Title
The Impacts of Trade on Labor Markets

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Publication Date
2015

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA
SANTA CRUZ

THE IMPACTS OF TRADE ON LABOR MARKETS

A dissertation submitted in partial satisfaction of the
requirements for the degree of

DOCTOR OF PHILOSOPHY

in

ECONOMICS

by

Quincy Chen

June 2015

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Abstract

The Impacts of Trade on Labor Markets

by

Quincy Chen

I develop and analyze three models which examine how labor markets are impacted by trade. The first model explores the effects of tariff reductions in a setting where multinational firms must choose not only where to sell their products but also where to locate their production. The second model introduces a new theory of offshoring in which production tasks are offshored due to differences in factor endowments between countries rather than differences in productivity. The third model explores the phenomenon of job polarization in which the share of high-skilled and low-skilled jobs increase at the expense of the share of medium-skilled jobs. I demonstrate that job polarization can be caused by complementarities between worker skill and more sophisticated production technologies and I analyze how this effect varies systematically with reductions in trade costs.

Acknowledgments

I thank my advisor, Alan Spearot, for his invaluable guidance and support. I also thank seminar and workshop participants at UCSC who provided helpful comments.

This thesis is dedicated to my wife, Ji Xiang, who has been with me on every step of the journey.

Chapter 1

Introduction

Though international trade is one of the oldest and most established fields of economics, recent advances in transportation, information, and communications technology have had dramatic effects on the way in which economies interact. It is cheaper than ever to ship goods and to deliver services remotely. Production itself is no longer confined to one location, as production processes can now be split into individual tasks with each performed in a different location.

The scope of these changes is unprecendented, leaving trade economists with much to do to understand their implications. This is especially important in light of the recent surge in concern over rising inequality. Many observers have noted that real wages for low-skilled and medium-skilled workers in developed countries have remained stagnant over the last few decades even as the number of medium-skilled jobs has fallen. To the extent that international trade is a driver of these changes to the labor market, correctly understanding the linkages between the changing nature of international trade and the labor market is critical for crafting effective policies to mitigate these issues.

In the following chapters, I present three theoretical models that advance our understanding of the impacts of international trade on the labor market. The first model examines the effects of tariff reductions and technology growth in a setting where firms can choose to locate their production anywhere and subsequently ship their output to any destination. Changes to tariffs and technology not only affect firms' export decisions but also their choices of production location; the resulting effects are therefore more complicated than in models where production is limited to the firm's location of origin. I then use country-level data to estimate model parameters and conduct counterfactual simulations. For example, I simulate the effects of China's WTO entry and technology growth and the potential effects of the Trans-Pacific Partnership free trade agreement currently in negotiations.

In the second model, I develop a theory of offshoring in which offshoring is driven by Heckscher-Ohlin-type differences in relative factor endowments. This is in contrast to existing models which rely on Ricardian differences in productivity to create the incentive to offshore. I demonstrate this theory with a two-country, two-factor, two-good model in which intermediate production tasks can be offshored. Also, there are frictions in final goods trade which prevents factor prices in the two countries from being equalized. The difference in factor prices between the two countries incentivizes firms to offshore some of their production tasks. One major implication of my theory is that it predicts not just unilateral North-to-South offshoring of unskilled production tasks but also South-to-North offshoring of skilled production tasks. I then consider the effects of this bilateral offshoring on wages, the extensive margin of offshoring, and the terms of trade.

The final chapter examines the phenomenon of job polarization, defined as the increase in the share of low- and high-skilled jobs at the expense of medium-skilled jobs. It is hard to overstate the importance of this issue, due to the obvious welfare impacts and the number of countries which experienced job polarization occur over the last few decades. Many of the likely causes of job polarization have already been identified by researchers. In this chapter, I propose a different cause of job polarization. To illustrate my hypothesis, I develop a model in which firms have a choice of production technologies and workers are differentiated by their skill. As worker skill increases, complementarity between worker skill and more productive technologies leads to an increase in employment share of firms using the most- and least-productive technologies. Finally, I analyze the effects of an increase in worker skill in an open economy setting in which trade costs are decreasing in order to study the interaction effects between worker skill and trade costs.

Chapter 2

Disentangling Trade and Multinational Production

Since joining the WTO in 2001, China has experienced accelerated growth relative to the United States.[1] This seems to back up the popular notion that WTO membership has benefited China at the expense of other countries.[2] However, China's post-2001 performance relative to the rest of the world might just as well be explained by technology improvement in China due to increased expenditure on research and development.[3] Given these two plausible alternatives to explain China's outperformance relative to the rest of the world, one would like to measure and compare their effects on global welfare. In essence, this involves asking two of the oldest questions in international trade. First, what are the global effects of trade liberalization? Second, what are the

[1] From 1992-2000, China's GDP growth rate exceed the US rate by an average of 6.9% per year. From 2001-2009, the difference in growth rates widened to 8.93% per year.

[2] *The Economist*, "China's Economy and the WTO: All Change"

[3] In 1996, China's R&D expenditure (in US$) was 2.64% of US R&D expenditure. By 2009, China's R&D expenditure was 21.0% of US R&D expenditure. Data from World Development Indicators.

global effects of productivity growth?

However, trade is not the only channel by which shocks to trade costs or productivity can propagate. Another important channel is multinational production (henceforth MP). The first reason is that MP is increasingly ubiquitous[4]. Furthermore, MP has complex interactions with trade (Ramondo and Rodríguez-Clare, 2013). For example, trade and MP substitute for each other as alternative means to serve a given foreign market but complement each other when multinational firms produce in a foreign location and export to a different market.[5]

The goal of this chapter is to estimate the global welfare effects of China's trade liberalization and productivity growth in the years following its 2001 WTO accession while carefully accounting for the interactions between trade and MP. To do so, I develop a general equilibrium model which extends the multicountry, multigood competitive framework of Eaton and Kortum (2002) to include MP, tariffs, and nontradable goods. In the model, firm productivities are drawn from a random distribution with firms from technologically-advanced countries having, on average, better draws. The impact of MP is that, instead of receiving a single productivity draw as in Eaton and Kortum (2002), firms receive a different productivity draw for each production location. Goods are divided into a tradable sector and a nontradable sector. In the nontradable sector, a foreign market can be served only via MP.[6] For tradable goods, a foreign market can

[4]Measured as the sales of foreign affiliates of multinational firms, multinational production in 2007 was significantly higher than the value of total world exports (UNCTAD, 2009).

[5]Tintelnot (2013) documents that around 40% of the output of European affiliates of US multinationals is subsequently exported.

[6]Looking at BEA data, Ramondo and Rodríguez-Clare (2013) report that "a significant part of MP flows is in nontradable goods."

be served via trade or MP (or both in the case of export platforms). Just as exporting a tradable good is costly, locating production abroad also incurs MP "implementation" costs.[7] The only factor of production is labor, which is homogeneous and fully mobile between sectors. MP benefits firms and host countries alike. Firms are able to locate production where it is most advantageous and are able to supply nontradable goods to foreign markets. For host countries, since only the most efficient producers survive regardless of whether they are domestic or foreign, the presence of foreign multinationals raises the average productivity of the host country's workers.[8]

Using a special case of the model with costless trade and without a nontradable sector, I analyze the degree to which productivity growth benefits other countries. I find that the effects of a productivity shock differ systematically depending on where the shock originates. I test this prediction later using the full model.

I then estimate the model with bilateral data on trade, tariffs, and foreign affiliate sales for 40 countries. The data covers the period from 1996-2001 but is averaged over this period due to foreign affiliate sales data being unavailable for many country-years. The countries in my sample accounted for 91.6% of world GDP in 2000.

I conclude the chapter by using the estimated model to conduct three counterfactual simulations. First, I revisit the spillover effects of technology growth, this time with trade costs and nontradable goods. Other studies (Tintelnot, 2013) find that the effects of technology growth in the US are much larger with trade and MP than in a

[7] Yeaple (2009) and Irarrazabal et al. (2013) provide evidence that MP costs are increasing in distance.

[8] In other words, MP grants the host country access to foreign production technology (McGrattan and Prescott, 2009).

trade-only scenario. I find that while this is true, the US is very much an outlier in terms of technology. When technology growth occurs in China instead, the effects are much smaller both on an absolute basis and relative to the trade-only scenario.

Second, I explore the impact of China's economic development in the years following its accession to the WTO in 2001. Holding all else constant, I quantify the effects of changing China's technology level and tariffs (both inbound and outbound) from their 1996-2001 levels to their 2009 levels. I find that the changes in technology and tariffs raise real wages in China by 11.58%, nearly all of which can be attributed to technology growth. All countries in the sample benefit in terms of real wages, with the largest benefits going to less-advanced countries in proximity to China.

For my last counterfactual simulation, I demonstrate the usefulness of the framework for policy analysis by quantifying the potential effects of the Trans-Pacific Partnership, or TPP.[9] I assess the effects of the TPP under the hypothetical scenario that it eliminates tariffs between member countries. In addition to reducing tariffs, the TPP is also intended to promote investment. In that spirit, I also assess the effects of the TPP if it were to reduce MP costs between member countries by an amount equal to the average tariff between TPP members.[10] I find that most TPP members benefit far more from the the reduction in MP costs than from the elimination of tariffs. The exception is the United States, which as the world's technology leader gains relatively

[9] The TPP is a wide-ranging free trade agreement which is still being negotiated.

[10] There are a number of ways by which a free trade agreement (FTA) may reduce MP costs. One major channel is the harmonization of regulatory frameworks (Thangavelu and Findlay, 2011). For example, coordinating investment regulations may reduce the cost of allocating capital between the parent firm and foreign affiliates. Also, an FTA often indicates political as well as economic cooperation, thereby signalling to multinationals a reduction in political or institutional risk.

little from increased access to foreign technology.

Only a handful of papers have considered the interaction between trade and MP in the context of technology growth or trade liberalization. Tintelnot (2013) quantifies the effect of US technology growth and of the adoption of a Canada-Europe trade agreement using a model in which foreign production incurs fixed costs and using a sample of developed countries. Arkolakis et al. (2013) measure the effect of a reduction in MP costs on welfare and innovation using a sample of OECD countries. Shikher (2014) examines the effect of an elimination in trade costs on multinational production using a framework in which trade and MP costs due to geography are indistinguishable from those due to policy. These three studies use general equilibrium frameworks similar to mine with a few key differences.

One difference is that my model includes tariffs. Using actual tariff data, I can estimate the effects of tariff reductions following China's entry into the WTO. A secondary benefit of modeling tariffs is that they provide a direct estimate of a crucial shape parameter which I would otherwise have to obtain using a multi-step procedure as in Eaton and Kortum (2002). Another difference is that my model features nontradable goods. This highlights how MP can circumvent some of the limitations of trade, thereby allowing for differences in the degree to which trade and MP shocks transmit. A third difference is that my country sample includes not only developed countries but also several developing countries, allowing me to contrast the effects of technology growth in countries at different levels of technological advancement. Finally, trade and MP costs in my paper are composed of a policy component (tariffs and membership in trade blocs) and a geographic component (distance and common languages) to reflect the reality that trade agreements can reduce policy barriers to trade and MP but not geographic barriers.

This chapter contributes more generally to the literature studying the impacts of trade liberalization. Due to the breadth of this literature I will highlight only a handful of studies. Trefler (2004) examines both the short-run and long-run effects of NAFTA on Canadian plants. Amiti and Konings (2007) and Amiti and Davis (2011) differentiate between tariffs on final goods and tariffs on intermediate inputs in their studies on Indonesian trade liberalization. Spearot (2014) explores the effect of tariff cuts using a framework in which productivity distributions vary by country and industry. By not considering the interactions between trade and MP, these papers ignore an important channel through which trade liberalization can take effect.

This chapter is also related to the literature on the global effects of productivity growth in China. Fieler (2011) extends Eaton and Kortum (2002) by allowing preferences to be non-homothetic and finds that a positive technology shock in China benefits those who consume low income-elasticity goods (poor countries) and exporters of high income-elasticity goods (rich countries) while hurting net importers (middle-income countries). Hsieh and Ossa (2011) and di Giovanni et al. (2013) use multi-sector models in order to account for heterogeneous productivity growth across sectors. Hsieh and Ossa (2011) find that only 3.0% of the worldwide gains from China's productivity growth from 1995 to 2007 accrues to the rest of the world and that the welfare of China's trading partners increases by an average of 0.4%. di Giovanni et al. (2013) evaluate two scenarios, one in which productivity growth is identical across sectors and one in which productivity growth is greater in sectors for which China is at a comparative disadvantage, and find that most countries benefit more from the latter. By expanding the set of firm choices to allow for multinational production, my model provides an additional channel for the effects of technology growth in China to propagate.

The rest of the chapter is organized as follows. Section 2.1 describes the model. Section 2.2 provides additional intuition with a special case of the model. Section 2.3 describes the data. Section 2.4 details the estimation procedure and the baseline estimates. The results of the counterfactual simulations are reviewed in section 2.5.

2.1 The Model

The model developed in this chapter generalizes the Ricardian model of Eaton and Kortum (2002) to allow for multinational production and a nontradable sector. Markets are assumed to be competitive. There are N countries and two types of goods, tradables and nontradables. Firms employ the production technology of their home country but may produce in any country and export to any destination market. Only tradable goods can be exported. There are variable costs but no fixed costs associated with trade or MP[11], so all goods are sold to every market and all countries host MP.

[11] Fixed MP costs are incorporated in Tintelnot (2013) but are omitted here for simplicity and for lack of publicly available firm-level data. Eaton et al. (2011) features a model with fixed trade costs, but there is no possibility for MP.

2.1.1 Consumer Preferences

There is a continuum of varieties of measure one for both tradable and nontradable goods. Tradable goods are indexed by $u \in [0,1]$ and nontradable goods are indexed by $v \in [0,1]$. The representative consumer has preferences

$$U = \left[\int_0^1 q_T(u)^{\frac{\sigma-1}{\sigma}} du \right]^{\frac{\sigma}{\sigma-1}\alpha} \left[\int_0^1 q_{NT}(v)^{\frac{\sigma-1}{\sigma}} dv \right]^{\frac{\sigma}{\sigma-1}(1-\alpha)} \tag{2.1}$$

where $q_T(u)$ is the quantity of tradable variety u consumed, $q_{NT}(v)$ is the quantity of nontradable variety v consumed, σ is the elasticity of substitution across varieties of tradables and nontradables, and α is the expenditure share going to tradable goods.

2.1.2 Distribution of Prices

Firms can serve foreign markets through trade or MP or both but incur costs for doing so. Trade costs (which include tariffs) are of the iceberg type where $d_{nh} \geq 1$ is the number of units of a tradable good that must be exported from h such that one unit arrives at n. Trade costs are assumed to satisfy the triangle inequality: $d_{nx}d_{xh} \geq d_{nh}$ for all $n \neq h$, $n \neq x$, and $h \neq x$. I allow d_{hh} to take values greater than 1 since internal distances may pose a barrier to intranational economic activity just as international distances impede international trade (Mayer and Head, 2002).

To represent the idea that there is a loss of efficiency when producing outside the home country (Keller and Yeaple, 2013), multinational production also incurs an iceberg-type cost. Let m_{hi} denote the MP cost of a firm from country i producing in country h where $m_{hi} > 1$ for $h \neq i$ and $m_{hi} = 1$ for $h = i$.

A firm from country i has a variety of ways to supply country n with a tradable good. It could produce in n and incur additional costs $d_{nn}m_{ni}$. Alternatively, it could choose to produce at home and export to n, incurring only trade costs d_{ni} (since m_{ii} is assumed to be 1). Lastly, it could produce in some country h and export to n, incurring trade and MP costs $d_{nh}m_{hi}$. For nontradable goods, only the first option is viable.

Let c_h be the cost of a bundle of inputs in country h and z_{hi} be the productivity of a firm from i producing in h. With competitive markets and constant returns to scale, the price of a tradable good u in country n that is produced in country h by a firm from country i is

$$p^T_{nhi}(u) = \frac{c_h d_{nh} m_{hi}}{z_{hi}(u)}$$

Whereas tradable goods may be exported, nontradable goods must be consumed in the country where they are produced. Thus the price of a nontradable good v produced in country h by a firm from country i is

$$p^{NT}_{hi}(v) = \frac{c_h d_{hh} m_{hi}}{z_{hi}(v)}$$

As the above notation implies, prices for nontradable goods are characterized by the MP-source and MP-host country pair while prices for tradable goods are characterized by the triplet of MP-source, MP-host, and destination market countries. To reduce confusion with the notation, I consistently use i to index the MP-source country, h to index the MP-host country, and n to index the destination market.[12]

The model's generality (multiple countries, goods, production locations, and

[12]Since the MP host and the destination market are the same for nontradable goods, I will sometimes write p^{NT}_{hi} as p^{NT}_{ni} if it helps clarify the exposition.

export destinations) presents a difficult permutation problem. The innovation introduced in Eaton and Kortum (2002) to deal with this complexity in a tractable and parsimonious way is to represent productivity as a random variable. Recall that z_{hi} is the productivity of a firm from country i producing in h. The key assumption (generalized to allow for MP) is that country i's firms have productivities which are drawn from the multivariate Fréchet distribution[13]:

$$F(z_{1i}, z_{2i}, \ldots, z_{Ni}) = \exp\{-\sum_{j=1}^{N} T_i z_{ji}^{-\theta}\}$$

The above assumes that productivities are independent across production locations.[14] The parameters T_i and θ determine absolute and comparative advantage, respectively. A country with a higher value of T has, on average, better firm productivity draws for all potential production locations. Thus, T_i is usually interpreted as a measure of country i's technology stock. A higher θ implies greater dispersion of productivity and thus a greater role for comparative advantage. The main difference from Eaton and Kortum (2002) is that each country's firms receive a different productivity draw for each potential MP host instead of a single productivity draw.

Given the above distribution of productivities, the price in destination market

[13]The Fréchet distribution arises from the probability theory of extremes. This is appropriate since a new production technique would only be put to use if it were more efficient than existing techniques.

[14]Observe that $F(z_{1i}, z_{2i}, \ldots, z_{Ni}) = \prod_{h=1}^{N} F(z_{hi})$ which is the product of the univariate Fréchet distributions $F(z_{hi}) = \exp\{-T_i z_{hi}^{-\theta}\}$. Rather than assume independence, Ramondo and Rodríguez-Clare (2013) include a correlation parameter ρ. The authors calibrate their model twice, once with $\rho = 0$ (no correlation) and once with $\rho = 0.5$ (partial correlation). The goodness of fit for their model is close under the two alternatives. Assuming $\rho = 0$ is common in the literature and allows for the use of gravity equations.

n of a tradable good produced in h by a firm from country i has the distribution

$$G^T_{nhi}(p) = \Pr(p^T_{nhi} \leq p) = \Pr(z_{hi} \geq \frac{c_h d_{nh} m_{hi}}{p}) = 1 - \exp\{-T_i(\frac{c_h d_{nh} m_{hi}}{p})^{-\theta}\}$$

while the price of a nontradable good has the distribution

$$G^{NT}_{hi}(p) = \Pr(p^{NT}_{hi} \leq p) = \Pr(z_{hi} \geq \frac{c_h d_{hh} m_{hi}}{p}) = 1 - \exp\{-T_i(\frac{c_h d_{hh} m_{hi}}{p})^{-\theta}\}$$

The distributions $G^T_{nhi}(p)$ and $G^{NT}_{hi}(p)$ describe all possible prices. However, consumers purchase a given good only at the lowest price offered. Therefore, the price of a nontradable good that is actually purchased in country h is $\min_i\{p^{NT}_{ni}\}$ and has the distribution

$$G^{NT}_h(p) = G^{NT}_{hi}(\min_i\{p^{NT}_{ni}\}) = 1 - \prod_{i=1}^{N}[1 - G^{NT}_{hi}(p)] = 1 - \exp\{-\tilde{T}_h(c_h d_{hh})^{-\theta} p^{\theta}\}$$

where $\tilde{T}_h = \sum_i m_{hi}^{-\theta} T_i$. This is the same $\tilde{T}$ that appears in Alviarez (2013) and Ramondo and Rodríguez-Clare (2013). Whereas T_i represents the average productivity of country i's firms, $\tilde{T}_h$ represents the productivity of country h's workers. As the average productivity of firms from country i increases (T_i goes up) or as i's firms are able to produce in country h more efficiently (m_{hi} goes down), workers in h employed by firms from i become more productive. This increases the aggregate productivity of h's workers ($\tilde{T}_h$ goes up). Analogously, the price of a tradable good that is actually purchased in country n is $\min_{h,i}\{p^T_{nhi}\}$ and has the distribution

$$G^T_n(p) = G^T_{nhi}(\min_{h,i}\{p^T_{nhi}\}) = 1 - \prod_{h=1}^{N}\prod_{i=1}^{N}[1 - G^T_{nhi}(p)] = 1 - \exp\{-[\sum_h \tilde{T}_h(c_h d_{nh})^{-\theta}]p^{\theta}\}$$

It must be the case that $G^T_n(p) \geq G^{NT}_h(p)$ for all $p > 0$ with equality only when trade is prohibitively expensive ($d_{nh} \to \infty$ for all $n \neq h$).

