Trade, Technological Change, and Wage Inequality: The Case of Mexico

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Abstract

In the decade following the Mexico-U.S. trade integration, the manufacturing skill premium rose by almost 60 percent in Mexico and by only 12 percent in the U.S. Standard trade theory predicts that when countries with different levels of skilled labor integrate, the skill premium should fall - not rise - in the skill-scarce country. In this paper, I reconcile theory and data by building a model in which intermediate goods are produced using rented technology. After integration, producers in Mexico begin to rent technologies from the United States, which are more advanced and, hence, more skill-intensive. This has two effects: The skill premium in Mexico rises due to adoption of the more advanced technology and the skill premium in the U.S. rises due to increased investment in this technology, which is driven by the increased marginal return on technology arising from its adoption in Mexico. The mechanism is supported by industry-level evidence: Mexican industries which are integrated into the U.S. supply chain have higher skill premia than their non-integrated counterparts. The calibrated model can account for about two-thirds of the increase in the skill premium in each country.

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1 Introduction

Standard trade theory has stark predictions for how factor prices should respond to trade integration between a skill-scarce and a skill-abundant country. In particular, models that are based on the Heckscher-Ohlin (henceforth H-O) theory predict that the ratio of wages paid to skilled versus unskilled workers (the skill premium) should rise in the skill-abundant country and fall in the skill-scarce country when the two countries open to trade with one another. A puzzle that has arisen in the context of this prediction is that when integrating with the world economy, many skill-scarce countries instead experience rising skill premia. Mexico is the canonical example of a country whose skill premium not only rose, but rose by much more than that of its more-developed counterpart, the United States, during the period in which Mexico opened its borders to trade with the United States. These observations have led many researchers to conclude that skill-biased technological change (SBTC), not increased openness to trade, has driven changes in developing economies’ skill premia.

In this paper, I argue that trade liberalization, by stimulating investment in skill-biased technologies and facilitating cross-border adoption of these technologies, plays an important role in explaining the aforementioned facts. I modify a standard trade model to include trade in technology, which occurs through the integration of supply chains across borders. I use the case of the Mexican trade liberalization and integration into the supply chain of American companies to explore the impact that technological transfer, which takes place as a part of this integration, has upon the wages of workers in Mexico and the United States. I calibrate the model using surveys of the Mexican and the U.S. manufacturing sectors and I find that a reduction in barriers to trade in goods and technology can account for about two-thirds of the observed increase in the skill premium in both Mexico and the United States.

To support my quantitative analysis, I provide empirical evidence at the industry-level that indicates that Mexican industries which trade more with the United States have higher skill premia on average and have greater increases in their skill premia in the late 1980s than their non-trading counterparts. This analysis suggests that trade connections are an important determinant of skill premia and that supply chains could be channels through which technology is transferred. While I do not have direct information about connections between the Mexican plants and the firms that they are supplying in the United States, I show that trade between the two countries rose dramatically over the course of the late
1980s and early 1990s. Moreover, intra-industry trade began to dominate Mexican-U.S. trade during the mid-1980s and has continued to do so ever since. I show that the use of intermediate imports is an important predictor of the skill premium, indicating that supply chain relationships play an important role in determining the skill premium in a given industry.

In order to assess the quantitative importance of supply chains on the skill premium, I adapt a standard trade model to allow for trade liberalization to increase both trade in goods and trade in ideas. I model “ideas” as technology capital, similar to the model in McGrattan and Prescott (2009), but I allow for technology capital to be rented from final goods producers, who own and invest in the stock of technology capital, to intermediate goods producers, who use it. I model trade liberalization as a reduction both in tariffs on goods and in taxes on flows of royalties. I discipline my exercise using manufacturing data from Mexico and the United States.

My model differs from those in the existing literature by incorporating two key ingredients. First, I allow for skill-biased technology to be endogenously accumulated by permitting firms to invest in a stock of technology that is assumed to be skill-augmenting. I consider final goods producers who own and invest in technology capital. Intermediate suppliers rent this technology capital in order to produce an intermediate product that will be a component of the final good. Consider for the moment a two country world in which both countries are in autarky. When the countries open to trade, the final goods producer does not need to open a plant in the foreign country in order to use his technology capital there. Instead, he can rent his technology to an intermediate goods producer that is already operating in the foreign country. This, in turn, increases the marginal product of a unit of technology capital since now it can be used by additional intermediate goods producers. It is key that technology capital is non-rivalrous so that using it in multiple locations actually increases its marginal productivity. Opening to trade, therefore, increases the return to technology capital, as in McGrattan and Prescott (2009). Firms respond to these increased returns to their technology capital by investing more. I refer to this as the “investment channel,” and it is the main channel that drives the increase in the skill premium seen in the United States. This is consistent with recent empirical work in Goel (2012) which provides evidence that firms in the United States respond to increased trade opportunities by increasing spending on innovation. Moreover, it is consistent with extant literature which has found that the rise in the skill premium in the United States is driven primarily by technological change. Note that this does not mean that opening to trade plays no role in increasing the skill premium, but rather, that its role manifests as an increase in technology, driven by increased returns
to investment in that technology.

Second, I allow technology capital to be rented across borders. I provide industry-level evidence that royalties paid as a percentage of output in Mexico co-varies positively with the skill-premium, meaning that industries that use more rented technologies are those that have larger skill premia; I take this as evidence of transfer of technology. Allowing for technology to be transferred through rental is the key to having the skill premium rise in both countries because it causes the skill premium to rise in the United States via the investment channel, as discussed above, and it causes the skill premium to rise in Mexico by what I will call the “adoption channel.” The “adoption channel” arises when intermediate goods producing firms in one country begin to produce for the supply chain of the final goods producer in the other and, therefore, adopt the technology of the final goods producer in the foreign country. In the model, intermediate goods producers in Mexico choose to adopt U.S. technology and supply U.S. final goods producers much more than vice versa. This is because, in the initial steady state, U.S. technology is much more productive than Mexican technology. Therefore, the adoption channel is the dominant force driving the increase in the skill premium in Mexico.

In my calibrated model, I find that moving from an autarkic steady state to a free trade steady state induces a skill premium increase of 39 percent in Mexico and 8 percent in the United States. This accounts for about two-thirds of the observed rise in both the Mexican skill premium and in the skill premium in the United States.

The adoption channel is key to obtaining these results. If I shut down the firm’s ability to trade technology, under my baseline calibration, results show the standard Stolper-Samuelson effect, with Mexico’s skill premium declining and that of the United States increasing. The Stolper-Samuelson effect is offset, in part, by the investment channel. I include two sectors in the model - one that is skilled-labor intensive and one that is unskilled-labor intensive - in order to allow for this type of effect, but both sectors use skill-augmenting technology capital. Opening to trade allows countries to specialize in the sector in which they have a comparative advantage, which in turn increases the return to the factors of production, thus inducing firms to invest more in the skill-augmenting technology in that sector. This raises the return to skilled workers for all countries, reducing the decline in the skill premium in Mexico. The big gain in the Mexican skill premium comes, however, through the rental of advanced technology from the United States. In the model, there is an initial jump in the skill premium in Mexico as U.S. technology becomes available to Mexican firms. This results from the sudden inflow of this technology into Mexico, which occurs when the distortion on royalties is reduced and the price of renting the U.S. technology falls as a consequence.

My quantitative results are disciplined by manufacturing data for the United States and
Mexico. Because my interest lies primarily in how the skill premium changed in the two countries, I target the level of the skill premium in the initial period. I use aggregated industry data from Mexico on royalty payments to pin down the parameter that governs the importance of technology capital in production. In particular, I match royalty payments as a percentage of payroll payments in the period before trade liberalization. I use 1985 as the “pre-reform” period; as I will document below, the majority of Mexican trade reforms began in 1986. I also set the relative productivity of the manufacturing sectors in the two countries and the relative supply of skilled workers in each country in 1985 to match the data. In order to see how trade reform impacts the skill premium, I then conduct an experiment where I lower tariffs on goods and taxes on royalties. While I am able to directly observe the reduction in tariffs that occurred in the data, I am not able to observe directly a measure of the distortions on royalty payments. This is because things such as the protection of intellectual property would have a strong impact on a firm’s willingness to rent proprietary information to other firms and these protections changed substantially over the period of interest. Therefore, I conduct the extreme experiment whereby I set initial distortions sufficiently high that there is no trade in technology and then I lower these distortions to zero. I then analyze how the results would change if I were to set the distortionary tax on royalties to some intermediate level. I find that opening to trade in both technology and goods increases the skill premium in both countries. I am able to decompose this change in the skill premium and attribute most of the rise in the skill premium in Mexico to the adoption channel and almost all of the rise in the United States to the investment channel.

