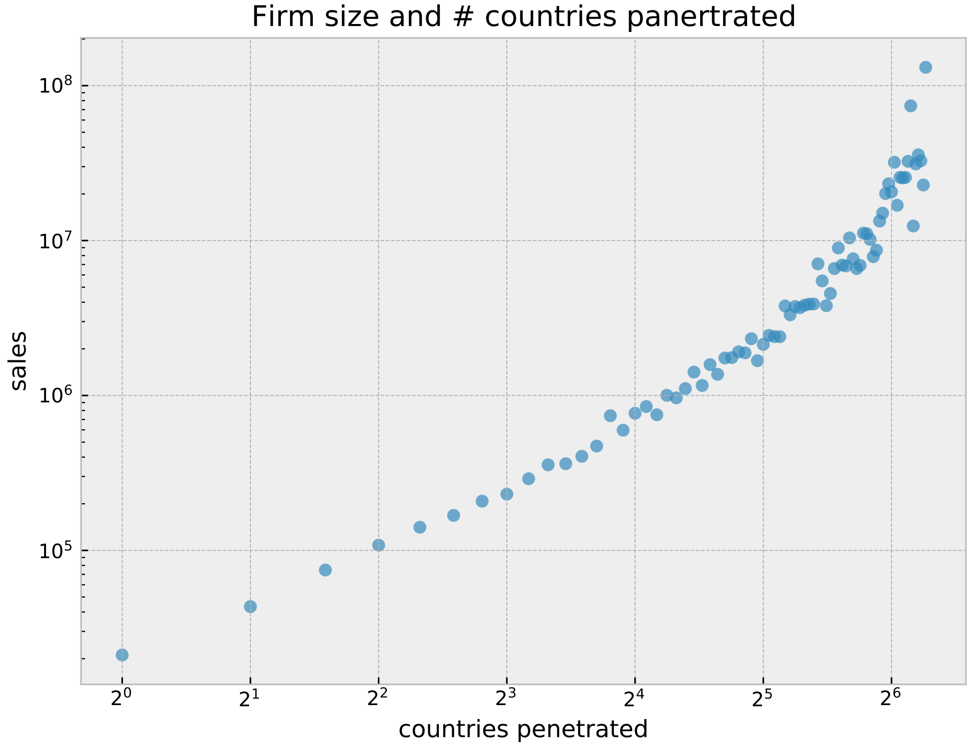
Our study sheds light on international trade in goods like computer games, movies, TV shows and e-books, for which shipping and replication costs are negligible and the content is language intensive. We find that distance still plays significant but only residual role for digital goods and language adoptions are important predictors for sales in the local markets. This evidence calls us to investigate how firms make choices about linguistic and more broadly cultural adaptation of their products to local markets.