In country n, the price indices for tradable and nontradable goods are

$$P_n^T = \gamma[\sum_h \tilde{T}_h (c_h d_{nh})^{-\theta}]^{-\frac{1}{\theta}} \tag{2.2}$$

$$P_n^{NT} = \gamma(\tilde{T}_n^{-\frac{1}{\theta}} c_n d_{nn}) \tag{2.3}$$

where γ is equal to $[\Gamma(\frac{1-\sigma}{\theta}+1)]^{\frac{1}{1-\sigma}}$.[15] As with the distributions of actual prices, $P_n^T \leq P_n^{NT}$ with equality only when there is no trade. The composite price index is

$$P_n = (P_n^T)^{\alpha}(P_n^{NT})^{1-\alpha} \tag{2.4}$$

2.1.3 Trade and MP Flows

Before finding expressions for trade and MP flows, some preliminary steps are required. The probability that a firm from country i provides a nontradable good at the lowest price in country h is:

$$\begin{aligned}
\pi_{hi}^{NT} &= \Pr[p_{hi}^{NT}(v) \leq \min_j \{p_{hj}^{NT}(v); j \neq i\}] \\
&= \int_0^{\infty} \prod_{j \neq i} [1 - G_{hj}^{NT}(p)] dG_{hi}^{NT}(p) \\
&= \frac{m_{hi}^{-\theta} T_i}{\tilde{T}_h} \qquad (2.5)
\end{aligned}$$

This probability is simply the share of country i's contribution to the aggregate productivity in h. If MP were costless ($m_{hi} = 1$ for all h and i), π_{hi}^{NT} would simply be i's share of the world's stock of technology, $\sum_i T_i$. For tradables, the probability that a firm from

[15] Γ is the Gamma function which requires that $\sigma < 1 + \theta$. The price indices are derived in Appendix A.1.

country i producing in country h provides a good at the lowest price in country n is:

$$
\begin{aligned}
\pi_{nhi}^{T} &= \Pr[p_{nhi}^{T}(u) \leq \min_{q,r}\{p_{nqr}^{T}(u); qr \neq hi\}] \\
&= \int_{0}^{\infty} \prod_{qr\neq hi} [1 - G_{nqr}^{T}(p)] dG_{nhi}^{T}(p) \\
&= \frac{m_{hi}^{-\theta} T_i (c_h d_{nh})^{-\theta}}{\sum_j \tilde{T}_j (c_j d_{nj})^{-\theta}} \qquad (2.6)
\end{aligned}
$$

One can think of the numerator $m_{hi}^{-\theta} T_i (c_h d_{nh})^{-\theta}$ as a measure of the competitiveness in destination market n of goods produced in country h by firms originating from country i. This measure incorporates the average productivity of i's firms, the cost of inputs in h, MP costs from i to h, and trade costs from h to n. The denominator is just the sum of the numerator over all h and i and so can be interpreted as a measure of n's overall market competitiveness.

Turning to trade and MP flows, let X_{hi}^{NT} be country h's expenditure on nontradable goods produced by firms from country i and $X_{h}^{NT} = \sum_i X_{hi}^{NT}$ be country h's total expenditure on nontradable goods. Likewise, let X_{nhi}^{T} be country n's expenditure on tradable goods which are assembled in country h by firms from country i and $X_{n}^{T} = \sum_h \sum_i X_{nhi}^{T}$ be country n's total expenditure on tradable goods. Since there is a continuum of varieties with measure equal to one for both types of goods, the expenditure shares must be equal to the probabilities π_{hi}^{NT} and π_{nhi}^{T}, respectively:

$$
\frac{X_{hi}^{NT}}{X_{h}^{NT}} = \pi_{hi}^{NT} \qquad (2.7)
$$

$$
\frac{X_{nhi}^{T}}{X_{n}^{T}} = \pi_{nhi}^{T} \qquad (2.8)
$$

Equation (2.8) suggests an elegant interpretation of the expenditure shares. By algebraic manipulation,

$$\frac{X^T_{nhi}}{X^T_n} = \frac{\tilde{T}_h (c_h d_{nh})^{-\theta}}{\sum_j \tilde{T}_j (c_j d_{nj})^{-\theta}} \cdot \frac{m_{hi}^{-\theta} T_i}{\tilde{T}_h} = \underbrace{\left(\sum_i \pi^T_{nhi} \right)}_{\text{trade share}} \cdot \underbrace{\pi^{NT}_{hi}}_{\text{MP share}} \tag{2.9}$$

The first term on the right-hand side, $\sum_i \pi^T_{nhi}$, is equal to $\frac{\sum_i X^T_{nhi}}{X^T_n}$ and represents the share of n's total expenditure on tradable goods that is spent on goods produced in h (in other words, the trade share). The second term is country i's share of MP in h.[16] Thus, $\frac{X^T_{nhi}}{X^T_n}$ is simply the product of the bilateral trade share between n and h and the bilateral MP share between h and i.[17] Furthermore, from (2.9) it is evident that the MP share for tradable goods is the same as the MP share for nontradable goods. These properties are central to my empirical strategy which I discuss in Section 2.4.

Before moving on, consider the effect of MP on trade. If MP were prohibitively costly ($m_{hi} \to \infty$ for $h \neq i$), then the trade share $\frac{\tilde{T}_h (c_h d_{nh})^{-\theta}}{\sum_j \tilde{T}_j (c_j d_{nj})^{-\theta}}$ would collapse to equation (10) in Eaton and Kortum (2002) in which the $\tilde{T}$'s are replaced by T's. A country's export competitiveness depends on the productivity of the country's workers. Without MP, the productivity of a country's workers is determined by the productivity of that country's firms. But with MP, the productivity of a country's workers is also determined by the productivity of foreign multinationals producing in that country. Holding constant the cost of inputs, higher inward MP costs reduces the production of foreign multinationals within a country which in turn reduces the average productivity

[16] To see this, observe that $\frac{m_{hi}^{-\theta} T_i}{\tilde{T}_h} = \frac{\pi^T_{nhi}}{\sum_i \pi^T_{nhi}} = \frac{X^T_{nhi}}{\sum_i X^T_{nhi}}$ for all n.

[17] $\frac{X^T_{nhi}}{X^T_n}$ can also be viewed as the product of $\sum_h \pi^T_{nhi}$ (the share of tradables expenditure in n due to firms from i) and $\frac{\pi^T_{nhi}}{\sum_h \pi^T_{nhi}}$ (the share of country i's firms' sales to n that was produced in h).

of the country's workers and its export competitiveness.

2.1.4 Equilibrium

To close the model, the cost of inputs and the tariff structure must be specified. To begin, assume that the production technology for both tradable and nontradable goods is Cobb-Douglas, combining labor and intermediate inputs with cost shares β and $1-\beta$, respectively. Also, labor is fully mobile between tradable and nontradable sectors so that workers in both sectors earn the same wage. In addition, intermediate inputs are combined according to the CES aggregator in (2.1). With these assumptions, production costs in country h are

$$c_h = Bw_h^{\beta}P_h^{1-\beta} \tag{2.10}$$

where $B = \beta^{-\beta}(1-\beta)^{-(1-\beta)}$.

Tariffs are levied on the total CIF (cost, insurance, and freight) value of exports and all tariff revenue is returned to the representative consumer in the levying country as a lump-sum payment. Trade costs are comprised of a tariff component and a non-tariff component:

$$d_{nh} = (1+\tau_{nh})\delta_{nh}$$

where $\tau_{nh} \geq 0$ is the tariff imposed by country n on imports from h and δ_{nh} represents non-tariff trade barriers such as geography.

I am now in a position to solve the model. Wages for workers in the nontradable sector must be equal to labor's share of total expenditures on nontradables. Wages for workers in the tradable sector must be equal to labor's share of total expenditures on tradables less tariff revenues. Then, the total wages paid to workers are given by

$$w_h L_h^{NT} = \beta X_h^{NT} \tag{2.11}$$

$$w_h L_h^{T} = \beta \sum_n \left(\frac{1}{1+\tau_{nh}} \sum_i X_{nhi}^T \right) \tag{2.12}$$

where L_h^{NT} and L_h^T represent the size of the labor force (measured in efficiency units[18]) in the nontradable and tradable sectors, respectively. Let $L_h = L_h^{NT} + L_h^T$ denote the effective size of the total labor force in h.

Total expenditure is equal to the sum of expenditure on final goods and expenditure on intermediate inputs:

$$X_h = \underbrace{w_h L_h + \sum_s \left(\frac{\tau_{hs}}{1+\tau_{hs}} \sum_i X_{hsi}^T \right)}_{\text{expenditure on final goods}} + \underbrace{(1-\beta) X_h^{NT} + (1-\beta) \sum_n \left(\frac{1}{1+\tau_{nh}} \sum_i X_{nhi}^T \right)}_{\text{expenditure on intermediate inputs}} \tag{2.13}$$

Expenditure on final goods is equal to the sum of labor income, $w_h L_h$, and tariff revenues, $\sum_s \left(\frac{\tau_{hs}}{1+\tau_{hs}} \sum_i X_{hsi}^T \right)$. Expenditure on intermediate inputs is equal to inputs' share of expenditure on nontradable goods, $(1-\beta)X_h^{NT}$, plus inputs' share of expenditure on tradable goods before tariffs, $(1-\beta)\sum_n \left(\frac{1}{1+\tau_{nh}} \sum_i X_{nhi}^T \right)$. Since α is the Cobb-Douglas expenditure share for both tradable final goods and tradable intermediate inputs, X_h^T and X_h^{NT} must have the following proportional relationships to X_h:

$$X_h^T = \alpha X_h \tag{2.14}$$

$$X_h^{NT} = (1-\alpha) X_h \tag{2.15}$$

[18]Using efficiency units allows me to account for differences in capital between countries when I estimate the model.

Together, equations (2.8)-(2.13) imply

$$X_h = w_h L_h + \sum_s \left(\frac{\tau_{hs}}{1+\tau_{hs}} \sum_i X_{hsi}^T \right) + \frac{1-\beta}{\beta} w_h (L_h^{NT} + L_h^T)$$
$$= \frac{w_h L_h}{\beta} + \sum_s \left(\frac{\tau_{hs}}{1+\tau_{hs}} \sum_i \pi_{hsi}^T \right) X_h^T$$

In Eaton and Kortum (2002), total expenditure in h is equal to $\frac{w_h L_h}{\beta}$, which is national income plus expenditure on intermediate inputs. Here, total expenditure also includes tariff revenues. Substituting equation (2.14), the above equation can be solved for X_h:

$$X_h = \frac{1}{1-\alpha\left[\sum_s \left(\frac{\tau_{hs}}{1+\tau_{hs}} \sum_i \pi_{hsi}^T\right)\right]} \cdot \frac{w_h L_h}{\beta} \tag{2.16}$$

Next, substitution of (2.11) and (2.16) into (2.15) gives the share of labor in the nontradable sector:

$$\frac{L_h^{NT}}{L_h} = \frac{1-\alpha}{1-\alpha\left[\sum_s \left(\frac{\tau_{hs}}{1+\tau_{hs}} \sum_i \pi_{hsi}^T\right)\right]} \tag{2.17}$$

with $\frac{L_h^T}{L_h} = 1 - \frac{L_h^{NT}}{L_h}$. Note that $\frac{L_h^{NT}}{L_h} \geq 1-\alpha$ and $\frac{L_h^T}{L_h} \leq \alpha$ with equality only when tariffs are zero or when there is no trade.

Substituting equations (2.4) and (2.10) into the price indices in equations (2.2) and (2.3) gives

$$P_n^{NT} = \gamma B \tilde{T}_n^{-\frac{1}{\theta}} w_n^{\beta} (P_n^T)^{\alpha(1-\beta)} (P_n^{NT})^{(1-\alpha)(1-\beta)} d_{nn}$$
$$P_n^T = \gamma B [\sum_h \tilde{T}_h (w_h^{\beta} (P_h^T)^{\alpha(1-\beta)} (P_h^{NT})^{(1-\alpha)(1-\beta)} d_{nh})^{-\theta}]^{-\frac{1}{\theta}}$$

The first equation above can be solved for P^{NT} in terms of P^T. Doing so and substituting the result into the second equation gives

$$P_n^{NT} = [\gamma B \tilde{T}_n^{-\frac{1}{\theta}} w_n^{\beta} (P_n^T)^{\alpha(1-\beta)} d_{nn}]^{\frac{1}{\beta+\alpha(1-\beta)}} \tag{2.18}$$

$$P_n^T = [\gamma B d_{nn}^{(1-\alpha)(1-\beta)}]^{\frac{1}{\beta+\alpha(1-\beta)}} [\sum_h \tilde{T}_h^{\frac{1}{\beta+\alpha(1-\beta)}} (w_h^{\frac{\beta}{\beta+\alpha(1-\beta)}} (P_h^T)^{\frac{\alpha(1-\beta)}{\beta+\alpha(1-\beta)}} d_{nh})^{-\theta}]^{-\frac{1}{\theta}} \tag{2.19}$$

Given model parameters and wages, the system of equations described by (2.19) can generally be solved for P_1^T, P_2^T, ..., P_N^T using numerical methods. The nontradable and composite price indices in terms of wages and parameters then follow from (2.18) and (2.4), respectively. Substituting the price indices into

$$\sum_i \pi_{nhi}^T = \frac{\tilde{T}_h (c_h d_{nh})^{-\theta}}{\sum_k \tilde{T}_k (c_k d_{nk})^{-\theta}} = \frac{\tilde{T}_h (w_h^{\beta} P_h^{1-\beta} d_{nh})^{-\theta}}{\sum_k \tilde{T}_k (w_k^{\beta} P_k^{1-\beta} d_{nk})^{-\theta}}$$

gives the trade shares $\sum_i \pi_{nhi}^T$ in terms of wages and parameters. Substituting the resulting expression for $\sum_i \pi_{nhi}^T$ into (2.17) gives the labor shares in terms of wages and parameters.

The last step is to solve for wages themselves. Equations (2.8), (2.12), (2.14), and (2.16) can be combined to get an expression for the total income of workers in the tradable sector:

$$\begin{aligned} w_h L_h^T &= \beta \sum_n \left(\frac{1}{1+\tau_{nh}} X_n^T \sum_i \pi_{nhi}^T \right) \\ &= \sum_n \left(\frac{\frac{\alpha}{1+\tau_{nh}} \sum_i \pi_{nhi}^T}{1 - \left[\sum_s \tau_{ns} \left(\frac{\alpha}{1+\tau_{ns}} \sum_i \pi_{nsi}^T \right) \right]} w_n L_n \right) \end{aligned} \tag{2.20}$$

This is a nonlinear system of N equations in N wages. In Section 2.1.5, I describe the numerical method used to solve this system.

2.1.5 Computing the Equilibrium

I follow the procedure outlined in Alvarez and Lucas (2007) to compute the general equilibrium. Given wages $\mathbf{w} = \{w_1, w_2, \ldots, w_N\}$, equation (2.19) describes a system of equations

$$\{P_1^T, P_2^T, \ldots, P_N^T\} = f(P_1^T, P_2^T, \ldots, P_N^T; \mathbf{w})$$

where $f(\cdot; \mathbf{w})$ is a function mapping $\mathbf{R}^N \times \mathbf{R}^N \to \mathbf{R}^N$. Alvarez and Lucas show that $f(\cdot; \mathbf{w})$ is a contraction on a compact space. Beginning with $\mathbf{w}$ and initial values for the price indices, iterations of the price indices generated by applying $f(\cdot; \mathbf{w})$ converge monotonically to the solution. Once the price indices are computed, the trade shares and labor shares immediately follow.

Thus, given wages $\mathbf{w}$, solutions for the other variables can be obtained. There remains the question of how to find a $\mathbf{w}^*$ which is consistent with general equilibrium. Equation (2.20) can be rewritten as excess demand

$$Z_h(\mathbf{w}) = \left[\sum_n \left(\frac{\frac{\alpha}{1+\tau_{nh}} \sum_i \pi_{nhi}^T(\mathbf{w})}{1 - \left[\sum_s \tau_{ns} \left(\frac{\alpha}{1+\tau_{ns}} \sum_i \pi_{nsi}^T(\mathbf{w}) \right) \right]} w_n L_n \right) - w_h L_h^T(\mathbf{w}) \right] \frac{1}{w_h}$$

Computing the equilibrium is equivalent to the task of find $\mathbf{w}^*$ such that $Z_h(\mathbf{w}^*) = 0$ for $h = 1, 2, \ldots, N$. Given a wage vector normalized to satisfy $\sum_i w_i L_i = 1$ and the function

$$T(\mathbf{w})_j = w_j \left(1 + \frac{v Z_j(\mathbf{w})}{L_j} \right)$$

for some constant $v \in (0, 1]$ and $j = 1, 2, \ldots, N$, Alvarez and Lucas (2007) show that two properties hold. First, if $\sum_i w_i L_i = 1$ then $\sum_i T(\mathbf{w})_i L_i = 1$. Second, iterations of

$\mathbf{w}$ obtained by applying $T(\cdot)$ converge to $\mathbf{w}^*$.

2.1.6 Gains From Openness

Substituting equations (2.2) and (2.3) into equations (2.5) and (2.6) gives

$$\pi^T_{nhi} = \frac{T_i (c_h d_{nh} m_{hi})^{-\theta}}{(P^T_n)^{-\theta}\gamma^\theta}$$
$$\pi^{NT}_{hi} = \frac{T_i (c_h m_{hi})^{-\theta}}{(P^{NT}_n)^{-\theta}\gamma^\theta}$$

Applying (2.10) to the own shares gives expressions for wages deflated by the tradable and nontradable price indices:

$$\frac{w_n}{P^T_n} = (\gamma B)^{-\frac{1}{\beta}} \left(\frac{T_n}{\pi^T_{nnn}}\right)^{\frac{1}{\beta\theta}} \left(\frac{P^{NT}_n}{P^T_n}\right)^{-\frac{(1-\alpha)(1-\beta)}{\beta}}$$
$$\frac{w_n}{P^{NT}_n} = (\gamma B)^{-\frac{1}{\beta}} \left(\frac{T_n}{\pi^{NT}_{nn}}\right)^{\frac{1}{\beta\theta}} \left(\frac{P^T_n}{P^{NT}_n}\right)^{-\frac{\alpha(1-\beta)}{\beta}}$$

Then real wages are:

$$\frac{w_n}{P_n} = \left(\frac{w_n}{P^T_n}\right)^\alpha \left(\frac{w_n}{P^{NT}_n}\right)^{1-\alpha} = (\gamma B)^{-\frac{1}{\beta}} \left[\frac{T_n}{(\pi^T_{nnn})^\alpha (\pi^{NT}_{nn})^{1-\alpha}}\right]^{\frac{1}{\beta\theta}}$$

Recall that π^T_{nhi} can be decomposed into the trade share $\sum_i \pi^T_{nhi}$ multiplied by the MP share π^{NT}_{hi}. Therefore,

$$\frac{w_n}{P_n} = \left(\frac{w_n}{P^T_n}\right)^\alpha \left(\frac{w_n}{P^{NT}_n}\right)^{1-\alpha} = (\gamma B)^{-\frac{1}{\beta}} \left[\frac{T_n}{(\sum_i \pi^T_{nni})^\alpha (\pi^{NT}_{nn})}\right]^{\frac{1}{\beta\theta}}$$

In autarky, $\sum_i \pi^T_{nni} = \pi^{NT}_{nn} = 1$ so that the real wage is $\frac{w_n}{P_n} = (\gamma B)^{-\frac{1}{\beta}} T_n^{\frac{1}{\beta\theta}}$. The gains in going from autarky to MP-only are given by $(\pi^{NT}_{nn})^{-\frac{1}{\beta\theta}} = (\frac{T_n}{\tilde{T}_n})^{-\frac{1}{\beta\theta}}$. Similarly, the gains in going from autarky to trade-only are $(\sum_i \pi^T_{nni})^{-\frac{\alpha}{\beta\theta}} = \left(\frac{\sum_i X^T_{nni}}{X^T_n}\right)^{-\frac{\alpha}{\beta\theta}}$. Thus, the trade elasticity is $\frac{\alpha}{\beta\theta}$ and the MP elasticity is $\frac{1}{\beta\theta}$. This is a different result than in Ramondo and Rodríguez-Clare (2013) where the trade and MP elasticities were the same. The reason why the trade elasticity is smaller than the MP elasticity by a factor of α in my model is because there are goods which cannot be traded yet can still be supplied to a foreign country via MP.

2.2 Case Without Trade Costs or Nontradable Goods

In this section, I analyze a special case of the model to illustrate the relationship between trade, MP, and productivity. I assume that trade is costless ($d_{st} = 1$ and $\tau_{st} = 0$ for all s and t) but MP remains costly. I also assume that there is no nontradable sector ($\alpha = 1$). This implies that price indices are the same in all countries since all goods may be costlessly traded. The price index in (2.19) simplifies to

$$P = (\gamma B)^{\frac{1}{\beta}} \left(\sum_h \tilde{T}_h w_h^{-\beta\theta} \right)^{-\frac{1}{\beta\theta}} \tag{2.21}$$

Dropping the T-superscripts since all goods are tradable, π_{nhi} simplifies to

$$\pi_{nhi} = \frac{m_{hi}^{-\theta} T_i w_h^{-\beta\theta}}{\sum_j \tilde{T}_j w_j^{-\beta\theta}} \tag{2.22}$$

Note that π_{nhi} no longer varies by destination market n. For convenience, normalize the price index to 1 so that wages are now in real terms. Equation (2.20) simplifies to

$$w_h L_h = \left(\sum_i \pi_{nhi} \right) \left(\sum_n w_n L_n \right) \tag{2.23}$$

This states that a country's real income is the product of its export share (which is the same across destination markets under the assumptions of this section) and the real value of global production. From equations (2.22) and (2.23), an expression for relative real wages can be obtained:

$$\frac{w_s}{w_t} = \left[\frac{\tilde{T}_s/L_s}{\tilde{T}_t/L_t}\right]^{\frac{1}{1+\beta\theta}} \tag{2.24}$$

Taking the log-derivative of (2.24) with respect to real wages in both countries and technology in s,

$$(1+\beta\theta)\left(\frac{w_s}{w_t}\right)^{1+\beta\theta}(\hat{w}_s - \hat{w}_t) = \left[\frac{\tilde{T}_s/L_s}{\tilde{T}_t/L_t}\right]\left[\frac{T_s}{\tilde{T}_s} - \frac{m_{ts}^{-\theta}T_s}{\tilde{T}_t}\right]\hat{T}_s$$

Substituting (2.24) into the above equation,

$$\hat{w}_s - \hat{w}_t = \frac{1}{1+\beta\theta}\left(\frac{T_s}{\tilde{T}_s} - \frac{m_{ts}^{-\theta}T_s}{\tilde{T}_t}\right)\hat{T}_s \tag{2.25}$$

Next, take the total derivative of the normalized price index in (2.21) with respect to real wages and T_s to obtain:

$$\sum_h \left(m_{hs}^{-\theta}T_s w_h^{-\beta\theta}\hat{T}_s - \beta\theta\tilde{T}_h w_h^{-\beta\theta}\hat{w}_h\right) = 0 \tag{2.26}$$

From (2.25), $\hat{w}_t$ can be expressed in terms of $\hat{w}_s$ and $\hat{T}_s$ for all $t \neq s$. Substituting these into (2.26) gives $\hat{w}_s$ as a function of $\hat{T}_s$. Finally, plugging this back into (2.25) delivers the technology elasticities

$$\varepsilon_{w_t,T_s} = \frac{\hat{w}_t}{\hat{T}_s} = \underbrace{\frac{1}{1+\beta\theta}\frac{m_{ts}^{-\theta}T_s}{\tilde{T}_t}}_{\text{productivity effect}} + \underbrace{\frac{1}{\beta\theta(1+\beta\theta)}\sum_h \frac{X_{ths}}{X_t}}_{\text{efficiency effect}}$$

for $t = 1, 2, \ldots, N$.