**Contribution to Related Literature**

There is a large body of literature dealing with the rise of the skill premium in the United States, and a somewhat smaller literature on the rise of the skill premium in Mexico. Studies such as Feenstra and Hanson (1996), Feenstra and Hanson (1997), and Grossman and Rossi-Hansberg (2008) have shown that increasing imports of intermediate goods from less-developed countries can increase skill premia in advanced economies. For a useful summary of articles that have explored the behavior of the skill premium of developing countries as they open to trade, see Goldberg and Pavcnik (2007).

The paper that is most closely related to my own is Feenstra and Hanson’s 1996 empirical and theoretical work on the importance of foreign direct investment (FDI) in Mexico. Empirically, the authors show that regions with a higher proportion of inward FDI from the United States have greater increases in the relative demand for skilled labor. Furthermore,
they build a theoretical model which rationalizes this prediction; capital is complementary with skilled labor, and as capital flows from the United States to Mexico via foreign direct investment, demand for skilled labor rises in Mexico. The Mexican subsidiary of the multinational in Mexico produces a less-skilled intermediate which is then substituted for less-skilled workers in the United States. Thus, the relative demand for unskilled workers falls in the United States as well. I see my paper as a complement to their work. At the aggregate level, flows of foreign direct investment between Mexico and the United States did not rise substantially until the mid-1990s. Moreover, the majority of growth in both maquiladora\textsuperscript{1} establishments and employment came after the North American Free Trade Agreement (NAFTA) (GAO, 2005), and, as such, post-dates the observed growth in the skill premium in Mexico. I focus on the transfer of technology through non-ownership channels precisely because trade increases substantially before NAFTA but direct investment does not. I provide evidence that supply chains are an important channel through which technology is transferred. The mechanism proposed in their paper is also similar to what I propose. However, in their setup, the investment channel that I describe is not present. This is because the type of capital they consider is physical capital, which can be only used in one location at a time. I, instead, consider technology capital which can be used in multiple locations at once. Therefore, once a firm has more than one location in which to use its technology, it has an increased incentive to invest in it. This is the primary driver of the increase of the skill premium in the United States in my model, whereas in the Feenstra and Hanson model, the increase in the skill premium in the United States is primarily driven by Stolper-Samuelson effects.

I also contribute to the emerging literature on the interaction between trade, technology, and inequality. Works such as Acemoglu (2009), Acemoglu, Gancia, and Zilibotti (2012), Burstein and Vogel (2012), and Goel (2012) all address the idea that trade and technological innovation are linked. All but Burstein and Vogel concentrate primarily on the rise of the skill premium in advanced countries. The papers by Acemoglu and coauthors mention that their mechanism can generate increasing skill premia in developing countries if technology is transmitted, though there is no evident way for the increase in the skill premium in the developing country to be greater than the increase in the skill premium in the developed country. My paper complements their work by providing a plausible mechanism by which this technological transmission occurs as well as provides a framework in which it is possible to get larger increases in the skill premium in the less-developed country. Goel provides evidence for increased investment in innovation resulting from increased imports of intermediate goods from less-developed countries and develops a model which generates the increasing in-

\textsuperscript{1}manufacturing plants in the free trade zone
vestment in innovation that she documents. However, her model does not include skilled workers in the developing country. If it did, the skill premium would counter-factually fall in the developing country. Burstein and Vogel build a quantitative trade model a la Bernard et al. (2003) with exogenous productivity which is skill-augmenting. Technology within a country is endogenous in that there is firm entry and exit in response to international competition. The most productive firms, which are consequently the most skill-intensive firms, are those that become exporters. The least productive firms exit in response to head-to-head foreign competition. While the model proposed by Burstein and Vogel allows for a quantitative exploration of trade linkages, it abstracts from the type of trade in ideas that I propose here. Additionally, they are able to account for only a small portion of the observed increase in the skill premium in Mexico and the United States, even when considering the case of complete autarky versus free trade.

This paper is also related to the literature that has explored the impact of globalization on Mexican labor markets. A number of studies (for example, see Esquivel and Rodriguez-Lopez, 2003; Harrison and Hanson, 1999; and Robertson, 2004) explore this question using the Stolper-Samuelson theorem as their basis, and find the correlation between changes in output prices and wages at the industry level to be very low. The conclusion from this strand of literature was that skill-biased technological change, and not trade, was responsible for the observed increase in the skill premium. Verhoogen (2008) explores both overall increase in inequality and the between-plant inequality in Mexico and hypothesizes that exporting opportunities increase wage dispersion across plants due to quality upgrading. Riano (2009) builds a model in which SBTC is embodied in capital equipment and measures the effect of increasing imports of capital equipment upon the skill premium in Mexico. The idea in his paper is similar to what I model here, but importantly, the capital that is traded in my model is technology capital or “ideas.” The non-rivalrous nature of technology capital creates an environment such that even as the capital begins to be used in Mexico, firms in the United States have an incentive to invest more in it. In fact, it is because the ideas are being used in an additional location that their marginal product increases.

Also related to this paper is the literature on the skill premia in developing countries. Ripoll (2005) builds a model in which the skill premium in the developing country responds non-monotonically to trade liberalization and depends heavily on the initial conditions in the economy. Trefler and Zhu (2005) show that those countries with the largest increase in skill premia following a trade liberalization are those which export relatively more skill-intensive goods, and they build a model akin to Feenstra and Hanson (1996), but allowing the “South” to catch up to the technology of the “North” instead of receiving FDI flows. They do not
propose a mechanism for how this catch-up occurs. Burstein, Cravino, and Vogel (2013) and Parro (2013) each propose capital-embodied technology as an avenue by which skill-biased technological change crosses borders. I contribute to this literature by proposing an alternative way that this technology is accumulated and then transmitted from one country to the next, and I provide evidence of my hypothesis.

The paper is organized as follows: In Section 2, I provide brief background information on the trade liberalization experience in Mexico in the late 1980s; in Section 3, I provide evidence for the importance of trade linkages for the skill premium: Section 4 contains my model and its theoretical analysis; Section 5 contains my calibration and results; and Section 6 concludes.

2 Background: Trade Reform in Mexico

This section briefly describes the liberalization policies that were implemented in Mexico in the mid-1980s.

Mexico’s Trade Liberalization

During the 1950s, Mexico began to pursue a set of policies based on the theory of import substitution. As such, during this time, Mexico became one of the most closed economies in the world, with more than 90 percent of its domestic production subject to import licenses by 1985. Import licenses are commonly viewed as the main source of restricted trade flows (Kehoe, 1995, TenKate 1992), though, in practice, Mexico utilized three instruments to restrict these flows: (i) ad-velorum tariffs, (ii) official minimum prices for custom valuation, and (iii) quantitative restrictions such as quotas and the aforementioned import licenses. As a result of the balance of payments crisis in 1982, the Mexican government decided to pursue a large-scale liberalization of the Mexican economy, including a massive trade liberalization (apertura), in order to restart economic growth.

In 1985, the Mexican government undertook a number of structural reforms, including reducing the import license coverage from 92 percent to 47 percent between June and December of that year. Many of these reforms were requirements of the debt restructuring agreement that Mexico entered with its international creditors in the wake of the debt crisis in the early 1980s. The government continued to phase out import licenses over the course of the decade, with the coverage falling to 23 percent in 1988 and 19 percent in 1989. Most
of the remaining import licenses covered agricultural and petroleum refining products. Over the same period, ad-velorum tariffs fell as well. In 1985, the maximum tariff was 100 percent; only a year later, in 1986, it was reduced to 50 percent. By 1987, the maximum tariff was 20 percent and the production-weighted average tariff was 11 percent (Esquivel and Tornell, 1995).

Mexico also entered into trade negotiations with the United States in 1987, which culminated in a four-part understanding known as the “Framework of Principles and Procedures for Consultation Regarding Trade and Investment Relations” or the “Bilateral Accord.” This Accord was the first-ever formal bilateral agreement governing commercial relations between the two countries, and it included a statement of principles, a mechanism for consultations, an agreement on data exchange, and an Immediate Action Agenda. The Immediate Action Agenda was the start of negotiations on a number of matters, including technology transfer. In particular, Mexico was interested in obtaining help from developed nations to develop its intellectual property rights protection laws so that technological transfer from companies in the United States would be more forthcoming. Mexico argued that access to new technologies was of utmost importance and was a necessary component to any improved trade arrangement between the two countries (DuMars, 1991). The recognition of intellectual property rights was an important step to allowing for transfer of technology between the two countries.

During this period, the government also began to loosen its restrictions on foreign ownership; however, the process was slower to change than other policies, and significant restrictions remained in place for the next decade. In particular, foreign companies were not allowed to acquire existing Mexican firms without submitting to a lengthy approval process. Establishing a new foreign-owned business was somewhat easier, but only if the business fit certain criteria, which included a requirement that the business have at least a non-negative net export balance over the first three years of its existence. Maquiladora firms were exceptions to these rules, but the process for obtaining a license establishing a firm as a maquiladora was viewed as relatively cumbersome until the process was reformed in December of 1989.