Figure 3.1. Sales distribution of US firms. Graphs by country



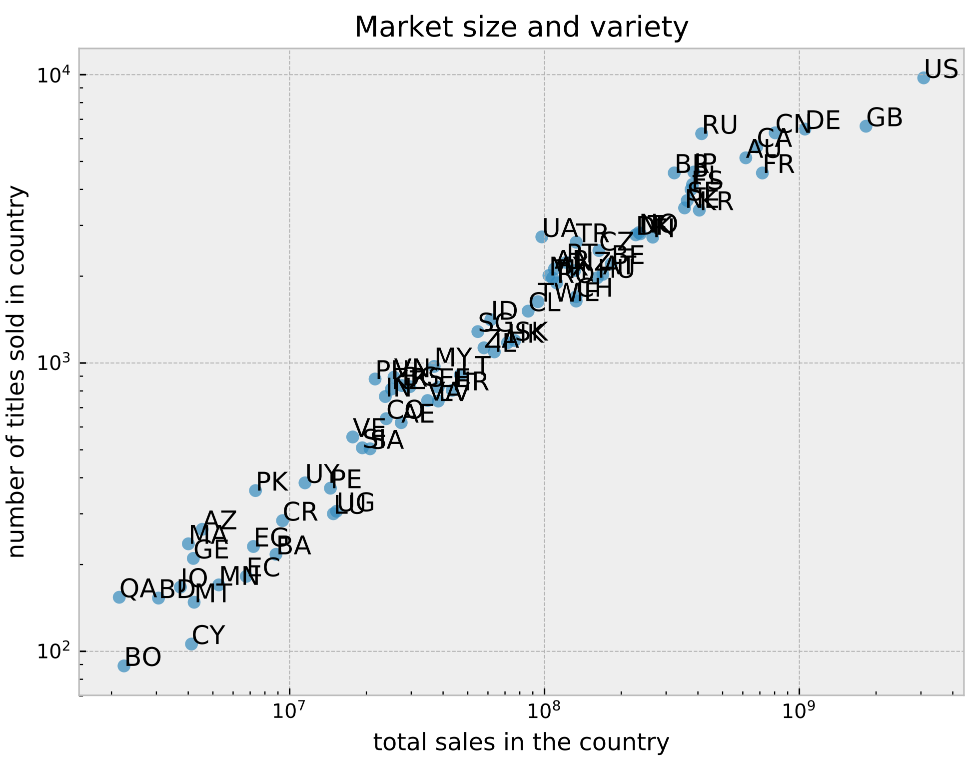
Notes: The figure plots sales in the market relative to the mean for US firms against the fraction of firms selling at least that much.

Figure 3.2. Size of a firm and markets penetrated



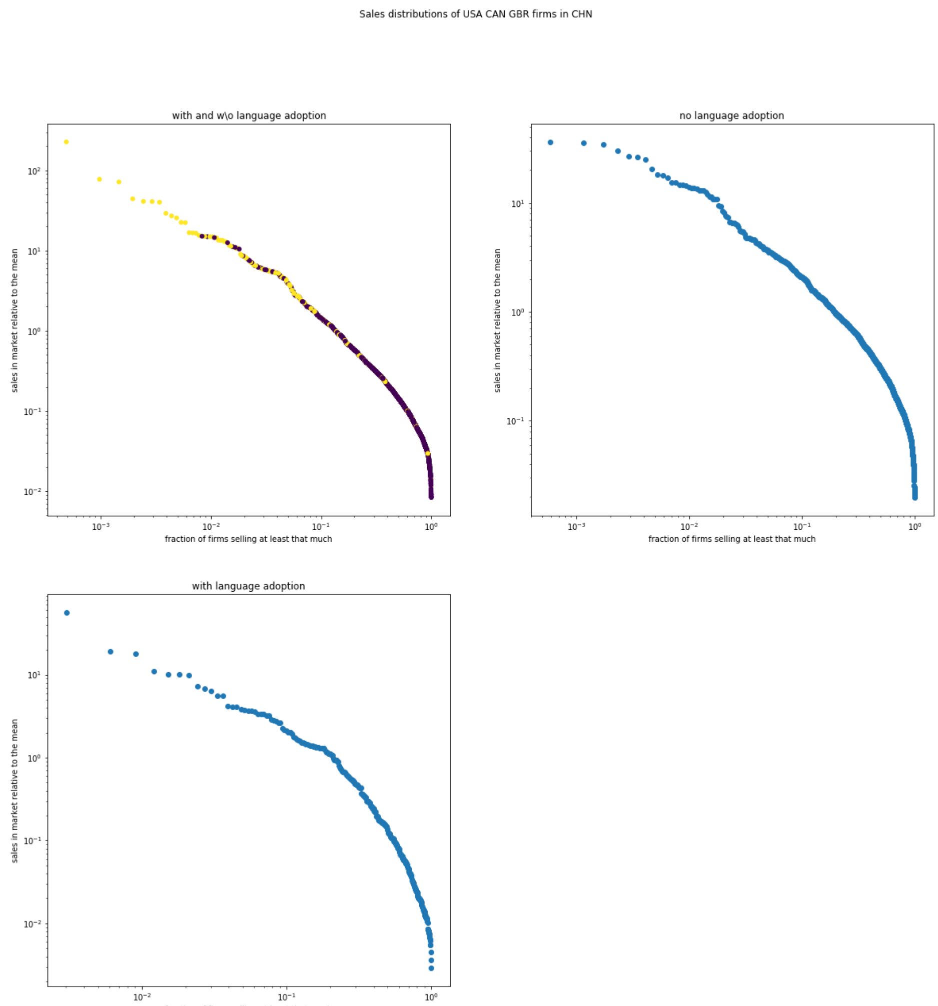
Notes: The figure plots sales of a firm against the number of countries where firm's products are sold.