These technology elasticities show that an increase in the average productivity of s's firms has two effects on real wages around the world. The first is a productivity effect due to country s's firms becoming more competitive thereby raising labor demand in all countries where s's firms produce. This effect is greater in countries for which country s's firms take up a larger MP share. If MP were prohibitively costly such as in trade-only models, then all of the gains from the productivity effect accrue to workers in the country where the productivity growth occurred. Thus, MP provides an additional channel for the benefits of foreign productivity growth to be transmitted.

The second effect is an efficiency effect coming from a decrease in world prices. Real wage gains due to efficiency are increasing in the share of t's expenditure spent on output produced by s's firms. All countries gain equally from the efficiency effect since $\sum_h \frac{X_{ths}}{X_t}$ is the same for all t.[19] The gains need not be the same, however, in the general model with trade costs and nontradable goods.

Both the productivity and efficiency effects are decreasing in β (the share of labor in production) and θ (the Fréchet dispersion parameter) but are increasing in T_s. Accordingly, productivity growth of a country's firms will have larger effects on real wages around the world if the firms have higher average productivity to begin with. In a later section, I verify that this statement holds in the general case of the model by comparing the effects of productivity growth in US firms and in China's firms.

[19] This is because $\sum_h \frac{X_{ths}}{X_t} = \frac{\sum_h m_{hs}^{-\theta} T_s (c_h d_{th})^{-\theta}}{\sum_j \tilde{T}_j (c_j d_{tj})^{-\theta}} = \frac{\sum_h m_{hs}^{-\theta} T_s w_h^{-\beta\theta}}{\sum_j \tilde{T}_j w_j^{-\beta\theta}}$ is independent of t.

2.3 Data

Bilateral data on MP comes from the UNCTAD data on sales of foreign affiliates in all non-financial sectors. Unfortunately, the UNCTAD data is not broken down by sector or industry and contains missing or potentially erroneous zero entries across countries and across years. To deal with the second issue issue, I rely on the dataset compiled by Ramondo et al. (2013) which uses Thomson and Reuters M&A data to extrapolate missing affiliate sales when possible. The extrapolated data is averaged over 1996-2001 and covers 61 countries. Out of $61 \times 60 = 3660$ possible observations, the original UNCTAD data contains 1224 missing observations and 1836 observations reporting zero affiliate sales. The extrapolated data is able to reduce the number of missing observations to 787 and the number of zero entries to 1618.

To estimate the model, I use a subset containing 40 of the 61 countries. A country was chosen to be in the subset if it had positive affiliate sales in at least 3 other countries.[20] The countries contained in the subset are listed in Table 2.1. Together, these countries accounted for 91.6% of world GDP in 2000. One limitation of this dataset is that it does not include multinationals' home sales.[21] Not including these own-country observations, there are a possible $40 \times 39 = 1560$ observations in the subset of which 357 are missing and 199 are reported as having zero affiliate sales.

Data on bilateral goods trade comes from UN Comtrade and is also averaged

[20] Four countries (Iran, Israel, Slovakia, and Taiwan) met this condition but were excluded from the subset for other reasons.

[21] This rules out the possibility of normalizing foreign affiliate sales by domestic affiliate sales as is common in MP gravity regressions.

Country	MP Partners	
	Aff. Rev. ≥ 0	Aff. Rev. > 0
Argentina	22	13
Australia	39	37
Austria	34	34
Belgium	38	37
Brazil	27	20
Bulgaria	23	5
Canada	39	39
Chile	17	3
China	31	29
Czech Republic	33	27
Denmark	37	36
Finland	37	36
France	39	39
Germany	39	39
Great Britain	39	39
Greece	33	29
Hungary	22	15
India	34	30
Indonesia	17	3
Ireland	36	36
Italy	39	39
Japan	37	37
Malaysia	4	3
Mexico	29	17
Netherlands	39	38
New Zealand	7	3
Norway	38	38
Poland	18	13
Portugal	29	28
Russia	35	22
South Africa	6	3
South Korea	29	29
Spain	38	38
Sweden	37	37
Switzerland	39	39
Thailand	14	3
Turkey	27	14
United States	39	39
Uruguay	33	7
Venezuela	30	11

Table 2.1: Columns 2 and 3 report the number of (outward) MP partners for which affiliate revenue is reported and the number of MP partners for which affiliate revenue is positive.

over 1996-2001. Averaging the trade data reduces the influence of year-to-year fluctuations and of trade imbalances. For the value of a country's non-exported production, I subtract the value of total exports to the rest of the world from GDP. Data on tariffs is from the UNCTAD TRAINS database. Tariffs are measured using effectively applied rates and domestic tariffs are set to zero.[22] Bilateral data commonly used in gravity models (such as bilateral distance, shared common language, and shared border) are from CEPII. Since the MP data is not available by sector or industry, all the data used in this paper is at the country level.

2.4 Estimation

Non-tariff trade costs and MP costs are not directly observable. To get around this, I follow the standard approach in the literature and use proxies:

$$\ln d_{nh} = \ln(1+\tau_{nh}) + \delta_{dist} \ln \mathrm{dist}_{nh} + \delta_{lang} D_{nh}^{\mathrm{lang}} + \delta_{bord} D_{nh}^{\mathrm{bord}} + \delta_{dom} D_{nh}^{\mathrm{dom}} + \dots$$

$$\ln m_{hi} = \mu_{dist} \ln \mathrm{dist}_{hi} + \mu_{lang} D_{hi}^{\mathrm{lang}} + \mu_{bord} D_{hi}^{\mathrm{bord}} + \dots$$

where dist_{st} is the distance between s and t. The coefficients δ_{lang} and μ_{lang} (δ_{bord} and μ_{bord}) belong to dummy variables that take a value of 1 if the two countries share a common official language (common border).[23] The coefficient δ_{dom} belongs to a dummy variable which is 1 only if $n = h$ and is meant to capture the effect of domestic "trade".[24]

[22] Australia, Brazil, China, Indonesia, and Thailand reported nonzero domestic tariffs. I ignored these and used zero tariffs anyway.

[23] Historical or cultural ties between countries can manifest themselves in other ways besides a shared language. I tested specifications for $\ln d_{nh}$ and $\ln m_{hi}$ that included dummies for colonial or other historical ties between countries but the results were not meaningfully different.

[24] There is no μ_{dom} since own-country MP is not observed in the data. This should not be an issue since $m_{hh} = 1$ by assumption.

Also included in the specifications for $\ln d_{nh}$ and $\ln m_{hi}$ are dummy variables indicating whether both countries are members of the same trade bloc (EU, NAFTA, MERCOSUR, ASEAN, or CEFTA) or monetary union (EMU) in 1996.

By measuring labor in efficiency units, I can at least partially account for differences in capital accumulation across countries. The trade-off is that $\mathbf{L} = \{L_1, L_2, \ldots, L_N\}$ must also be estimated. Rather than estimate $\mathbf{L}$ directly, I back out the size of the effective labor force in each country by solving for wages and then using nominal GDP data as a calibration target for national factor income.

I select values for the tradable goods expenditure share α and the labor cost share β. For the countries in my sample, the median value-added of services as a percentage of GDP in 2000 was approximately 65%. Since this figure also includes tradable services, I choose a value of $\alpha = 0.5$. Alvarez and Lucas (2007) calibrate the labor cost share in the tradable sector (comprising agriculture, mining, and manufacturing) to 0.5 and in the nontradable sector to 0.75. As I use β to represent the labor cost share in the overall economy, I take the average using 0.35 and 0.65 as weights to get $\beta = 0.6625$.

The parameters which need to be estimated are: the Fréchet average productivity parameters $\mathbf{T} = \{T_1, T_2, \ldots, T_N\}$, the Fréchet dispersion parameter θ, the proxies for non-tariff trade costs $\boldsymbol{\delta} = \{\delta_{dist}, \delta_{lang}, \delta_{bord}, \delta_{dom}, \ldots\}$ and for MP costs $\boldsymbol{\mu} = \{\mu_{dist}, \mu_{lang}, \mu_{bord}, \ldots\}$, and the effective labor force sizes $\mathbf{L}$.

The value of exports from h to n is the the expenditure in n on tradable goods produced in h (regardless of the MP source) less the tariffs collected:

$$\text{Trade}_{nh} = \frac{1}{1+\tau_{nh}} \sum_i X_{nhi}^T$$

Using Equation (2.9), the trade value can be written as

$$\text{Trade}_{nh} = \frac{d_{nh}^{-\theta}}{1+\tau_{nh}} \cdot \underbrace{\tilde{T}_h c_h^{-\theta}}_{\text{varies by } h} \cdot \underbrace{\frac{X_n^T}{\sum_j \tilde{T}_j (c_j d_{nj})^{-\theta}}}_{\text{varies by } n}$$

which can be estimated with

$$\begin{aligned} \ln(\text{Trade}_{nh}) = &-(\theta+1)\ln(1+\tau_{nh}) - \theta\delta_{dist} \cdot \ln \text{dist}_{nh} - \theta \boldsymbol{\delta}' \mathbf{D}_{nh} \\ &+ \sum_{s=1}^{N} D_s^{\text{Dest}} + \sum_{t=1}^{N} D_t^{\text{Host}} + \varepsilon_{nh} \end{aligned} \tag{2.27}$$

where ε is the error term and D^{Dest} and D^{Host} are two sets of country fixed effects absorbing level differences between MP-host countries and destination markets, respectively. As all the countries in my sample trade with each other, I am able to estimate (2.27) using OLS. One advantage of including tariffs is that θ can be estimated directly[25]. Once θ is estimated, the non-tariff trade cost proxies $\boldsymbol{\delta}$ follow.

The remaining parameter estimates come from the MP data. I begin with the share of production in h due to firms from i:

$$\text{MP Share}_{hi} = \frac{\text{MP}_{hi}}{\text{GDP}_h} = \frac{1}{\beta}\left(\frac{m_{hi}^{-\theta} T_i}{\tilde{T}_h}\right) \tag{2.28}$$

This equation, which I derive in Appendix A.2, can be estimated with

$$\ln(\text{MP Share}_{hi}) = \mu_0 - \theta\mu_{dist} \ln \text{dist}_{hi} - \theta \boldsymbol{\mu}' \mathbf{D}_{hi} + \sum_{s=1}^{N} D_s^{\text{Source}} + \sum_{t=1}^{N} D_t^{\text{Host}} + \varepsilon_{hi} \tag{2.29}$$

[25] Previous studies (Arkolakis et al., 2013; Spearot, 2014) have used tariffs to estimate Pareto shape parameters.

where D^{Source} is a set of MP-source country fixed effects and D^{Host} is a set of MP-host country fixed effects. Since approximately 16.5% of non-missing bilateral MP shares are zeros, I estimate (2.29) using Pseudo Poisson Maximum Likelihood (PPML).[26] For each $s = 1, 2, \ldots, N$, the technology stock T_s is estimated by exponentiating the coefficient of D_s^{Source}.

2.4.1 Estimation Results

Estimates for the regression coefficients are reported in Table 2.2. An increase in tariffs of 1% is estimated to decrease trade by 7.714%. This gives an estimated value of $\hat{\theta} = 7.714 - 1 = 6.714$.[27] The estimated coefficients indicate that distance impedes trade moreso than MP. Sharing a common official language promotes MP more than it does trade. Countries produce approximately 16 times as much for their home market as they export to their average trade partner. Shared borders have a positive impact on trade flows but their effect on MP is not significantly different from zero.

The results for trade agreements are mixed. MERCOSUR and CEFTA promote trade and MP between their member countries, whereas all else constant mutual EU or ASEAN membership actually reduces trade flows. One possible explanation for EU and ASEAN trade flows is that membership in the blocs requires countries to lower tariff barriers more than they would like, so to compensate they raise non-tariff barriers not covered by the trade agreements.

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[26] Silva and Tenreyro (2006) show that PPML is well-suited to measuring trade flows exhibiting heteroskedasticity and zeros.

[27] This is consistent with earlier estimates. In their preferred specification, Eaton and Kortum (2002) use $\theta = 8.28$.

Covariate	Dependent Variable	
	log(Trade)	log(MP Share)
log(Tariff)	-7.714***	
	(1.5508)	
log(Distance)	-1.068***	-0.6250***
	(0.0391)	(0.103)
Common Language	0.437***	0.6190***
	(0.0887)	(0.218)
Domestic	2.692***	
	(0.2360)	
Shared Border	0.232*	0.0549
	(0.1245)	(0.216)
EU	-0.353**	-0.2710
	(0.0951)	(0.273)
NAFTA	0.423	-0.5299
	(0.3681)	(0.366)
MERCOSUR	0.390	1.1165***
	(0.3763)	(0.378)
ASEAN	-1.249***	
	(0.4631)	
CEFTA	1.465***	1.3439***
	(0.1919)	(0.449)
EMU	-0.197*	0.0155
	(0.1055)	(0.250)
Observations	1600	1203
Method	OLS	PPML
Country Fixed Effects	✓	✓
Robust SE	✓	✓

Table 2.2: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.1$. Standard errors are in parentheses. EMU stands for the European Monetary Union.

Parameter	Min	Median	Mean	Max
$d_{nh}(n \neq h)$	2.127	4.435	4.242	6.294
d_{nn}	1.130	1.691	1.663	2.183
$m_{hi}(h \neq i)$	1.263	2.302	2.217	2.510
m_{hh}	1	1	1	1

Table 2.3: Trade and MP costs

Bilateral trade and MP costs are computed from the coefficients reported in Table 2.2. Cross-border trade costs (d_{nh} for $n \neq h$) range from 2.131 to 6.673 with a median value of 4.463. Internal "trade" costs (d_{nn}) range from 1.130 to 2.183 with a median value of 1.691. MP costs (m_{hi} for $h \neq i$) range from 1.272 up to 2.581 with a median value of 2.362. These costs are summarized in Table 2.3.

If two countries had trade and MP costs equal to these median values, it would mean that serving the foreign market through exporting would increase costs by a factor of 4.435 while serving the foreign market through horizontal FDI (incurring both MP and internal "trade" costs) would increase costs by a factor of $2.302 \times 1.691 = 3.893$. By this crude measure, MP is less costly than trade. Of course, the choice between these two modes of economic interaction depends on specific bilateral trade and MP costs and differences in production costs.

Baseline estimates for the country-level parameters are reported in Table 2.4. In column 2, the US, Japan, and Germany are estimated to have the highest levels of T. The US itself accounts for 49% of the total technology stock of the countries in my sample. At first glance, it may be surprising that the US accounts for such a large portion of the world's technology stock. However, Figure 2.1 shows a clear linear

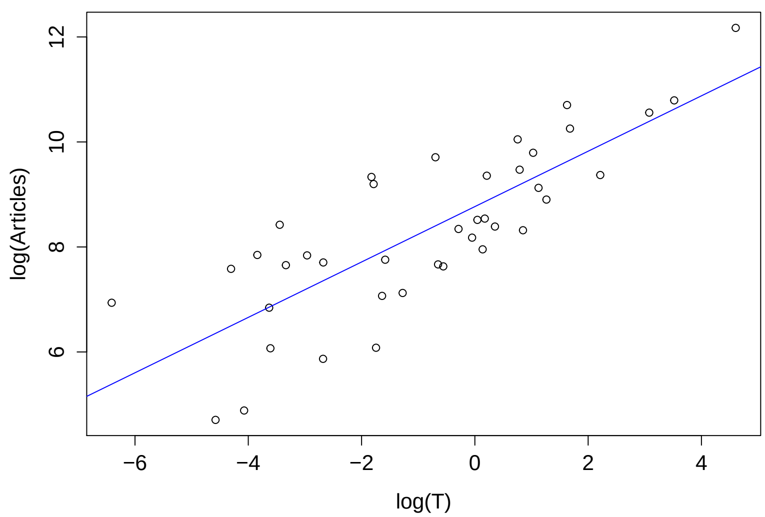

Figure 2.1: Number of articles published in research journals (1990-2001)

relationship between the estimates of T and each country's average number of research articles published in scientific and technical journals from 1990-2001.[28] As the figure shows, the extrapolated US technology stock is even higher than its actual value.

Each country's available technology $\tilde{T}$ is computed using the estimated MP costs and technology stocks T and is reported in column 3 of Table 2.4. By construction, $\tilde{T} > T$ for each country since hosting MP raises the productivity of a country's workers. Furthermore, the ratio $\frac{\tilde{T}}{T}$ is increasing in T as shown in Figure 2.2. The reason is simply that countries with high T (like the US) will have lower $\frac{\tilde{T}}{T}$ since the denominator is larger. This means that hosting MP raises the productivity of a country's workers

[28]The data on the number of research articles is from the World Development Indicators. In addition to the number of research articles, I also looked at patent applications filed by residents of each country. However, patent application data is missing for many country-years.

Country	T	$\tilde{T}$	L	c
Argentina	0.52	1.17	6.65	73.34
Australia	2.14	2.87	7.81	73.63
Austria	1.08	2.61	2.92	88.28
Belgium	1.21	4.22	2.86	99.05
Brazil	0.74	1.41	15.36	69.12
Bulgaria	0.00	1.12	0.14	104.25
Canada	2.09	4.78	10.52	83.31
Chile	0.03	0.67	1.47	75.93
China	0.16	1.00	27.18	61.55
Czech Republic	0.02	1.61	0.63	107.29
Denmark	1.46	2.80	2.14	94.04
Finland	2.57	3.69	1.74	92.26
France	5.45	7.04	21.71	81.84
Germany	21.40	22.83	24.59	96.02
Great Britain	5.75	7.59	19.57	86.32
Greece	0.07	0.98	2.28	77.96
Hungary	0.02	1.34	0.50	106.49
India	0.16	1.16	8.86	74.67
Indonesia	0.02	0.61	4.54	61.39
Ireland	0.29	2.10	1.21	92.46
Italy	2.81	3.94	19.54	77.24
Japan	32.95	33.49	46.90	97.98
Malaysia	0.06	0.68	1.95	70.52
Mexico	0.56	1.28	10.62	73.39
Netherlands	9.61	11.37	3.98	107.82
New Zealand	0.05	0.81	1.02	79.44
Norway	1.11	2.51	2.31	87.38
Poland	0.03	1.38	2.19	91.09
Portugal	0.20	1.23	1.95	81.26
Russia	0.50	1.56	6.62	70.62
South Africa	0.19	1.03	2.55	75.82
South Korea	1.02	1.95	7.76	82.59
Spain	1.35	2.43	10.86	74.32
Sweden	3.27	4.45	3.53	89.67
Switzerland	3.27	5.48	2.92	102.33
Thailand	0.03	0.69	3.02	69.40
Turkey	0.04	1.05	4.25	73.95
United States	100.00	100.46	100.00	100.00
Uruguay	0.01	0.77	0.30	97.51
Venezuela	0.17	1.13	1.66	81.78

Table 2.4: Values for T, L, and c are scaled so that the United States has a value of 100.

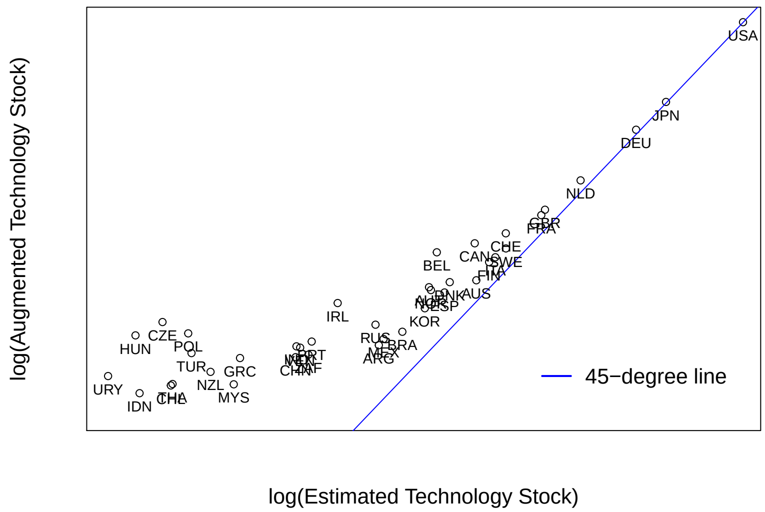

Figure 2.2: MP increases the technology available to countries

more in countries with low values of T. As a result, US share of technology falls from nearly half to 40% when measured as $\tilde{T}$ instead of T.

Columns 4 and 5 report the size of the labor force in efficiency units and the cost of production in each country. The US has the largest labor force in the sample followed by Japan, China, and Germany. With regards to production costs, the US is expensive with only five countries in the sample having higher production costs. Interestingly, Bulgaria, the Czech Republic, and Hungary rank among the five most expensive production locations. This is due to labor being measured in efficiency units. Wages are therefore per efficiency unit of labor rather than per worker, so countries with little capital tend to have higher wages. Indonesia, China, Brazil, and Thailand are the lowest-cost production locations.