In 1992, the Mexican government signed an agreement to enter into the North American Free Trade Agreement (NAFTA) with the United States and Canada on January 1, 1994. As part of NAFTA, all remaining tariffs on goods traded between the two countries would be phased out over the next decade. Moreover, the three countries agreed to abide by the intellectual property rights laws of the United States.
3 Evidence on Skill Premia and Trade

3.1 Data Description

Data for Mexico’s manufacturing sector comes from INEGI (Instituto Nacional de Estadística y Geografía), Mexico’s national statistics bureau. I gather aggregate skill premium data from the EIA (Encuesta Industrial Anual), which is an annual survey of manufacturers which covers about 80 percent of the manufacturing sector. Aggregate data from 1980 through 2004 is publicly available on INEGI’s website. I gather data on production and non-production employees and payments to these two groups and construct the skill premium as the ratio of non-production wages to production wages, as is standard in the literature. Industry-level data is available by request for years 1984 through 1994, and plant-level data is available from 1984 through 1990. The plant-level data includes information on imports and exports by plant for the years 1986 to 1990. This information was gathered in a special survey conducted by the World Bank. For a more detailed description of the plant-level data, see Tybout and Westbrook (1995).

Data for the U.S. manufacturing sector is obtained from the NBER-CES Manufacturing Productivity Database (Bartelsman and Gray, 1996). This data is available from 1959 through 2010. Again, the database provides information on production and non-production employees, as well as payments to each group. I then construct the skill premium as the ratio of non-production wages to production wages. I compare the manufacturing skill premium to the ratio of college to non-college wages, which I compute using the Current Population Survey (CPS). I obtain the March CPS from Integrated Public Use Microdata Series, Current Population Survey (IPUMS CPS) at the Minnesota Population Center. I then compute the ratio of wages for working age people with some college and above to those with no college, and call this the “college premium.”

Aggregate trade data for Mexico is obtained from the World Bank World Development Indicators Database (WDI). I gather information on imports, exports, and gross domestic product, as well as subsets of the trade data. In particular, I examine merchandise trade, merchandise trade with advanced economies, and trade in manufactures. Each variable gathered is expressed in millions of U.S. dollars. I then express each trade variable as a percentage of gross value added in manufacturing. I cross reference these trade data with data from the NBER’s U.S. imports and exports database, 1972-1994, (Feenstra 1996, 1997) to verify that the majority of the increase in Mexico’s trade was with the United States.

Information on intermediate imports is gathered from the Organization for Economic Co-
operation and Development’s (OECD) Structural Analysis (STAN) Database. This database provides total bilateral imports and exports, as well as intermediate bilateral imports and exports, between the U.S. and Mexico for years 1990 through 2010 for broad industries. I match this data (1990-1994) with the industry-level data for Mexican manufacturing for the same broad sectors.

### 3.2 Skill Premia in Mexico and the United States

In what follows, I will use the term “skill premium” to mean the ratio of the wages of non-production workers to the wages of production workers, as is typical in the literature that examines the skill premium in developing countries. Amiti and Cameron (2011) use data that includes educational attainment and production/non-production status of workers in Indonesian manufacturing for several years and they show that the production/non-production breakdown is a good proxy for skill or educational attainment. Therefore, I will focus my analysis on this measure of the skill premium. In Mexico, the skill premium was stable with non-production wages being about twice as high as production wages during the late 1970s and early 1980s, but began to rise around 1986. It grew for the next decade and peaked with non-production wages being about 3.1 times higher than production wages in 1996. This can be seen in Figure 1a. The U.S. experienced similar timing in the rise of the same variable. Note that the college premium, measured as the ratio of college to non-college wages, began to rise earlier in the 1980s. The college premium is the measure which is frequently the concentration of papers dealing only with the United States, but I will concentrate on comparable measures of the skill premium in this paper. As can be seen in Figure 1a, the manufacturing skill premium in the United States also began to rise in the mid-1980s.

Figure 1a also shows that the skill premium in Mexico was substantially higher than that in the United States and rose by much more over the period of interest. Figure 1b shows that the timing of the increases in the two skill premia largely coincided. It also highlights that the increase in Mexico was substantially bigger than that in the United States. In particular, over the course of the decade from 1986 to 1996, the skill premium in Mexico rose by about 60%, while the skill premium in the United States rose by about 10 to 15%.

2 The timing and magnitude of the increase in the college premium is similar to that of the manufacturing skill premium, though the manufacturing skill premium does not exhibit the same drop as the college premium in the 1970s.

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2 Again, the measure of the skill premium is different from the one that is often cited in the literature concerning the rise of inequality in the United States.
Figure 2 shows how the college premium and the manufacturing skill premium move together in the United States. I measure the college premium as the ratio of wages of those with at least one year of college to those with no college education. As is well known, the college premium fell over the course of the 1970s as the supply of college-educated workers grew. During this period, the manufacturing skill premium remained flat. If you disregard the education premium drop that occurred over the 1970s, the panels of figure 2 show that the timing of the rise in the education and manufacturing skill premium largely coincide. In
particular, when I normalize the college premium to 1 in 1970 (as in the second panel of the figure), it can be seen that the two series begin to rise above their long-run trend at about the same time, and by 2000 they had risen by roughly the same amount. The rise in the skill and education premia from 1985 to 2000 is roughly 12 percent. Therefore, the skill premium in Mexico rose by about four times as much as its American counterpart from 1986 to 2000.

3.3 Increase of Manufacturing Trade

In this section, I show that the increase in the skill premium in Mexico largely coincides with an increase in manufacturing trade. Figure 3a shows Mexican imports and exports of manufactured goods as a percentage of total value added in manufacturing. We can see that trade in manufactured goods began to rise in the mid-1980s and continued to rise through the early 2000s. This timing is consistent with the growth of the skill premium in Mexican manufacturing documented above. Notably, the growth in exports and imports begins well before the implementation of the North American Free Trade Agreement (NAFTA).

![Figure 3a: Mexican Manufacturing Trade](image)

(a) Manufacturing Trade

![Figure 3b: Merchandise Trade](image)

(b) Merchandise Trade

Figure 3: Mexican Manufacturing Trade

Figure 3b documents the percent of merchandise trade that was taking place with high-income countries. The solid lines represent the total amount of merchandise imports (blue) and exports (red) as a percentage of value added and the dotted lines show the merchandise trade occurring with high-income OECD countries. I use this measure because I do not have an accurate measure of trade in manufactured goods with high-income countries, but I do have a measure of trade in merchandise goods with high-income countries. Merchandise trade consists almost entirely of trade in manufactured products, especially in the later periods. I
use aggregated data from the NBER’s import and export database to verify that this trade is predominantly with the United States. This figure is meant to illustrate that Mexico’s trade liberalization in the 1980s predominantly increased its trade with the United States, a more-developed country. This means that according to a standard H-O model, we should expect to see a falling skill premium in Mexico. If Mexico had opened to more skill-scarce countries during this period, one might anticipate that its skill premium would rise, but since it was increasing trade predominantly with the United States, the opposite should be true.

3.4 Evidence that Supply Chains Matter

In order to explore how trade integration impacts the skill premium, I match the industry-level data on manufacturing wages and employment to trade data from the OECD STAN database. I have information on intermediate imports, intermediate exports, total imports, and total exports for 20 industries from 1990 to 1994. I match this information to the information on the skill premium for the same broad industries. I then examine the relationship between imports of intermediates as a fraction of output, exports as a fraction of output, royalty payments, and the skill premia by industry. In order to do this, I first estimate the following equation, where \( i \) indexes the industry and \( t \) indexes the year:

\[
SP_{i,t} = \beta_0 + \beta_1 \left( \frac{\text{Royalties}}{Y} \right)_{i,t} + \beta_2 \left( \frac{\text{Exports}}{Y} \right)_{i,t} + \gamma_t + \eta_i + \epsilon_{i,t}
\]

Table 1 reflects that this estimation mimics what other authors have found. In particular, exporting is associated with increasing skill premia when we do not consider other sources of variation. Moreover, royalties are positively correlated with increasing skill premia, indicating that those industries that make large payments for technology rental (as a percentage of output) have, on average, higher skill premia. In order to test whether integration into supply chains is an important determinant of the skill premium, I include both imports of intermediates and exports of intermediates and estimate the following equation.

\[
SP_{i,t} = \beta_0 + \beta_1 \left( \frac{\text{Royalties}}{Y} \right)_{i,t} + \beta_2 \left( \frac{\text{Exports}}{Y} \right)_{i,t} + \beta_3 \left( \frac{\text{Imports}}{Y} \right)_{i,t} + \gamma_t + \eta_i + \epsilon_{i,t}
\]

From Table 2, we can see that including intermediate imports negates the effects of exporting. In particular, the coefficient on exporting becomes negative, which is in line with the Stolper-Samuelson predictions, whereas the coefficient on intermediate imports
is positive, statistically significant, and large. So, exporting in the absence of intermediate imports is associated with low skill premia and importing of intermediate inputs is associated with high skill premia.

