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 roughly 50 percent in Mexico while also rising 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 increases the skill premium in Mexico due to the diffusion of the U.S. technology to Mexico. Furthermore, the skill premium in the U.S. rises modestly due to increased investment in this technology, which is driven by the increased marginal return on the technology arising from its adoption in Mexico. The mechanism is supported by plant- and industry-level evidence: Mexican plants and industries which are more integrated into the U.S. supply chain have higher skill premia than their non-integrated counterparts. The calibrated model can account for about 29% of the increase in the skill premium in Mexico. I show that technological diffusion is a key driver of this increase in the skill premium.

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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.1 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 to trade. These observations have led researchers to propose several mechanisms by which trade liberalizations induce an increase in the relative demand for skill. In this paper, I add to this literature by arguing that trade liberalization, by stimulating investment in skill-biased technologies and facilitating cross-border diffusion of these technologies, plays a significant role in explaining the aforementioned facts. 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 on the wages of workers in Mexico. I show that, while a reduction in tariffs may cause an endogenous increase in domestic technologies, a key component to the increase in Mexico’s skill premium is the diffusion of technology from the U.S. to Mexico.

I begin by providing empirical evidence of the importance of two policy levers in determining the change in the skill premium in Mexico: tariffs and intellectual property rights (IPR) protections. I use complete U.S. ownership as a proxy for IPR protections and show that Mexican plants and industries that experience lower tariffs and stronger IPR protections tend receive more transferred technology, as measured by royalty payments. I find that, while both policy levers are important, IPR protections are far more important in determining the extent of technological diffusion. I then show that these royalty payments for technological transfers correlate to higher average skill premia both at the plant- and industry-level. I interpret these results as supporting the idea that supply chains are a channel through which technology is transferred and that this technology transfer is an important determinant of the skill premium. The plant-level surveys have been used in the past in order to analyze the impact of trade on the skill premium; however, I am the first, to my knowledge, to use the information on royalty payments to provide evidence that rental of technology has an impact on the skill premium. I use these results to guide my modeling choices and find that the model produces consistent results in which both policy levers impact the skill premium, with the IP wedge having a greater impact.

I then adapt a standard trade model in a way that consistent with these observations in that it allows for trade liberalization to increase both trade in goods and diffusion of technology. I model technology as

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1 See Goldberg and Pavcnik (2007) for a nice summary of this literature.
technology capital, similar to the model in McGrattan and Prescott (2009), but I allow for the technology capital to be rented from final goods producers, who own and invest in it, to intermediate goods producers, who use it. The model, thus, allows for technology capital to be endogenously accumulated and diffused across borders through trade. Importantly, technology capital is non-rivalrous, which means that using it in multiple locations increases its marginal productivity. This will impact both the extent of technological diffusion and its accumulation. I model trade liberalization as a reduction both in tariffs on goods and in distortions to the use of foreign technology capital and use this model in order to quantitatively assess the importance of technological diffusion for driving increases in the skill premium.

I discipline my exercise using manufacturing data from Mexico and the United States. Because my interest lies primarily in how the skill premium changed in Mexico, I target the level of the skill premium in the initial period. I use aggregated industry data from Mexico on royalty payments to identify 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 1984-1986 as the “pre-reform” period; as documented below, the majority of Mexican trade reforms began in 1986. I also set the relative productivity of the manufacturing sectors in the two countries, the relative supply of skilled workers in each country, and the skill intensity of each industry to match the data in the pre-reform period. In order to analyze the impact of trade reform on the skill premium, I then conduct an experiment where tariffs on goods and frictions on the use of foreign technology capital are lowered. While direct observation of the reduction in tariffs that occurred in the data is possible, I am not able to directly observe a measure of the distortions on foreign technology capital. I instead set initial distortions to match the industry-by-industry fraction of intermediate goods that are traded between the two countries, as well as industry-by-industry royalty payments, in the pre-reform period.

My baseline experiment includes both a change in tariff rates between the U.S. and Mexico and a reduction in the distortions to the use of foreign technology capital (IP wedge) which matches the change in trade flows and royalty payments observed during the liberalization between the two countries in the late 1980’s. I find that this reduction in both barriers to trade in goods and in technology results in an increase in the Mexican skill premium of 15% in the model economy. I furthermore find that if there were complete erosion of barriers to using foreign technology, the skill premium would have risen by 30% in Mexico, as compared to the 53% increase observed in the data.

Technological diffusion is key to these results. In order to show this, I contrast the baseline in which both distortions are reduced with the case in which tariffs and non-tariff barriers fall, but distortions to the use of foreign capital remain high, thus impeding the diffusion of technology from the U.S. to Mexico. I find that this is only able to account for a 2% increase in the skill premium in Mexico, which is consistent with what is found in Burstein and Vogel (2017). In the model, the large increase in the skill premium is generated by a shift in production towards more skill-intensive sectors as the IP wedge in those sectors falls. The reduction in the distortions to the use of foreign technology capital increase the incentive of Mexican

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2In the appendix, I have included a case study of this type of technological transfer which occurs partially through ownership channels and partially through trade. It describes transfer of technology capital in the form of “know-how” and blueprints.
producers to adopt this technology, but also may induce an increase in the domestic stock of technology capital as the returns to investing in technology capital increase, similar to results in related works such as Burstein and Vogel (2017) and Bustos (2011). However, the domestic technological deepening is small and thus adoption of foreign technology capital generates much larger increases in the skill premium as firms move towards producing for the U.S. supply chain and thus adopt U.S. technologies.

This has implications for how we think about the impact of trade liberalization on the skill premium. My findings suggest that, even when tariffs are reduced by the same margins in two developing countries, the impact of these liberalizations could be very different. In particular, a country that integrates more fully into the supply chain of a more advanced country is the beneficiary of the diffusion of technology capital. This diffusion is the primary force that drives changes in the skill premium. Countries that simply lower tariffs but do not integrate more fully into the supply chain of firms headquartered in their more advanced counterparts will be less likely to gain access to more advanced technologies. This in turn will imply that the skill premium will not increase by as much following this type of liberalization. This results is significant, as part of the puzzle facing this literature has been the fact that developing countries experience very different impacts of trade liberalization on the skill premium. Moreover, this result suggests that there is a missing component in the literature that studies the interaction between trade and technology. Existing works are frequently silent on the source of the technologies that are adopted following a trade liberalization, assuming that these more advanced technologies exist within the liberalizing country and are simply not being operated pre-liberalization. In contrast, when the model forces countries to develop their own technologies through investment, there is little change in the domestic stock of this technology capital following the liberalization and, hence, little change in the skill premium. This suggests that, especially in the case of developing countries integrating with advanced ones, the extent of technological diffusion is going to be a key driver of changes in the skill premium and thus previous studies may be overstating the increases in the skill premium that should be expected following a trade liberalization.

I conduct an additional experiment in which I consider a liberalization between two developed countries, the U.S. and Canada. I use the calibrated parameters of the baseline model, but set skill abundance, productivity, and tariffs to the observed levels in these two countries in 1980. I then exploit the change in trade that occurred after the signing of the Canada-U.S. Trade Agreement to test the implications of the model for this kind of liberalization. I find that, in part because the H–O forces are no longer playing a large role, this has a larger impact on the U.S. skill premium than the integration with Mexico did, primarily because of the increased return to investment in technology capital for both countries due to its non-rivalrous nature. U.S. firms face fewer distortions to using their technology capital in Canada than to its use in Mexico. We can think of this as being due to stronger intellectual property protection laws in Canada, which look more similar to those in the U.S. than their Mexican counterparts. Therefore, both U.S. and Canadian firms exploit the increased opportunity to use their non-rivalrous technology capital in the foreign country, thus increasing the return to investing in it. This causes the stock of technology capital to rise in both countries, inducing an increase in the skill premia. Because this exercise is not fully calibrated, I do not place a heavy weight on its quantitative implications; however, qualitatively, the model predicts that trade volumes between the U.S. and Canada increase more than they do with the liberalization between Mexico and the U.S. and the skill
premium in the U.S. is more heavily impacted than it was after the liberalization with Mexico.

In contrast to the case of a liberalization between a developing country and an advanced one, this experiment suggests that the existing literature may be underestimating the change in the skill premium that occurs in response to a trade liberalization between two advanced countries. By assuming that countries are only upgrading to technologies that exist within their borders, previous studies may be missing some of the technological deepening that occurs when countries are able to use technologies that were developed by their trading partners. This observation is consistent with findings in Keller and Yeaple (2009). Both the non-rivalrous nature of the technology capital considered here and the fact that firms can invest in it are especially important here in accounting for changes in the skill premium in advanced countries, as technological diffusion increases the returns to investing in it. Thus, the model predicts that liberalizations between advanced countries increase the skill premium by more for those countries than a liberalization with a developing one would, even in the context of a model that includes standard H–O forces.

Contribution to Related Literature

This paper primarily contributes to the literature that has studied the interaction between trade and skill-biased technical change and the joint impact that these have had upon inequality. In particular, in both Burstein and Vogel (2017) and Bustos (2011), the observed skill intensity of production endogenously responds to trade liberalization. Burstein and Vogel (2017) build a quantitative multi-country model, a la Bernard, Eaton, Jensen, and Kortum (2003), in which trade liberalizations cause increased international competition, driving the least productive (and hence least skill-intensive) firms to shut down, thus inducing reallocation within economies towards more productive and skill-intensive firms. They assume that producers draw firm-specific productivity from the same distribution in every country and the increase in the skill premium, therefore, results from reallocation within the economy towards existing technologies that are more skill intensive. Similarly, Bustos (2011) proposes a modified Melitz model in which firms draw firm-specific technologies from a given distribution and can pay a high fixed cost to access an existing technology which is more productive and skill-intensive, but has a lower marginal cost to operate. In this model, a reduction in tariffs causes the per-unit profit of exported goods to increase, thus inducing the firms with the highest productivity draws to export and to upgrade to the better technology, thus increasing the skill premium. Again, there is an endogenous increase in the skill-intensity of total production in the economy and the technologies are assumed to exist within the borders of the liberalizing country. The main innovation here relative to these papers is twofold. First, because increases in the skill intensity are the result of costly investment in new technology capital and not simply reallocation towards more productive firms, the model presented here allows us to think about the growth of available technology that is spurred by trade liberalizations, as is shown to occur in Goel (2012), among others. Second, I draw on the literature that has shown that there are differences in the technologies that are available across countries, as shown