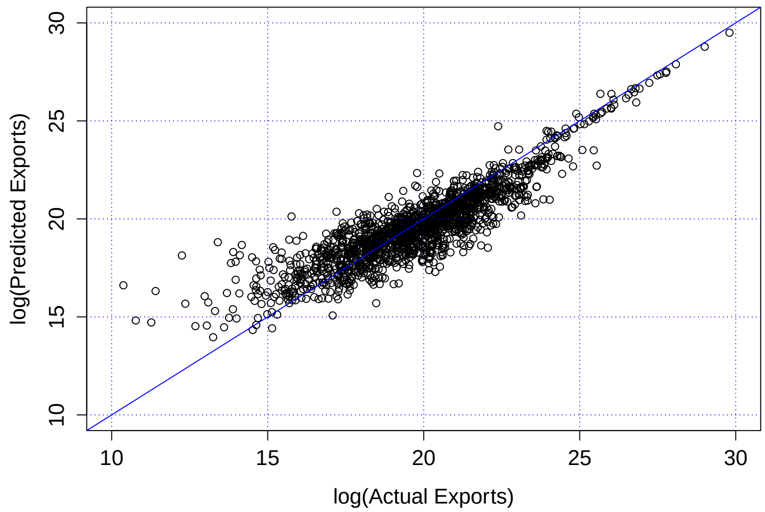

Figure 2.3: Actual versus predicted exports

Parameter	Value
α	0.5
β	0.6625
θ	6.714
T	Table 2.4
L	Table 2.4
$-\theta\boldsymbol{\delta}$	Table 2.2
$-\theta\boldsymbol{\mu}$	Table 2.2

Table 2.5: Calibrated parameters

Using these estimates, one can compute the equilibrium. Doing so yields predicted bilateral export flows which I plot against actual export flows in Figure 2.3. Table 2.5 summarizes the calibrated parameters.

2.5 Counterfactuals

In this section, I conduct three counterfactuals to better understand the effects of shocks to technology and trade and MP costs. First, I compare the effects of technology growth in the US and in China. Previous papers (Eaton and Kortum, 2002; Tintelnot, 2013) estimate the effects of the former, but I argue that the US is very much an outlier in terms of technology. Second, I separate the effects of tariff reductions following China's accession to the WTO in 2001 from the effects of its technology growth over the same period. Lastly, I consider the potential effects of the proposed Trans-Pacific Partnership.

2.5.1 Technology Growth in the US and in China

In Section 2.2, I used a special case of the model to analyze the effects of foreign technology growth. I return to this topic now that I have parameter estimates for the general model. Table 2.6 reports the results of hypothetical 20% increases in the technology stocks of the US and China under two different scenarios: fully-open (trade and MP) and trade-only.

Explaining columns 3 and 4 (and 6 and 7) requires a bit of effort. Column 3 reports the relative gains from US technology growth in the fully-open scenario. Column 4 reports the relative gains from US technology growth in the trade-only scenario. *Both columns 3 and 4* are normalized so that the value for the US *in column 2* has a value of 100. The results are consistent with Tintelnot (2013) in that relative gains due to an

Country	(i) Increase in T_{US}			(ii) Increase in T_{China}		
	With MP		No MP	With MP		No MP
	$\%\Delta(w/P)$	US=100		$\%\Delta(w/P)$	CH=100	
Argentina	1.309	31.491	0.071	0.001	0.188	0.037
Australia	0.682	16.397	0.082	0.001	0.147	0.139
Austria	0.687	16.523	0.096	0.001	0.173	0.139
Belgium	0.462	11.124	0.069	0.001	0.102	0.086
Brazil	1.164	28.004	0.068	0.001	0.166	0.037
Bulgaria	1.452	34.944	0.323	0.003	0.391	0.415
Canada	2.127	51.179	4.667	0.001	0.075	0.067
Chile	2.278	54.819	0.206	0.002	0.332	0.114
China	1.315	31.649	0.041	0.701	100.000	594.303
Czech Republic	1.114	26.805	0.122	0.002	0.256	0.146
Denmark	0.679	16.332	0.096	0.001	0.164	0.127
Finland	0.505	12.140	0.155	0.001	0.167	0.255
France	0.286	6.879	0.056	0.000	0.064	0.062
Germany	0.091	2.186	0.042	0.000	0.027	0.050
Great Britain	0.501	12.045	0.080	0.000	0.059	0.052
Greece	1.618	38.932	0.123	0.003	0.415	0.205
Hungary	1.283	30.875	0.119	0.002	0.307	0.152
India	1.993	47.951	0.059	0.004	0.576	0.242
Indonesia	1.684	40.510	0.122	0.006	0.869	0.580
Ireland	1.832	44.073	0.322	0.001	0.203	0.198
Italy	0.455	10.936	0.050	0.001	0.105	0.064
Japan	0.042	1.010	0.015	0.000	0.053	0.138
Malaysia	1.558	37.492	0.117	0.011	1.601	0.966
Mexico	1.342	32.284	0.301	0.002	0.226	0.047
Netherlands	0.180	4.337	0.064	0.000	0.048	0.074
New Zealand	2.455	59.070	0.175	0.003	0.400	0.208
Norway	0.777	18.704	0.138	0.001	0.191	0.173
Poland	1.268	30.519	0.077	0.002	0.304	0.106
Portugal	1.634	39.317	0.181	0.002	0.288	0.150
Russia	1.071	25.776	0.149	0.003	0.374	0.390
South Africa	2.136	51.389	0.149	0.002	0.284	0.123
South Korea	0.677	16.288	0.029	0.006	0.824	0.610
Spain	0.817	19.656	0.096	0.001	0.156	0.090
Sweden	0.430	10.354	0.114	0.001	0.126	0.169
Switzerland	0.349	8.390	0.064	0.001	0.082	0.077
Thailand	1.631	39.231	0.100	0.007	1.018	0.644
Turkey	1.499	36.075	0.123	0.003	0.405	0.202
United States	4.156	100.000	100.289	0.000	0.007	0.020
Uruguay	1.946	46.831	0.166	0.002	0.287	0.087
Venezuela	2.348	56.492	0.416	0.002	0.244	0.125

Table 2.6: Columns 2 and 5 report percentage welfare gains due to 20% technology improvement in the US and in China. Gains in columns 3 and 4 (6 and 7) are scaled relative to US (China) gains in column 2 (5).

increase in US technology are substantially higher in the fully-open scenario compared to the trade-only scenario.

However, this is something of a best-case scenario since the US accounts for such a large portion of world technology. The analysis of Section 2.2 predicts that productivity growth in a country with a smaller technology stock will have more muted productivity and efficiency effects on other countries. Indeed, I find that the results differ along two dimensions when technology growth occurs instead in China. First, the gains in column 5 are smaller than the gains in column 2. Even China benefits nearly twice as much with an increase in US technology than with an increase in its own technology. Second, the gains in column 6 are of roughly the same order of magnitude as the gains in column 7. This suggests that the ability of MP to spread the benefits of technology growth depends very much on the source of the technology growth.

This counterfactual considers the effects of a modest 20% increase in China's technology. Actual technology growth in China has been far more dramatic. In the next counterfactual, I separate the effect of China's technology increasing to its 2009 level from the effect of tariff reductions that ocurred over the same period.

2.5.2 China's Accession to the WTO

Since joining the WTO in 2001, China has enjoyed lower tariffs directed against its exports. At the same time, China has lowered its own tariff barriers towards fellow WTO members. What are the effects of these tariff reductions? How do they compare to the effects of China's dramatic increase in R&D spending? These questions are the subject of this counterfactual, in which I change China's technology level and tariffs involving China from their 1996-2001 values to their 2009 values. I explore the effects of these changes first in isolation and then jointly, assuming nothing else changes in the world.

Over the post-accession period, China reduced the tariffs levied against every country in the sample with cuts ranging from 4.76 percentage points (Venezuela) to 15.96 percentage points (Thailand). The tariffs facing China's exports fell in every country with the exception of Japan, with reductions ranging up to 21.52 percentage points. To replicate China's technology growth, I multiple T_{China} by 4.85. To arrive at this number, I assume that the technology stock in any year is linearly related to the number of research articles published in scientific and technical journals over a trailing five-year period. Using data from World Development Indicators, I total the number of articles published by researchers in China over a trailing five-year window for each year from 1996 to 2001 and for 2009. The ratio of the 2009 total (287325) to the average of the 1996-2001 totals (59274) gives a multiple of 4.85. This is consistent with Hsieh and Ossa (2011), who estimate that average productivity across industries in China increased by a factor of 4.72 from 1995-2007.

The results of this counterfactual are reported in Table 2.7. In column 3, reductions in China's tariffs increase real wages in China by 0.20%. All countries benefit from greater access to China, but the benefit is generally increasing in the size of the bilateral tariff reduction and in the country's proximity to China. Malaysia, which is close to China, shares with China an official common language, and experienced one of the largest bilateral tariff reductions, benefits slightly more than China itself. To observe the effect of distance, note that China reduced tariffs against Argentina, Hungary, and South Korea by approximately the same amount but the gains for South Korea are notably greater.

Reductions in the tariffs facing Chinese exports raises real wages in China by 0.066% (column 5). Most countries benefit from increased exposure to exports from China. The exceptions are those countries that reduced tariffs the least, Japan and Switzerland. India, which reduced tariffs the most, experienced the largest benefit (moreso than China itself).

Increasing China's technology to its 2009 level raises welfare in China by 11.3% (column 6). All countries benefit from this increase but 88% of the worldwide gains from China's technology growth accrue to China.[29] In general, the greatest gains are enjoyed by those countries in close proximity to China. The exception is Japan, which despite being near China relies primarily on its large stock of native technology in production.

When ocurring simultaneously, these changes increase real wages in China by 11.6% (column 7). Though tariff reductions do have a positive effect on real wages in China, the vast majority of the increase can be attributed to China's technological advancement. All other countries are better off due to these changes with the smallest gains going to the most technologically-advanced countries (the US, Japan, Germany).

[29] Using a trade-only framework, Hsieh and Ossa (2011) find less of a spillover effect. They report that only 3.0% of the worldwide gains accrue to the rest of the world.

Country	(i) World → China		(ii) China → World		(iii) $T_{\text{China}} \uparrow$	(iv) All
	$\Delta\tau$	$\%\Delta(w/P)$	$\Delta\tau$	$\%\Delta(w/P)$	$\%\Delta(w/P)$	$\%\Delta(w/P)$
Argentina	-9.43	0.0048	-2.03	0.0007	0.0251	0.0311
Australia	-8.23	0.0159	-2.19	0.0040	0.0192	0.0412
Austria	-7.10	0.0136	-1.40	0.0020	0.0227	0.0393
Belgium	-5.96	0.0067	-1.40	0.0015	0.0134	0.0220
Brazil	-7.68	0.0039	-1.32	0.0004	0.0222	0.0268
Bulgaria	-9.84	0.0393	-12.62	0.0655	0.0515	0.1834
Canada	-8.22	0.0077	-1.76	0.0015	0.0098	0.0198
Chile	-13.52	0.0180	-7.35	0.0102	0.0444	0.0783
China	0.00	0.1951	0.00	0.0663	11.2626	11.5600
Czech Republic	-8.40	0.0128	-3.67	0.0056	0.0340	0.0550
Denmark	-7.62	0.0136	-1.40	0.0019	0.0215	0.0382
Finland	-7.28	0.0274	-1.40	0.0041	0.0212	0.0551
France	-7.84	0.0070	-1.40	0.0010	0.0083	0.0170
Germany	-7.70	0.0057	-1.40	0.0008	0.0034	0.0104
Great Britain	-7.27	0.0054	-1.40	0.0010	0.0077	0.0145
Greece	-7.39	0.0172	-1.40	0.0025	0.0552	0.0762
Hungary	-8.97	0.0133	-9.01	0.0196	0.0409	0.0817
India	-7.88	0.0229	-21.52	0.0843	0.0766	0.2145
Indonesia	-15.47	0.1068	-6.61	0.0435	0.1151	0.2948
Ireland	-7.02	0.0172	-1.40	0.0032	0.0266	0.0485
Italy	-8.53	0.0077	-1.40	0.0010	0.0139	0.0233
Japan	-8.40	0.0171	0.16	-0.0010	0.0065	0.0231
Malaysia	-15.11	0.1961	-6.50	0.0784	0.2116	0.5400
Mexico	-7.43	0.0047	-6.44	0.0040	0.0303	0.0406
Netherlands	-7.02	0.0076	-1.40	0.0013	0.0062	0.0157
New Zealand	-12.08	0.0310	-3.05	0.0064	0.0532	0.0958
Norway	-7.14	0.0171	-2.84	0.0066	0.0249	0.0515
Poland	-7.11	0.0080	-10.13	0.0148	0.0406	0.0691
Portugal	-8.05	0.0146	-1.40	0.0021	0.0382	0.0562
Russia	-5.53	0.0293	-2.45	0.0111	0.0487	0.0928
South Africa	-7.01	0.0106	-2.84	0.0038	0.0378	0.0538
South Korea	-9.20	0.0783	-0.48	0.0014	0.1083	0.1929
Spain	-7.71	0.0095	-1.40	0.0014	0.0206	0.0323
Sweden	-7.36	0.0182	-1.40	0.0028	0.0162	0.0388
Switzerland	-7.08	0.0076	-0.00	-0.0006	0.0107	0.0175
Thailand	-15.96	0.1269	-7.19	0.0509	0.1349	0.3480
Turkey	-8.45	0.0178	-3.91	0.0090	0.0538	0.0848
United States	-8.38	0.0024	-0.64	0.0001	0.0009	0.0036
Uruguay	-8.41	0.0079	-4.17	0.0033	0.0384	0.0511
Venezuela	-4.76	0.0070	-0.01	0.0001	0.0324	0.0391

Table 2.7: Predicted effects as a result of China moving from 1996-2001 values to 2009 values for the following: (i) inward tariffs, (ii) outward tariffs, (iii) technology, and (iv) all three at once.

2.5.3 Potential Effects of the Trans-Pacific Partnership

Negotiations surrounding the proposed Trans-Pacific Partnership (TPP) free-trade agreement are ongoing as of the writing of this paper. The TPP is ambitious in scope, aiming to promote trade and foreign investment among a group of potential signatories.[30] My model is well-suited to capture the effects of reductions in tariffs and MP costs among the potential TPP members, which is the focus of this counterfactual.

Table 2.8 reports the results of two scenarios involving the potential TPP members: an elimination of tariffs and a reduction in MP costs. I chose the magnitude of the MP cost reduction (5.3%) to be equal to the mean tariff between TPP members in my sample.

Eliminating tariffs has a large impact on trade flows (column 2) in the TPP countries. Total trade flows in TPP countries increase by substantial amounts, up to 50.6% in the case of Mexico (more on Mexico in a moment). This comes at the expense of non-TPP countries, all of whom see a decline in their total trade volumes. As a result of these changes to trade, MP (column 3) is diverted towards from the rest of the world to a subset of TPP countries. In terms of real wages (column 4), TPP countries benefit from the tariff reductions at the expense of those outside the agreement.

Interestingly, the large increase in Mexico's trade flows is accompanied by a 4.32% drop in foreign multinational activity in Mexico. This is due to the fact that Mexico had the highest tariff barriers among TPP countries. As tariff barriers fall,

[30] My sample includes two countries (Chile and New Zealand) which signed the agreement in 2005 and another six (Australia, Canada, Japan, Malaysia, Mexico, and the United States) which are currently still negotiating.

Country	(i) Elimination of Tariffs			(ii) MP Costs Fall by 5.3%		
	%Δ(Ex+Im)	%ΔMP	%Δ(w/P)	%Δ(Ex+Im)	%ΔMP	%Δ(w/P)
Australia	18.552	-0.249	0.130	1.079	25.336	1.905
Canada	8.073	0.678	1.146	2.629	18.152	4.314
Chile	18.791	-1.227	0.317	2.823	6.195	5.910
Japan	9.150	0.237	0.021	-0.005	25.213	0.094
Malaysia	14.643	-0.854	0.269	2.580	7.065	5.411
Mexico	50.566	-4.320	0.461	1.724	14.952	3.622
New Zealand	19.476	1.143	0.285	3.407	7.505	6.643
United States	9.509	0.320	0.057	1.779	14.841	0.030
Argentina	-0.528	-0.374	-0.003	0.067	-0.240	0.004
Austria	-0.162	-0.134	-0.002	-0.215	-0.247	0.002
Belgium	-0.146	-0.133	-0.002	-0.234	-0.247	0.002
Brazil	-0.423	-0.250	-0.002	-0.020	-0.246	0.002
Bulgaria	-0.161	-0.137	-0.004	-0.217	-0.245	0.004
China	-0.177	-0.090	-0.000	-0.058	-0.247	0.001
Czech Republic	-0.154	-0.130	-0.002	-0.226	-0.248	0.001
Denmark	-0.163	-0.133	-0.002	-0.212	-0.247	0.002
Finland	-0.170	-0.134	-0.004	-0.203	-0.245	0.003
France	-0.172	-0.133	-0.002	-0.209	-0.247	0.001
Germany	-0.157	-0.132	-0.001	-0.220	-0.247	0.001
Great Britain	-0.176	-0.124	-0.002	-0.204	-0.247	0.001
Greece	-0.162	-0.134	-0.002	-0.194	-0.247	0.002
Hungary	-0.145	-0.131	-0.001	-0.223	-0.247	0.001
India	-0.267	-0.115	-0.001	-0.059	-0.248	0.001
Indonesia	-0.319	-0.167	-0.002	0.046	-0.242	0.005
Ireland	-0.180	-0.121	-0.007	-0.198	-0.245	0.004
Italy	-0.174	-0.134	-0.001	-0.193	-0.248	0.001
Netherlands	-0.148	-0.132	-0.002	-0.229	-0.247	0.001
Norway	-0.170	-0.134	-0.003	-0.206	-0.245	0.002
Poland	-0.157	-0.128	-0.001	-0.225	-0.247	0.001
Portugal	-0.186	-0.138	-0.003	-0.185	-0.247	0.002
Russia	-0.198	-0.132	-0.003	-0.178	-0.246	0.003
South Africa	-0.382	-0.146	-0.004	-0.014	-0.246	0.003
South Korea	-0.096	-0.033	0.000	-0.126	-0.248	0.001
Spain	-0.189	-0.153	-0.002	-0.172	-0.247	0.002
Sweden	-0.170	-0.134	-0.003	-0.205	-0.246	0.002
Switzerland	-0.163	-0.134	-0.002	-0.226	-0.247	0.001
Thailand	-0.255	-0.146	-0.001	-0.003	-0.245	0.004
Turkey	-0.182	-0.127	-0.002	-0.192	-0.248	0.002
Uruguay	-0.379	-0.360	-0.004	-0.189	-0.241	0.005
Venezuela	-0.501	-0.286	-0.009	0.027	-0.242	0.006

Table 2.8: Columns 3 and 6 report changes in foreign multinational activity within the country.

other TPP countries find it more attractive at the margin to export to Mexico than to produce there. The increase in imports and decrease in MP lowers wages in Mexico, decreasing its production costs and making it more attractive as an export platform. Foreign multinationals respond and increase exports to all other countries; however, this is not enough to offset the initial decrease in MP.

Besides eliminating tariffs, the TPP is also intended to increase investment among its members. To study the potential effects, I decrease MP costs among TPP countries by 5.3% to match the mean reduction in trade costs from eliminating tariffs among TPP countries.[31] The result is that MP is diverted away from non-TPP countries (column 6). Also, trade volumes for all TPP countries increase with the exception of Japan (column 5). While trade is diverted away from most non-TPP countries, some do see an increase in trade volumes. All countries benefit from the decrease in MP costs, though the real wage gains for non-TPP countries are less than 0.01%.

With the exception of the US, the gains among TPP countries from the reduction in MP costs are much greater than the gains from tariff reductions. This may help explain why, even as other TPP countries benefit far more from a reduction in MP costs, the focus in the US has largely revolved around tariff reductions.

[31] The effects of existing trade agreements on MP costs can be imputed from Table 2.2. They range from an *increase* of 8.2% (though imprecisely estimated) in the case of NAFTA to decreases of 15.3% and 18.1% for MERCOSUR and CEFTA.

2.6 Closing Remarks

More than ever, multinational production warrants attention from trade economists. Not only does MP have complex interactions with trade, but MP now accounts for a larger share of global economic activity than trade. In this paper, I develop a model of trade and MP and take it to the data in order to focus on the role of MP in some classic trade issues.

After replicating previous work showing that the spillover effects from technology growth in the US are far higher with MP than without MP, I verify the model's prediction that the spillover effects of technology growth are smaller when the growth instead occurs in a country with a lower level of technology like China. In fact, I find that the spillover effects of technology growth in China are roughly of the same order of magnitude with or without MP.

I then quantify the global effects of changes in China's inward and outward tariffs and of technology growth in China in the years following China's accession to the WTO. I find that the gains to China's real wage are almost totally due to technology growth rather than to tariff reductions, largely because 88% of the gains due to China's technology growth accrue to China.

The last counterfactual analyzes the potential effects of the Trans-Pacific Partnership. Since the TPP is being designed to promote both trade and investment among its members, I contrast the effects of an elimination in tariffs and an "equivalent" reduction in MP costs among TPP countries. With the exception of the US, TPP countries benefit more from the reduction in MP costs than from the elimination of tariffs.

This model can be extended in various ways for future research. One interesting extension would be to differentiate labor by skill level.[32] This would allow for an exploration of the effects of globalization and technology growth on wage inequality and job polarization (the growth in developed countries of the share of high-skilled and low-skilled jobs at the expense of medium-skilled jobs) in a setting where globalization occurs via trade and via MP.

[32]Existing models of trade and MP have included labor and capital but have not included human capital. See Shikher (2014) and Alviarez (2013).

Chapter 3

A Heckscher-Ohlin Theory of Offshoring

Advances in information and communication technologies and decreases in transportation costs have allowed production to become increasingly fragmented across geographic locations and even across national boundaries. Rather than confining their production to one location, firms are now able to produce intermediate goods and services in many different countries to exploit differences in factor prices.[1] This is referred to as "task trade" or "offshoring".

To date, the offshoring literature has focused on offshoring from the global North to the South motivated mainly by productivity differences between the two regions (Grossman and Rossi-Hansberg, 2008; Baldwin and Robert-Nicoud, 2010; Rodriguez-Clare, 2010). Classic trade theory, however, suggests that there could be other reasons to offshore. One alternative motivation is the Heckscher-Ohlin (H-O) theory based on relative factor endowments. That is, the relocation of unskilled tasks from the North

[1] Many authors have documented this phenomenon. For example, see Hummels, Ishii, and Yi (2001) and Hanson, Mataloni Jr, and Slaughter (2005).

may be driven in part by the relative abundance of unskilled labor in the South. Though the previous statement is unlikely to be controversial, another implication of the H-O theory is that the relative abundance of skilled labor in the North should cause skilled tasks to be offshored from the South to the North.