<table>
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<th>$SP_{i,t}$ (2)</th>
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<td></td>
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<td>Exports</td>
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<td>0.413***</td>
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<td></td>
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<td>(0.243)</td>
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<td>Time Fixed Effects?</td>
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<td>$R^2$</td>
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Table 1: Regression Results

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<td>Industry Fixed Effects?</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Time Fixed Effects?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.075</td>
<td>0.200</td>
</tr>
</tbody>
</table>

Table 2: Regression Results
I interpret these results as indicating that supply chains are an important determinant of skill premia. In light of this evidence, I build a model in which importing plays a role in determining the skill premium. I am going to think of this as importing “ideas” or technology. Those plants that export intermediate goods are going to need to use imported ideas in order to produce intermediate goods for the final goods producer in the other country. I will have two sectors: one which is high-skill-intensive and one which is low-skill-intensive. The two sectors are important to allow for the existence of standard Stolper-Samuelson effects. There will be a single market for each type of labor, so all plants will experience the same increase in the skill premium, but the increase in the skill premium in Mexico will be driven by the sector which integrates into the supply chain of the United States and shares the technology of the U.S. final goods producers. One sector will not integrate into the supply chain of the other country, though there will be trade in the final goods produced by both sectors, and this will produce the standard Stolper-Samuelson effect. The relative importance of technology in production will determine the size of the increase of the skill premium.

4 Model

In this section, I first lay out a modified trade model with two sectors and trade in both goods and in ideas. I then illustrate how the mechanism operates in the context of a one-sector model. Finally, I compare the model to the Heckscher-Ohlin model and discuss how the two differ from one another.

4.1 Model of Trade in Goods and Ideas

I describe a two-sector trade model in which allow labor is allowed to move freely across sectors but not across countries. In this environment, I can explore how technology sharing interacts with Stolper-Samuelson effects.

Environment

There are two countries (U and M), each with two perfectly competitive final good producing sectors (Sector X and Sector Y) which purchase differentiated intermediate goods from monopolistic competitors. Final goods producers in country k and sector j invest in a stock of technology capital (Z_{k,j}) which is assumed to be skill-augmenting. They will rent this technology to the producers of the intermediate goods which will be used for the production
of the final good. Households in country \( k \) value consumption, inelastically supply skilled labor (\( H_k \)) and unskilled labor (\( L_k \)), and save using a one period bond (\( b_k \)). Time is infinite and discrete.

**Final Goods Producers: Sector X**

The final good producers in Sector \( X \) in country \( k \) maximize their discounted stream of dividends. They produce a single final consumption good (\( X \)), using differentiated intermediates produced in country \( k \) (\( x_k(i) \)), and invest in a skill-augmenting technology capital (\( Z_{k,x} \)) that they rent out to the intermediate goods producers that supply them parts. The numeraire good will be \( Y \) and \( P_x \) is the relative price of good \( X \) in terms of good \( Y \).

The problem of the final goods producers in country \( k \) is:

\[
V(Z_{k,x}) = \max \left( D_{k,x} + mV(Z'_{k,x}) \right)
\]

\[s.t.
\]

\[
D_{k,x} = P_x (X_k - I_{k,x}) + r_{k,x}Z_{k,x} - \int_{N_{k,x}} p_x(i)x_k(i)di
\]

\[
I_{k,x} = B_k(Z'_{k,x} - (1 - \delta_y)Z_{k,x})
\]

\[
X_k = \left[ \int_{N_{k,x}} x_k(i)^{\phi}di \right]^{1/\phi}
\]

where \( m \) is the stochastic discount factor. Here, dividends are equal to output minus investment plus royalty payments minus payments for intermediates. I am assuming that the investment technology converts a single unit of good \( X \) into \( B_k \) units of investment goods.

**Intermediate Goods Producers: \( x(i) \)**

The intermediate goods producer in country \( k \) can produce intermediates for the domestic market only. He chooses output (\( x_k(i) \)), skilled labor (\( h_{k,x}(i) \)), unskilled labor (\( l_{k,x}(i) \)), and amount of rented technology (\( Z_{k,x} \)) to maximize profits, taking wages, the rental rate for technology, and the inverse demand function for their variety as given. The producer must use the technology of the firm that they are supplying in order to produce the intermediate
good for that firm. There is a country-specific productivity parameter, $A_k$. 

$$\max p_x(i)x_k(i) - w_k^H h_{k,x}(i) - w_k^L l_{k,x}(i) - r_{k,x}Z_{k,x}$$

s.t

$$x_k(i) = A_k \left[ \omega_x \left( Z_{k,x} h_{k,x}(i)^{1-\alpha} \right) \frac{\sigma-1}{\sigma} \right] + (1 - \omega_x)l_{k,x}(i) \frac{\sigma-1}{\sigma} \right] \frac{\sigma}{\sigma-1}$$

$$x_k(i) = p_x(i) \frac{1}{\varphi} X_k$$

Here, I assume that intermediate goods producers of goods $x_k(i)$ only supply the final goods producers in their own country. Therefore, they only have access to the technology of the final goods producers in their own country; in other words, there is no trade in technology in Sector $X$. I will assume that Sector $X$ is more unskilled labor intensive than Sector $Y$.

**Final Goods Producers: Sector $Y$**

The final good producers in Sector $Y$ in country $k$ maximize their discounted stream of dividends. They produce a single final consumption good ($Y_k$), using differentiated intermediates produced in country $k$ ($y_{k,k}(i)$) and in country $j$ ($y_{j,k}(i)$), and invest in a skill-augmenting technology capital ($Z_{k,y}$) that they rent to the producers of the intermediate goods which they use for production. Here, the first subscript refers to the country in which the intermediate goods producer is located and the second subscript refers to the country in which the final goods producer is located.

The problem of the final goods producers in country $k$ is:

$$V(Z_{k,y}) = \max D_{k,y} + mV(Z'_{k,y})$$

s.t.

$$D_{k,y} = Y_k - I_{k,y} + Z_{k,y} (r_{k,y} + r_{j,y}) - \int_{N_{k,y}} p_y(i)y_{k,y}(i)di - (1 + \tau_y) \int_{N_{j,y}} p_y(i)y_{j,k}(i)di$$

$$I_{k,y} = B_k (Z'_{k,y} - (1 - \delta_y)Z_{k,y})$$
\[ Y_k = \left[ \int_{N_{k,y}} y_{k,k}(i)^\rho di + \int_{N_{j,y}} y_{j,k}(i)^\rho di \right]^{1/\rho} \]

Again, dividends are equal to output minus investment plus royalties received for rental of technology minus the cost of intermediate inputs. In Sector Y, the final goods producer rents its technology to and buys intermediates from firms in the foreign country, as well as the home country. In this sense, in Sector Y there is “trade in ideas”, or technology sharing. Moreover, notice that in Sector Y, the final good producer purchases intermediates from both countries, so they integrate over all intermediate goods produced in their own country \((N_{k,y})\) and intermediate goods produced in the foreign country \((N_{j,y})\).

**Intermediate Goods Producers: \(y(i)\)**

The intermediate goods producer that produces intermediate \(i\) in country \(k\) can produce both for the domestic market and for the foreign market. He chooses output for the domestic market \((y_{k,k}(i))\), output for the foreign market \((y_{k,j}(i))\), skilled labor to produce for the domestic market \((h_{k,k,y}(i))\), skilled labor to produce for the foreign market \((h_{k,j,y}(i))\), unskilled labor to produce for the domestic market \((l_{k,k,y}(i))\), unskilled labor to produce for the foreign market \((l_{k,j,y}(i))\), and amount of domestic and foreign technology \((Z_{k,y}, Z_{j,y})\) to maximize profits, taking the inverse demand functions, wages, and the rental rate for technology as given. Again, the first subscript refers to the country in which the intermediate good is produced and the second refers to the country in which the final good is produced and the producer of the intermediate good must use the technology of the final goods producing firm that they are supplying in order to produce the intermediate for that firm.

\[
\text{max } p_y(i)\ (y_{k,k}(i) + y_{k,j}(i)) - w^H_k\ (h_{k,k,y}(i) + h_{k,j,y}(i)) - w^L_k\ (l_{k,k,y}(i) + l_{k,j,y}(i)) - r_{k,y} Z_{k,y} - (1 + \tau_z) r_{j,y} Z_{j,y}
\]

\[ \text{s.t.} \]

\[
\begin{align*}
y_{k,k}(i) &= A_k \left[ \omega_y \left( Z_{k,y}^{\frac{\alpha}{\sigma}} h_{k,k,y}^{\frac{1-\alpha}{\sigma}}(i) \right)^{\frac{\sigma-1}{\sigma}} + (1 - \omega_y) l_{k,k,y}^{\frac{\sigma-1}{\sigma}}(i) \right]^{\frac{\sigma-1}{\sigma}} \\
y_{k,j}(i) &= A_k \left[ \omega_y \left( Z_{j,y}^{\frac{\alpha}{\sigma}} h_{k,j,y}^{\frac{1-\alpha}{\sigma}}(i) \right)^{\frac{\sigma-1}{\sigma}} + (1 - \omega_y) l_{k,j,y}^{\frac{\sigma-1}{\sigma}}(i) \right]^{\frac{\sigma-1}{\sigma}} \\
y_{k,k}(i) &= p_y(i)^{\frac{1}{\sigma-1}} Y_k \\
y_{k,j}(i) &= ((1 + \tau_y)p_y(i))^{\frac{1}{\sigma-1}} Y_j
\end{align*}
\]
I assume that if an intermediate goods producer supplies intermediates to the foreign final goods producer, it must pay a tax $\tau_z$ on the royalties paid to the final goods producer. I allow for intermediate goods producers to supply both the domestic and the foreign markets and the amount of production they choose to do in each will endogenously adjust to the amount of tax they have to pay on royalties. I will discuss this tax in detail in the next section. Also, the demand for the amount of goods this intermediate goods producer will supply to the foreign market will be affected by the tariffs levied on intermediate goods.