Figure 3.3. Market size and variety



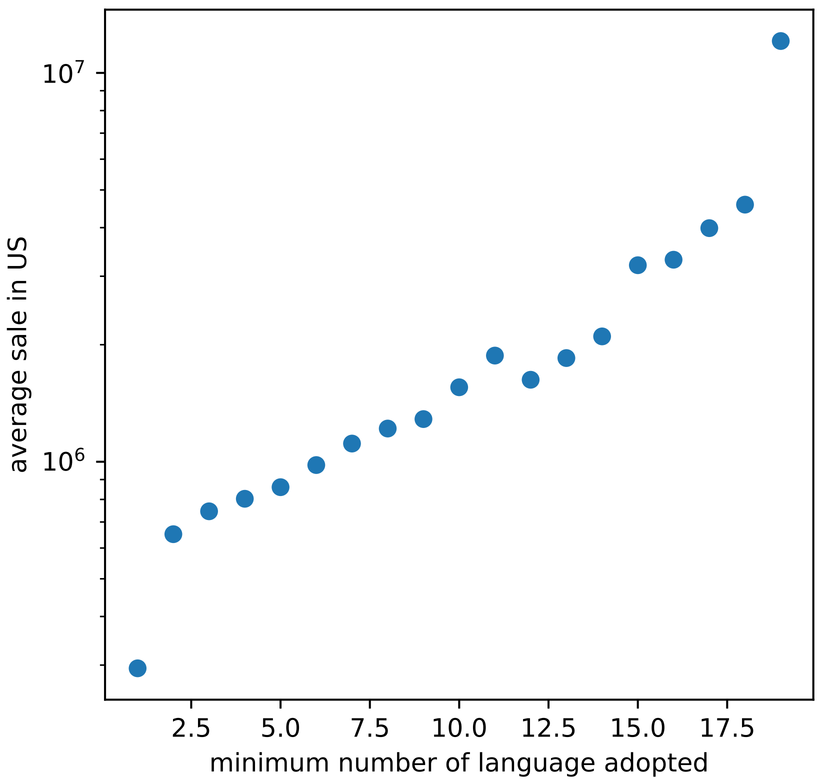
Notes: The figure plots total number of games sold in the market against the market size in USD.

Figure 3.4. Sales distributions and language adoption



Notes: The figure plots sales distributions in China for computer games from the US, Canada and the UK. Yellow dots in the first figure are for games which adopt simplified or traditional Chinese. Purple dots are for games without translation.

Figure 3.5. Sales distributions and language adoption



Notes: Each dot relates the average sales in the US market on y-axis over games with at least a number of languages adopted on x-axis.