Evidence of South-to-North offshoring has not yet been rigorously documented in the economic literature. The ideal evidence would be firm-level data on the overseas activities of multinational firms from emerging countries. Unfortunately, I do not know of such data being available to the public. In lieu of this, there is anectdotal evidence[2] and evidence in the form of US service exports (Table 3.1). The rapid growth of these export figures is particularly noteworthy (for example, US exports of management, consulting, and PR services to Brazil are growing at an annualized rate of 37%). The problem with the export figures is that they cannot be disaggregated to find the value of service tasks relocated from developing countries to the US.

Thus, our understanding of South-to-North offshoring is limited by a lack of both theory and data. In this chapter, I address the lack of theory by developing a model in which both final goods and intermediate production tasks are traded due to differences in relative factor endowments. Trade in final goods is implemented using a standard H-O model (two final goods, two factors of production, two countries with identical production technologies but different relative factor endowments) with trade

[2]Evidence of South-to-North offshoring has appeared in the popular press. An article in the *Financial Times* ("Offshoring Goes Into Reverse Gear") profiles an online market for UK professionals to perform freelance work for companies in developing countries. Even though the UK freelancers cost more, they generally provide work of a higher quality. Skills which are in demand include copywriting, organizational abilities, design, and technical development.

Country	Financial	Computer and Information	Management, Consulting, and PR	Research, Development, and Testing	Construction, Architectural, Engineering
Brazil	2084	355	882	58	455
	(0.182)	(0.034)	(0.368)	(0.177)	(0.226)
China	2310	346	865	127	1540
	(0.204)	(0.205)	(0.170)	(0.230)	(0.186)
India	552	312	187	44	151
	(0.102)	(0.136)	(0.074)	(0.075)	(0.031)
Mexico	1310	377	582	118	968
	(0.086)	(0.088)	(0.049)	(0.146)	(0.094)

Table 3.1: U.S. service sales by destination and type. Sales are in millions of dollars for 2012. Numbers in parentheses are average log growth rates from 2006-2012. Data from the BEA.

costs.[3] To implement trade in intermediate tasks, I adopt the framework of Grossman and Rossi-Hansberg (2008) in which production of the final goods involves each factor completing a continuum of tasks each with its own offshoring cost.

Costly trade for final goods plays a critical role in the model. In the standard H-O model with free trade, factor prices are equalized between countries as long as both have relative factor endowments that lie within the “cone of diversification”. In the context of offshoring, factor price equalization (FPE) is uninteresting since firms would have no incentive to relocate production tasks abroad. Costly trade, on the other hand, prevents factor prices from equalizing and leads to an interesting pattern of task trade: each country offshores some of tasks performed by its relatively-scarce factor. Trade in final goods follows the same pattern with both countries importing the good

[3]If the assumption that the North and South have identical productions technologies is objectionable, then one can think of the factors as being measured in productivity-equivalent units. Trefler (1993) shows that the Heckscher-Ohlin-Vanek model performs well empirically once technology differences are accounted for.

intense in their relatively-scarce factors.

To my knowledge, this is the first paper which considers bilateral offshoring. One important consequence of this is the effect on the terms of trade. It is well known that an increase in trade, though increasing global welfare, may harm an individual country if it worsens that country's terms of trade (Ohyama, 1972). This is no less true for trade in tasks. Many authors (Deardorff, 2001; Bhagwati et al., 2004; Baldwin and Robert-Nicoud, 2010) have found that the gains from offshoring can be eroded partially or even completely if the country's terms of trade deteriorates. This issue is more complicated when offshoring is bilateral, since a decrease in offshoring costs increases offshoring in *both* directions.

Using the model, I am able to identify three factors which determine terms of trade movements. I find that, following a decrease in offshoring costs, the terms of trade are more likely to improve for the country which (all else equal): is larger in terms of factor endowments, is currently offshoring the broader range of tasks, and has reduced costs by less from offshoring.

In Section 3.1, I review the literature. In Section 3.2, I introduce a simple closed version of the model. In Section 3.3, I allow for costly trade in final goods between two countries. In Section 3.4, I break up the production process into a continuum of tasks and allow these tasks to be traded along with final goods.

3.1 Literature Review

This paper follows Grossman and Rossi-Hansberg (2008) in implementing offshoring and is also closely related to Baldwin and Robert-Nicoud (2010), who extend the 2x2x2 model in Grossman and Rossi-Hansberg (2008) to an arbitrary number of factors and industries and allow for trade in both tasks and final goods. In both of these papers, the two countries are differentiated by an exogenous, Hicks-neutral technology gap. Because firms can use their own technology when they offshore, opportunities arise for firms in the technologically-advanced country to exploit differences in factor prices. In contrast, the two countries in my model are identical in technology but differ in relative factor endowments and they both offshore. Another difference is that my model allows for costly trade in both intermediate and final goods while Grossman and Rossi-Hansberg (2008) only allow intermediate tasks to be traded and Baldwin and Robert-Nicoud (2010) assume final goods trade is costless. Lastly, in Baldwin and Robert-Nicoud (2010) offshoring provides Ricardian motives for final goods trade whereas in my model it is frictions in final goods trade which provides motives for offshoring.

Deardorff (1998, 2001) considers a H-O model in which factor endowments in the countries differ sufficiently so that under free trade not enough goods can be produced to equalize factor prices. In a two-good economy, this means that at least one of the countries lies outside of the cone of diversification. In contrast, my model assumes that both countries lie within the cone so that both final goods are produced in both countries. Venables (1999) studies a 2x2x2 model where one of the goods is fragmentable into an intermediate good and a final good. Factor prices are not equalized due a factor-intensity reversal, which I rule out in my model. Kohler (2004a) employs a specific factors model where capital used in production is specific to a good or fragment, but in my model both factors are used to produce both goods. Unlike my two-country model, Markusen and Venables (2007) develop a multi-country model where countries differ in their factor endowments and trade costs. These models consider offshoring for only one intermediate good whereas my model represents the extensive margin of trade as a continuous variable.

Rodriguez-Clare (2010) studies the short-run and long-run effects of offshoring by integrating the Ricardian trade model of Eaton and Kortum (2002) and the task trade framework of Grossman and Rossi-Hansberg (2008). The model has an arbitrary number of countries and a continuum of final goods but only one factor. Offshoring is incentivized by a technological gap, so that an expansion of offshoring is accompanied in the relatively-advanced country by increased production and trade of the good in which it has comparative advantage. Because there is only one factor, any increase in offshoring must necessarily worsen a country's terms of trade. In my two-factor model, offshoring occurs for tasks belonging to both factors so the terms of trade may change in either direction.

There are also related models which feature a continuum of intermediate inputs or production stages (Feenstra and Hanson, 1995; Yi, 2003; Kohler, 2004b). These models do not have heterogeneous trade costs nor do they associate an input or a production stage with a particular factor.

The papers reviewed thus far have employed neoclassical models. One alternative approach focuses on factor heterogeneity and matching. Kremer and Maskin (2006) develop a model with one-to-one matching where two agents with different skill levels can match and produce in an international team. Antràs, Garicano, and Rossi-Hansberg (2006) instead allow for one-to-many matching so that international teams form with one manager and several workers. The authors find that this increases wage inequality in the South but has ambiguous effects on wage equality in the North. A follow-up paper (Antràs et al., 2008) expands the framework to allow for multiple layers of management. Unlike these papers, I assume that all workers of a given factor type are homogenous and that there is no skill complementarity.

There is also a literature on firm boundaries which examines whether firms choose to conduct offshoring within the firm via foreign direct investment (FDI) or at arm's length via outsourcing. Antràs (2003) extends the property-rights approach of Grossman and Hart (1986) where contracts are incomplete and where investments in capital and labor are specific to each pair of final-goods producers and intermediate-goods suppliers. For capital-intensive inputs, it is optimal for final-goods producers to invest in capital on the behalf of suppliers when the latter have poor bargaining power. But this exacerbates the hold-up problem for final-goods producers and leads to vertical integration as final-goods producers assume the residual rights of control and take ownership of the suppliers. Whereas Antràs (2003) uses product differentiation and monopolistic competition (Helpman and Krugman, 1985) as the basis for trade, Antràs and Helpman (2004) allow for intraindustry heterogeneity as in Melitz (2003) and Helpman, Melitz, and Yeaple (2004) and find equilibria in which firms within the same industry choose different organizational forms. Antràs and Helpman (2007) extends this model to allow contractual frictions to vary across inputs and countries. In an update of the Vernon (1966) theory of the product cycle, Antràs (2005) shows that hold-up problems stemming from incomplete contracts can limit the extent to which production can be fragmented across borders. This results in a product cycle in which production of mature products occurs in the South through unaffiliated foreign foreign suppliers. If, however, the product is still relatively immature when production is first transferred from the North to the South then production will take place through wholly-owned subsidiaries until the product is sufficiently mature. In contrast to these papers, I assume that there is no difference between FDI and arm's-length offshoring and that final-goods producers are able to costlessly switch between suppliers.

In addition to the "make or buy" decision, there are other choices that firms must make when offshoring. In Keller and Yeaple (2013), firms that offshore assembly tasks to foreign affiliates must decide how to provide the affiliate with the necessary inputs. They may choose to produce an input at home and incur a transportation cost to ship it to the affiliate, or the affiliate can produce the input and incur a knowledge transfer cost. I do not distinguish between different types of offshoring costs (other than to assume that they are heterogeneous across tasks) and instead differentiate between trade costs for intermediate inputs and for final goods.

Many empirical studies have examined the effects of offshoring. One unique contribution is Liu and Trefler (2008), who look at service offshoring from the U.S. to China and India on the U.S. as well as service "inshoring" (sales of services produced in the U.S. to unaffiliated buyers in China and India). Using worker-level data, they find that offshoring has negative (though not always significant) effects on a variety of labor outcomes (industry switching, occupation switching, share of weeks unemployed, and earnings). In contrast, inshoring has positive (though not always significant) effects. The net effect of offshoring and inshoring is always positive or zero. To my knowledge, this is the only empirical study that considers two-way offshoring.[4]

Becker, Ekholm, and Muendler (2012) use detailed data on German multinational firms to study the impact of offshoring (measured as the share of employees working at a firm's foreign plants out of the total number of employees working at that firm's German and foreign plants) on the task composition and skill composition of German plants. They find that increased offshoring is associated with a shift in the task composition of German plants towards nonroutine and interactive tasks. Even after controlling for this task recomposition, firms which offshore more have a larger share of highly-educated workers at their German plants. This consistent with firm behavior in my model, in which firms in the skill-abundant country choose to offshore unskilled tasks.

[4]In a more recent version of their working paper, Liu and Trefler (2011) distinguish between workers who switch "up" (to better jobs) versus those who switch down. Under this framework they find larger effects from Chinese and Indian service imports. However, inshoring is omitted from this version.

3.2 The Closed Economy Model

I first consider a closed economy model with two final goods, X and Y. The markets for both goods are perfectly competitive. The representative consumer has homothetic preferences:

$$U(x, y) = x^{\phi} y^{1-\phi}$$

There are two factors of production, L and H, representing unskilled and skilled labor respectively. X and Y are produced according to the following production functions:

$$F_X(l, h) = l^{\frac{1}{2}} h^{\frac{1}{2}} \tag{3.1}$$

$$F_Y(l, h) = l^{\alpha} h^{1-\alpha} \tag{3.2}$$

where $\frac{1}{2} < \alpha < 1$ (hence X is relatively more skill-intensive than Y). Letting w and s be the factor prices for L and H, respectively, these production technologies imply that the amounts of L and H required to produce one unit of X or Y are:

$$a_{Lx} = \left(\frac{s}{w}\right)^{\frac{1}{2}} \tag{3.3}$$

$$a_{Hx} = \left(\frac{w}{s}\right)^{\frac{1}{2}} \tag{3.4}$$

$$a_{Ly} = A\left(\frac{s}{w}\right)^{1-\alpha} \tag{3.5}$$

$$a_{Hy} = B\left(\frac{w}{s}\right)^{\alpha} \tag{3.6}$$

where $A = (\frac{\alpha}{1-\alpha})^{1-\alpha} > 1$ and $B = (\frac{1-\alpha}{\alpha})^{\alpha} < 1$.

Letting Y be the numeraire good and p be the relative price of X, the zero-profit conditions are:

$$p = wa_{Lx} + sa_{Hx} = 2(ws)^{\frac{1}{2}} \tag{3.7}$$

$$1 = wa_{Ly} + sa_{Hy} = (A+B)w^{\alpha}s^{1-\alpha} \tag{3.8}$$

The factor-market clearing conditions are:

$$a_{Lx}x + a_{Ly}y = \left(\frac{s}{w}\right)^{\frac{1}{2}} x + A\left(\frac{s}{w}\right)^{1-\alpha} y = L \tag{3.9}$$

$$a_{Hx}x + a_{Hy}y = \left(\frac{w}{s}\right)^{\frac{1}{2}} x + B\left(\frac{w}{s}\right)^{\alpha} y = H \tag{3.10}$$

The goods-market clearing condition is:

$$y = (1-\phi)(px + y) \tag{3.11}$$

Solving equations (3.7)-(3.11) for the 5 unknowns (p, w, s, x, y) is straightforward (see Appendix B.1).

3.3 Trade in Final Goods Only

I now extend the model to allow for trade in final goods. Let there be two countries (Home and Foreign) with preferences and production technologies as described in the closed model. Foreign variables are denoted with an asterisk. Trading Y is costless but delivering one unit of X requires shipping $1+\tau$ units.[5] Allowing Y, which I again take to be the numeraire good, to be traded freely is a matter of convenience since it allows the numeraire to be the same in both countries.

[5] This is known as an iceberg transportation cost since some of the exported good "melts" along the way.

When trade is costless and both countries produce both goods, prices in the factor and goods markets are equalized across the two countries. Even when trade is costly, the law of one price dictates that the price of X must be the same in both countries after adjusting for trade costs. Without any loss of generality, I assume that trade is characterized by Home exporting the skill-intensive good X and Foreign exporting the unskilled-intensive good Y. This assumption implies restrictions on the relative factor endowments. For now, I assume the necessary conditions are met. In Appendix B.2, I solve the model and back out the exact requirements which are:

$$(1+\tau)^{\frac{2}{2\alpha-1}}\frac{H^*}{L^*} < \frac{H}{L} < D\frac{H^*}{L^*} + [D(1+\tau)^{-\frac{2\alpha}{2\alpha-1}} - (1+\tau)^{\frac{2(1-\alpha)}{2\alpha-1}}]\frac{H}{L^*} \tag{3.12}$$

where $D(\alpha, \phi)$ is a constant term greater than 1. The inequalities in (3.12) are satisfied when: 1) τ is not too high, 2) Home is skill-abundant relative to Foreign, but 3) Home is not *too* skill-abundant relative to Foreign.

Since $\frac{1}{1+\tau}$ units of X are lost for every unit shipped from Home to Foreign, the price of X in Foreign must be $(1+\tau)p$. Thus, the zero-profit conditions for Foreign firms are

$$(1+\tau)p = 2(w^* s^*)^{\frac{1}{2}} \tag{3.13}$$

$$1 = (A+B)(w^*)^{\alpha}(s^*)^{1-\alpha} \tag{3.14}$$

while the zero-profit conditions for Home firms are the same as in equations (3.7) and (3.8). Comparing the two sets of zero-profit conditions makes it clear that a divergence in goods prices necessarily leads to a divergence in factor prices for $\tau > 0$.

The factor-market clearing conditions are comprised of equations (3.9) and (3.10) and their Foreign equivalents. Letting E_x be Home exports of X and E_y^* be Foreign exports of Y, the Cobb-Douglas expenditure shares imply that the goods-market clearing conditions are:

$$p(x - E_x) = \phi(px + y) \tag{3.15}$$

$$y^* - E_y^* = (1 - \phi)[(1 + \tau)px^* + y^*] \tag{3.16}$$

The balanced trade condition is

$$pE_x = E_y^* \tag{3.17}$$

The model has 11 equations and 11 unknowns (p, w, s, w^*, s^*, x, y, x^*, y^*, E_x, E_y^*). Combining the zero-profit conditions leads to the following relationship between relative factor prices:

$$\frac{s^*}{w^*} = (1 + \tau)^{\frac{2}{2\alpha - 1}} \frac{s}{w} \tag{3.18}$$

This equation implies that $\frac{s^*}{w^*} > \frac{s}{w}$ for $\tau > 0$. Furthermore, from Appendix B.2 it is clear that $s^* > s$ and $w > w^*$. Skilled labor is cheaper in the Home country while unskilled labor is cheaper in the Foreign country despite identical production technology in the two countries. Because of these wage disparities, both countries have incentive to offshore some of the work performed by their relatively-scarce factor when trade in tasks is introduced.

3.4 Trade in Final Goods and Intermediate Tasks

I now implement task trade in the manner of Grossman and Rossi-Hansberg (2008). The first step is to represent the production process as a series of individual tasks. In both countries and in both industries, I assume there is a continuum of L-tasks and and a continuum of H-tasks with measures normalized to one. A firm in industry j needs a_{fj} units of domestic factor $f = \{L, H\}$ to perform an f-task. All f-tasks must be completed once in order to produce an aggregate unit of f.[6] The final goods X and Y are produced by combining aggregate units of L and H according to equations (3.1) and (3.2). Because both L-tasks and H-tasks have measures equal to one, a_{fj} is also the quantity of f needed to produce one unit of j. Thus, the a_{fj}'s are the same as equations (3.3)-(3.6).

The actual mechanism of offshoring is as follows. If completing task i domestically requires a_{fj} units of factor f, then completing it abroad requires $a_{fj}\beta t_f(i)$ units of foreign labor. β is a shift parameter embodying general offshoring technology and $t_f(\cdot)$ captures the variation in offshoring costs across tasks. I assume that $t_f(\cdot)$ is the same for both industries and is continuously differentiable. I also assume that $\beta t_f(i) > 1$ for all f and i. Tasks are ordered such that $t'_f(i) > 0$.[7]

There are various explanations for why offshoring costs vary by task. For example, Blinder (2009a) emphasizes that certain tasks are tied to physical locations while

[6] Production of aggregate units of L and H uses Leontieff technology. That is, an f-task cannot substitute for another f-task.

[7] In their appendix, Grossman and Rossi-Hansberg (2008) consider the case where $t'_f(i) \geq 0$. I assume that the inequality is strict.

Jensen and Kletzer (2010) argue that tasks which are more creative or nonroutine are more difficult to codify and perform remotely. Alternately, one may interpret offshoring costs as the transportation or tariffs costs incurred in the production or processing of intermediate goods. Under this interpretation, a decrease in τ represents a reduction in trade costs for final goods but not for intermediate goods. Several papers (Crino, 2010; Hummels et al., 2011; Becker et al., 2012; Oldenski, 2012a,b) provide empirical evidence that the effects of offshoring vary depending on task characteristics.

I assume that β satisfies $w > \beta t_L(0)w^*$ and $s^* > \beta t_H(0)s$. It is therefore profitable for Home firms to offshore some L-tasks and for Foreign firms to offshore some H-tasks. Let I and I^* index the marginal task completed in Home and in Foreign, respectively, so that

$$w = \beta t_L(I)w^* \tag{3.19}$$

$$s^* = \beta t_H(I^*)s \tag{3.20}$$

Thus, Home (Foreign) firms divide their L-tasks (H-tasks) into a portion $1-I$ ($1-I^*$) which are performed domestically and a portion I (I^*) which are offshored. Letting Y once again be the numeraire (with p defined as before), the zero-profit conditions for Home and Foreign firms can be written as

$$p = wa_{Lx}(1-I) + w^* a_{Lx} \int_0^I \beta t_L(i)di + sa_{Hx} \tag{3.21}$$

$$1 = wa_{Ly}(1-I) + w^* a_{Ly} \int_0^I \beta t_L(i)di + sa_{Hy} \tag{3.22}$$

$$(1+\tau)p = w^* a^*_{Lx} + s^* a^*_{Hx}(1-I^*) + sa^*_{Hx} \int_0^{I^*} \beta t_H(i)di \tag{3.23}$$

$$1 = w^* a^*_{Ly} + s^* a^*_{Hy}(1-I^*) + sa^*_{Hy} \int_0^{I^*} \beta t_H(i)di \tag{3.24}$$

By substituting in equations (3.19) and (3.20), these conditions can be written as

$$p = wa_{Lx}\Omega(I) + sa_{Hx}$$

$$1 = wa_{Ly}\Omega(I) + sa_{Hy}$$

$$(1+\tau)p = w^* a^*_{Lx} + s^* a^*_{Hx}\Omega^*(I^*)$$

$$1 = w^* a^*_{Ly} + s^* a^*_{Hy}\Omega^*(I^*)$$

where

$$\Omega(I) = 1 - I + \frac{\int_0^I t_L(i)di}{t_L(I)} \qquad \text{and} \qquad \Omega^*(I^*) = 1 - I^* + \frac{\int_0^{I^*} t_H(i)di}{t_H(I^*)}$$

Note that $\Omega(I) \leq 1$ and $\Omega^*(I^*) \leq 1$ with $\Omega(I) = 1$ only if no L-tasks are offshored and $\Omega^* = 1$ only if no H-tasks are offshored. Written this way, it is evident that offshoring reduces unskilled (skilled) labor costs for Home (Foreign) firms by a factor of $\Omega(I)$ ($\Omega^*(I^*)$). With offshoring, a_{Lx} and a_{Ly} are functions of $\Omega(I)w$ and s rather than w and s; likewise, a^*_{Lx} and a^*_{Ly} are functions of w^* and $\Omega^*(I^*)s^*$ rather than

w^* and s^*. This allows the zero-profit conditions to be expressed simply as:

$$p = 2(\Omega ws)^{\frac{1}{2}} \tag{3.25}$$

$$1 = (A + B)(\Omega w)^{\alpha} s^{1-\alpha} \tag{3.26}$$

$$(1 + \tau)p = 2(\Omega^* w^* s^*)^{\frac{1}{2}} \tag{3.27}$$

$$1 = (A + B)(w^*)^{\alpha}(\Omega^* s^*)^{1-\alpha} \tag{3.28}$$

I now consider the labor-market clearing conditions for unskilled workers. In Home, unskilled workers perform a fraction $1 - I$ of the L-tasks needed to produce the amounts of X and Y supplied by Home firms. In Foreign, unskilled workers must perform all of the L-tasks needed by Foreign firms, as well as a fraction I of the L-tasks needed by Home firms (with each offshored task having an additional offshoring cost $\beta t_L(i) > 1$). Thus, the market-clearing conditions for L are:

$$L = a_{Lx}(1 - I)x + a_{Ly}(1 - I)y$$

$$L^* = a^*_{Lx}x^* + a^*_{Ly}y^* + \int_0^I \beta t_L(i)(a_{Lx}x + a_{Ly}y)di$$

which can be re-written as:

$$\tilde{L} = \left(\frac{s}{\Omega w}\right)^{\frac{1}{2}} x + A\left(\frac{s}{\Omega w}\right)^{1-\alpha} y \tag{3.29}$$

$$\tilde{L}^* = \left(\frac{\Omega^* s^*}{w^*}\right)^{\frac{1}{2}} x^* + A\left(\frac{\Omega^* s^*}{w^*}\right)^{1-\alpha} y^* \tag{3.30}$$

where $\tilde{L} = \frac{L}{1-I} > L$ and $\tilde{L}^* = L^* - \frac{L}{1-I}\beta \int_0^I t_L(i)di < L^*$. The labor-market clearing conditions for skilled workers can be similarly expressed as:

$$\tilde{H} = \left(\frac{\Omega w}{s}\right)^{\frac{1}{2}} x + B\left(\frac{\Omega w}{s}\right)^{\alpha} y \tag{3.31}$$

$$\tilde{H}^* = \left(\frac{w^*}{\Omega^* s^*}\right)^{\frac{1}{2}} x^* + B\left(\frac{w^*}{\Omega^* s^*}\right)^{\alpha} y^* \tag{3.32}$$

where $\tilde{H} = H - \frac{H^*}{1-I^*}\beta \int_0^{I^*} t_H(i)di < H$ and $\tilde{H}^* = \frac{H^*}{1-I^*} > H^*$.