Households

Households in country $k$ choose a consumption bundle $(c_{k,x}, c_{k,y})$ and bond holdings $(b'_k)$ to solve the following problem:

$$\max \sum_{t=0}^{\infty} \beta^t (u(c_{k,x}) + u(c_{k,y}))$$

s.t.

$$p_x c_{k,x} + c_{k,y} + b'_k = w^H_k h_k + w^L_k l_k + (1 + r)b_k$$

In a given country, the households are identical and so in the closed economy, no bonds will be traded. Across countries, the endowment of high-skilled and low-skilled labor varies.

Market Clearing

Market clearing requires that bond, labor, and goods markets clear:

$$\sum_k b_k = 0$$

$$H_k = \int_{N_{k,x}} h_{k,x}(i) di + \int_{N_{k,y}} (h_{k,k,y}(i) + h_{k,j,y}(i)) di$$

$$L_k = \int_{N_{k,x}} l_{k,x}(i) di + \int_{N_{k,y}} (l_{k,k,y}(i) + l_{k,j,y}(i)) di$$

$$\sum_{k \in U,M} X_k = \sum_{k \in U,M} c_{k,x} + B_k \left( Z'_{k,x} - (1 - \delta_x)Z_{k,x} \right)$$

$$\sum_{k \in U,M} Y_k = \sum_{k \in U,M} c_{k,y} + B_k \left( Z'_{k,y} - (1 - \delta_y)Z_{k,y} \right)$$
Efficiency

It can be shown that the allocations resulting from solving the above problem are efficient.\(^3\) Therefore, I can solve for the allocations by solving for the efficient allocation. Consider first a closed economy. The efficient allocation for a given country \(k\) solves:

\[
V(Z_x, Z_y) = \max u(c_x, c_y) + \beta V(Z'_x, Z'_y)
\]

s.t.

\[
\begin{align*}
c_x + B(Z'_x - (1 - \delta)Z_x) &= A \left[ \omega_x \left( Z^\alpha_x h_x^{1-\alpha} \right)^{\sigma-1} + (1 - \omega_x)l_x^{\sigma-1} \right]^{\sigma-1} \\
c_y + B(Z'_y - (1 - \delta)Z_y) &= A \left[ \omega_y \left( Z^\alpha_y h_y^{1-\alpha} \right)^{\sigma-1} + (1 - \omega_y)l_y^{\sigma-1} \right]^{\sigma-1} \\
H &= h_x + h_y \\
L &= l_x + l_y
\end{align*}
\]

Consider now the open economy. In this economy, final and intermediate goods are traded and technology is transferred in Sector \(Y\) between the United States (\(U\)) and Mexico (\(M\)). In Sector \(X\), only final goods are traded. The efficient allocation for the open economy solves:

\[
V(Z_{U,x}, Z_{U,y}, Z_{M,x}, Z_{M,y}) = \max \lambda u(c_{U,x}, c_{U,y}) + (1 - \lambda) u(c_{M,x}, c_{M,y}) + \beta V(Z'_{U,x}, Z'_{U,y}, Z'_{M,x}, Z'_{M,y})
\]

\[
\begin{align*}
X &= A_U \left[ \omega_x \left( Z^\alpha_{U,x} h_{U,x}^{1-\alpha} \right)^{\sigma-1} + (1 - \omega_x)l^{\sigma-1}_{U,y} \right]^{\sigma-1} + A_M \left[ \omega_y \left( Z^\alpha_{M,x} h_{M,x}^{1-\alpha} \right)^{\sigma-1} + (1 - \omega_y)l^{\sigma-1}_{M,y} \right]^{\sigma-1} \\
Y &= \sum_{k \in U,M} \sum_{j \in U,M} \left( \frac{A_j}{1 + \tau_{z,j}} \right)^\rho \left[ \omega_y \left( Z^\alpha_{j,y} h_{j,y}^{1-\alpha} \right)^{\sigma-1} + (1 - \omega_y)l^{\sigma-1}_{j,k,y} \right]^{\sigma-1} \left[ \frac{\sigma}{\sigma-1} \right]^{1/\rho} \\
X &= \sum_k \left( c_{k,x} + B_k(Z'_{k,x} - (1 - \delta)Z_{k,x}) \right) \\
Y &= \sum_k \left( c_{k,y} + B_k(Z'_{k,y} - (1 - \delta)Z_{k,y}) \right)
\]

---

\(^3\)See online appendix for a proof.
Note that here I have used the fact that there is no heterogeneity across intermediate goods producers and thus each of them will choose the same levels of output, labor, and rented technology. This allows me to eliminate the integral across producers and instead write the variables that were chosen by the intermediate producers as the levels that will be chosen optimally by each of them, ignoring the index of the producer $i$. Also, $\tau_z,j$ is equal to zero if $k = j$; this means that there is no distortion to the return on or use of technology capital if it is used in the country in which it is produced. Now, when the implicit tax on foreign technology ($\tau_z$) is lowered, more technology ($Z_u,y$) is shared between the United States and Mexico. The total amount of technology used by producers of intermediate goods $y_M(i)$ will be an average of the technology capital produced by local producers and that produced by foreign producers. Therefore, if this economy goes from being in autarky (or near autarky) to totally open ($\tau_z = 0$), there will be a substantial jump in the technology capital used in Mexico.

In order to see how this mechanism operates, consider the following simplified problem in which there is only the integrated Sector ($Y$):

$$ V(Z_u,Z_M) = \max \lambda u(c_U) + (1 - \lambda)u(c_M) + \beta V(Z'_U,Z'_M) $$

s.t.

$$ Y = \left[ A_U^\rho \left[ \omega_y \left( Z_u^\alpha h_{U,U}^{1-\alpha} \right)^{\sigma-1} + (1 - \omega_y)l_{U,U}^{\sigma-1} \right]^{\sigma-1} + \left( \frac{A_M}{1 + \tau_z} \right)^\rho \left[ \omega_y \left( Z_M^\alpha h_{M,M}^{1-\alpha} \right)^{\sigma-1} + (1 - \omega_y)l_{M,M}^{\sigma-1} \right]^{\sigma-1} \right]^{1/\rho} $$

$$ + \left[ \left( \frac{A_U}{1 + \tau_z} \right)^\rho \left[ \omega_y \left( Z_M^\alpha h_{U,U}^{1-\alpha} \right)^{\sigma-1} + (1 - \omega_y)l_{U,M}^{\sigma-1} \right]^{\rho\sigma} + A_M^\rho \left[ \omega_y \left( Z_M^\alpha h_{M,M}^{1-\alpha} \right)^{\sigma-1} + (1 - \omega_y)l_{M,M}^{\sigma-1} \right]^{\rho\sigma} \right]^{1/\rho} $$

$$ Y = \sum_k \left( c_k + B_k(Z_k - (1 - \delta)Z_k) \right) $$

$$ H_k = h_{k,k} + h_{k,j} $$

$$ L_k = l_{k,k} + l_{k,j} $$

I have written the planner’s problem for the open economy; recall that in the closed economy, each country only operates and invests in its own technology ($Z_k$). In the context
of this problem, it is easier to see how reductions in \( \tau_z \) will affect both the United States and Mexico. First, consider the effect in Mexico. As \( \tau_z \) falls, Mexican firms substitute towards using \( Z_y \) because it is becoming relatively more productive. Therefore, the overall level of technology used in Mexico increases. Because technology is skill-augmenting, this increases the skill premium. The increasing productivity of \( Z_U \) will also affect the incentive to invest in that technology. As \( \tau_z \) falls, the productivity of \( Z_U \) rises, inducing increased investment in this technology. Therefore, the level of \( Z_U \) is higher in the open economy than the closed economy. In this setting, \( Z_U \) is decreasing in \( \tau_z \). 4