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3 There is also a large literature that has debated whether trade or skill biased technology is to blame for increasing skill premia. Goldberg and Pavcnik (2007) summarize much of that literature. More recent papers have instead focused on the interaction of the two.
for example in Caselli and Coleman (2006), and propose a mechanism by which technology capital is diffused through trade channels in order to show the importance of diffusion in accounting for changes to the skill premium. The distinction that technology must be diffused, as opposed to being available for firms to upgrade within the liberalizing country is non-trivial given that the technologies that are available differ substantially across countries. Moreover, because technological innovations are easily appropriated if not well-protected, a firm’s willingness to license innovations across countries depends crucially on the extent to which intellectual property is protected in the foreign market. When a country liberalizes its tariff regime, one might expect to see more technological diffusion from the innovating country when this liberalization is accompanied by improved intellectual property rights (IPR). In contrast with the set-up proposed by Bustos (2011), this paper incorporates two policy levers that impact the extent to which technologies diffuse across countries: tariffs and IPR protections. Better IPR protections encourage more technological diffusion and therefore increase the extent to which liberalization impacts skill premia. I show that IPR protections are, in fact, a key driver of increased technological diffusion and therefore the observed increase in the skill premium in Mexico.\(^4\) Furthermore, the two policy levers help to explain the fact that trade liberalizations of similar magnitudes often result in notably different observed changes in skill premia, as reported by Goldberg and Pavcnik (2007). The set-up proposed by Bustos would predict that two tariff liberalizations of the same magnitude should result in the same change in the skill premium, whereas the model proposed here allows for these differences to be related back to the extent to which the liberalizing country protects IPR and the resulting degree of technological diffusion. I discipline the change in IPR protection using changes in royalty payments, allowing me to measure the magnitude of the policy change. Previous studies, such as Yi (2003), have explored the idea that trade liberalizations especially encourage trade associated with vertical integration. I expand on this idea by considering the importance of this vertical integration as a vehicle for technological diffusion.

My work also complements papers such as Acemoglu (2002a) and Acemoglu, Gancia, and Zilibotti (2012) which provide a theory for the endogenous increase in technology and its subsequent diffusion across borders. Although these papers are similar in spirit to the idea presented here, they do not propose a mechanism by which technology can be diffused. I, on the other hand, propose such a mechanism and quantitatively assess its importance. Feenstra and Hanson (1997, 1996), Burstein, Cravino, and Vogel (2013), Parro (2013), Caselli (2014), and Riano (2009) also explore the idea that technology diffusion matters for the skill premium; however, they study capital-embodied technologies. I study instead the diffusion of intangible non-rivalrous technology capital and I show in my empirical work this is strongly correlated with the skill premium in Mexico.

Lastly, I contribute to the empirical literature which measures the impact of trade and foreign direct investment on the skill premium in Mexico, much of which is summarized in Goldberg and Pavcnik (2007). The case of Mexico has been extensively studied, by for example, Caselli (2014), Kurokawa (2011), Riano (2009), and Verhoogen (2008). This is the first paper, to my knowledge, to use the royalties data to examine the role that technological diffusion may have played in increasing the skill premium therein.

\(^4\)Mirroring this finding, Branstetter, Fisman, and Foley (2005) show that IPR protections are a key determinant of technological diffusion within multinational corporations.
The paper is organized as follows: In Section 2, I provide a description of the data and brief background information on the trade liberalization experience in Mexico in the late 1980s; in Section 3, I provide evidence of both trade liberalization and improved IP protections for the diffusion of technology and the connection of this to the skill premium; Section 4 presents the model; Section 5 contains comparative statics exercises to highlight the key mechanisms in the model; Section 6 contains the calibration and results; and Section 7 concludes.

2 Background and Data

This section briefly describes the data that will be used in the empirical analysis and establishes the relevant patterns of skill premia. It then describes the liberalization policies that were implemented in Mexico in the mid-1980s and establishes that trade began opening between the United States and Mexico before the implementation of NAFTA.

2.1 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 utilize 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 the years 1984 through 1994, and plant-level data is available also by request for 1984 through 1990. Both data sets include information on production and non-production employment, hours, and wages, as well as information on royalties paid, the value of production, and various production costs. The plant-level data includes information on imports, exports, and the percentage of trade conducted with the United States for the years 1986 to 1990. The trade-related 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). The plant-level data also includes information on tariffs and license coverage for the period from 1984 to 1990, as well as foreign ownership. In addition to analyzing the plant-level data on its own, I will exploit these data to get industry-level measures of trade costs, which are not available for the years 1984-1990 from other sources, to my knowledge. I will collapse the plant-level observations on tariffs paid into weighted average industry-level tariffs and then combine them with the tariff data discussed below in order to construct a complete time series of trade frictions.

In order to explore how trade integration impacts the transfer of technology and the skill premium, I first use a balanced panel of 2,598 Mexican manufacturing plants, whose cumulative output accounts for roughly 80% of the country’s manufacturing output. I have eliminated plants in which the skill premium fluctuates by more than 1000% from one year to the next and those whose production values of exports exceeds their
total value of production. This panel includes information on employment, wages, production value, tariffs, license coverage, and ownership for all years, as well as information on trade, including the proportion of trade done with the United States, for the years 1986 through 1990. Information on imports is limited to imports of machinery and of raw materials, though exports are the total amount of production that the plant sells abroad. I use data on royalties paid, tariffs on both imports and exports, imports, exports, and foreign ownership to investigate the role of supply chain integration between foreign entities and Mexican plants in diffusing technology capital.

In order to explore the impact of technological diffusion on the skill premium, I use royalty payments as an indicator of technology transfer. It is important to note that the data does not include information on the entity to which these royalties are paid. Specifically, it does not distinguish between royalties paid to domestic firms versus foreign firms. However, the data also has information on royalty payments received by each plant, and so I can compare the sector-wide average of these numbers to determine that royalties paid are 10 times as large as royalties received, indicating that either royalties are being paid to firms that are outside of the manufacturing industry or outside of the country. Over the entire sample, the average value for royalties paid as a fraction of output is 0.38%, with a standard deviation of 1.62%, whereas average royalties received as a fraction of output is 0.033%, with a standard deviation of 0.535.

I extend my analysis to the industry-level, using data that spans from 1984 to 1994. Aggregate trade data for Mexico is obtained from the World Bank World Development Indicators Database (WDI) and information on bilateral trade between the U.S. and Mexico is gathered from the database compiled in Schott (2008). This database provides bilateral imports and exports, as well as customs duties paid, between the U.S. and its trade partners (including Mexico) for the years 1972 through 2005 for SIC industries. I construct a concordance in order to match this data (1984–1994) with the industry-level data for Mexican manufacturing. Bilateral tariffs between Mexico and the United States are not available at the industry-level or good-level for the entire period of interest, with most tariff data beginning in 1991. Therefore, I estimate trade costs as in Bernard, Jensen, and Schott (2006) as a proxy for industry-level tariffs between the U.S. and Mexico. This data is available from 1989 to 2005 and I use the observations from 1989 to 2000. For 1989 and 1990, I have two sources of data for trade costs: the plant-level data from INEGI and the Schott (2008) database. For those two years, the trade cost data does not match up exactly, so I average across the two data sets.

In order to discipline the model, I use data for the U.S. manufacturing sector, which was 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 em-

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5See the appendix for information on the distribution of plants.
6Tariffs and license coverage are product-specific, and therefore, may vary at the plant level. For multi-product plants, this variation could reflect both variation in tariff rates and the product-mix of the plant. In practice, there is little variation in tariff rates across plants within the same 4-digit industry.
7This variable does not vary across time for any plant in the sample, likely due to restrictive foreign-ownership laws that were in effect until 1989. Even though the restrictions were loosened in mid-1989, there was little change in aggregate foreign investment in Mexico until 1991, while the last year of the sample is 1990.
8The variable name in the original data is gastos por transferencia de tecnología, which translates as “expenditures for the transfer of technology.”
employees, as well as payments to each group. I then construct the skill premium as the ratio of non-production wages to production wages and measure skill-intensity using data from this database for robustness checks.

2.2 Skill Premia in Mexico and the United States

For the remainder of the paper, 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.9 The U.S. experienced similar timing in the rise of the same variable. 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 in 1996, with non-production wages that were about 3.1 times higher than production wages. This can be seen in Figure 1a. As can be seen in Figure 1a, the skill premium in the manufacturing sector in the United States also began to rise in the mid-1980s.

Figure 1: Skill Premia in U.S. and Mexico

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 50%, while the skill premium in the United States rose by about 10 to 15%. Therefore, the skill premium in Mexico rose by about three times as much as its American counterpart from 1986 to 2000.

One might notice that the Mexican skill premium began to decline in 1996; because this is not the

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9 Amiti and Cameron (2011) use data that includes the educational attainment and production/non-production status of workers in Indonesian manufacturing over several years; they show that the production/non-production breakdown is a good proxy for skill or educational attainment. Bustos (2011) shows that in Argentina, non-production employment is 3.2 times more skill-intensive than production employment.
focus of this particular paper, I will not attempt to model this decline. There is a related literature (see, for example, Robertson 2007) which relates the decline in the skill premium to changes in the Mexican labor supply, both in terms of a decrease in unskilled workers due to emigration and an increase in skilled workers due to increased education, with the fraction of college graduates in Mexico remaining roughly static between 1985 and 1990 but doubling between 1990 and 2000. I will conduct the analysis for static supplies of high- and low-skilled workers, abstracting from educational decisions, as well as emigration.

2.3 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.

![Figure 2: Measures of Trade Distortions](image)

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. The government continued to phase out import licenses over the course of the decade, with coverage falling to 19 percent by 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). Furthermore, in 1986, Mexico joined the General Agreement on Tariffs and Trade (GATT), which ensured that tariffs faced...
by its exporters also fell. Figures 2a and 2b show the progression of production-weighted tariffs and license coverage for the average manufacturing plant in Mexico.\(^{10}\)

Figure 3a documents the ensuing increase in Mexican imports and exports of manufactured goods as a percentage of total value added in manufacturing. Figure 3b shows 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. The United States accounted for roughly 70% of all of Mexico’s manufacturing trade throughout this period (Patrick, 1994). As can be seen in the figures, the increase in trade came predominantly from increased trade with developed countries, namely the United States.

During this period, Mexico also entered into trade negotiations with the United States, which culminated in the first-ever formal bilateral agreement governing commercial relations between the two countries, and began 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 to ease technological transfer from companies in the United States (DuMars, 1991). The recognition of intellectual property rights was an important step to allowing for the transfer of technology between the two countries.\(^{11}\)

\(^{10}\)Note that these tariffs rates have been inferred from actual duties paid and are not officially recorded tariff rates.