The variables $\tilde{L}$, $\tilde{L}^*$, $\tilde{H}$, and $\tilde{H}^*$ are the "effective" factor endowments. The effect of offshoring is that it changes the amounts of each factor available to domestic firms. Each country gains more of its relatively-scarce factor and loses some of its relatively-abundant factor so that, with offshoring, the two countries have effective relative factor endowments which are more similar than their actual relative factor endowments. That is, $\frac{H}{L} > \frac{\tilde{H}}{\tilde{L}}, \frac{\tilde{H}^*}{\tilde{L}^*} > \frac{H^*}{L^*}$.[8]

To complete the set-up of the model, the goods-market and balanced trade conditions are the same as in equations (3.15)-(3.17). Observe that this model and the model without offshoring are identical with the replacement of a few variables.[9] This means that all of the results in Appendix B.2 are still valid as long as the transformed variables are used in place of the original variables and as long as (3.12) is satisfied with the effective factor endowments in place of the actual factor endowments.

[8] This a manifestation of the well-known result by Mundell (1957) that trade substitutes for factor mobility.

[9] w in the "final goods-only" model is replaced by Ωw, s^* becomes $\Omega^* s^*$, and the actual factor endowments are replaced by the effective factor endowments.

3.4.1 "Adjusted" Factor Price Equalization

From the zero-profit equations (3.25)-(3.28), I can solve for the factor prices in terms of p:

$$s = (A+B)^{\frac{1}{2\alpha-1}} \left(\frac{p}{2}\right)^{\frac{2\alpha}{2\alpha-1}} \tag{3.33}$$

$$\Omega w = (A+B)^{-\frac{1}{2\alpha-1}} \left(\frac{2}{p}\right)^{\frac{2(1-\alpha)}{2\alpha-1}} \tag{3.34}$$

$$\Omega^* s^* = (A+B)^{\frac{1}{2\alpha-1}} \left(\frac{(1+\tau)p}{2}\right)^{\frac{2\alpha}{2\alpha-1}} \tag{3.35}$$

$$w^* = (A+B)^{-\frac{1}{2\alpha-1}} \left(\frac{2}{(1+\tau)p}\right)^{\frac{2(1-\alpha)}{2\alpha-1}} \tag{3.36}$$

These equations imply "adjusted" factor price equalization (FPE):

$$\Omega w = (1+\tau)^{\frac{2(1-\alpha)}{2\alpha-1}} w^* \tag{3.37}$$

$$\Omega^* s^* = (1+\tau)^{\frac{2\alpha}{2\alpha-1}} s \tag{3.38}$$

Home (Foreign) firms offshore L-tasks (H-tasks) until their effective cost of unskilled (skilled) labor is equal to cost of unskilled (skilled) labor in the other country adjusted by a term involving trade costs τ.[10]

Proposition 1. *A reduction in the trade costs of final goods moves factor prices in the two countries* towards *FPE (that is,* $\frac{d(w/w^*)}{d\tau} > 0$ *and* $\frac{d(s^*/s)}{d\tau} > 0$*), whereas a reduction in offshoring costs moves factor prices in the two countries* away from *FPE (*$\frac{d(w/w^*)}{d\beta} < 0$ *and* $\frac{d(s^*/s)}{d\beta} < 0$*).*

[10]This is similar to Grossman and Rossi-Hansberg (2008). In that paper, however, the adjustment term was the gap in technology between the two countries, not trade costs.

Proof. From equation (3.37), w and w^* are separated by a "wedge" term, $\frac{(1+\tau)^{\frac{2(1-\alpha)}{2\alpha-1}}}{\Omega}$, that depends on τ and β. This term is greater than 1 and increasing in τ. And, because $\frac{d\Omega}{dI} = -\frac{t_L'(I)}{t_L(I)^2}\int_0^I t_L(i)di < 0$ and $\frac{dI}{d\beta} < 0$ (from Proposition 2), the wedge term is decreasing in β. A parallel result for the wedge separating s and s^* can be obtained from equation (3.38). $\square$

According to equations (3.33)-(3.36), the factor prices are sensitive to changes in offshoring costs β through the terms of trade (p) and the measures of labor cost savings (Ω and Ω^*). By log-differentiating these equations, it is evident that $\hat{w}$ and $\hat{w}^*$ respond identically to changes in the terms of trade. Therefore, any differential impact of a reduction in offshoring costs on $\hat{w}$ relative to $\hat{w}^*$ must be due to $\hat{\Omega}$. For Home firms, a reduction in offshoring costs lowers the effective price of unskilled labor. This has the effect of raising the productivity of unskilled labor for Home firms (Grossman and Rossi-Hansberg, 2008), which increases Home demand for unskilled labor and increases w. However, a change in β only impacts w^* through the terms of trade and not through $\hat{\Omega}$. This is because there is no change in the effective productivity of unskilled labor for Foreign firms; any increase in demand for Foreign unskilled labor by Home firms is exactly offset by a decrease in demand by Foreign firms. Using similar reasoning, a reduction in offshoring costs increases s^* relative to s.

3.4.2 The Range of Tasks Offshored

Another outcome of interest is the extent to which firms in Home and Foreign choose to offshore. Combining equations (3.19) and (3.20) with the adjusted FPE equations (3.37) and (3.38) leads to the following relationships between final trade costs, offshoring costs, and the range of tasks which are offshored:

$$(1+\tau)^{\frac{2(1-\alpha)}{2\alpha-1}} = \beta\Omega t_L(I) = \beta\left[(1-I)t_L(I) + \int_0^I t_L(i)di\right] \tag{3.39}$$

$$(1+\tau)^{\frac{2\alpha}{2\alpha-1}} = \beta\Omega^* t_H(I^*) = \beta\left[(1-I^*)t_H(I^*) + \int_0^{I^*} t_H(i)di\right] \tag{3.40}$$

Note that $\frac{d}{dI}[(1-I)t(I) + \int_0^I t(i)di] = (1-I)t'(I) > 0$. Thus, it immediately follows from log-differentiating these equations that $\frac{dI}{d\beta} < 0$, $\frac{dI^*}{d\beta} < 0$, $\frac{dI}{d\tau} > 0$ and $\frac{dI^*}{d\tau} > 0$. This leads to the next proposition.

Proposition 2. *A reduction in offshoring costs increases the range of tasks offshored in both countries. In contrast, a reduction in trade costs for final goods decreases the range of tasks offshored in both countries.*

Firms decide to offshore a task if the labor cost savings exceed the offshoring costs. As general offshoring costs go down, tasks which previously could not generate sufficient cost savings can now be profitably offshored. In contrast, a decrease in trade costs for final goods reduces the differences in factor prices between the two countries (see Proposition 1). This decreases the potential cost savings from offshoring for each task and thus fewer tasks can be profitably offshored.

3.4.3 The Terms of Trade

Recall that with good Y as the numeraire good, Home's terms of trade is equal to the price of X in Home, p. As I derive in Appendix B, Home's terms of trade is a function of the world output of X and Y:

$$p = \frac{\phi}{1-\phi}\left[\frac{y+y^*}{x+(1+\tau)x^*}\right]$$

Whether Home's terms of trade improve or worsen in response to a decrease in offshoring costs depends on the relative changes in world output of X and Y. But because offshoring occurs in both sectors, a fall in offshoring costs increases world output of both X and Y. Hence, the effect on the terms of trade of a decrease in offshoring costs is not immediately obvious.

To dig deeper, I begin with the solution for p from Equation (B.1) in Appendix B.2 with effective factor endowments:

$$p = \left[C(\alpha,\phi)\left(\frac{\tilde{L}+(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}\tilde{L}^*}{\tilde{H}+(1+\tau)^{\frac{2\alpha}{2\alpha-1}}\tilde{H}^*}\right)\right]^{\frac{2\alpha-1}{2}}$$

The next step is to replace the effective factor endowments with the actual endowments. For $\tilde{L}$ and $\tilde{L}^*$,

$$\begin{aligned}
\tilde{L}+(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}\tilde{L}^* &= \frac{L}{1-I}+(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}\left[L^*-\frac{1}{1-I}\beta L\int_0^I t_L(i)di\right] \\
&= (1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}L^*+\frac{L}{1-I}\left[1-\frac{\int_0^I t_L(i)di}{(1-I)t_L(I)+\int_0^I t_L(i)di}\right] \\
&= (1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}L^*+\frac{L}{\Omega}
\end{aligned}$$

where the second equality is due to Equation (3.39). Similarly,

$$\tilde{H} + (1+\tau)^{\frac{2\alpha}{2\alpha-1}}\tilde{H}^* = H + (1+\tau)^{\frac{2\alpha}{2\alpha-1}}\frac{H^*}{\Omega^*}$$

So in terms of the actual factor endowments, p is written as:

$$p = \left[C(\alpha,\phi)\left(\frac{(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}L^* + \frac{L}{\Omega}}{H + (1+\tau)^{\frac{2\alpha}{2\alpha-1}}\frac{H^*}{\Omega^*}}\right)\right]^{\frac{2\alpha-1}{2}} \tag{3.41}$$

A fall in β changes the terms of trade only through Ω and Ω^*. After taking the derivative of p with respect to β, I find that for $\frac{dp}{d\beta}$ to be positive the following condition must be true:

$$\frac{\epsilon_{\Omega^*,\beta}}{\epsilon_{\Omega,\beta}} > \frac{(1+\tau)^{-\frac{2\alpha}{2\alpha-1}}\frac{H}{H^*}\Omega^* + 1}{(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}\frac{L^*}{L}\Omega + 1}$$

Next, I find expressions for $\epsilon_{\Omega^*,\beta}$ and $\epsilon_{\Omega,\beta}$, the elasticities of Ω^* and Ω with respect to β:

$$\begin{aligned}
\epsilon_{\Omega,\beta} &= \frac{d\Omega}{dI}\frac{dI}{d\beta}\frac{\beta}{\Omega} \\
&= -\frac{t_L'(I)\int_0^I t_L(i)di}{t_L(I)^2}\left[-\frac{\Omega t_L(I)}{\beta(1-I)t_L'(I)}\right]\frac{\beta}{\Omega} \\
&= \frac{\int_0^I t_L(i)di}{(1-I)t_L(I)}
\end{aligned}$$

and $\epsilon_{\Omega^*,\beta} = \frac{\int_0^{I^*} t_H(i)di}{(1-I^*)t_H(I^*)}$. Substituting these into the inequality above, I find the condition that must hold if a reduction in β is to worsen Home's terms of trade:

$$\begin{aligned}
1 - I + \left[(1-I)^2(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}\frac{L^*}{L} + 1\right]\frac{t_L(I)}{\int_0^I t_L(i)di} \quad &> \\
1 - I^* + \left[(1-I^*)^2(1+\tau)^{-\frac{2\alpha}{2\alpha-1}}\frac{H}{H^*} + 1\right]\frac{t_H(I^*)}{\int_0^{I^*} t_H(i)di}
\end{aligned}$$

From this condition, I can identify three factors that (all else equal) play a role in determining whether the terms of trade improve or deteriorate after a decline in offshoring costs: the sizes of the two countries (HL and H^*L^*), the extent of offshoring (I and I^*), and the total savings from offshoring ($\frac{\int_0^I t_L(i)di}{t_L(I)}$ and $\frac{\int_0^{I^*} t_H(i)di}{t_H(I^*)}$).[11]

First, if firms in the two countries offshore the same range of tasks and have the same total cost savings from offshoring, then Home's terms of trade are more likely to deteriorate if Home is smaller than Foreign ($HL < H^*L^*$). In this case, $\epsilon_{\Omega^*,\beta} = \epsilon_{\Omega,\beta}$ so a decrease in β causes Ω and Ω^* to fall by the same amount. The relatively-scarce factor in both countries becomes cheaper and both countries shift production towards the good intensive in their relatively-scarce factor: Y in Home and X in Foreign. World output of X increases by more than world output of Y since Foreign is the larger nation so p falls as a result.

Second, if both countries are the same size and save the same total amount from offshoring, then p is more likely to decrease if Home firms offshore a smaller range of tasks than Foreign firms. This is because a fall in offshoring costs generates savings not only by allowing more tasks to be offshored but also by further reducing the cost of those tasks which were already offshored. By having offshored a broader range of tasks than Home, Foreign is able to enjoy more cost savings from a reduction in offshoring costs and increases production of X by more than Home increases production of Y.

Third, if both countries are the same size and offshore the same range of tasks, then Home's terms of trade are more likely to deteriorate if Home's total cost savings

[11] Smaller values of $\frac{\int_0^I t_L(i)di}{t_L(I)}$ and $\frac{\int_0^{I^*} t_H(i)di}{t_H(I^*)}$ correspond to greater savings from offshoring.

from offshoring are greater than Foreign's. Because Home's savings are higher than Foreign's, there is less scope for a reduction in offshoring costs to reduce Home's costs relative to Foreign's. This is reflected in the fact that $\epsilon_{\Omega^*,\beta} < \epsilon_{\Omega,\beta}$. Therefore a fall in β decreases offshoring costs by a greater amount in Foreign than in Home, so world output of X increases by a larger amount than world output of Y.

3.5 Closing Remarks

As communications technology continues to advance, firms will continue to exploit differences in factor prices and further fragment their production processes across national boundaries. This phenomenon has typically been understood as production tasks from the North being relocated to the South. However, this paper suggests that both the causes and the effects of offshoring are more complex than theories of unilateral offshoring would indicate. I find that the countries most in danger of a deterioration in their terms of trade are those that (relative to their trading partners) are small, offshore a narrow range of tasks, or have already achieved a high level of cost savings from offshoring. Using the U.S. and China as an example (and assuming that both countries are roughly of the same size), this implies that going forward the terms of trade for the U.S. ought to improve as a result of lower offshoring costs.

Chapter 4

Worker Skill and Job Polarization

The structure of employment has become increasingly polarized over the last few decades in rich economies. Studies for the United States (Autor et al., 2006), the United Kingdom (Goos and Manning, 2007), and Europe (Goos et al., 2009) have shown gains in the shares of low-skilled and high-skilled jobs at the expense of medium-skilled jobs. These deep and broad changes to the structure of employment have attracted much attention from researchers. Their efforts to explain this phenomenon (commonly referred to as "job polarization") have yielded several hypotheses.

The most popular of these is the "routinization" hypothesis (Autor et al., 2003, 2006; Autor and Dorn, 2013) in which technological progress has made automation of routine data-driven tasks much cheaper. Since these routine tasks were typically performed by workers employed in medium-skilled clerical jobs, increased automation has displaced many medium-skilled workers. Another body of literature points to offshoring as the culprit (Blinder, 2009b; Jensen and Kletzer, 2010; Blinder and Krueger, 2013).

In this chapter, I propose a new driver of job polarization. My hypothesis is that complementarity between worker skill and more sophisticated production technologies have lead to job polarization. To illustrate this, assume that there are two types of goods, one of which is skill-intensive. As worker skill increases over time[1], firms using the most productive technologies increasingly dominate the market for skill-intensive goods at the expense of firms using less productive technologies. As incomes rise, demand for both types of goods rises leading to an expansion of the non-skill-intense sector as well. In the end, the firms that increase their share of workers employed are those that utilize the most- and least-productive technologies.[2]

To demonstrate these ideas, I develop a model based primarily on Yeaple (2005). Workers are differentiated by their skill levels which are randomly drawn from a continuous distribution. Firms are ex ante identical but before producing output must choose which workers to employ and which production technology to utilize. As in Melitz (2003), fixed costs play a large role. Since more productive technologies incur larger fixed costs, there is sorting so that firms which use the most productive technology hire the most-skilled workers and firms which use the least productive technology hire the least-skilled workers. Trade occurs between two identical countries; again, fixed exporting costs make it so that only the firms which use the most productive technology export. Unlike Yeaple (2005), I assume that production technologies have specific

[1]UNESCO data shows that the gross tertiary enrollment ratio for the United States has increased from 47% in 1971 to 95% in 2010. Gains in educational attainment for other countries are equally dramatic, if not more so.

[2]Whereas the routinization hypothesis posits that job polarization is driven by technological progress, in my framework job polarization can occur even if production technologies do not change.

functional forms and that worker skill is distributed according to the Pareto distribution. In exchange for a loss of generality, these additional assumptions allow for sharper analytical results.

In the model, a rightward shift of the worker skill distribution causes job polarization by shrinking the number of firms employing medium-skilled workers and expanding the low-skilled and high-skilled sectors. Thus, an increase in worker skill can impact the average wage in two ways: by increasing worker productivity and by changing the structure of employment. There are levels of worker skill high enough such that the medium-skilled sector disappears entirely. At these levels, additional increases in worker skill cannot cause further job polarization, thereby reducing their effects on the average wage.

Another key finding of the model concerns the interaction between trade and worker skill. Not only does a reduction in trade costs increase job polarization, but increases in worker skill and reductions in trade costs interact in a complementary fashion to further increase the expansion of the high-skilled sector. The interaction effect on the low-skilled sector is ambiguous, however. Broadly speaking, the expansion of the low-skilled sector is further increased in less-developed countries but is dampened if the countries have relatively productive high-skilled sectors and skilled workforces. These open-economy results are important for two reasons. First, most of the world has experienced simultaneous increases in worker skill and reductions in trade costs over the recent past. Therefore, these interaction effects should in reality be relevant in explaining today's structure of employment. Second, these interaction effects exhibit a knife's-edge behavior suggesting that the experience of developed and developing countries should be different.

The paper most similar to this is Acemoglu (1999), where an increase in the proportion of skilled workers leads firms to replace "middling jobs" suitable for both high- and low-skilled workers with jobs specifically targeted for the skilled or the unskilled. One major difference in my model is that the proportion of skilled workers is not increasing; instead, workers at all points of the skill distribution are increasing their skill. Again, the cause of job polarization here is not the number of skilled workers but the complementarity between worker skill and production technologies along with a rightward shift of the skill distribution.

In addition to the literature already mentioned, other literature has also linked productivity growth and job polarization. One strand of the literature has focused on unbalanced productivity growth as in Baumol (1967). Ngai and Pissarides (2007) present a model in which different sectors experience different rates of total factor productivity (TFP) growth. This leads to shifts of employment shares to sectors with low TFP growth. Acemoglu and Guerrieri (2008) develop a model with sectors that differ in factor proportions. Capital deepening increases the output of the more capital-intensive sector but causes capital and labor to reallocate away from that sector. Within the routinization literature, Autor et al. (2006) develop a model in which "computers complement nonroutine cognitive tasks, substitute for routine tasks, and have little impact on nonroutine manual tasks" which is consistent with job polarization. In addition, Autor and Dorn (2013) argue that for the United States the expansion of the service sector is the primary cause for the increase in the share of low-skilled employment. My model differs from these by focusing on a different mechanism behind job polarization and by extending the model to the open economy.

This chapter is organized as follows. Section 4.1 presents the setup of the closed model. Then, Section 4.2 discusses the results of the model. Section 4.3 extends these results to the open economy.

4.1 Setup of the Model

4.1.1 Demand

The representative consumer has preferences according to

$$U = (1-\beta)\ln Y + \beta \ln X$$

where Y is a homogenous good and X is a composite good made up of a continuum of differentiated goods where

$$X = \left[\int_0^N x(i)^\alpha di\right]^{\frac{1}{\alpha}}$$

The elasticity of substitution across varieties given by $\sigma = \frac{1}{1-\alpha} > 1$. Dixit and Stiglitz (1977) shows that consumption of the differentiated varieties of X can be represented in aggregate as consumption of a composite good with aggregate price P_X:

$$P_X = \left[\int_0^N p(i)^{1-\sigma} di\right]^{\frac{1}{1-\sigma}}$$

Total demand for any variety is then

$$x(i) = \frac{\beta E}{P_X}\left(\frac{p(i)}{P_X}\right)^{-\sigma}$$

where E is total expenditure.

4.1.2 Production

There is a continuum of workers with mass M. Workers differ by their productivity level Z, which is used as an index along the continuum of workers. My main departure from Yeaple (2005) is that I assume that worker productivities are distributed according to a Pareto distribution with density

$$g(Z) = \frac{\eta\theta^\eta}{Z^{\eta+1}}$$

where $\eta > 0$ is the shape parameter, $\theta > 0$ is the scale parameter (as well as the minimum level of worker productivity), and $Z \in [\theta, \infty)$. Note that a general increase in worker skill can be represented as an increase in θ which has the effect of shifting the entire distribution of worker skill to the right.