**Skill Premium**

The skill premium, or the ratio of wages for skilled workers relative to unskilled workers, can be expressed as

\[
SP_k = \frac{w^H_k}{w^L_k} = (1 - \alpha) \frac{\omega_y}{1 - \omega_y} \left( \frac{Z_{k,y}}{H_{k,y}(Z_{k,y})} \right)^{(1 - \alpha)} \left( \frac{H_{k,y}(Z_{k,y})}{L_{k,y}(Z_{k,y})} \right)^{-1/\sigma}
\]

In order to contrast this with the standard Heckscher-Ohlin model, let’s turn again to the stylized one-sector model. First, recall that in the standard H-O model, the skill premium is expressed as

\[
SP_k = \frac{w^H_k}{w^L_k} = \frac{\omega_y}{1 - \omega_y} \left( \frac{H_{k,y}}{L_{k,y}} \right)^{-1/\sigma}
\]

And in the one-sector model, we have:

\[
SP_k = (1 - \alpha) \frac{\omega_y}{1 - \omega_y} \left( \frac{Z_k}{H_k} \right)^{(1 - \alpha)} \left( \frac{H_k}{L_k} \right)^{-1/\sigma}
\]

4See online appendix for a proof.
In this simplified model, there is no shifting of labor from one sector to the next and so the ratio of skilled to unskilled labor is fixed since there is no labor supply choice. Therefore, in the H-O analog with only one sector, opening to trade does not affect the skill premium since the skill intensity of Sector Y ($\omega_y$) is fixed and labor allocations will not change since labor is inelastically supplied. Equation 1 is reminiscent of the expression for the skill premium that is typically derived in models with skill-biased technical change. From this expression, we can see that in the simple model there are two forces at play. The first ratio, the ratio of technology to skilled workers ($\frac{Z_k}{H_k}$), can be interpreted as the demand for skilled workers. The second ratio, the ratio of unskilled to skilled workers ($\frac{L_k}{H_k}$), is the relative supply of each kind of worker. In the basic H-O model, the skill premium is determined solely by the relative supply of skilled to unskilled workers and the skill-intensity of production. In the modified model, however, increasing technology essentially serves to increase the skill-intensity of production and so the demand for skilled workers changes as the level of technology ($Z$) changes. Therefore, when Mexico begins to adopt the technology of the final goods producer in the U.S., the demand for skilled workers will increase and, as a result, so will the skill premium. I refer to the force that drives the increase in the skill premium in Mexico as the “adoption channel.” The stock of technology in the U.S. is larger than that in Mexico initially because there are more skilled workers in the U.S. than in Mexico. Therefore, in the closed economy, technology is more productive in the U.S. and is accumulated to a greater extent. When the countries open to one another, Mexican firms will switch from less productive technology ($Z_M$) to more productive technology ($Z_U$), and the relative demand for skilled labor will increase in Mexico. The size of the initial jump in the skill premium in Mexico will be related to the difference in the initial steady state levels of technology between the two countries.

This gives rise to an increase in the skill premium in the United States which is driven by what I call the “investment channel.” Because investment in $Z_U$ is decreasing in $\tau_z$, when the level of distortions to the use of U.S. technology in Mexico fall, total investment in this technology increases, thus increasing the level of technology in the U.S. Therefore, the ratio of technology to high skilled workers in the United States ($\frac{Z_U}{H_U}$) must increase. This, in turn, causes the skill premium in the United States to increase. Moreover, the skill premium in Mexico will continue to grow with the skill premium in the U.S. as $Z_U$ grows to its new steady state level. So, the increase in the skill premium in Mexico experiences an initial jump as Mexican firms switch to the more productive technology (the “adoption channel”) and continues to grow as the stock of this technology grows via the “investment channel.” Therefore, the increase in the skill premium should be substantially larger than the increase in the skill premium in the U.S.
In the full (two-sector) model, there is also a Stolper-Samuelson effect whereby workers are reallocated towards sectors in which the country has a comparative advantage. This means that in Mexico, workers should shift toward the unskilled-intensive sector (Sector $X$) and away from the skill-intensive sector (Sector $Y$). Because the skill-intensity of Sector $X$ ($\omega_x$) is lower than the skill intensity of Sector $Y$ ($\omega_y$), all else equal, this would cause the skill premium in Mexico to fall. However, this effect is offset by the adoption of U.S. technology ($Z_{U,y}$) in Mexico, which serves to increase the demand for workers in Sector $Y$ and, in particular, high-skill workers. Consider for a moment the case where all intermediate goods producers in Mexico begin to produce for the final goods producer in the United States. In this case, they will be using the American technology ($Z_{U,y}$) exclusively. Therefore, if workers were to remain in the sectors in which they were working before the reform, the skill premium in Mexico would increase simply because the producers of intermediates in Sector $Y$ would be using more productive technology, thereby increasing demand for skilled workers. Moreover, the adoption of $Z_{U,y}$ will also cause the shift from Sector $Y$ to Sector $X$ to be smaller than it would otherwise be. The extent to which the Stolper-Samuelson effect is offset depends on the specific parametrization that is used. I will calibrate the model to match some key observations in the “pre-reform” period and will conduct sensitivity analysis to show how my results would change for different parameter choices. For instance, if technology’s share of income ($\alpha$) is low, the offsetting effects of technology adoption may not be large enough to completely overturn the Stolper-Samuelson result. This is intuitive: If technology is relatively unimportant in production, then having access to new technology will have little impact upon the skill premium. In order to assess the extent to which this mechanism can account for the joint increase in the skill premia in both countries, I will need to calibrate the model.

5 Calibration and Quantitative Results

I now turn to the calibration of the model and the implications of the calibrated model for the key observations in both countries. Additionally, I discuss sensitivity of the results to the selected calibration.

5.1 Calibration

I now calibrate the model to quantify the extent to which it can account for the increase in the skill premia. Table 3 details the fixed parameter values chosen, as well as the source for
these parameter selections.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>0.96</td>
<td>Annual return on risk-free bonds</td>
</tr>
<tr>
<td>$\rho, \phi$</td>
<td>0.63</td>
<td>Trade literature</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.08</td>
<td>McGrattan &amp; Prescott</td>
</tr>
<tr>
<td>$A_M$</td>
<td>0.25</td>
<td>Relative value-added per worker in 1985</td>
</tr>
<tr>
<td>$H_U$</td>
<td>0.28</td>
<td>CPS - Fraction of Population with Some College 1985</td>
</tr>
<tr>
<td>$H_M$</td>
<td>0.09</td>
<td>ENOE - Fraction of Population with Some College 1985</td>
</tr>
<tr>
<td>$L_U$</td>
<td>0.72</td>
<td>CPS - Fraction of Population with No College 1985</td>
</tr>
<tr>
<td>$L_M$</td>
<td>0.91</td>
<td>ENOE - Fraction of Population with No College 1985</td>
</tr>
</tbody>
</table>

Table 3: Fixed Parameter Values

Some of these parameters deserve discussion. In particular, I calculate the relative total factor productivity (TFP) in Mexico ($A_M$) to be 0.25. Note that I normalize TFP in the United States to be 1. I then calculate the relative value added per worker in the manufacturing sector in Mexico in 1985. I choose the manufacturing sector instead of the overall economy because my skill premium data pertains to the manufacturing sector only. For the relative supply of high-skilled workers, I use the household surveys that are available for both countries. The data analog to high-skilled workers are non-production employees. Since these are defined to be managers and technicians, I look at individuals with some college. This includes individuals with technical training. I do not want to rely on the ratio of non-production to production employees in manufacturing because this is an equilibrium outcome which is reflective of the skill intensity of manufacturing. While both countries have similar ratios of non-production to production employees in manufacturing, the ratio of college to non-college individuals differs substantially across the two. I utilize this difference in order to rationalize the large observed difference in initial skill premia. The rate of time discounting ($\beta$) and the substitutibility of intermediate goods ($\rho, \phi$) are taken directly from the literature. The model unit of time is one year. Although changing these parameters would affect the initial calibration, they do not impact the qualitative results in terms of changes in skill premia. Moreover, the initial calibration is not particularly sensitive to these parameter choices. As in McGrattan and Prescott (2009), $\delta$ is not separately identified from $\alpha$; the parameters jointly determine the return to technology capital. I am going to hold fixed $\delta$ and conduct sensitivity analysis on $\alpha$ but it should be noted that each value of $\alpha$ is dependent upon the associated rate of depreciation, $\delta$. 