\(^{11}\)The government also began to loosen its restrictions on foreign ownership over this period; 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. However, to the extent that foreign ownership was allowed, this also served as a channel for technological transfer across the two countries.
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. Contrary to commonly held beliefs, the trade liberalization that took place during the 1980s was more substantial than NAFTA. By the time that NAFTA was signed, approximately 95% all of imports into Mexico from the U.S. were subject to import tariffs of 20% or less and 80% of imports into the U.S. from Mexico were subject to tariffs of 5% or less. This stands in stark contrast to the 100% tariffs that were common in 1985.

3 Evidence on Technology Transfer

In this section, I explore the idea that diffusion of technology capital from the United States to Mexico through supply chains had a significant impact on the skill premium in Mexico. In the model that will follow, there are two policy levers which affect the extent of technology diffusion: tariffs and intellectual property protection. As tariffs fall, trade in intermediate inputs becomes more profitable and so the probability that a given plant will produce for a foreign supply chain increases. To produce intermediates for any supply chain, plants must use the technology capital associated with the particular supply chain for which they are producing. For example, a Mexican plant that produces engine parts for Ford must use the blueprint for the parts needed by Ford. Those blueprints are a form of technology capital that is thus transferred when the supply-chain linkages between the two countries deepen following a trade liberalization. One can imagine that this technology capital may be transferred both through ownership channels, from a multinational parent company to its foreign subsidiary, or through arms-length channels, whereby the developers of the blueprints contract with plants in which they have no ownership stake to produce parts for their final good. In both cases, as tariffs fall, plants shift away from producing for domestic final goods producers toward producing for the foreign supply chain; therefore, royalties paid for the use of this technology capital should increase. The second policy, protection of intellectual property rights (IPR), affects the willingness of those that produce technology capital to license it to foreign entities, whether the foreign parties are affiliated subsidiaries or unaffiliated plants. An improvement in IPR enforcement should therefore have a similar effect to a reduction in tariffs, inducing a deepening of supply chain relationships and increasing technology transfers. This increase in technology transfers can be measured as an increase in royalty payments. Moreover, if technology is skill-biased, this increase in technology transfer should then result in an increase in the skill premium.

First, I explore the impact the two policy levers on royalty payments. I directly observe royalty payments and tariff rates, but do not observe any measure of the strength of IP protection. Therefore, I draw on the

12The model in which technology is transferred within ownership channels is isomorphic to the one in which it is transferred through arms-length relationships. I will focus on the latter, as transfer within ownership channels may be thought of as a special case of the more general setting in which technology capital may be licensed to subsidiaries and non-subsidaries alike.

13Branstetter, Fisman, and Foley (2005) show that intellectual property protection impacts transfers from multinational parents to their foreign affiliates; Lee and Mansfield (1996) find that firms are likely to only transfer the most advanced technologies to wholly owned subsidiaries in countries with strong intellectual property protections, and they transfer less advanced technologies to all parties in countries with stronger enforcement.

14Recall that royalty payments are payments for technology transfer.
insight of Lee and Mansfield (1996) that firms are more likely to transfer technologies within ownership channels when IP protections are lax and exploit information on the fraction of U.S. ownership to act as a proxy for strong IPR laws. In particular, I create a dummy variable equal to one when a plant is wholly owned by a U.S. entity and zero otherwise in order to reflect that technology that is transferred within those plants is more protected than when the plant is only under partial U.S. control. In order to control for the effect of foreign direct investment in which the foreign owner does not have complete ownership and control over any transferred technology, I include the fraction of the plant that is owned by the U.S. as a separate variable. I estimate the following regression by OLS:

\[
\ln(\text{roy}_{ijt} + 1) = \alpha + \beta_1 \ln(\tau_{ijt}) + \beta_2 US_{ij} + \beta_3 (\ln(\tau) \ast US)_{ijt} + USFDI_{ij} + X_{ijt} + \gamma + T_t + \epsilon_{ijt},
\]

where \(i\) indexes the 4-digit industry, \(j\) indexes plants and \(t\) indexes the year. Furthermore, \(\ln(\tau_{ijt})\) is the log of the average export tariff levied on the plant’s output, \(US_{ij}\) is a dummy variable indicating whether the plant is a wholly U.S.-owned entity, \(USFDI_{ij}\) is the fraction of the plant that is owned by a U.S. entity,\(^{15}\) \(X_{ijt}\) is a vector of plant specific controls, and \(\gamma\) and \(T_t\) are vectors of industry\(^{16}\) and year dummies, respectively. The plant level controls include plant size (as measured by log employment), the ratio of capital to value added, and the plant’s initial skill intensity. The left-hand side variable is the log of royalty payments made by a given plant, where I have added one to avoid dropping observations.\(^{17}\)

In Column (1) of Table 1, I investigate the simple relationship between tariff rates and royalties. The estimated coefficient on export tariffs indicates that a 1 percent decrease in tariffs is correlated with a 0.39 percent increase in royalty payments. As can be seen in Column (2), when the proxy for control over transferred technology from the United States (the dummy variable indicating full U.S. ownership of the plant) and its interaction with log tariffs, both full U.S. ownership of a plant and the interaction term are statistically and economically significant. In particular, full U.S. ownership (i.e. full control over transferred technology) is associated with royalty payments that are 328 percent higher than plants that are not fully U.S.-owned. Furthermore, a reduction in tariffs of 1 percent is associated with a total increase in royalties of roughly 1 percent for plants that are wholly U.S. owned, where as this same 1 percent reduction in tariffs is associated with the same 0.36 percent increase in royalties for plants that are not fully under U.S. control.\(^{18}\)

Notice that every specification controls for the skill- and capital-intensity of each plant, so the increase in royalty payments cannot be attributed simply to the idea that these U.S.-owned plants may be more skill or capital intensive. In Column (3), the fraction of the plant that is owned by the United States is included as a control in order to further explore the idea that the extent of control over the transferred technology is important in determining the amount of technology transferred, as measured by royalty payments. Here we

---

\(^{15}\)The percent ownership of any given plant is constant across the periods of the sample so I am not able to test the extensive margin of U.S. ownership, but rather the differential impact of a change in tariffs on the intensive margin for U.S.-owned plants.

\(^{16}\)The industries are classified using the 4-digit Mexican classification of manufacturing industries (CMAP).

\(^{17}\)Because royalties paid are measured in pesos, the positive values tend to be large and adding one has no impact on the average value of logged royalties paid.

\(^{18}\)Note that this group would include plants that are 99% U.S. owned.
see that a 1 percentage point reduction in the fraction of the plant that is owned by a U.S. entity is associated with a 1.4 percent reduction in royalty payments. This implies that as a plant is controlled less completely by the U.S. entity, royalties paid by that plant are lower. I interpret this as a sign that there is less willingness on the part of the owner of the technology to make transfers to plants over which they have less control.

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \ln(\tau_{ij}) )</td>
<td>-0.391***</td>
<td>-0.365***</td>
<td>-0.365***</td>
</tr>
<tr>
<td></td>
<td>(0.034)</td>
<td>(0.034)</td>
<td>(0.034)</td>
</tr>
<tr>
<td>( US_{ij} )</td>
<td></td>
<td>3.287***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.579)</td>
<td>(0.593)</td>
</tr>
<tr>
<td>((\ln(\tau) + US)_{ijt})</td>
<td>-0.666***</td>
<td>-0.674***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.178)</td>
<td>(0.178)</td>
<td></td>
</tr>
<tr>
<td>( USFDI_{ij} )</td>
<td></td>
<td>0.014***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.001)</td>
<td></td>
</tr>
</tbody>
</table>

Plant-level controls | Yes | Yes | Yes |
Industry Fixed Effects | Yes | Yes | Yes |
Time Fixed Effects | Yes | Yes | Yes |
\( R^2 \) | 0.222 | 0.237 | 0.245 |
\( N \) | 15,637 | 15,637 | 15,637 |

Table 1: Royalties and Tariffs
Robust standard errors in parentheses. * denotes significance at the 10% level, ** significance at the 5% level, and *** significance at the 1% level.

When viewed through the lens of the policy levers described at the beginning of the section, these results imply that, although barriers to exporting output produced by the plant play some role in determining the royalties paid by the plant, the more important policy is the protection of intellectual property. In fact, plants that are fully U.S.-owned pay royalties that are on average 10 times higher than domestically owned plants and 60% of plants that are fully U.S.-owned pay positive royalties, whereas only 14% of plants that are not full U.S.-owned pay royalties. There is also a striking difference between plants that are fully U.S. owned and those that are majority U.S.-owned, which have U.S. ownership shares that are greater than 50% but less than 100%. The average royalty payments for this set of plants is about 4 times higher than those of domestically-owned plants, but about one fifth the size of the average royalties paid by wholly U.S.-owned plants. Furthermore, this set of plants is isolated, the fraction that pay positive royalties drops to 26%. The fact that technology transfer increases dramatically with full U.S. ownership implies that foreign ownership itself isn’t the main driver of the difference in royalties, but rather the control over the technologies that are being transferred.

In Column (1) of Table 2, I re-do the analysis with data that has been aggregated from the firm-level to

---

\(19\) The average U.S. ownership share among these plants is 77%. 

13
the industry level. Specifically, I estimate:

\[
ln(roy_{it} + 1) = \alpha + \beta_1 ln(\tau_{it}) + \beta_2 US_i + \beta_3 (ln(\tau) \ast US)_{it} + Y_{it} + T_t + \varepsilon_{it},
\]

where, again, \(i\) indexes the 4-digit industry, \(t\) indexes the year, and \(ln(\tau_{it})\) is the log of the average export tariff levied at the industry-level. \(US_i\) now measures the fraction of plants in the industry which are wholly U.S.-owned entities. Because of this change, there is no longer a clear interpretation of including both the fraction of wholly U.S.-owned plants in a given industry, which corresponds to \(US_{ij}\) in Equation 1, and the fraction of U.S. ownership at the industry level, which corresponds to \(USFDI_{ij}\) in Equation 1. Therefore, I exclude \(USFDI_i\) as a regressor and focus on the more important variable from the previous results, \(US_i\). \(Y_{it}\) is a vector of industry-specific controls, and \(T_t\) is a vector of year dummies. Recall that foreign ownership does not vary across the sample, so I am unable to include industry-level dummies. The time-varying industry-level controls include industry size (as measured by log employment), the ratio of capital to value added and initial skill intensity.