Appendix

1 Data Appendix

Wages and labor endowments: Data on wages and labor endowments for years 1995-2009 comes from WIOD SEA file released in July 2014. The correspondence between the model consistent variables and data is described here:

$$\begin{aligned}
H_i + L_i &\rightarrow H_EMP_i \\
H_i &\rightarrow H_HS \cdot H_EMP_i \\
L_i &\rightarrow (H_MS + H_LS) \cdot H_EMP_i \\
w_i^l L_i + w_i^h H_i &\rightarrow LAB_i \\
w_i^h H_i &\rightarrow LAB_HS_i \cdot LAB_i \\
w_i^l L_i &\rightarrow (LAB_MS_i + LAB_LS_i) \cdot LAB_i \\
w_i^h &\rightarrow (LAB_HS_i \cdot LAB_i)/(H_HS \cdot H_EMP_i) \\
w_i^l &\rightarrow ((LAB_MS_i + LAB_LS_i) \cdot LAB_i)/((H_MS + H_LS) \cdot H_EMP_i)
\end{aligned}$$

There is only one way to calculate relative supply of skilled labor, because the variables available are total (both skilled and unskilled) employment and hours worked and shares of skilled/unskilled only in total hours worked. The shares uniquely define relative supply.

2 Calibration of production function

Production function for vatiety ω is given by

$$y_i^j(\omega) = z_i^j(\omega)\left[(1-\alpha_i^j)^{1/\rho}\left(H_i^j\right)^{\frac{\rho-1}{\rho}} + \alpha_i^{j\,1/\rho} K_i^{j\,\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}\gamma_i^j} L_i^{j\,\gamma_{l,i}^j} \Pi_{j'} q_i^{j,j'\,\gamma_i^{j,j'}}$$

where i stands for country and j for sector. I calibrate $\{\alpha_i^j, \gamma_i^j, \gamma_{l,i}^j, \gamma_i^{j,j'}\}$ from the data on factor shares. Factor shares for sectors in the model are constructed by aggregating from 34 original industries in WIOD SEA. The share of capital in gross output is split between equipment and structures. The share of equipment in capital compensation is assumed constant at $\alpha_e = .25$. The remaining share of capital in gross output is represented by structures and added to inputs share in the data to construct inputs share in the model. This is justified by the fact that strutrures are produced by construction sector and construction sector is a part of low-skilled services. Shares of sectoral inputs in total intermediate inputs come directly from WIOT tables. Then I multiply them by total share of intermediates in gross output to get $\{\gamma_i^{j,j'}\}_{i,j,j'}$. Alternatively the share of structures capital services in gross output could be added to the gamma of low-skill services directly.

3 Equilibrium in Changes

The model yields expression for $\pi^j_{ni} \equiv \frac{X^j_{ni}}{X^j_n}$ the share of i's imports X^j_{ni} in n's absorption of sector j X^j_n:

$$\pi^j_{ni} = \frac{T^j_i[\tau^j_{ni}c^j_i]^{-\theta_j}}{\sum_k T^j_k[\tau^j_{nk}c^j_k]^{-\theta_j}} \tag{.1}$$

the expression for sectoral price index:

$$P^j_n = B^j\Big[\sum_k T^j_k[\tau^j_{nk}c^j_k]^{-\theta_j}\Big]^{-1/\theta_j} \tag{.2}$$

and the expression for unit costs:

$$c^j_i = \left[\alpha^j_i P^{e\,1-\rho}_i + (1-\alpha^j_i)w^{h\,1-\rho}_i\right]^{\gamma_j/(1-\rho)} w^{l\,1-\gamma^j_i}_i \tag{.3}$$

Denote $\hat{x} \equiv \frac{x'}{x}$, where x' and x are the values in a counterfactual and initial equilibria. Simple algebra delivers changes in trade shares

$$\hat{\pi}^j_{ni} = \hat{T}^j_i[\hat{\tau}^j_{ni}\hat{c}^j_i]^{-\theta_j}\hat{P}^{j\,\theta_j}_n \tag{.4}$$

and changes in prices

$$\hat{P}^j_n = \Big[\sum_i \pi^j_{ni}\hat{T}^j_i[\hat{\tau}^j_{ni}\hat{c}^j_i]^{-\theta_j}\Big]^{-1/\theta_j} \tag{.5}$$