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The most important parameters for the results are technology capital’s share of income (α) and the elasticity of substitution between high- and low-skill labor (σ). Also important is the ratio of the factor share parameters in the production function \( \frac{\omega_y}{\omega_x} \) which determines how relatively skill intensive each sector is. In order to pin these parameters down, I match three moments in the data: (1) the ratio of royalties to payroll in Mexico in 1985; (2) the Mexican skill premium in 1985; and (3) the U.S. skill premium in 1985. I match the parameters via the general method of moments (GMM).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{\omega_y}{\omega_x} )</td>
<td>1.41</td>
<td>Relative Skill Intensity of the Sectors</td>
</tr>
<tr>
<td>α</td>
<td>0.39</td>
<td>Technology Capital’s Share</td>
</tr>
<tr>
<td>σ</td>
<td>1.98</td>
<td>Elasticity of Substitution between H &amp; L</td>
</tr>
</tbody>
</table>

Table 4: Calibrated Parameters

Table 5 displays the targeted moments in the data and the model’s fit with them. As Table 5 shows, the model hits the target moments. The estimated elasticity of substitution between high- and low-skill labor is in keeping with estimates from the literature, though it is on the high side of the acceptable range. I assume that the elasticity of substitution is the same across countries. Likewise, I assume that technology’s share of income is the same across countries. I do this for two reasons. The first is that I have data on royalty payments only for Mexican manufacturing. Because royalty payments over payroll is the obvious data analog to technology’s share of income, I want to match this moment precisely in order to discipline α. In the absence of royalty data, I have no way of pinning down this parameter. The second reason is that these two parameters (α, σ) are the parameters to which my model results are most sensitive. I do not want the difference in production functions to be driving the results. I will conduct sensitivity analysis to the choice of these variables but will not allow them to

<table>
<thead>
<tr>
<th>Moment</th>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of Royalties to Payroll - Mexico 1985</td>
<td>0.055</td>
<td>0.058</td>
</tr>
<tr>
<td>Skill Premium - Mexico 1985</td>
<td>2.03</td>
<td>2.03</td>
</tr>
<tr>
<td>Skill Premium - U.S. 1985</td>
<td>1.42</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Table 5: Target Moments

Table 4 shows the parameter values resulting from the calibration exercise and Table 5 displays the targeted moments in the data and the model’s fit with them. As Table 5 shows, the model hits the target moments. The estimated elasticity of substitution between high- and low-skill labor is in keeping with estimates from the literature, though it is on the high side of the acceptable range. I assume that the elasticity of substitution is the same across countries. Likewise, I assume that technology’s share of income is the same across countries. I do this for two reasons. The first is that I have data on royalty payments only for Mexican manufacturing. Because royalty payments over payroll is the obvious data analog to technology’s share of income, I want to match this moment precisely in order to discipline α. In the absence of royalty data, I have no way of pinning down this parameter. The second reason is that these two parameters (α, σ) are the parameters to which my model results are most sensitive. I do not want the difference in production functions to be driving the results. I will conduct sensitivity analysis to the choice of these variables but will not allow them to
vary across countries.

5.2 Results

I now conduct an experiment in which I move the countries from the fully closed economy (autarky) to the one with no barriers to trade or technology flow \((\tau_y, \tau_z = 0)\). This is the extreme case and will serve as an upper bound on the extent to which the increase in the skill premia can be accounted for by the proposed mechanism.

<table>
<thead>
<tr>
<th></th>
<th>Closed</th>
<th>Trade in Goods &amp; Technology</th>
<th>%Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data Model</td>
<td>Data Model</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>2.03</td>
<td>3.1</td>
<td>50.4</td>
</tr>
<tr>
<td>U.S.</td>
<td>1.42</td>
<td>1.6</td>
<td>11.0</td>
</tr>
</tbody>
</table>

Table 6: Results - Autarky to Free Trade

As Table 6 shows, the model is able to capture over two thirds of the rise in the skill premium in Mexico and in the skill premium in the United States. For contrast, in Table 7, I report the rise in the skill premium that occurs in the model without technology capital \((\alpha = 0)\), which is the H-O analog. Here, I use the same values for \(\omega_y, \omega_x\), and \(\sigma\) as in the model with technology capital and simply set \(\alpha = 0\). This implies that the initial steady state will not match the target moments, so I only report the percent change between the closed and open steady states, not the levels. In this case, the Stolper-Samuelson effect is present for Mexico; the skill premium in Mexico in the open economy is 10% lower than it is in autarky. You will notice that, perhaps surprisingly, the increase in the skill premium in the United States is smaller in the world without technology capital. This means that the Stolper-Samuelson effects are not the main driver of the increase in the skill premium in the United States. There are two reasons for this. First, is the investment channel that I explored above serves to increase the skill premium. Second, the Stolper-Samuelson effects are not as strong here as they would be in the most basic H-O model. This is because, here, intermediate inputs are relative complements, and in the most basic H-O model, there are only two goods which are substitutes for one another. Therefore, when industries integrate, the intermediate inputs from the two countries are relative complements and so there is a tendency for demand for the factors of production to move in the same direction in the two countries. This implies that the fact that Sector Y integrates is, in part, responsible for the skill premia moving in the same direction in both countries. In the absence of technology
capital, however, the increased (world) supply of unskilled workers dominates and the skill premium falls. There are parameter values for which the skill premium rises in the United States and falls in Mexico. However, the skill premium in the United States never rises as much as it would in a world in which goods are gross substitutes.

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>%Δ</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With Z</td>
<td>No Z</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>50.4</td>
<td>39.4</td>
<td>-9.78</td>
</tr>
<tr>
<td>U.S.</td>
<td>11.0</td>
<td>8.0</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 7: Results - Baseline Model vs H-O Analog

Figure 4a shows the fit of the skill premium in the model relative to the data and its transition path from one steady state to the next. The red lines correspond to Mexico and the blue lines correspond to the United States. Consider first the output for Mexico. The line with circular markers denotes the data and the solid line corresponds to my baseline model. Notice that, while the baseline model features a smooth transition between the autarkic steady state and the free trade steady state, the initial jump in the skill premium in the first period is pronounced. This is due to the fact that there is no cost to the producers of the intermediate goods for switching from producing for the Mexican supply chain, which uses the Mexican technology capital, $Z_{M,y}$, to producing for the American supply chain, which uses the U.S. technology, $Z_{U,y}$. Because the more advanced technology becomes immediately adopted, there is a large initial jump in the skill premium. This is the adoption channel at play. The rest of the increase in the skill premium is driven by the investment channel. As the U.S. invests more and more into the stock of U.S. technology capital, $Z_{U,y}$, Mexican firms continue to adopt this technology. This additional adoption would not happen, however, if the U.S. were not investing additional resources into $Z_{U,y}$. For contrast, I have also included the results for the world without technology capital (setting $\alpha = 0$ but keeping all other parameter values fixed at the calibrated values), which is the basic H-O model. This is represented by the red dashed line for Mexico. Notice that in the absence of technology capital, the skill premium falls immediately. This is because there are no dynamics in the basic H-O model and so the model transitions immediately to the new steady state, where Mexican firms specialize entirely in the production of the unskilled-intensive good, or the good produced in Sector X. The new steady state in the H-O world features a falling skill premium in Mexico, just as standard trade theory predicts.
Now, I turn my attention to the results for the United States, which are denoted by the blue lines. Again, the line with circular markers is the data, the solid line is the result of the baseline model, and the dashed line is the result of the basic H-O analog using the calibrated parameter values from the baseline model. We can see in Figure 4a that my baseline model also increases the skill premium in the United State by more than the H-O analog. This is precisely because of the investment channel. In the basic H-O setup, there is an immediate jump in the skill premium due to specialization. Because firms can switch immediately to production of the good in which they have the comparative advantage and there is no dynamic accumulation of any sort of capital (technology or otherwise), the transition from one steady state to the next is immediate. In the model with technology capital, however, there is a slower transition to the new steady state, while the stock of technology capital is being accumulated to its new steady state level. As the Mexican firms adopt more and more of the U.S. technology capital, the return to investing in this technology capital continues to increase. Therefore, the U.S. final goods producer will continue to invest in additional technology capital until the marginal return on that investment is maximized, which occurs once all of the Mexican firms that will switch to producing for the American supply chain have completed their transition. We see this as a gradual transition from the initial closed economy steady state to the one in which supply chains are integrated across countries.

Figure 5 displays the results of the model for imports to and exports from Mexico as a fraction of the value added in manufacturing. In the model, all output is manufacturing output, so the closest data analog is manufacturing imports and exports over value added in manufacturing. Recall that the model does not fully incorporate the back and forth trade
that is inherent in supply chain relationships. Therefore, it is natural that the model would underestimate imports and over-estimate exports, since it is not accounting for some of the re-importation that occurs via the supply chain and it is, therefore, over counting the value-added of the exported goods. Exports increase to about 12% of value added in the data and to about 16% of value added in the model, while imports increase to about 12% of value added in the data and to about 4% of value added in the model.