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
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</thead>
<tbody>
<tr>
<td>(ln(\tau_{it}))</td>
<td>-0.431**</td>
<td>-0.573***</td>
</tr>
<tr>
<td></td>
<td>(0.177)</td>
<td>(0.072)</td>
</tr>
<tr>
<td>(US_i)</td>
<td>0.118***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.028)</td>
<td></td>
</tr>
<tr>
<td>((ln(\tau) \ast US)_{it})</td>
<td>-0.035***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td></td>
</tr>
<tr>
<td>(IPR_{it})</td>
<td></td>
<td>2.583***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.167)</td>
</tr>
<tr>
<td>Industry-level controls</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.292</td>
<td>0.837</td>
</tr>
<tr>
<td>(N)</td>
<td>896</td>
<td>1,193</td>
</tr>
</tbody>
</table>

Table 2: Royalties and Tariffs
Robust standard errors in parentheses. * denotes significance at the 10% level, ** significance at the 5% level, and *** significance at the 1% level.

Here, again, a the coefficient on export tariffs is statistically significant and carries roughly the same magnitude; a decrease in tariffs of 1 percent is associated with an increase in royalty payments of roughly 0.4 percent. However, a one percentage point increase in the fraction of the industry that is fully U.S. owned is associated with a 11.8 percent increase in royalty payments and industries with a greater fraction of firms under full U.S. ownership see a 1 percentage point decrease in tariffs being associated with an increase in royalty payments of 0.04 percentage points. In terms of size of the effect, control over transferred technology
appears to be more significant than a change in tariffs. The results at the industry-level mirror the results from the firm-level analysis; the extent of U.S. control a given industry is a strong predictor of the royalty payments made by that industry.

In order to further explore the hypothesis that IPR protections and tariffs both play a role in determining the extent of technological transfer, as measured by royalty data, I extend my analysis to the industry-level data that is available from 1984 through 1994, which allows me to analyze the impact of the IPR reform that occurred in Mexico in 1991. This data does not include information on the fraction of the industry that is owned by foreign entities and so Equation 2 can be modified to instead estimate

\[
\ln (\text{roy}_i + 1) = \alpha + \beta_1 \ln (\tau_i) + \beta_2 \text{IPR}_t + Y_i + \gamma + T_t + \epsilon_{it},
\]

where, again, \(i\) denotes the industry and \(t\) denotes the year. As before, \(\tau_i\) are industry-level export tariffs, \(Y_i\) is a vector of time-varying industry-level controls, and \(\gamma\), \(T_t\) are industry and time fixed effects, respectively. Following Branstetter, Fisman, and Foley (2005), I control for IPR reform by including \(\text{IPR}_t\), a dummy variable that is equal to one in 1991 and after, when Mexico underwent a major reform to its IPR protection laws.\(^{20}\) \(Y_i\) includes industry sales and skill-intensity. Results of this estimation are reported in Column (2) of Table 2. Again, I find that both policy levers are correlated with royalty payments, with a 1% decrease in export tariffs being associated with a 0.57% increase in royalty payments and an improved IPR enforcement regime being associated with royalty payments that are 258% higher than the pre-reform period. Both the size and the sign of the effects of the two policy levers are consistent across specifications.

I now turn to relating technology transfer, as measured by royalty payments, to changes in the skill premium. I build on the work of Amiti and Cameron (2011) and Caselli (2014), and control for the direct effect of trade liberalization, as measured by changes in import tariffs, export tariffs, and tariffs on machinery and equipment. Because factor prices are determined contemporaneously, royalty payments may be endogenously determined along with the skill premium and so I will implement an instrumental variables approach. In particular, based on the evidence presented above that both tariffs and IPR protections are important determinants of royalty payments, I will use the interaction between export tariffs and the proxy for IPR protections, full U.S. ownership of a plant, as an instrument for royalty payments and include export tariffs as a regressor in both the first and the second stage regressions. The U.S. ownership dummy is a valid instrument if it is uncorrelated with the residual in the main equation determining wages, which will be the case if full U.S. ownership is unaffected by the demand for technology transfers in Mexican manufacturing. As discussed previously, U.S. ownership is predetermined at the beginning of the sample and does not vary across years; therefore, it must be the case that U.S. ownership is not affected by the demand for technology transfers.\(^{21}\) The interaction between export tariffs and the full U.S. ownership dummy is included as the

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\(^{20}\)Note that Mexico’s accession to the GATT in 1987 also required a strengthening of its intellectual property protections, while additional protections were enacted in 1991.

\(^{21}\)Moreover, the correlation between the U.S. ownership dummy at the skill premium is nearly zero (0.03). One might be concerned that there are other channels by which U.S. ownership would impact the skill premium. For example, it has been shown that foreign-owned firms tend to be more skill-intensive, larger, and more capital intensive. Thus, these are included as regressors in the main specification to ensure that the other channels by which full U.S. ownership might impact the skill premium are accounted for. Furthermore, I include FDI as a control and am using an indicator of full U.S. control as the instrument.
regressor also due to the lack of variation in U.S. ownership across time. Following Amiti and Cameron (2011) and Caselli (2014), the following equation is estimated via two stage least squares:

$$SP_{it} = \alpha + \beta_1 \ln (\text{roy}_{it} + 1) + \beta_2 \ln (\tau_{ix}^{it}) + \beta_3 \ln (\tau_{ix}^{it}) + \beta_4 \left( \ln (\tau_{ix}^{it}) + \ln (\text{ExpY}_{it}) \right) + \beta_5 \left( \ln (\tau_{ix}^{it}) + \ln (\text{ImpM\&E}_{it}) \right) + \beta_6 \left( \ln (\tau_{ix}^{it}) + \ln (\text{ImpM\&E}_{it}) \right) + \beta_7 \left( \ln (\tau_{ix}^{it}) + \ln (\text{ImpM\&E}_{it}) \right) + \beta_8 X_{it} + \gamma_i + T_t + \epsilon_{it},$$ (4)

where $SP_{it}$ is the plant-level skill premium, $\ln (\text{roy}_{it} + 1)$ are predicted plant-level royalty payments, and $\tau_{ix}^{it}$, $\tau_{ix}^{it}$, $\tau_{ix}^{it}$ are tariffs on exports, imports, and machinery and equipment, respectively. Tariffs on machinery and equipment are reported in TenKate (1992) at the annual level for the broad industry of “machinery and equipment” and therefore only vary across years. Following Amiti and Cameron (2011) and Caselli (2014), export, import and machinery and equipment tariffs are interacted with the export share of total sales ($\text{ExpY}_{it}$), share of material costs that are imported ($\text{ImpM\&E}_{it}$), and the share of machinery and equipment that is imported ($\text{ImpM\&E}_{it}$), respectively. $X_{it}$ controls for plant-level variation in number of employees (a proxy for size), initial skill intensity, ratio of capital to value added, capital share owned by foreign entities (foreign direct investment), and the shares of exports to total sales, materials imported, and machinery and equipment. Industry- and time-fixed effects ($\gamma_i$ and $T_t$) are also included.

Table 3 reports the baseline results from estimating Equation 4 via OLS (Columns 1 and 2) and by two-stage least squares (Columns 3 and 4). I will focus on Column (4), which is the preferred specification. Consistent with Caselli (2014), I find that export tariffs do not have a statistically significant impact on the skill premium on their own. However, predicted royalties, which are impacted by both trade liberalization and by IP protections have a statistically and economically significant impact on the skill premium; a 1 percent increase in predicted royalties is associated with an increase in the skill premium of 0.07 percent.\footnote{Caselli (2014) tests the impact of log royalties on the skill premium and finds that they do not have a statistically significant impact on the skill premium. Here, I use log(1 + royalties) in order to avoid dropping observations, as there are many firms that pay zero royalties and these are an important determinant of the relationship between royalties and the skill premium.}

Average royalty payments increased roughly tenfold between 1986 and 1990, while the average skill premium increased by 28% over the same period. Tariffs of all kinds do not have a statistically significant impact on the skill premium, including those on machinery and equipment imports.

In Column (5) of Table 3, I repeat the exercise at the industry-level, estimating the equation via two-stage least squares with the same instruments as above. As in the estimation of Equation 2, industry-level fixed effects cannot be included, as U.S. ownership does not vary across time, only across industries. In Column (6), the industry-level exercise is repeated, only using the IPR reform dummy as the proxy for IPR protections, instead of U.S. ownership. Results are consistent across specifications: higher royalty payments are strongly associated with higher skill premia. Furthermore, the results at at the industry-level are consistent with the findings at the plant-level: trade liberalization affects the skill premium through the transfer of technology. Trade liberalization itself, or the reduction of tariffs, appears to have no statistically significant variation with the skill premium once other factors are considered. In the model that follows, I focus on technology diffusion as the primary channel through which the skill premium is affected following a trade liberalization. The diffusion of technology will be affected by tariffs and by the extent to which
### Table 3: Skill Premium and Liberalization

<table>
<thead>
<tr>
<th></th>
<th>Firm-Level Analysis</th>
<th>Industry-Level Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OLS (1)</td>
<td>OLS (2)</td>
</tr>
<tr>
<td><strong>Constant</strong></td>
<td>0.797***</td>
<td>0.796***</td>
</tr>
<tr>
<td></td>
<td>(0.096)</td>
<td>(0.096)</td>
</tr>
<tr>
<td>$\ln(roy_{ijt} + 1)$</td>
<td>0.017***</td>
<td>0.017***</td>
</tr>
<tr>
<td></td>
<td>(0.022)</td>
<td>(0.022)</td>
</tr>
<tr>
<td>$\ln(\tau_{ijt}^I)$</td>
<td>-0.011</td>
<td>-0.012</td>
</tr>
<tr>
<td></td>
<td>(0.020)</td>
<td>(0.020)</td>
</tr>
<tr>
<td>$\ln(\tau_{ijt}^I)$</td>
<td>0.005</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td>(0.016)</td>
<td>(0.019)</td>
</tr>
<tr>
<td>$\ln(\tau_{ijt}^{me}) \times \frac{\text{ImpM&amp;E}<em>{ijt}}{M&amp;E</em>{ijt}}$</td>
<td>-0.0004</td>
<td>-0.004</td>
</tr>
<tr>
<td></td>
<td>(0.0004)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>$\ln(\tau_{ijt}^{exp}) \times \frac{\text{Exp}<em>{ijt}}{\tau</em>{ijt}}$</td>
<td>0.021</td>
<td>0.021</td>
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<tr>
<td></td>
<td>(0.027)</td>
<td>(0.028)</td>
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<td>$\ln(\tau_{ijt}^{ImpMC})$</td>
<td>0.002</td>
<td>0.003</td>
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<td>(0.003)</td>
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<td>Plant-level controls?</td>
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<tr>
<td>Industry-level controls?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Industry Fixed Effects?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time Fixed Effects?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.166</td>
<td>0.166</td>
</tr>
<tr>
<td>$N$</td>
<td>10,865</td>
<td>10,865</td>
</tr>
</tbody>
</table>

Standard errors in parentheses. * denotes significance at the 10% level, ** significance at the 5% level, and *** significance at the 1% level.

intellectual property is protected.