Labor is the only factor of production. Firms can produce either Y or a variety of X. Firms producing X must choose whether to produce using the superior technology H or the inferior technology L. There are fixed costs to producing X but not Y. Using the H technology incurs fixed cost F_H and using the L technology incurs fixed cost F_L with $F_H > F_L$. These fixed costs are measured in terms of units of output.

I assume that the amount that a worker with productivity Z can produce using the various technologies is given by

$$\varphi_Y(Z) = Z$$

$$\varphi_L(Z) = Z^l$$

$$\varphi_H(Z) = Z^h$$

where $\eta > h > l > 1$. Though a Pareto distribution simply requires that $\eta > 0$, I require that $\eta > h$ for reasons that will be apparent later. With these production technologies, a worker with a given level of productivity will be most productive if employed by a H firm and least productive if employed in the Y sector.

4.2 Closed-Economy Results

4.2.1 Determining Unit Costs

Firms in the perfectly competitive Y sector charge a price equal to unit costs. Monopolistically competitive firms producing the heterogenous good X charge a constant mark-up over unit cost. A firm in the X sector producing variety k earns revenue

$$R_k = (\beta E P_X^{\sigma-1}) p_k^{1-\sigma} \tag{4.1}$$

With a perfectly competitive labor market, the wage distribution over Z is such that all firms using the same technology have the same unit costs. In this environment, the least-skilled workers maximize their earnings by working in the Y sector, the most-skilled workers maximize their earnings by working for H firms, and medium-skilled workers maximize their earnings by working for L firms (we assume for now that this sector exists). This wage distribution is shown in Figure 1 of Yeaple (2005). Given this pattern of worker sorting, there must be a marginal worker whose skill level makes him or her indifferent between working in the Y sector and working for a L firm in the X sector. Let us call this skill level Z_1. Likewise, there is a marginal worker whose skill level (which we will call Z_2) makes him or her indifferent between working for a L firm or for a H firm. Another way to describe these cutoffs is that Z_1 is the skill level of the most-skilled worker in the Y sector and Z_2 is the skill level of the least-skilled worker employed by H firms.

As in Yeaple (2005), let C_Y, C_L, and C_H be the unit costs of producing Y, L, and H respectively. These unit costs are dependent on the parameters of the Pareto distribution, η and θ. A worker with skill level Z can then earn $C_Y\varphi_Y(Z)$, $C_L\varphi_L(Z)$, or $C_H\varphi_H(Z)$ depending on the sector in which he/she is employed. Since workers with productivity equal to Z_1 or Z_2 must be indifferent between working for two different types of firms, it must be the case that $C_L\varphi_L(Z_1) = C_Y\varphi_Y(Z_1)$ and $C_H\varphi_H(Z_2) = C_L\varphi_L(Z_2)$. Thus, the unit costs of L and H firms can be expressed in terms of the unit costs of firms producing Y:

$$C_L = \frac{\varphi_Y(Z_1)}{\varphi_L(Z_1)}C_Y$$
$$C_H = \frac{\varphi_L(Z_2)}{\varphi_H(Z_2)}C_L$$

4.2.2 Finding Z_1 and Z_2

Even though the monopolistically competitive firms in the X sector are able to charge constant mark-ups over unit costs, free entry into the X sector ensures that these firms earn zero profits. Denoting the choice of production technology as $j \in \{H, L\}$, the zero-profit condition for firms in the X sector can be written as

$$R_j = C_j(x_j + F_j) = \sigma C_j F_j \tag{4.2}$$

Combining Equations (4.1) and (4.2),

$$\frac{R_H}{R_L} = \left(\frac{C_H}{C_L}\right)^{1-\sigma} = \frac{C_H F_H}{C_L F_L}$$

from which Z_2 follows directly (recall that $C_H = \frac{\varphi_L(Z_2)}{\varphi_H(Z_2)} C_L$):

$$Z_2 = \left(\frac{F_H}{F_L}\right)^{\frac{1}{\sigma(h-l)}} \tag{4.3}$$

Equation (4.3) implies that the high-tech portion of the X sector expands as the entry costs for high-tech firms become cheaper relative to the entry costs for low-tech firms and as high-tech firms becomes more productive relative to low-tech firms.

The next step is to solve for Z_1. The total expenditure on Y is its Cobb-Douglas share $(1 - \beta)$ of total expenditures, which in turn must be equal to total wages paid. Total wages paid can be expressed as $M\overline{W}$ where

$$\overline{W} = C_Y \int_{\theta}^{Z_1} \varphi_Y(Z) g(Z) dZ + C_L \int_{Z_1}^{Z_2} \varphi_L(Z) g(Z) dZ + C_H \int_{Z_2}^{\infty} \varphi_H(Z) g(Z) dZ$$

is the average wage per worker. Total expenditure on Y must also be equal to the wages paid to workers in the Y sector, $MC_Y \int_{\theta}^{Z_1} \varphi_Y(Z) g(Z) dZ$. These two conditions together imply the market-clearing equation

$$\frac{\beta}{1-\beta}C_Y\int_{\theta}^{Z_1}\varphi_Y(Z)g(Z)dZ = C_L\int_{Z_1}^{Z_2}\varphi_L(Z)g(Z)dZ + C_H\int_{Z_2}^{\infty}\varphi_H(Z)g(Z)dZ \quad (4.4)$$

which can be written simply as

$$\frac{\beta}{1-\beta}Z_1^{l-1}\int_{\theta}^{Z_1}Z^{-\eta}dZ = \int_{Z_1}^{Z_2}Z^{l-\eta-1}dZ + Z_2^{l-h}\int_{Z_2}^{\infty}Z^{h-\eta-1}dZ \quad (4.5)$$

The integrals in Equation (4.5) are straightforward to solve.[3] Doing so gives a polynomial in Z_1:

$$\frac{\beta Z_2^{\eta-l}}{(1-\beta)(\eta-1)\theta^{\eta-1}}Z_1^{\eta-1} + \left(\frac{1}{\eta-l}-\frac{1}{\eta-h}\right)Z_1^{\eta-l} - \left[\frac{\beta}{(1-\beta)(\eta-1)}+\frac{1}{\eta-l}\right]Z_2^{\eta-l} = 0 \quad (4.6)$$

In general, there are no analytic solutions for this polynominal. However, by setting $\eta = 3$ and $l = 2$ Equation (4.6) becomes a quadratic polynominal. Therefore, for the remainder of this paper I assume that $\eta = 3$ and $l = 2$.[4] With these assumptions, the quadratic has the solution

$$Z_1 = \frac{1-\beta}{\beta}\left(\frac{1}{3-h}-1\right)\frac{\theta^2+\theta\sqrt{\theta^2+A}}{Z_2} \quad (4.7)$$

where for ease of notation I introduce the term

$$A = \left(\frac{1}{3-h}-1\right)^{-2}\left(\frac{\beta}{1-\beta}\right)\left(\frac{\beta}{1-\beta}+2\right)Z_2^2$$

Note that because $l < h < \eta$, Z_1 must be positive.

[3] Evaluating the antiderivative of $Z^{h-\eta-1}$ at infinity requires $\eta > h$.

[4] Is $\eta = 3$ a feasible value for the shape parameter of Pareto-distributed worker productivity? The closest comparisons come from estimates of firm productivity. Di Giovanni et al. (2011) estimate that $\frac{\eta}{\sigma-1} = 1.05$. If $\eta = 3$, this implies that $\sigma = 3.86$. Eaton et al. (2011) estimate that $\frac{\eta}{\sigma-1} = 2.46 \Rightarrow \sigma = 2.22$.

4.2.3 Alternate Equilibria

Up to this point I have assumed that L firms exist. There is, however, an alternate set of equilibria in which they do not exist.

Proposition 3. *There exists a value of* θ, $\overline{\theta} = Z_2\sqrt{\frac{1}{1+\frac{1-\beta}{\beta}(\frac{2}{3-h})}}$, *such that if* $\theta > \overline{\theta}$ *then no* L*-firms exist.*

Proof. Recall that θ is the scale parameter representing the productivity of the least-productive worker. From Equations (4.3) and (4.7), it is apparent that Z_1 is increasing in θ whereas Z_2 is independent of θ. It is also true that $\lim\limits_{\theta \to 0} Z_1 < Z_2 < \lim\limits_{\theta \to \infty} Z_1$. Therefore, there must be some value of θ such that $Z_1 = Z_2$. It can be verified that this value is $\theta = Z_2\sqrt{\frac{1}{1+\frac{1-\beta}{\beta}(\frac{2}{3-h})}}$.

Since L firms only exist if $Z_1 < Z_2$, the result must necessarily follow. $\square$

If no L firms exist, then all firms must either be H firms or producers of Y. Instead of two cutoffs there is now only a single cutoff, which I call Z_0, separating workers employed in the Y sector and those employed by H firms in the X sector. The market-clearing condition for Y expressed in Equation (4.5) now becomes

$$\frac{\beta}{1-\beta}\int_{\theta}^{Z_0} Z^{-\eta} dZ = Z_0^{1-h}\int_{Z_0}^{\infty} Z^{h-\eta-1} dZ \tag{4.8}$$

which has the solution

$$Z_0 = \theta\sqrt{1 + \frac{1-\beta}{\beta}\left(\frac{2}{3-h}\right)} \tag{4.9}$$

4.2.4 Changes in θ

I am interested in exploring the effects of a general increase in worker productivity. This is captured in the model by an increase in the parameter θ, which causes a rightward shift of the worker productivity distribution. Ultimately, the goal is to analyze the effects of an increase in θ on the structure of employment and on wages, but first I establish the effects of an increase in θ on the cutoffs.

Proposition 4. *For the case where $\theta < \overline{\theta}$, an increase in θ (corresponding to a rightward shift in the distribution of worker productivity) increases Z_1 but has no effect on Z_2. For the case where $\theta > \overline{\theta}$, an increase in θ increases Z_0.*

Proof. The result immediately follows from the derivatives of Equations (4.3), (4.7), and (4.9) with respect to θ: $\frac{dZ_1}{d\theta} > 0$, $\frac{dZ_2}{d\theta} = 0$, and $\frac{dZ_0}{d\theta} > 0$. $\square$

When $\theta < \overline{\theta}$, an increase in θ causes Z_1 to approach Z_2. When θ reaches $\overline{\theta}$, Z_1 and Z_2 collapse into a single cutoff (Z_0) as the last L firm exits the market. Any further increase in θ simply raises Z_0.

The next step is to define job polarization in the context of the model. There are three types of jobs in the economy: low-skilled jobs in the Y sector, medium-skilled jobs at L firms, and high-skilled jobs at H firms. *Job polarization* occurs when the share of workers employed by L firms goes down and the shares of workers employed in the Y sector and by H firms goes up.

The following result builds on Proposition 4 to determine the effects of an increase in θ on the shares of employment.

Proposition 5. *For the case where $\theta < \overline{\theta}$, an increase in θ increases job polarization. For the case where $\theta > \overline{\theta}$, an increase in θ does not change the proportion of workers employed in the Y sector or by H firms.*

Proof. First, the case where $\theta < \overline{\theta}$. Let $S_Y = G(Z_1) = 1 - (\frac{\theta}{Z_1})^3$ be the share of workers employed in the Y sector and let $S_L = G(Z_2) - G(Z_1) = (\frac{\theta}{Z_1})^3 - (\frac{\theta}{Z_2})^3$ and $S_H = 1 - G(Z_2) = (\frac{\theta}{Z_2})^3$ be the shares of workers employed by L and H firms, respectively. The result follows from the signs of the derivatives:

$$\frac{dS_Y}{d\theta} = \frac{3\theta^2}{Z_1^3}\left(\frac{\theta}{Z_1}\frac{dZ_1}{d\theta} - 1\right) > 0 \qquad (\text{since } \frac{dZ_1}{d\theta} > 0)$$
$$\frac{dS_L}{d\theta} = -\frac{3\theta^2}{Z_1^3}\left(\frac{\theta}{Z_1}\frac{dZ_1}{d\theta} - 1\right) - \frac{3\theta^2}{Z_2^3} < 0$$
$$\frac{dS_H}{d\theta} = \frac{3\theta^2}{Z_2^3} > 0$$

Similarly, for the case where $\theta > \overline{\theta}$ the proportions of workers employed in the Y sector and by H firms are $S_Y = G(Z_0) = 1 - (\frac{\theta}{Z_0})^3$ and $S_H = 1 - G(Z_0) = (\frac{\theta}{Z_0})^3$, respectively. Again the result follows from the sign of the derivatives:

$$\frac{dS_Y}{d\theta} = 0$$
$$\frac{dS_H}{d\theta} = 0$$

□

An increase in θ causes a reallocation of X workers towards H firms and away from L firms as a more skilled workforce increases the viability of adopting the H technology. This raises the overall output of the X sector. Cobb-Douglas preferences dictate that the Y sector must also expand in order to maintain constant shares of consumption. Therefore, as θ increases the structure of employment becomes more polarized with some workers leaving L firms to join the Y sector and some leaving to join H firms. When θ reaches $\overline{\theta}$, then no L firms remain and any further increase in θ has no impact on worker allocation.

Having established that a general increase in worker productivity can generate job polarization, I can extend the analysis to examine the net effect on wages.

Proposition 6. *An increase in θ raises the average wage paid to all workers ($\frac{d\overline{W}}{d\theta} > 0$). Furthermore, suppose that $\theta_A < \theta_B$. Then, $\left.\frac{d\overline{W}}{d\theta}\right|_{\theta=\theta_A} > \left.\frac{d\overline{W}}{d\theta}\right|_{\theta=\theta_B}$ if $\theta_A < \overline{\theta}$ and $\left.\frac{d\overline{W}}{d\theta}\right|_{\theta=\theta_A} = \left.\frac{d\overline{W}}{d\theta}\right|_{\theta=\theta_B}$ if $\theta_A \geq \overline{\theta}$.*

Proof. With Cobb-Douglas preferences, the amount of Y produced (denoted as Q_Y) is directly proportional to total output. Also, Q_Y is directly proportional to the average wage $\overline{W}$ since total output is equal to total wages $M\overline{W}$ (with M constant). Therefore, to show an increase in $\overline{W}$ it is sufficient to show an increase in Q_Y.

For the case where $\theta < \overline{\theta}$, $Q_Y = \int_{\theta}^{Z_1(\theta)} \varphi_Y(Z)g(Z)dZ$ and

$$\frac{dQ_Y}{d\theta} = \frac{\theta^2}{Z_1^2}\left(\frac{3}{\sqrt{1+\frac{A}{\theta^2}}}\right) + \left(1 - \frac{\theta^2}{Z_1^2}\right)\frac{3}{2} > 0$$

This expression is the weighted mean of $\frac{3}{\sqrt{1+\frac{A}{\theta^2}}}$ and $\frac{3}{2}$ with weights $\frac{\theta^2}{Z_1^2}$ and $1 - \frac{\theta^2}{Z_1^2}$, respectively.

For the case where $\theta \geq \overline{\theta}$, $Q_Y = \int_{\theta}^{Z_0(\theta)} \varphi_Y(Z)g(Z)dZ$ with

$$\frac{dQ_Y}{d\theta} = \frac{3}{2}\left(1 - \frac{\theta^2}{Z_0^2}\right) = \frac{3(1-\beta)}{(3-h)\beta + 2(1-\beta)} > 0$$

Since $\frac{dQ_Y}{d\theta} > 0$ for all values of θ, it follows that $\frac{d\overline{W}}{d\theta} > 0$. Furthermore, since $\frac{d^2Q_Y}{d\theta^2} < 0$ for $\theta < \overline{\theta}$ and $\frac{d^2Q_Y}{d\theta^2} = 0$ for $\theta \geq \overline{\theta}$, it follows that:

1. $\left.\frac{dQ_Y}{d\theta}\right|_{\theta=\theta_A} > \left.\frac{dQ_Y}{d\theta}\right|_{\theta=\theta_B}$ when $\theta_A < \overline{\theta}$ and $\theta_A < \theta_B$
2. $\left.\frac{dQ_Y}{d\theta}\right|_{\theta=\theta_A} = \left.\frac{dQ_Y}{d\theta}\right|_{\theta=\theta_B}$ when $\overline{\theta} \leq \theta_A < \theta_B$.

□

When $\theta < \overline{\theta}$, a general increase in worker skill boosts average wage via two channels. The first channel is that all workers are more productive. The second channel is through job polarization as the increase in productivity from workers leaving L firms to join H firms outweighs the loss in productivity from workers leaving L firms for the Y sector. A given $\Delta\theta > 0$ has a larger absolute effect on average wage for smaller θ than for larger θ because the impact of the second channel is directly proportional to the share of workers employed L. As fewer workers remain employed by L firms, further increases in θ have less of an effect on the structure of employment.

When $\theta \geq \overline{\theta}$, the absence of L firms means that no more job polarization can occur, leaving only the first channel through which increases in θ can increase the average wage. Thus, a given $\Delta\theta > 0$ has a smaller effect on the average wage for $\theta \geq \overline{\theta}$ than for $\theta < \overline{\theta}$.

4.3 Trade Between Identical Countries

4.3.1 The Open-Economy Model

As with Yeaple (2005), to maintain tractability I only consider trade between two identical countries. Trade is costly, with both a fixed entry cost F_X to begin exporting and a per-unit iceberg transport cost τ. As a consequence, producers of X that serve both the domestic and foreign markets earn foreign revenue that is less than their domestic revenue by a proportion $\tau^{1-\sigma}$. I assume that $F_H > F_X \tau^{\sigma-1} > F_L$, in which case L firms only sell domestically while H firms sell to both the domestic and foreign markets.[5]

Compared to the closed-economy model, L firms continue to earn revenue R_L but H firms now earn $R_H(1+\tau^{1-\sigma})$. With the same parameter values $\eta = 3$ and $l = 2$ that were used for the closed economy, the solution for Z_2 becomes

$$Z_2 = \left[\frac{F_H + F_X}{F_L(1+\tau^{1-\sigma})}\right]^{\frac{1}{\sigma(h-2)}} \tag{4.10}$$

The market-clearing conditions for the homogeneous good Y do not change with the advent of trade, so the solutions for Z_0 and Z_1 are still given by Equations (4.7) and (4.9). With the updated cutoffs, all previous propositions still hold.

[5]That more productive firms self-select into exporting is also a feature of the benchmark model in Melitz (2003). A review of the empirical evidence in support of this relationship can also be found in that paper.

4.3.2 Changes in τ

Having opened the model to trade between two identical countries, I turn to analyzing the impact of falling trade costs on job polarization.

Proposition 7. *A fall in τ decreases the critical value $\overline{\theta}$. For the case where $\theta < \overline{\theta}$, a fall in τ also increases job polarization as Z_1 goes up and Z_2 goes down. For the case where $\theta > \overline{\theta}$, a fall in τ has no effect on Z_0.*

Proof. Because θ is not changing, the result follows immediately from the derivatives of Equations (4.7), (4.9), and (4.10) with respect to τ:

$$\begin{aligned}
\frac{dZ_2}{d\tau} &= \frac{\sigma - 1}{\sigma\tau^{\sigma}(1+\tau^{1-\sigma})(h-2)}\left(\frac{F_L}{F_H+F_X}\right) Z_2 > 0 \\
\frac{dZ_1}{d\tau} &= -\frac{1-\beta}{\beta}\left(\frac{1}{3-h} - 1\right)\frac{1}{Z_2^2}\frac{dZ_2}{d\tau}\left[\theta^2 + \frac{\theta^3}{\sqrt{\theta^2 + A}}\right] < 0 \\
\frac{dZ_0}{d\tau} &= 0
\end{aligned}$$

□

As τ falls, exporting becomes more viable so more H firms enter the market. The increase in total output of X must be balanced by an increase in the production of Y. Thus, both an increase in θ and a fall in τ can increase job polarization. Unlike an increase in θ, however, a decline in τ produces a change in $\overline{\theta}$. By reducing the share of workers employed by L firms, falling trade costs reduce the scope for a subsequent increase in θ to increase job polarization. This reduction in scope is represented by a lower $\overline{\theta}$ as there is less room for θ to increase until the point is reached where no L firms remain.

The results so far demonstrate how increases in worker skill and decreases in trade costs can lead to increased job polarization. But in trying to quantify the impact of these changes on job polarization, it is important to note that worker skill and trade costs have changed *simultaneously* in recent decades. This introduces potentially important interaction effects which are the focus of the next result.

Proposition 8. *For the case where $\theta < \overline{\theta}$, $\frac{d^2 S_H}{d\theta d\tau} < 0$. Also, if θ is sufficiently close to $\overline{\theta}$, β is sufficiently close to its lower bound (0), and h is sufficiently close to its upper bound (3), then $\frac{d^2 S_Y}{d\theta d\tau} \geq 0$. Otherwise, $\frac{d^2 S_Y}{d\theta d\tau} < 0$. (Proof in Appendix A)*

Job polarization consists of increases in the shares of high-skilled and low-skilled jobs. According to Proposition 8, an increase in worker skill and a decrease in trade costs interact in a complementary fashion to further increase the share of high-skilled jobs. There is also an interaction effect on the share of low-skilled jobs but its direction can go either way depending on the values of β, h, and θ. Specifically, $\frac{d^2 S_Y}{d\theta d\tau} \geq 0$ for countries that have large consumption shares for Y goods, highly-productive H firms, and highly-skilled workforces. The last two traits in particular are associated with developed countries, implying that there ought to be a qualitative difference between developed and developing countries.

The importance of this result is that it predicts how the effects of a reduction in trade costs on job polarization vary with changes in worker skill, and vice-versa. The effect on the share of high-skilled jobs is magnified whereas the effect on the share of low-skilled jobs can either be magnified or muted depending on the country's characteristics.

This has immediate consequences for empirical studies of the evolution of the structure of employment. Empirical models are misspecified if they fail to account for the interaction between worker skill and trade costs. To illustrate this, a model that does not include the interaction effect would fail to identify that the effects of a reduction in trade costs on the share of high-skilled jobs increase as worker skill rises. Instead, this model would produce an estimated coefficient conditioned on the average level of worker skill over this period. This is unlikely to produce an accurate estimate of the true value of the coefficient for extreme values of worker skill.

4.4 Closing Remarks

In this chapter, I analyze a new potential cause behind the recent increase in job polarization in many countries. I have also shown how this mechanism systemically interacts with reductions in trade costs. As worker skill and trade costs have changed simultaneously, the results in this chapter offer a framework for analyzing how the structure of employment changes depending on country characteristics.