Changes in unit costs are solved for conidtional on factor prices and initial factor shares:

$$\hat{c}_i^j = \left[\hat{P}_i^{e\,1-\rho} \cdot \frac{\alpha_i^j p_i^{e\,1-\rho}}{\alpha_i^j p_i^{e\,1-\rho} + (1-\alpha_i^j) w_i^{h\,1-\rho}} + \hat{w_i^h}^{1-\rho} \cdot \frac{(1-\alpha_i^j) w_i^{h\,1-\rho}}{\alpha_i^j p_i^{e\,1-\rho} + (1-\alpha_i^j) w_i^{h\,1-\rho}}\right]^{\gamma_i^j/(1-\rho)} \hat{w_i^l}^{1-\gamma_i^j}$$
$$= \left[\hat{P}_i^{e\,1-\rho} \cdot \frac{\gamma_{i,e}^j}{\gamma_i^j} + \hat{w_i^h}^{1-\rho} \cdot \frac{\gamma_{i,h}^j}{\gamma_i^j}\right]^{\gamma_i^j/(1-\rho)} \hat{w_i^l}^{1-\gamma_i^j} \tag{.6}$$

where $\gamma_{i,e}^j \equiv \frac{P_i^e K_{i,e}^j}{VA_i^j}$ and $\gamma_{i,h}^j \equiv \frac{w_i^h H_i^j}{\gamma_i^j VA_i^j}$.

Unlike the share of unskilled labor compensation, updated shares $\{{\gamma_{i,e}^j}', {\gamma_{i,h}^j}'\}$ are different from the original ones because of capital-skill complementarity:

$${\gamma_{i,h}^j}' = \frac{\gamma_i^j}{1 + \frac{\gamma_{i,e}^j}{\gamma_{i,h}^j}\left[\frac{\hat{P}_i^e}{\hat{w}_i^h}\right]^{1-\rho}} \quad \text{and} \quad {\gamma_{i,e}^j}' = \frac{\gamma_i^j}{1 + \frac{\gamma_{i,h}^j}{\gamma_{i,e}^j}\left[\frac{\hat{w}_i^h}{\hat{P}_i^e}\right]^{1-\rho}} \tag{.7}$$

From the demand system we have expressions for the shares in consumption for final sectors $j \in s, g$:

$$\begin{aligned} \omega_i^j &= \Omega_i^j \left(\frac{P_i^j}{P_i}\right)^{1-\sigma} C_i^{\epsilon_j - 1} \\ \hat{\omega}_i^j &= \left(\frac{\hat{P}_i^j}{\hat{P}_i}\right)^{1-\sigma} \hat{C}_i^{\epsilon_j - 1} \end{aligned} \tag{.8}$$

where P_i is a CPI and C_i is real consumption in country i. A model-based CPI and the relative shock to it are given by:

$$P_i = \frac{1}{C_i}\left[\sum_j \Omega_i^j C_i^{\epsilon_j - \sigma} {P_i^j}^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{.9}$$

using the expressions for consumption shares w_i^j we can derive the change in CPI:

$$\begin{aligned}\hat{P}_i &= \frac{1}{\hat{C}_i}\left[\sum_j \hat{C}_i^{\epsilon_j-\sigma}\hat{P}_i^{j\,1-\sigma}\cdot\frac{\Omega_i^j C_i^{\epsilon_j-\sigma}P_i^{j\,1-\sigma}}{\sum_j \Omega_i^j C_i^{\epsilon_j-\sigma}P_i^{j\,1-\sigma}}\right]^{\frac{1}{1-\sigma}} \\ &= \frac{1}{\hat{C}_i}\left[\sum_j \omega_i^j \hat{P}_i^{j\,1-\sigma}\hat{C}_i^{\epsilon_j-\sigma}\right]^{\frac{1}{1-\sigma}}\end{aligned} \tag{.10}$$