## 4 The Model Environment

The model economy features two countries, Mexico (denoted by $M$) and the United States (denoted by $U$), and $I$ industries, indexed by $i$. I include only the U.S. and Mexico because the primary focus of this paper is the change in Mexico’s skill premium and during the period of interest, Mexico traded almost exclusively with the United States. In each country and industry, there is a non-tradeable final good produced by perfectly competitive firms. This final good is a CES aggregate of a continuum of varieties, some of which are produced domestically and some of which are imported and subject to an iceberg trade cost. The
final good can be used either for consumption or for investment in the stock of technology capital, which is used in the production of the intermediate varieties. The production of these varieties requires skilled and unskilled labor, as well as the aforementioned technology capital. The producer of an individual variety is a monopolistic competitor and may produce that variety for a domestic final goods producer and for a foreign final goods producer at the same time, meaning that they may operate two different technologies within a single firm. I will refer to the operation of different technologies within a single variety as production lines within that variety or firm. Aggregate labor of each type is inelastically supplied and is immobile across countries, though it is perfectly mobile across industries and production lines.

4.1 Final Goods Producers

In each industry and each country, there are perfectly competitive producers of a non-tradeable final good which seek to maximize the infinite sum of discounted dividends. The final good in country $k$ and industry $i$ is denoted $Y_{ki}$ and is composed of a CES aggregation of intermediate varieties $y_{kji}^d(\omega)$, where the variety is denoted by $\omega$ and the country of origin for that particular variety is indexed by $j$. The final goods producer owns and invests in a stock of technology capital, $Z_{ki}$, which it rents to the producers of the intermediate varieties of which its final good is composed. It earns returns $r_{kki}$ and $r_{kji}$ from renting its technology capital to domestic and foreign producers of intermediate varieties, respectively. To economize on notation, I will suppress the time subscript. These final goods producers in country $k \in \{U, M\}$ and industry $i$ maximize the sum of discounted dividends by solving the following problem:

$$\max \sum_{t=0}^{\infty} P_{ki}D_{ki}$$

s.t.

$$D_{ki} = Y_{ki} + Z_{ki}(r_{kki} + r_{kji}) - I_{ki} - \int p_{kji}(\omega) y_{kji}^d(\omega) d\omega,$$

$$I_{ki} = Z_{ki}' - (1-\delta)Z_{ki},$$

$$Y_{ki} = \left[ \int y_{kji}^d(\omega) \rho d\omega \right]^{1/\rho}.$$  

The dividend is equal to the producer’s total output ($Y_{ki}$), plus rental income earned by renting the technology capital to domestic producers ($Z_{ki}r_{kki}$) and to foreign producers ($Z_{ki}r_{kji}$), minus investments in technology capital ($I_{ki}$), minus payments for intermediate goods. Technology capital is accumulated via a standard law-
of-motion, in which today’s stock of technology capital depreciates at a rate \( \delta \), so that tomorrow’s stock of technology capital, \( Z'_{ki} \), is equal to undepreciated technology capital \( Z_{ki} \) plus investment, \( I_{ki} \). A variety \( \omega \) is producer country-specific, and the final producer will purchase varieties from both countries, substituting towards more domestic varieties if the cost of foreign intermediates is higher. All varieties are aggregated to make the final good in the industry and \( \frac{1}{1-\rho} \) is the elasticity of substitution between these varieties within the industry. \( P_{ki} \) is the price of the final good produced by industry \( i \) to be consumed in country \( k \), expressed in units of the aggregate price index \( P_k = \left[ \sum_i P_{ki}^{1-\phi} \right]^{1/(1-\phi)} \).

**Technology Capital: Investment and Rental**

The technology capital that I consider, \( Z_{ki} \), can be thought of as a stock of ideas, blueprints, or production techniques and, as such, is non-rivalrous in nature. These ideas and production techniques are the ones that are necessary in order to make an intermediate part for the final product so that when the final goods producer begins to purchase more intermediates from foreign producers, the foreign producer will have to rent more of this technology capital in order to produce these parts. This causes the rate of return on technology capital to increase for the final goods producer, thus inducing them to increase investment in it. Moreover, the rental of technology capital in order to produce the appropriate part for the foreign final goods producer is the channel by which this technology capital will be diffused across borders.

I assume that this technology is high skill-augmenting and low-skill saving. This assumption is based on the large literature that shows that technological advancements since the early 1980s have favored high skill workers. I extend this observation to technology capital, assuming that production techniques have changed the mix of high- and low-skill workers. The extent to which this is true in the model will depend on parameter values, which will be discussed in more detail in the following sections.

### 4.2 Production of Varieties

The intermediate goods producer producing intermediate variety \( \omega \) for industry \( i \) in country \( k \) can produce both for the domestic market \((k)\) and for the foreign market \((j)\). He chooses the output for the domestic market \((y_{kki}(\omega))\), the output for the foreign market \((y_{jki}(\omega))\), skilled labor to produce for the domestic market \((h_{kki}(\omega))\), skilled labor to produce for the foreign market \((h_{jki}(\omega))\), unskilled labor to produce for the domestic market \((l_{kki}(\omega))\), unskilled labor to produce for the foreign market \((l_{jki}(\omega))\), and an amount of domestic and foreign technology \((Z_{ki}, Z_{ji})\) to maximize profits, taking the inverse demand function, wages \((w^H_k, w^L_k)\), and the rental rates for technology \((r_{jki}, r_{kki})\) as given. The first subscript refers to the country for which the intermediate variety is produced and the second refers to the country in which production takes place. The producer of the intermediate good must use the technology of the supply chain for which they are producing in order to make the variety for that firm. The intermediate-goods producing firm therefore solves the following problem:
\[
\max \sum_{j \in \{U, M\}} \frac{p_{jki}(\omega)}{\tau_{jki}} y_{jki}(\omega) - w^H_k h_{jki}(\omega) - w^L_k l_{jki}(\omega) - Z_{ji} r_{jki} \tau_{jki}^z
\]  

\text{s.t.} 

\[
y_{jki}(\omega) = A_k \left[ \theta_i \left( Z_{ji}^\alpha h_{jki}^{1-\alpha}(\omega) \right)^{\frac{\alpha-1}{\alpha}} + (1-\theta_i) l_{jki}(\omega)^{\frac{\alpha-1}{\alpha}} \right]^{\frac{\sigma}{\sigma-1}} \quad \forall j \in \{U, M\} 
\]

\[y_{jki}(\omega) = \left( \frac{p_{jki}(\omega)}{P_{ji}} \right)^{\frac{1}{1-\rho}} Y_{ji} \quad \forall j \in \{U, M\}, \]  

where \( \sigma > 0 \) is the elasticity of substitution between high- and low-skilled labor. The skill-intensity of production will be jointly governed by \( \alpha \in (0, 1) \) and \( \theta_i \in (0, 1) \). \( A_k > 0 \) is the level of the country-specific total factor productivity (TFP) and \( P_{ji} \) is the cost of the final good produced in industry \( i \) in country \( j \), the country for whose supply chain the intermediate variety is being produced. There are two wedges on production, \( \tau_{jki} \) and \( \tau_{jki}^z \), which are both equal to one if the variety is produced for the domestic final goods producer \( (j = k) \) and greater than one otherwise \( (j \neq k) \). The first of these is an iceberg trade cost on goods, and the second can be thought of as an implicit tax on or distortion to the use of foreign technology. This implicit tax is a stand-in for imperfect intellectual property protection. As detailed in Section 2, part of the liberalization between the United States and Mexico was the adoption of stricter protection of intellectual property by Mexican firms; \( \tau_{jki}^z \) is included in order to capture this feature.

\subsection{4.3 Households}

Households in country \( k \) own all firms in their own country and therefore are the residual claimants of all profits and dividends earned therein. They choose a consumption bundle \( \{c_{ki}\}_{i \in I} \), share holdings of domestic final goods producing firms in each industry \( \{S'_{ki}\}_{i \in I} \), and bond holdings \( \{b_k^i\} \) to solve the following problem:

\[
\max \sum_{t=0}^{\infty} \beta^t \left[ \sum_i c_{ki} \right]^{\frac{1}{\sigma-1}} 
\]

\text{s.t.} 

\[
\sum_i P_{ki} c_{ki} + b_k' - b_k + \sum_i V_{ki} (S'_{ki} - S_{ki}) = w^H_k H_k + w^L_k L_k + (1+r) b_k + \sum_i S_{ki} D_{ki} + \sum_{i} \int_{\Omega_i} \pi_{ki}(\omega) d\omega, \]  

where \( D_{ki} \) denotes the dividends and \( V_{ki} \) is the share price of firms in industry \( i \) in country \( k \) and \( \pi_{ki}(\omega) \) are the profits from the intermediate producer of variety \( \omega \) producing for industry \( i \) in country \( k \).
4.4 Aggregation and Market Clearing

Final output in each industry $i$ and each country $k$ must equal domestic demand for consumption and investment from that industry

$$Y_{ki} = c_{ki} + I_{ki} \quad \forall i \in I, \quad k \in U, M,$$  \hspace{1cm} (14)

and total output for each variety $\omega$ in each industry $i$ must equal its world demand,

$$y_{kki}(\omega) + y_{jki}(\omega) = y_{kki}^d(\omega) + \tau_{jki}y_{jki}^d(\omega).$$  \hspace{1cm} (15)

Labor market clearing in each country requires that the labor used in country $k$ to produce all varieties for the domestic production line and all varieties for the foreign production line across all industries $i$ is equal to the aggregate inelastic supply of high- and low-skilled labor respectively. The labor market clearing conditions are expressed:

$$H_k = \sum_{i \in I} \int_{\Omega_i} (h_{kki}(\omega) + h_{jki}(\omega)) \, d\omega,$$  \hspace{1cm} (16)

$$L_k = \sum_{i \in I} \int_{\Omega_i} (l_{kki}(\omega) + l_{jki}(\omega)) \, d\omega.$$  \hspace{1cm} (17)

Recall that a firm producing variety $\omega$ may produce both for the domestic production line, $y_{kki}(\omega)$, and for the foreign one, $y_{jki}(\omega)$.