One limitation of this model is that trade occurs between identical countries. It is not clear to what extent the analysis in this chapter applies to trade between countries at different levels of development. A welcome avenue of future research would be to extend the model to allow for trade between non-identical countries.

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Appendix A

Proofs

A.1 Price Indices

Preferences for tradable goods are CES across a continuum of varieties with measure 1. Therefore, the price index for tradable goods in country n is given by

$$(P_n^T)^{1-\sigma} = \int_0^1 p^T(u)^{1-\sigma} du$$

where $p^T(u)$ is the price of the individual tradable good indexed by u. But since the price of each tradable good is randomly distributed (i.i.d.), this is the same as

$$\begin{aligned}
(P_n^T)^{1-\sigma} &= \int_0^\infty p^{1-\sigma} dG_n^T(p) \\
&= \int_0^\infty p^{1-\sigma} \theta [\sum_h \tilde{T}_h (c_h d_{nh})^{-\theta}] p^{\theta-1} \exp\{-[\sum_h \tilde{T}_h (c_h d_{nh})^{-\theta}] p^\theta\} dp \\
&= \theta [\sum_h \tilde{T}_h (c_h d_{nh})^{-\theta}] \int_0^\infty p^{\theta-\sigma} \exp\{-[\sum_h \tilde{T}_h (c_h d_{nh})^{-\theta}] p^\theta\} dp
\end{aligned}$$

Next, perform a variable transformation using $x = [\sum_h \tilde{T}_h (c_h d_{nh})^{-\theta}] p^\theta$ so that

$$dp = \frac{1}{\theta} [\sum_h \tilde{T}_h (c_h d_{nh})^{-\theta}]^{-1} p^{1-\theta} dx$$

After the variable transformation,

$$\begin{aligned}(P_n^T)^{1-\sigma} &= \int_0^\infty p^{1-\sigma} e^{-x} dx \\ &= [\sum_h \tilde{T}_h (c_h d_{nh})^{-\theta}]^{\frac{\sigma-1}{\theta}} \int_0^\infty x^{\frac{1-\sigma}{\theta}} e^{-x} dx\end{aligned}$$

where the integral is by definition the gamma function evaluated at $\frac{1-\sigma}{\theta} + 1$. Thus, the price index tradable goods is given by

$$P_n^T = \gamma [\sum_h \tilde{T}_h (c_h d_{nh})^{-\theta}]^{-\frac{1}{\theta}}$$

where $\gamma = [\Gamma(\frac{1-\sigma}{\theta} + 1)]^{\frac{1}{1-\sigma}}$. The price index for nontradable goods is derived in the same way.

A.2 Share of Multinational Production

In this section, I derive Equation (2.28) beginning with the total value of MP in h due to firms from i:

$$\begin{aligned}\text{MP}_{hi} &= \sum_n \frac{1}{1+\tau_{nh}} X_{nhi}^T + X_{hi}^{NT} \\ &= \sum_n \frac{1}{1+\tau_{nh}} X_n^T \cdot \frac{X_{nhi}^T}{X_n^T} + X_{hi}^{NT} \\ &= \sum_n \frac{1}{1+\tau_{nh}} X_n^T \cdot \left(\sum_i \frac{X_{nhi}^T}{X_n^T} \right) \frac{m_{hi}^{-\theta} T_i}{\tilde{T}_h} + X_{hi}^{NT} && \text{(due to Equation 2.9)}\end{aligned}$$

$$
\begin{aligned}
&= \sum_n \frac{1}{1+\tau_{nh}} \left(\sum_i X^T_{nhi} \right) \frac{m_{hi}^{-\theta} T_i}{\tilde{T}_h} + X^{NT}_{hi} \\
&= \left(\sum_n \sum_i \frac{1}{1+\tau_{nh}} X^T_{nhi} + X^{NT}_h \right) \frac{m_{hi}^{-\theta} T_i}{\tilde{T}_h} \\
&= \left(\frac{1}{\beta} w_h L^T_h + \frac{1}{\beta} w_h L^{NT}_h \right) \frac{m_{hi}^{-\theta} T_i}{\tilde{T}_h} \qquad \text{(due to Equations 2.11 and 2.12)} \\
&= \left(\frac{1}{\beta} w_h L_h \right) \frac{m_{hi}^{-\theta} T_i}{\tilde{T}_h}
\end{aligned}
$$

Dividing both sides by $w_h L_h$ delivers Equation (2.28).

A.3 Proof of Proposition 8

Proof. The cross-derivative of S_H is

$$
\frac{d^2 S_H}{d\theta d\tau} = -9 \frac{\theta^2}{Z_2^4} \frac{dZ_2}{d\tau} < 0
$$

Next, we determine the sign of the cross-derivative of S_Y. We start by finding $\frac{dS_Y}{d\tau}$. Since $\frac{dZ_1}{dZ_2} = -\frac{1-\beta}{\beta} \left(\frac{1}{3-h} - 1 \right) \left(1 + \frac{\theta}{\sqrt{\theta^2+A}} \right) \frac{\theta^2}{Z_2^2}$,

$$
\begin{aligned}
\frac{dS_Y}{d\tau} &= 3 \frac{\theta^3}{Z_1^4} \frac{dZ_1}{dZ_2} \frac{dZ_2}{d\tau} \\
&= -3 Z_2^2 \frac{dZ_2}{d\tau} \left(\frac{\beta}{1-\beta} \right)^3 \left(\frac{1}{3-h} - 1 \right)^{-3} \frac{\theta}{\sqrt{\theta^2+A}} \left(\frac{1}{\theta + \sqrt{\theta^2+A}} \right)^3 < 0
\end{aligned}
$$

Note that only a few terms in $\frac{dS_Y}{d\tau}$ contain θ. Then,

$$
\frac{d^2 S_Y}{d\theta d\tau} = -3 Z_2^2 \frac{dZ_2}{d\tau} \left(\frac{\beta}{1-\beta} \right)^3 \left(\frac{1}{3-h} - 1 \right)^{-3} \cdot \frac{d}{d\theta} \left[\frac{\theta}{\sqrt{\theta^2+A}} \left(\frac{1}{\theta + \sqrt{\theta^2+A}} \right)^3 \right]
$$

where

$$
\frac{d}{d\theta} \left[\frac{\theta}{\sqrt{\theta^2+A}} \left(\frac{1}{\theta + \sqrt{\theta^2+A}} \right)^3 \right] = \frac{1}{\theta^2+A} \left(\frac{1}{\theta + \sqrt{\theta^2+A}} \right)^3 \left[\frac{A}{\sqrt{\theta^2+A}} - 3\theta \right]
$$

We see that $\frac{d^2 S_Y}{d\theta d\tau} < 0$ only when $\frac{A}{\sqrt{\theta^2+A}} > 3\theta \Leftrightarrow \left(\frac{A}{\theta^2}\right)^2 - 9\frac{A}{\theta^2} - 9 > 0 \Leftrightarrow \frac{A}{\theta^2} > \frac{9+\sqrt{117}}{2}$.

Recalling the definition of A, this is equivalent to the condition

$$\theta < \frac{Z_2}{\frac{1}{3-h}-1}\sqrt{\frac{\beta}{1-\beta}\left(\frac{\beta}{1-\beta}+2\right)\frac{2}{9+\sqrt{117}}}$$

This implies that $\frac{d^2 S_Y}{d\theta d\tau} \geq 0$ for large values of θ. But recall that the cutoff Z_1 exists only when $\theta < \overline{\theta}$. Therefore, the condition for which $\frac{d^2 S_Y}{d\theta d\tau} \geq 0$ and $\theta < \overline{\theta}$ both hold is

$$\begin{aligned}
\frac{Z_2}{\frac{1}{3-h}-1}\sqrt{\frac{\beta}{1-\beta}\left(\frac{\beta}{1-\beta}+2\right)\frac{2}{9+\sqrt{117}}} &< \overline{\theta} \\
\Leftrightarrow \frac{Z_2}{\frac{1}{3-h}-1}\sqrt{\frac{\beta}{1-\beta}\left(\frac{\beta}{1-\beta}+2\right)\frac{2}{9+\sqrt{117}}} &< Z_2\sqrt{\frac{1}{1+\frac{1-\beta}{\beta}(\frac{2}{3-h})}} \\
\Leftrightarrow \left(\frac{1}{3-h}-1\right)^{-2}\left(\frac{\beta}{1-\beta}+2\right)\left(\frac{\beta}{1-\beta}+\frac{2}{3-h}\right) &< \frac{9+\sqrt{117}}{2}
\end{aligned}$$

Recall that $2 < h < 3$. The left-hand side of this inequality is increasing in β. Also,

$$\lim_{h\searrow 2}\frac{\frac{\beta}{1-\beta}+\frac{2}{3-h}}{\left(\frac{1}{3-h}-1\right)^2} = \frac{\frac{\beta}{1-\beta}+2}{\lim_{h\searrow 2}\left(\frac{1}{3-h}-1\right)^2} \to \infty$$

and (applying L'Hospital's Rule)

$$\lim_{h\nearrow 3}\frac{\frac{\beta}{1-\beta}+\frac{2}{3-h}}{\left(\frac{1}{3-h}-1\right)^2} = \lim_{h\nearrow 3}\frac{1}{\frac{1}{3-h}-1} = 0$$

Therefore, if h is large enough and β is small enough then there exist values of θ that are large enough (though do not exceed $\overline{\theta}$) that $\frac{d^2 S_Y}{d\theta d\tau} \geq 0$. Otherwise, $\frac{d^2 S_Y}{d\theta d\tau} < 0$. $\square$

Appendix B

Solving the Models

B.1 Solving the Closed Model

Solving equation (3.11) for p gives $p = \frac{\phi}{1-\phi}\frac{y}{x}$. From equations (3.7) and (3.8), I obtain:

$$s = (A+B)^{\frac{1}{2\alpha-1}} \left(\frac{p}{2}\right)^{\frac{2\alpha}{2\alpha-1}}$$
$$w = (A+B)^{-\frac{1}{2\alpha-1}} \left(\frac{2}{p}\right)^{\frac{2(1-\alpha)}{2\alpha-1}}$$

Relative factor prices are $\frac{s}{w} = \left(\frac{A+B}{2}p\right)^{\frac{2}{2\alpha-1}} = \left(\frac{\phi}{1-\phi}\frac{A+B}{2}\frac{y}{x}\right)^{\frac{2}{2\alpha-1}}$. Using these equations, I can substitute p, s, and w out of equations (3.9) and (3.10) and solve the system:

$$
\begin{aligned}
x &= [(A+1)(B+1)]^{-\frac{1}{2(2\alpha-1)}}(HL)^{\frac{1}{2}} \\
y &= \frac{1-\phi}{\phi}\frac{2}{A+B}(A+1)^{-\frac{\alpha}{2\alpha-1}}(B+1)^{-\frac{1-\alpha}{2\alpha-1}}H^{1-\alpha}L^{\alpha} \\
p &= \frac{2}{A+B}\left(\frac{B+1}{A+1}\right)^{\frac{1}{2}}\left(\frac{L}{H}\right)^{\alpha-\frac{1}{2}} \\
s &= \frac{1}{A+B}\left(\frac{B+1}{A+1}\right)^{\frac{\alpha}{2\alpha-1}}\left(\frac{L}{H}\right)^{\alpha} \\
w &= \frac{1}{A+B}\left(\frac{A+1}{B+1}\right)^{\frac{1-\alpha}{2\alpha-1}}\left(\frac{H}{L}\right)^{1-\alpha}
\end{aligned}
$$

B.2 Solving the Model With Final Goods Trade Only

As with the closed model, I begin by solving for the factor prices in terms of p:

$$
\begin{aligned}
s &= (A+B)^{\frac{1}{2\alpha-1}}\left(\frac{p}{2}\right)^{\frac{2\alpha}{2\alpha-1}} \\
w &= (A+B)^{-\frac{1}{2\alpha-1}}\left(\frac{2}{p}\right)^{\frac{2(1-\alpha)}{2\alpha-1}} \\
s^* &= (A+B)^{\frac{1}{2\alpha-1}}\left(\frac{(1+\tau)p}{2}\right)^{\frac{2\alpha}{2\alpha-1}} \\
w^* &= (A+B)^{-\frac{1}{2\alpha-1}}\left(\frac{2}{(1+\tau)p}\right)^{\frac{2(1-\alpha)}{2\alpha-1}}
\end{aligned}
$$

Plugging the ratios of these factor prices into the factor-market clearing conditions, I find output in terms of p:

$$x = \left(\frac{A}{A-B}\right) H \left[\frac{(A+B)p}{2}\right]^{\frac{1}{2\alpha-1}} - \left(\frac{B}{A-B}\right) L \left[\frac{2}{(A+B)p}\right]^{\frac{1}{2\alpha-1}}$$
$$y = \left(\frac{1}{A-B}\right) L \left[\frac{2}{(A+B)p}\right]^{\frac{2(1-\alpha)}{2\alpha-1}} - \left(\frac{1}{A-B}\right) H \left[\frac{(A+B)p}{2}\right]^{\frac{2\alpha}{2\alpha-1}}$$
$$x^* = \left(\frac{A}{A-B}\right) H^* \left[\frac{(A+B)(1+\tau)p}{2}\right]^{\frac{1}{2\alpha-1}} - \left(\frac{B}{A-B}\right) L^* \left[\frac{2}{(A+B)(1+\tau)p}\right]^{\frac{1}{2\alpha-1}}$$
$$y^* = \left(\frac{1}{A-B}\right) L^* \left[\frac{2}{(A+B)(1+\tau)p}\right]^{\frac{2(1-\alpha)}{2\alpha-1}} - \left(\frac{1}{A-B}\right) H^* \left[\frac{(A+B)(1+\tau)p}{2}\right]^{\frac{2\alpha}{2\alpha-1}}$$

From equations (3.15)-(3.17), I find p, E_x, and E_y^* in terms of the outputs:

$$p = \frac{\phi}{1-\phi}\left[\frac{y+y^*}{x+(1+\tau)x^*}\right]$$
$$E_x = (1-\phi)\left(\frac{xy^* - (1+\tau)x^*y}{y+y^*}\right)$$
$$E_y^* = \phi\left(\frac{xy^* - (1+\tau)x^*y}{x+(1+\tau)x^*}\right)$$

With the outputs in terms of p and with p in terms of the outputs, I can solve for p in terms of the model parameters. Before solving for p, it is useful to find the following sums:

$$\begin{aligned} y+y^* =& \frac{1}{A-B}\left[\frac{2}{(A+B)p}\right]^{\frac{2(1-\alpha)}{2\alpha-1}} \left[L + (1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}} L^*\right] \\ &- \frac{1}{A-B}\left[\frac{(A+B)p}{2}\right]^{\frac{2\alpha}{2\alpha-1}} \left[H + (1+\tau)^{\frac{2\alpha}{2\alpha-1}} H^*\right] \\ x+(1+\tau)x^* =& \frac{A}{A-B}\left[\frac{(A+B)p}{2}\right]^{\frac{1}{2\alpha-1}} \left[H + (1+\tau)^{\frac{2\alpha}{2\alpha-1}} H^*\right] \\ &- \frac{B}{A-B}\left[\frac{2}{(A+B)p}\right]^{\frac{1}{2\alpha-1}} \left[L + (1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}} L^*\right] \end{aligned}$$

Then,

$$p = \left[C(\alpha,\phi)\left(\frac{L + (1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}} L^*}{H + (1+\tau)^{\frac{2\alpha}{2\alpha-1}} H^*}\right)\right]^{\frac{2\alpha-1}{2}} \tag{B.1}$$

where

$$C(\alpha,\phi)=\left(\frac{B\left(\frac{2}{A+B}\right)^{\frac{1}{2\alpha-1}}+\frac{\phi}{1-\phi}\left(\frac{2}{A+B}\right)^{\frac{2(1-\alpha)}{2\alpha-1}}}{A\left(\frac{A+B}{2}\right)^{\frac{1}{2\alpha-1}}+\frac{\phi}{1-\phi}\left(\frac{A+B}{2}\right)^{\frac{2\alpha}{2\alpha-1}}}\right)$$

The solutions for the factor prices and the output levels follow immediately from equation (B.1). I wish to find the conditions that ensure that both countries are diversified in production. That is, all four output levels (x, y, x^*, y^*) must be positive. For x to be positive requires

$$\frac{A}{B}\left(\frac{A+B}{2}\right)^{\frac{2}{2\alpha-1}}C\left[1+(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}\frac{L^*}{L}\right]>1+(1+\tau)^{\frac{2\alpha}{2\alpha-1}}\frac{H^*}{H}$$

and for y to be positive requires

$$\left(\frac{A+B}{2}\right)^{\frac{2}{2\alpha-1}}C\left[1+(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}\frac{L^*}{L}\right]<1+(1+\tau)^{\frac{2\alpha}{2\alpha-1}}\frac{H^*}{H}$$

Similarly, for x^* and y^* to be positive requires

$$\frac{A}{B}\left(\frac{(A+B)(1+\tau)}{2}\right)^{\frac{2}{2\alpha-1}}C\left[1+(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}\frac{L^*}{L}\right]>1+(1+\tau)^{\frac{2\alpha}{2\alpha-1}}\frac{H^*}{H}$$

and

$$\left(\frac{(A+B)(1+\tau)}{2}\right)^{\frac{2}{2\alpha-1}}C\left[1+(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}\frac{L^*}{L}\right]<1+(1+\tau)^{\frac{2\alpha}{2\alpha-1}}\frac{H^*}{H}$$

All four conditions hold if the following is true:

$$(1+\tau)^{\frac{2}{2\alpha-1}}<D(\alpha,\phi)\left[\frac{1+(1+\tau)^{\frac{2\alpha}{2\alpha-1}}\frac{H^*}{H}}{1+(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}\frac{L^*}{L}}\right]<\frac{A}{B}=\frac{\alpha}{1-\alpha} \tag{B.2}$$

where

$$D(\alpha,\phi)=\left(\frac{2}{A+B}\right)^{\frac{2}{2\alpha-1}}\frac{1}{C}=\frac{A\left(\frac{A+B}{2}\right)^{\frac{1}{2\alpha-1}}+\frac{\phi}{1-\phi}\left(\frac{A+B}{2}\right)^{\frac{2\alpha}{2\alpha-1}}}{B\left(\frac{A+B}{2}\right)^{\frac{1}{2\alpha-1}}+\frac{\phi}{1-\phi}\left(\frac{A+B}{2}\right)^{\frac{2\alpha}{2\alpha-1}}}$$

Note that $D > 1$ because $A > B$. Also, the inequalities in (B.2) imply that $(1+\tau)^{\frac{2}{2\alpha-1}}$ cannot be larger than $\frac{\alpha}{1-\alpha}$. It will be useful later on to write (B.2) as:

$$(1+\tau)^{\frac{2}{2\alpha-1}}\frac{H^*}{L^*} - \left(\frac{A}{BD}-1\right)(1+\tau)^{\frac{2(1-\alpha)}{2\alpha-1}}\frac{H}{L^*} < \frac{H}{L}$$
$$< D\frac{H^*}{L^*} + [D(1+\tau)^{-\frac{2\alpha}{2\alpha-1}} - (1+\tau)^{\frac{2(1-\alpha)}{2\alpha-1}}]\frac{H}{L^*} \tag{B.3}$$

To find the export volumes, I first find

$$xy^* - (1+\tau)x^*y = \left[\frac{(A+B)p}{(A-B)2}\right][(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}HL^* - (1+\tau)^{\frac{2\alpha}{2\alpha-1}}H^*L]$$

After substitutions and some algebra, I obtain:

$$E_x = \left[\frac{1-\phi}{\left(\frac{2}{A+B}\right)^{\frac{1}{2\alpha-1}}C^{-\frac{1}{2}} - \left(\frac{A+B}{2}\right)^{\frac{1}{2\alpha-1}}C^{\frac{1}{2}}}\right]\times$$
$$\left[\frac{(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}HL^* - (1+\tau)^{\frac{2\alpha}{2\alpha-1}}H^*L}{\sqrt{[H+(1+\tau)^{\frac{2\alpha}{2\alpha-1}}H^*][L+(1+\tau)^{-\frac{2(1-\alpha)}{2\alpha-1}}L^*]}}\right]$$

The first term in brackets is positive. Hence, exports are positive (and the law of one price holds) if $\frac{H}{L} > (1+\tau)^{\frac{2}{2\alpha-1}}\frac{H^*}{L^*}$. Compare this inequality to the first inequality in (B.3) and observe that, because $\frac{A}{BD} > 1$, $\frac{H}{L} > (1+\tau)^{\frac{2}{2\alpha-1}}\frac{H^*}{L^*}$ is the more binding of the two. It follows that the condition ensuring that both countries are diversified in production *and* that the law of one price holds is:

$$(1+\tau)^{\frac{2}{2\alpha-1}}\frac{H^*}{L^*} < \frac{H}{L} < D\frac{H^*}{L^*} + [D(1+\tau)^{-\frac{2\alpha}{2\alpha-1}} - (1+\tau)^{\frac{2(1-\alpha)}{2\alpha-1}}]\frac{H}{L^*}$$

Again, τ cannot be too large since

$$(1+\tau)^{\frac{2}{2\alpha-1}}\frac{H^*}{L^*} < D\frac{H^*}{L^*} + [D(1+\tau)^{-\frac{2\alpha}{2\alpha-1}} - (1+\tau)^{\frac{2(1-\alpha)}{2\alpha-1}}]\frac{H}{L^*}$$
$$\Leftrightarrow -[D-(1+\tau)^{\frac{2}{2\alpha-1}}] < [D-(1+\tau)^{\frac{2}{2\alpha-1}}](1+\tau)^{-\frac{2\alpha}{2\alpha-1}}\frac{H}{H^*}$$

which, regardless of the factor endowments, can only be true if $(1+\tau)^{\frac{2}{2\alpha-1}} < D$. Since $D < \frac{\alpha}{1-\alpha} = \frac{A}{B}$, this supercedes the earlier restriction on τ from (B.2).

Thus, both countries are diversified in their production and goods prices in the two countries are equal (net of trade costs) if: 1) τ is sufficiently small, 2) Home is more skill-abundant than Foreign by a sufficient margin, but 3) Home is not *too* skill-abundant relative to Foreign.