Since $\hat{I}_n = \hat{P}_n\hat{C}_n = \frac{w_n^h H_n}{w_n^h H_n + w_n^l L}\hat{w_n^h} + \frac{w_n^l L_n}{w_n^h H_n + w_n^l L}\hat{w_n^l}$, equation (.10) allows to solve for $\hat{C}$ implicitly:

$$\frac{w_n^h H_n}{w_n^h H_n + w_n^l L}\hat{w_n^h} + \frac{w_n^l L_n}{w_n^h H_n + w_n^l L}\hat{w_n^l} = \left[\sum_j \omega_i^j \hat{P}_i^{j\,1-\sigma}\hat{C}_i^{\epsilon_j-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{.11}$$

The equation for $\hat{\omega}_i^j$ can be rearranged as:

$$\hat{\omega}_i^j = \frac{\hat{P}_i^{j\,1-\sigma}\hat{C}_i^{\epsilon_j-\sigma}}{\hat{I}_i^{1-\sigma}} \tag{.12}$$

So that the counterfactual consumption shares depend on original shares: data, change in real consumption and changes in sectoral prices: computed within the model.

Goods markets clearing:

$$\begin{aligned}X_n^{j\prime} &= \omega_j{}' I_n' + \sum_i \pi_{in}^j{}' X_i^{j\prime} \\ I_n' &= w_n^h H_n \hat{w}_n^h + w_n^l L_n \hat{w}_n^l\end{aligned} \tag{.13}$$

Labor markets clear for high skill labor:

$$w_i^h H_i \hat{w}_i^h = \sum_j \gamma_{i,h}^j{}' \sum_n \pi_{ni}^j{}' X_n^{j\prime} \tag{.14}$$

4 Solution Algorithm

The model in changes is solved given:

- shocks to technology levels and trade costs $\{\hat{T}_i^j, \hat{\tau}_{ni}^j\}_{i,n}$
- initial trade shares$\{\pi_{ni}^j,\}$ on sector country-pair level
- initial factor shares in production $\{\gamma_i^j, \alpha_i^j\}_{i,j}$
- initial consumption shares $\{\omega_i^j\}_{i,j}$

shocks to technology levels and trade costs $\{\hat{T}_i^j, \hat{\tau}_{ni}^j\}_{i,n}$ as well as initial trade shares$\{\pi_{ni}^j,\}$. First, I take an initial guess for changes to wages $\{\hat{w}_i^h(0), \hat{w}_i^l(0)\}_i$. The next steps apply to any iteration $\xi = 0, 1, 2.., \xi_{stop}$:

1. changes in price of equipment and unit costs:
   (a) guess $\hat{P}_i^e$.
   (b) given the guess solve for a change in unit costs using (.11)
   (c) update a guess of $\hat{P}_i^e$ using (.5)

   Repeat (a)-(c) until convergence
2. From (.5) calculate the changes in sectoral prices for the remaining sectors
3. From (.4) calculate new trade shares ${\pi_{ni}^j}'$
4. Calculate new incomes $\{I_n'\}_n$. Calculate new onsumption shares $\{{\omega_n^j}'\}$ using (.12),(.11).
5. Solve system of linear equations (.13) for new sectoral absorptions ${X_n^j}'$.

6. Calculate excess demand for each labor type:

$$Z_i^h = \frac{\sum_j {\gamma_{i,h}^j}' \sum_n {\pi_{ni}^j}' X_n^{j\prime} - w_i^h H_i \hat{w}_i^h}{w_i^h H_i \hat{w}_i^h} \tag{.15}$$

7. Update guess for wages: [1]

$$\hat{w}_i^h(\xi+1) = \hat{w}_i^h(\xi)\Big(1 + \nu Z_i^h\Big) \tag{.16}$$

8. If $max_{i,t\in(h,l)}\left|\frac{\hat{w}_i^t(\xi+1)-\hat{w}_i^t(\xi)}{\hat{w}_i^t(\xi)}\right| < tol$, stop.

   Else repeat steps (1)-(7) conditional for an updated guess $\{\hat{w}_i^h(\xi+1), \hat{w}_i^l(\xi+1)\}_i$

[1] ν is a tuning parameter

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