In a given country, the households are identical and so in a closed economy, no bonds will be traded. Across countries, the endowment of high-skilled and low-skilled labor varies. In addition to the market clearing conditions above, the bond market must clear:

$$\sum_k b_k = 0.$$  \hspace{1cm} (18)

5 Skill Premium

The skill premium in country $k$ in this model can be expressed as

$$\frac{w_k^H}{w_k^L} = (1 - \alpha) \frac{\theta_i}{1 - \theta_i} \left( \frac{Z_{ji}}{h_{jki}} \right)^{\frac{\sigma - 1}{\sigma}} \left( \frac{h_{jki}}{l_{jki}} \right)^{\frac{1}{\sigma}},$$  \hspace{1cm} (19)
where I denote by $h_{jki}$ and $l_{jki}$ the equilibrium choices for high- and low-skilled labor that are made by all firms in industry $i$ producing in country $k$ for the supply chain of country $j$. Recall that producers of all varieties $\omega$ in a particular industry are identical in their productivities and the prices they face, so their equilibrium choices will be the same; therefore, I suppress the notation indicating the variety. Because labor is perfectly mobile across all industries, wages will equalize across industries and this equation will hold for every industry $i$. In the expression above, we can think of the term $\left(\frac{Z_{j}}{h_{jki}}\right)^{\frac{1}{\sigma}}$ as representing the relative demand for high-skill labor and $\left(\frac{h_{jki}}{l_{jki}}\right)^{\frac{1}{\sigma}}$ as representing the relative supply of labor in industry $i$. The demand will be affected by the amount of technology being utilized in a given country and industry and the supply will be subject to the normal Stolper–Samuelson forces.

In what follows, for simplicity, I will consider only two industries $i \in \{1, 2\}$ with Industry 1 being relatively high-skill intensive and Industry 2 being relatively low-skill intensive ($\theta_1 > \theta_2$). The results and logic will extend to the multi-industry case.

### 5.1 Standard H–O Mechanism

In the case where $\alpha$ is equal to zero, the role of technology capital disappears and the production function becomes a standard CES technology:

$$y_{jki}(\omega) = A_k \left[ \theta_i h_{jki}(\omega)^{\frac{\sigma-1}{\sigma}} + (1 - \theta_i) l_{jki}(\omega)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}}.$$  

Therefore, the standard Hecksher-Ohlin and Stolper-Samuelson theorems apply. Thus, one would expect to see a decrease in the wage of high-skilled workers relative their low-skilled counterparts because Mexico is low-skill abundant relative to their trade partner, the United States, and so one would expect trade liberalization to cause a reallocation of Mexican workers towards more low-skill intensive industries, thereby increasing the relative demand for low-skill workers.

### 5.2 Role of Technology Capital

Now, if $\alpha > 0$, technology capital will be a necessary part of the production process, the skill premium will be expressed as in Equation (19), and the relative demand for labor will therefore be affected by technology capital. In order to understand how the skill premium is impacted by a trade liberalization, first note that if $\sigma > 1$ and $Z_{j}$ increases following liberalization, then the skill premium will increase, all else equal. Therefore, an increase in technology capital may offset or completely overturn the pressure on the skill premium that arises due to labor reallocation across industries. Moreover, the increased availability of more productive technology due to a decrease in trade barriers will decrease the incentive for labor to reallocate across industries.

There are two forces that may cause technology capital in a country to increase. The first is what I refer to as
the “diffusion channel,” whereby Mexican producers upgrade to using the more skill-intensive technology of the U.S. final goods producers in order to produce for the U.S. supply chain. This occurs as the tariff on the intermediate good produced for the U.S. ($\tau_{jki}$) falls or the distortion to the use of the U.S. technology capital ($\tau_{zjki}$) falls. A reduction in either distortion results in the Mexican intermediate goods producer shifting towards producing more for the U.S. final goods producer than they did pre-liberalization.

The second force is what I refer to as the “investment channel,” which is the increase in investment in technology capital by the final goods producer that will occur as a result of an increase in the rental rate for that technology. As barriers to trade fall, the technology of the United States will begin to be used more intensively in Mexico, as discussed above. This increases the return to investing in that technology for the American final goods producers. All else equal, these producers will increase investment in their technology capital. This is a secondary driver of increased technology in Mexico and the primary driver of increased technology in the United States. I will explore each of these pieces through some simple comparative statics. I will provide the intuition the following sections, while details can be found in the Appendix.

**Diffusion channel**

In order to understand how the diffusion channel operates, suppose for the moment that there is only one industry, $i$, so high- and low-skilled laborers are fully employed therein and there is no reallocative pressure from the H–O mechanism discussed above. Changes both to the tariff, $\tau_{jki}$, and to the distortion to the use of foreign technology capital, $\tau_{zjki}$, will contribute to the diffusion channel. Suppose first that there is a reduction in the tariff on the good, and consider the problem of the final goods producer in the United States (Equations (5) through (8)). Because the intermediate goods producers are monopolistic competitors, they will charge a constant mark-up over marginal cost, $c(w^H_k, w^L_k, r^{kki}, r^{rjki})$:

$$p_{jki} = \rho \tau_{jki} c(w^H_k, w^L_k, r^{kki}, r^{rjki}),$$

(20)

which is proportional to the tariff charged on the intermediate good. When the tariff falls, all else equal, the effective price paid by the final goods producer for the Mexican intermediate will also fall, therefore increasing the amount that the U.S. final goods producer demands from the Mexican intermediate firm. In order to meet this demand, the Mexican intermediate goods producer must rent more of the U.S. technology capital, $Z_{Ui}$, and allocate more labor toward producing for the U.S. production line, which is more skill-intensive ($Z_{Ui} > Z_{Mi}$) since the autarkic levels of technology capital will be determined by the skill level within a given country. This reallocation towards producing for the U.S. final good will, therefore, increase the skill premium in Mexico.

To see the second way in which the diffusion channel might be activated, consider the intermediate goods producer’s problem in Mexico (Equations (9) through (11)) and suppose that there is a reduction in the distortion to foreign technology capital, which is effectively a tax on his use of foreign technology capital, $Z_{Ui}$. As the distortion on that technology capital falls, it becomes less costly for him rent the foreign
technology capital and, therefore, to produce for the foreign final goods producer. Therefore, all else equal, he will reallocate resources toward that production line. This will again cause the producer to adopt more U.S. technology capital, thus affecting the skill premium as before.

**Investment Channel**

In order to understand the investment channel, consider the expression for the rental rate for the U.S. technology (\(Z_{Ui}\)) being used in Mexico by an intermediate goods producer for Industry \(i\):

\[
 r_{jki} = \rho \theta_i \alpha \frac{P_{jki}(\omega)}{\tau} A_j \left[ \theta_i \left( Z_{ki}^{\alpha} h_{jki}^{1-\alpha} \right)^{\frac{\sigma-1}{\sigma}} + (1 - \theta_i) l_{jki}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} Z_{ki}^{\alpha} h_{jki}^{1-\alpha} \frac{(1-\alpha)(\sigma-1)}{\sigma-1},
\]

where

\[
\tau = \tau_{jki} \tau_{jki}.
\]

As can be seen in Equation (21), the tariff on the good and the tax on technology capital serve to reduce the return to renting technology across borders. Therefore, as either of these distortions decrease, the return to investing in the technology capital increases, thus increasing the U.S. final goods producer’s investment. The key assumption here is that the technology capital is non-rivalrous and so the total return to investing in it is equal to the sum of the return in each country. All else equal, the domestic return will be unaffected by the reduction of the trade distortions, while the foreign return will increase. This means that the total return increases, incentivizing the final goods producer to increase the stock of technology capital.

**6 Calibration and Quantitative Results**

The main goal of this paper is to examine the changing skill premium in Mexico. To facilitate this analysis, I focus on the liberalization between the United States and Mexico, as the United States is the dominant trade partner for Mexico and much of this trade features the supply chain channels considered here. As such, the calibration matches features of the Mexican manufacturing sector. In this section, I first calibrate the model and discuss the ability of the calibrated model to match key features of the data. I then conduct a series of counter-factual exercises and analyze the impact of liberalization on the Mexican economy. I will report results for the United States; however, the model will not be calibrated to match characteristics for specific U.S. industries. Instead, I will use the results generated for the United States to validate the model.
6.1 Calibration

The model is parameterized to fit features of the Mexican manufacturing sector and its trade with the United States averaged over the pre-reform period, 1984 to 1986. I restrict attention to only the manufacturing sector and set the number of industries to 20, which corresponds to the 20 (2-digit) broad manufacturing industries in Mexico (CMAP classification). Each period in the model corresponds to one year. My general calibration strategy is to group parameters into those that can be directly assigned and those that will be assigned such that endogenous outcomes of the model match observations in the data.

I begin by assigning parameters directly. Table 4 presents the selected parameter values, as well as the source for these parameter selections. Because I have assumed that one model period equals one year, the risk-free interest rate is set to 4%, which implies a discount rate of 0.96. This is an innocuous assumption for the initial calibration, as it plays little role in determining relative steady-state values and simply acts as a scale factor. It does, however, play some role in the speed of the transition from one steady state to the next. I follow McGrattan and Prescott (2009) and set the depreciation rate of technology capital to be 0.08. Again, this plays little role in the determination of the steady state values and acts as a factor that scales steady-state values of technology capital up or down. The results hinge more on the relative stocks of technology capital in Mexico versus the U.S., so as long as I assume no asymmetry in depreciation across countries, $\delta$ can be set to any value and it will not change the relative steady-state values. The value selected for $\delta$ will, again, affect the speed of transition between steady states.

The parameters $\rho$ and $\phi$ respectively determine the elasticity of substitution across intermediate goods for final goods production and across final goods for the consumer. These are set to match the median 5-digit SITC elasticity of substitution between 1990 and 2001, estimated by Broda and Weinstein (2006). These estimates are consistent with others used frequently in the trade literature.\footnote{See, for example Burstein and Vogel (2017).} I calculate the relative total factor productivity (TFP) in Mexico ($A_M$) to be 0.25, while normalizing TFP in the United States to be 1 and 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 data based on household surveys for both countries. 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 use this difference in order to rationalize the large observed difference in initial skill premia. I follow the existing literature in defining skilled workers as those who have some college education (some enrollment in tertiary education). Bustos (2011) shows that, while the mapping between non-production and college-educated workers is not perfect, non-production workers are a good proxy for those with some college. Berman, Bound, and Griliches (1994) also make the case that using the production/non-production distinction yields similar results to using educational categories.