I now turn to the fit of the model with shifts in employment from one sector to the next. In order to compare this measure to the data, I will have to decide which industries belong
in the integrated sector (Sector Y) and which belong in the non-integrated sector (Sector X). The choice of these industries is not obvious because every industry in Mexico imports some inputs and exports some goods. I do not have data directly linking Mexican firms to their American counterparts, so I cannot directly measure the percentage of firms that are actually part of the U.S. supply chain in the data. Therefore, I instead define the industries using skill-intensity. I have assumed in the model that the integrated sector is the more skill-intensive of the two. Therefore, I use those industries with skill-intensities that are above average to be those industries that are in Sector Y. Figure 6 displays the data (solid line) versus the baseline model and the H-O analog. As expected, in the H-O model, employment in the integrated (skill-intensive) sector falls as Mexico begins to specialize in production of the unskilled-intensive good. In the baseline model, as in the data, employment in the integrated (skill-intensive) sector rises. There is a greater rise in employment in Sector Y in the model than in the data, which may be attributed to the fact that much of the specialization that occurs after trade liberalization occurs within, not across industries (see Goldberg & Pavcnik, 2007). I have abstracted from heterogeneity across firms within a given sector. Therefore, one would expect to see more intra-industry shifting of employment in the model than in the data. Ideally, I would be able to identify firms as having integrated or not, but this observation is not available in the data.

Recall that the experiment above is for the extreme case of complete autarky to fully open economies. This may not be a bad exercise to do because in the early 1980s, Mexico was one of the most closed economies in the world and by the late 1990s, it was one of the most open and in many ways was almost completely integrated into the U.S. market. Notably, full adoption of the intellectual property rights laws of the United States was part of the NAFTA agreement, though Mexico began to adopt these laws as early as 1989 (DuMars, 1991). I view this adoption as one of the important reduction in distortions that occurred to allow supply chains to integrate and final goods producers to share technology with their intermediate goods producers.

In Figure 7, I show the sensitivity of my results to the proposed change in \( \tau_z \). Recall that moving from autarky to free trade is essentially moving from a high level of distortions to no distortions (\( \tau_z = \infty \) to \( \tau_z = 0 \)). Figure 7 shows how my results would change in a less extreme case. Notice that if these distortions are sufficiently high (\( \tau_z > 3 \)) the Mexican intermediate goods producing firms choose to specialize in producing intermediates for Mexican final goods producers using Mexican technology. If the change in this distortion is sufficiently small, there are no changes in the skill premium due to the “investment channel” in the United States. This is because sufficiently small amounts of U.S. technology are adopted
so that the return on technology capital does not change. This, in turn, reduces the firm’s incentive to increase investment, thus eliminating the investment channel. As discussed above, the skill premium may rise as a result of integration of supply chains, depending on the relative complementarity of intermediate goods.

5.3 Sensitivity Analysis

The most important parameter for determining the change in the skill premium is $\alpha$, as it governs the importance of technology in production and its complementarity with high-skilled labor. Figure 8a shows how the skill premium changes with $\alpha$.

Notice that when $\alpha$ is very close to zero, the Stolper-Samuelson effect dominates and the skill premium in Mexico actually falls as Mexico integrates with the United States. However, as $\alpha$ approaches one, the Stolper-Samuelson effect is no longer important and trade in technology dominates.

Also important for determining the change in the skill premium is $\sigma$, which dictates how substitutable skilled and unskilled labor are. Figure 8b shows the sensitivity of the change in the skill premium to this variable. Estimates in the data for $\sigma$ range between 1.4 and about 2, so I show that range of value for $\sigma$ on the x-axis of figure 8b. In Figure 8b, we see that if skilled and unskilled labor are more substitutable, the change in the skill premium is greater in the open economy than if the two types of labor are less substitutable, though the results
are not particularly sensitive to this value. Figure 9 shows how the results change when $\alpha$ and $\sigma$ jointly change. As both parameters increase, the change in the skill premium in response to a trade liberalization increases. These parameters cannot be estimated individually from the data, but have to be determined jointly from the calibration procedure. As seen in Figures 8a and 8b, the results for the change in the skill premium are much more sensitive to the value of $\alpha$, though the value of $\sigma$ is important matching the initial levels of the skill premia.

Also of interest is the relative productivity of the trade partner, $A_M$. Although this can be directly calculated from the data and so its value is not in question here, it may be of interest so that we can think about how the model would operate when the trade integration
is between two countries that are more similar in terms of their initial productivities. In Figure 10, I show how the results change for different levels of productivity. Moreover, in figure 10 if the countries have greater differences in their productivity, trade increases the skill premium in Mexico by much more. This exercise gives implications of the model for the impact of trade in technology between two countries with similar productivities. In particular, if two advanced economies, such as Canada and the United States, were to engage in trade in technology, it would be far less likely that Canada would adopt the technology of the United States to the same extent that Mexico did. The investment channel would still be at work, however, and so there could be a modest rise in the skill level of technology capital in each country, depending on how much of the American technology was used in Canada and vice versa. The increased marginal return to technology capital of the final goods producer in the U.S. depends on the Canadian intermediate goods producing firms’ willingness to switch from producing for the domestic final goods producer to producing for the American final goods producer. Because the two countries would have initial stocks of technology capital that would be similar, it is unlikely that the return to investing in the technology would change substantially after liberalization. This is broadly consistent with the data on the Canadian manufacturing skill premium following NAFTA. The skill premium in Canada rose by an amount similar to the increase in the skill premium in the U.S.

![Figure 10: Sensitivity of Changes in Skill Premium to $A_M$](image)

The sensitivity analysis suggests that even for values of $\alpha$ and $\sigma$ which are lower than the calibrated values, the model can deliver growth in the skill premium of the sort that we observed over the late 1980s and early 1990s in Mexico. Notice that the sensitivity analysis was all done with respect to changes in the Mexican skill premium. A robust feature of the model is that it delivers a relatively larger increase in the skill premium in Mexico than
in the United States, which is a feature that other models of the skill premium lack. The disproportionate rise of the skill premium that occurs in Mexico arises because Mexican intermediate goods producers begin to produce for the supply chain of the U.S. final goods producers, and hence, adopt of these firms. There is an investment effect on the skill premium in both countries, but the majority of the increase in the skill premium in Mexico will come from the adoption of the American technology.

6 Conclusion

In this paper, I have shown that integration of supply chains is an important channel by which technology may be shared across countries and, thus, is an important determinant of the impact that a trade liberalization has upon relative wages. The theoretical model that I use to generate predictions for the changes in the skill premia following a trade liberalization is a standard two-country trade model, modified to include technology capital which can be traded across countries. I conclude that, once we consider the trade in technology that inherently occurs as part of integrated supply chains, the increase in the skill premium in both the United States and Mexico, with a disproportionate increase in the Mexican skill premium, is not a puzzle. The model predicts that, while the skill premium rises in both countries, it rises in Mexico by much more than the skill premium in the United States. I have provided evidence of supply chain linkages, as well as evidence that these linkages are important predictors of technological transfer and increasing skill premia. I have further shown that the patterns observed empirically are quantitatively consistent with those predicted by this theory.

My model embeds the standard Heckscher-Ohlin forces and when I shut down the importance of technology in production, I find the standard prediction of a falling skill premium in the Mexico and a rising skill premium in the United States. Allowing for trade in technology overturns this result because it allows for technology adoption in Mexico to spur increases in investment in that same technology in the United States. A key reason that this was possible in the case of Mexico is Mexico’s adherence to U.S. intellectual protection laws, which decreased the distortions to using American technology in Mexico. This has implications for other trade relationships and liberalizations. Perhaps the reason that we do not observe such large increases in the skill premium in other developing countries as they open to trade is that trade in technology is hindered by the lack of intellectual property protection in those countries. In future work, I plan micro-found the distortion to the use of U.S. technology in Mexico and then to extend the analysis to other countries whose skill premia rose following
trade liberalizations, such as Chile and Colombia, but by much more modest amounts than the increase observed in Mexico. As a first pass, it is evident that these countries conduct far less intra-industry trade with the developed world than Mexico does, which indicates that their firms are far less integrated into the supply chains of the advanced economies.

The framework developed here can be extended along a number of dimensions. An interesting avenue for future research would be to model the strategic interaction between the final goods producer and the intermediate goods producer which gives rise to the distortion on the use of technology capital in the foreign country, $\tau_z$. Better understanding of this relationship will provide a framework to explore the disparate responses to trade liberalization across countries. Another possible extension would be to allow for heterogeneity in some exogenous productivity at the firm-level. Burstein and Vogel (2012) show that reallocation across firms can have an impact on inequality. Allowing for this feature in my current framework would allow me to use more of the plant-level data to test the accuracy of the model. Moreover, it would allow me to study how technology capital gets allocated across intermediate goods producers in Mexico and, therefore, how this contributes to cross-plant variation in wages and the skill premium. A third extension is to model the costs to the worker of changing sectors. This will create cross-industry variation in wages and the skill premium, again allowing for more external checks of the theory.

This paper provides a model for beginning to think about technological transfer and the impact that this transfer has both upon countries that adopt it and upon the firms who invest in it. I have demonstrated that technological transfer can play an important role in determining the skill premia of countries that liberalize to one another. An interesting issue that remains is identifying the reasons that technological transfer occurs to a greater or lesser extent when certain countries open to trade and the implications that this has for inequality.
References

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