The data analog to high-skilled workers are non-production employees. In manufacturing, non-production
workers include managers and technicians. As such, many have two-year technical degrees, and so the definition is extended to include those workers with some college in order to capture individuals with technical training. I set the skill ratio in the model to match the percentage of the population aged 25 or older who have completed some college, as calculated using the Current Population Survey (accessed via IPUMS) in the case of the United States and the Barro-Lee Educational Attainment Database in the case of Mexico. Following Burstein and Vogel (2017), I set the skill intensity parameters, $\theta_i$, to be equal to the share of hours worked by those with some college education in Industry $i$ in the United States in 1985, again using data from the Current Population Survey. My approach differs from that of Burstein and Vogel in that, as previously discussed, I choose to include those with some college education to capture those with technical degrees. Here, I only report the minimum and maximum values of $\theta$ for parsimony; the other values are reported in the online appendix. The last set of parameters that I impose exogenously are industry-level tariffs on exports from Mexico to the U.S. and on exports from the U.S. to Mexico. I use the tariffs described and exploited in the empirical section above. I allow these tariffs to differ across the countries and across industries. In my initial calibration, I use tariff rates that have been trade-weighted and averaged from the 4 digit industry to the 2 digit industry and then averaged from 1984 to 1986. The vector of tariff rates can be found in the online appendix. I will additionally calibrate non-tariff barriers to match trade flows and so that total trade distortions, $\tau_{UMi}$ and $\tau_{MUi}$, will be a combination of tariffs read from the data and non-tariff barriers, which are calibrated as described below. I assume that the distortions on using Mexican technology capital within the U.S. are zero ($\tau_{MU}^i = 1$).

<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>$\delta$</td>
<td>0.08</td>
<td>McGrattan and Prescott (2009)</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.63</td>
<td>Broda and Weinstein (2006)</td>
</tr>
<tr>
<td>$\phi$</td>
<td>2.7</td>
<td>Broda and Weinstein (2006)</td>
</tr>
<tr>
<td>$A_M$</td>
<td>0.25</td>
<td>Relative value-added per worker in 1985</td>
</tr>
<tr>
<td>$H_U/H_L$</td>
<td>0.26</td>
<td>CPS—Fraction of Population with Some College 1985</td>
</tr>
<tr>
<td>$H_M/H_{L_M}$</td>
<td>0.07</td>
<td>Barro &amp; Lee —Fraction of Population with Some College 1985</td>
</tr>
<tr>
<td>$(\theta_{\min}, \theta_{\max})$</td>
<td>(0.198, 0.426)</td>
<td>CPS—Fraction of Industry $i$ with Some College 1985</td>
</tr>
</tbody>
</table>

Table 4: Exogenously Set Parameter Values

I now turn to calibration of the parameters that are assigned in order to match endogenous outcomes from the model with moments from the data. These include the importance of technology capital in the production of intermediate goods, $\alpha$; the substitutability of high- and low-skilled labor, $\sigma$; non-tariff barriers to trade, $t_y^{UMi}$ and $t_y^{MUi}$, and the distortions on technology capital from the United States being used in Mexico, $\tau_{UMi}$. I assume that $\alpha$ and $\sigma$ do not differ by country or by industry, but I allow $t_y^{UMi}$, $t_y^{MUi}$, and $\tau_{UMi}$ to vary across

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25I do not 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.
industries. If I set the number of industries, \( I \), to be equal to 20, then I have 62 free parameters.

I choose 62 moments of the data to match: the average skill premium in Mexico in the period from 1984 to 1986 (the pre-reform period), the ratio of royalties to payroll over the same time period, industry-by-industry intermediate exports from Mexico to the U.S. over total output of intermediates in Mexico, industry-by-industry exports of intermediate goods from the U.S. to Mexico over total output of intermediates in the United States, and the industry-by-industry ratio of royalty payments over low-skilled payroll in Mexico. I match these moments in the data and the model via the Generalized Method of Moments (GMM), jointly minimizing the distance between the endogenous outcomes of the model and the observations from the data. I solve for these parameters iteratively in three stages. In the innermost loop, I assume values for all parameters and solve for the equilibrium of my model, producing model observations for trade flows, skill premia, wages, and royalty payments. In a middle loop, I use the bilateral industry-level distortions on technology capital moving between the United States and Mexico (\( \tau_{UM} \)) in order to match industry-level royalty payments relative to low-skill payroll\(^{26}\) and the bilateral industry-level non-tariff trade barriers in order to match bilateral trade flows. In an outer loop, I take these distortions as given and then solve for \( \alpha \) and \( \sigma \) in order to match the skill premium in Mexico and total royalty payments over total payroll. I use the inner two loops to solve for my counterfactual exercises.

### 6.2 Model Fit

Table 5 presents the parameter values that most impact the results and the model generated value for the moments that were targeted in order to calibrate these. I begin by matching the skill premium in Mexico and the average ratio of royalties to payroll in Mexican manufacturing. The estimated elasticity of substitution between high- and low-skill labor is consistent with estimates from the literature (see, for example Acemoglu and Autor, 2011). The model matches both of these moments exactly. I will analyze how the model performs relative to the data for the United States as check of its implications.

<table>
<thead>
<tr>
<th>Moment Parameter</th>
<th>Data</th>
<th>Model Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of Royalties to Payroll - Mexico 1984-1986</td>
<td>0.055</td>
<td>0.055</td>
</tr>
<tr>
<td>Skill Premium - Mexico 1984-1986</td>
<td>2.03</td>
<td>2.03</td>
</tr>
</tbody>
</table>

Table 5: Target Moments

Figures 4a - 4c present the moments generated in the model and those observed in the data for exports of intermediates from Mexico to the U.S. exports of intermediates from the U.S. to Mexico, and royalties paid relative to low-skill payroll in Mexico, respectively; these are the additional moments that I target for

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\(^{26}\)I choose to scale royalty payments by the payroll of low-skill workers (\( w_L \)) because the theory predicts that this measure should increase when distortions to technology capital fall, though not necessarily when tariffs fall, as tariffs impact wages and payments to technology, whereas the wedge of the use of U.S. technology in Mexico directly impact royalty payments only.
my calibration. I have included the 45 degree line for reference. As can be seen in the figures, the model is general able to replicate the industry-by-industry percentage of intermediate output that is exported from Mexico to the United States and industry-level royalty payments relatively well. In particular, the model replicates those industries that export a large proportion of their output well, such as industries dedicated to the production of auto parts, though it over predicts exports over output at the low end. the model matches the average exports over output, when averaged across industries in Mexico. On average, 5.3% of output in intermediates was exported from Mexico to the United States in 1985. The model predicts that 5.27% of output is exported from Mexico to the United States and slightly over-predicts exports of intermediates from the United States to Mexico. This is due, in part, to the fact that I have assumed that the input-output structure of United States industries is equal to that in Mexico in my calculation of what constitutes an “intermediate good”; if this is not true, the measure of intermediates in the data for the United States may be inaccurate. The magnitude of this over-prediction by the model is, on average, about 0.5 percentage points.  

Both non-tariff barriers and barriers to the use of foreign technology capital, which I will also call the “IP wedge,” are large. On average non-tariff barriers are roughly 150%, while the IP wedge is closer to 500%, though both of these vary dramatically across industries. It has been well documented that in the pre-reform era, both tariffs and non-tariff barriers were high in Mexico, making it one of the most closed countries in the world. The IP wedge is much harder to quantify, though the World Bank reports that even after many improvements to Mexico’s regulatory framework, in 2017 Mexico’s IPR index score was 4.03, as compared to the United States score of 5.83, and the Property Rights Alliance ranked Mexico as 71 out of 129 countries in terms of the quality of their IPR protections. Furthermore, in a survey conducted in 1990, following Mexico’s trade reform but preceding its IPR reform, between 17 and 47 percent of 100 U.S. multinationals surveyed reported that they would be unwilling to invest in joint ventures in Mexico due to weak intellectual property rights and between 8 and 56 percent of those surveyed stated that they would be unwilling to license their intellectual property to Mexican firms, with responses varying across industries.

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27 The model predicts 1.5% of output of intermediates from the U.S. are exported to Mexico, while in the data, this is closer to 1%.
(Council, 1993). It is difficult to map these statistics into the size of the IP wedge, but they do indicate that one would expect it to be large.

I have not targeted the skill premium in the United States and the model under-performs on this metric. In the data, the skill premium in the United States is roughly 1.38 in the pre-reform period, whereas the model predicts that it should be closer to 1.14 for the same year. Again, I have assumed that the production technologies are the same across the two countries. However, one can imagine that technology capital is more important in production in the United States than it is in Mexico. This would imply higher royalty payments relative to payroll, which in turn, would imply a higher value for $\alpha$. I do not have information on royalty payments for the United States, nor is it the focus of the paper. The model will predict changes in the skill premium in the U.S. that are qualitatively consistent with what is observed in the data.

6.3 Counterfactual Experiments

I now conduct a series of counterfactual experiments. I begin by re-calibrating the wedges in the model to match the bilateral trade and royalty data in the post-reform period (1992-1994). I then proceed by analyzing each of the forces in the model and the relative contribution of trade liberalization versus an increase in protections for intellectual property, simulated by a decrease in the friction on the use of foreign technology capital. I then conduct several experiments to explore the main mechanisms in more depth. I analyze the case where barriers to the use of foreign technology completely erode, to get a sense of what would happen, for example, if there were an international court with jurisdiction over all intellectual property and to highlight the diffusion channel. I complete the counterfactual exercises by considering the integration between two more developed countries, using the United States and Canada as an example, which allows me to further highlight the investment channel.

Change in Trade Barriers and Frictions on Use of Foreign Technology Capital

I begin by evaluating the baseline scenario in which tariffs, non-tariff trade barriers, and barriers to the use of foreign technology capital change. In this exercise, tariffs are lowered as observed in the data and non-tariff trade barriers and the frictions on foreign technology capital are re-calibrated to match exports of intermediate goods as a fraction of their output and the ratio of royalties paid to low-skill payroll, respectively, in the post-reform period. I re-calibrate the non-tariff trade barriers for both exports from Mexico to the United States and vice versa. Figure 5 shows the fit of the model to the data in the post-reform period for Mexican exports to the U.S and royalty payments in Mexico, with the blue circles representing this baseline experiment in both plots. As the figure illustrates, the model generates trade flows and royalty payments that are commensurate with the observations in the data. Average exports of intermediates as a fraction of their output from Mexico to the United States are roughly 16% post-reform, in both the model and the data. The model continues to over-predict exports from the United States to Mexico by approximately 0.2 percentage points. This over-prediction has a similar magnitude in the pre- and post-reform periods.\textsuperscript{28}

\textsuperscript{28}In the post-reform period, average exports from the United States to Mexico are 2.5% in the data and 2.7% in the model.
Column (4) of Table 6 reports the impact of these reforms on the skill premium. When both non-tariff barriers to trade and frictions, the model generates a 15% increase in the skill premium in Mexico, as compared to the 52% increase observed in the data. Moreover, the model produces an increase in the skill premium in the United States. This increase in the skill premium in the U.S. is substantially lower than the observed increase in the data; however, the goal of the model is to explore the impact on Mexico, while producing results that do not move in a counterfactual direction in the United States.

Table 6: Results - Trade Liberalization

<table>
<thead>
<tr>
<th></th>
<th>Pre-Reform</th>
<th>Post-Reform</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data (1)</td>
<td>Model (2)</td>
</tr>
<tr>
<td>Mexico</td>
<td>2.03</td>
<td>2.03</td>
</tr>
<tr>
<td>U.S.</td>
<td>1.42</td>
<td>1.14</td>
</tr>
</tbody>
</table>

Table 6: Results - Trade Liberalization

Figure 6 presents the time path for the changes in the skill premium post-reform. The data is represented by the line with circles, while the baseline reform is represented by the solid line. Here, I assume that the policy is implemented immediately in 1986, with no phase in. This largely mimics the reform that was implemented in Mexico, as tariffs were reduced over the latter half of 1986. I also assume that IP wedge falls at the end of 1986 when the other reforms are put in place. This is in line with what DuMars (1991) finds; part of the 1986 negotiation included discussions of intellectual property protections that resulted in Mexico stating that it was adopting U.S. intellectual property protections. We can see that the change

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29There was an additional IPR reform in Mexico in 1991; however, in the simulations, I will treat the reforms as all being phased
in the skill premium in Mexico occurs primarily in the first few periods after the reform. This is due to
the operation of the diffusion channel. When the barriers to producing for the foreign final goods producer
fall, Mexican intermediate goods producers immediately switch part of their production line from producing
for the domestic final goods producer to producing for the foreign one. The rest of the increase in the skill
premium comes from increased investment in skill-augmenting technology capital, both in Mexico and in the
United States. As revenues for the final goods producer rise as a function of renting more of its technology
capital, the returns to investing in technology capital increase, thus inducing the final goods producer to
invest more heavily in technology capital, and results in additional increases in the skill premium. Initial
adoption accounts for roughly 60% of the increase in the skill premium that is generated by the model, with
the investment channel generating the rest of the increase.

The model predicts impacts on labor markets that match previous studies. Several other authors, includ-
ing Bustos (2011) have found that trade liberalizations primarily cause labor reallocation within industries,
and not across them. The model is largely consistent with this finding. In the case where tariffs change in
isolation, there is no labor reallocation across industries. In the case where both tariffs and frictions to tech-
nology capital fall, there is some reallocation across industries, as the relative barriers to the use of foreign
technology change across industries. However, most industries see less than 10% change in the fraction
of labor allocated towards their industry, with the one exception being the production of automobiles and
auto-parts. Employment in this industry increases by 38%. In the pre-reform period, this industry accounted
for roughly 8% of the total labor market employed in manufacturing in the model and by 1994, it accounts
for 11%. This growth in the fraction of employment that can be accounted for by this industry is similar in
the data; in 1986, this the auto industry accounted for roughly 10% of Mexican manufacturing employment.
By 1994, it accounted for roughly 13%. The model generates results mainly through reallocation of labor
from domestic production to foreign production. There are some industries in which Mexican intermediate
goods producers reallocate towards domestic production.

I now analyze the importance of the various mechanisms for these results, starting with the role of the
Stolper Samuelson mechanism.

Role of the H–O Mechanism

The H–O mechanism is present in the model and plays a role similar to that observed in related works such as Burstein and Vogel (2017), as well as in the data. In order to highlight this, I set the role of technology capital to zero and simulate the same change in tariffs and non-tariff barriers as in the baseline scenario. Because technology capital is no longer part of the model, I do not adjust any frictions on its diffusion. When I set $\alpha = 0$, the skill premium in Mexico and the United States move in the direction that standard theory would predict. That is, the skill premium drops in Mexico and rises in the U.S. However, the main impact in the model is not one of reallocation across industries, but rather within industry from the domestic to the export-oriented sector. It is well documented that following trade liberalizations, much of the reallocation the is observed is within industry, from non-exporters to exporters. Even though the model does not include firm heterogeneity, the main reallocation that occurs following trade liberalization is this within-industry reallocation. Without trade barriers and absent technology capital, the marginal benefit of producing for the domestic versus the foreign production line is equal and so producers in every industry shift towards equalizing their production for the domestic and foreign production lines. There is also reallocation across industries, as would be predicted in the standard 2x2x2 Hecksher Ohlin model, towards less skill-intensive industries in Mexico and more skill-intensive ones in the U.S. The larger reallocation, however, is within-industry towards the export-oriented production line. This induces a slight decrease in the skill premium in Mexico of about 3.5%.$^{30}$ Therefore, the Stolper-Samuelson mechanism is operational in the model; however, the strength of its effect is dampened by the fact that most reallocation that occurs is within industries, as is true in the data.

Change in Tariff Rates and Non-Tariff Barriers

In order to compare my results with existing studies that study the role of tariff reduction in accounting for changes in the skill premium, I begin with an experiment where I hold fixed all parameters of the model but vary the tariff rates to match the observed tariff rates in the post-reform period. The average observed tariffs faced by Mexican intermediate goods producers who exported to the United States in the pre-reform period were 30% and for U.S. intermediate goods producers who exported to Mexico, they were about 24%. By 1994, these had fallen to an average of 7% for Mexican intermediate goods producers and 8% for U.S. intermediate goods producers. This is a large reduction in tariffs relative to most trade liberalizations. Some industries experienced an 80% drop in their tariff rates. However, as Column (5) of Table 6 shows, this decrease in tariffs alone has very little impact on the skill premium in either country; when tariffs fall, the skill premium in Mexico increases from 2.03 to 2.04 and average exports from Mexican producers of intermediates over their total output changes by just under one percentage point. This is roughly a 17%

$^{30}$Because the model is not re-calibrated to match the initial skill premium in Mexico when there is no technology capital, the initial level of the skill premium in this experiment is higher than in the main model specification. The initial skill premium in Mexico in this case is 2.26 and it declines to 2.19 after a complete trade liberalization.
increase in these flows. In the data, exports of intermediates as a percentage of their total output increases by nearly fourfold over this time period. The skill premium in the United States only increases by 0.001 when the new bilateral tariff schedule is imposed, though exports of intermediates from the United States to Mexico increase by 9% in the model following this liberalization.

The small change in the skill premium in Mexico can be accounted for by the fact that exports of intermediates change by very little when only tariffs fall. Because the Mexican intermediate goods producing firm must be part of the supply chain of U.S. final-goods producer in order to use the more advanced technology capital, low exports of intermediates from Mexico to the U.S. predict low adoption of U.S. technology capital by Mexican intermediate goods producers. Likewise, low adoption of U.S. technology capital by Mexican producers implies that the change in the return to that capital will also be low, therefore predicting that the skill premium in the United States should remain virtually unchanged. Perhaps more importantly, in this experiment exports increase in less skill-intensive industries, again highlighting the operation of the Stolper-Samuelson mechanism. The reallocation towards exporting in industries that are less skill intensive dampens the effect of technology adoption.

In addition to simply decreasing tariffs, I consider the case where non-tariff barriers are lowered as in the baseline experiment. This results in an increase in the Mexican skill premium of roughly 2%, from 2.03 pre-reform to 2.07 post-liberalization. In Figure 5, square markers represent exports of intermediates from Mexico to the United States following a tariff reduction, while the diamond shaped markers represent the same variable following the full trade liberalization in which both tariffs and non-tariff barriers are reduced. Notice that trade flows are over-predicted for industries that trade very little in the data under this parameterization, while under-predicting trade for industries that trade a lot in the data. A reduction in the barriers to the use of foreign technology serves to induce more trade in skill-intensive industries by increasing Mexican intermediate producers’ willingness to use foreign technology capital and, therefore, to produce for the U.S. supply chain. It is also clear from this case, however, that non-tariff barriers are a substantial impediment to trade. It is well documented that Mexico had a number of laws and regulations that impeded the flow of goods across borders, including quotas. These non-tariff barriers were also decreased dramatically during the 1986 trade liberalization, inducing much more trade between the United States and Mexico. This exercise highlights the importance of this portion of the liberalization. However, even the reduction in these barriers leads to a modest increase in the skill premium.

A number of existing studies focus on the impact that a reduction in tariffs and non-tariff barriers has upon the distribution of firm productivity within an economy. Qualitatively, each of these studies is consistent with the data, producing an increase in the skill premium when tariffs fall. The analysis done by Bustos is qualitative in nature and focuses on the case of the Argentina, whereas Burstein and Vogel, 2017 is quantitative and predicts an increase in the Mexican skill premium of roughly 2% when considering total eradication of trade barriers as their baseline experiment. The mechanism in both models is similar: when tariffs fall, there is reallocation of resources and production away from less productive firms towards more

31 See, for example DuMars (1991), for an in depth discussion.
32 See, for example Bustos (2011) and Burstein and Vogel (2017).
productive ones. In Bustos (2011), trade liberalization increases revenues, allowing firms to pay a higher fixed cost to operate the more skill-intensive and productive technology; in Burstein and Vogel (2017) more productive firms, which are more skill intensive, have lower marginal costs of production and, therefore, trade liberalization drives less productive firms out of business via an increase in competition from foreign producers. Because the most productive firms are operating technologies which are more skill-intensive, this endogenous increase in the use of skill-biased technology within these economies is analogous to the change in the stock of technology capital of the operating firms that is present in my model. In both the existing literature and the exercise that I consider here, there is technological deepening that is induced by a reduction in tariffs. This particular exercise shows, however, that if the economy is forced to produce technology capital, instead of allowing for this technology to simply be available to firms, technological deepening following a trade liberalization is limited and does not lead a large impact on the skill premium.

**Barriers to Use of Foreign Technology Capital Erode as in Data**

I now turn to the case where only the barriers to the use of foreign technology capital fall, holding tariffs and non-tariff barriers at their pre-reform levels, in order to explore the importance of the strengthening of IP protections that occurred as part of the Mexican liberalization. Column (7) of Table 6 highlights these results. In this case, the skill premium increases to 2.27, substantially more than in the case where trade barriers are reduced. This is consistent with the findings in the empirical section which indicated that while tariff reduction was correlated with an increase in the skill premium, strengthening of IP protections were more impactful. Part of the driver of this increase in the skill premium is reallocation to more skill-intensive industries, despite the Stolper-Samuelson forces that are present in the model. Particular industries experienced large increases in their royalty payments, which the model attributes to a decrease in the relative IP wedge of those industries. This is reflected as a reallocation of skilled workers towards those industries. Furthermore, as was the case when trade barriers declined, there is a reallocation within industries towards producing for the U.S. supply chain and, thus, towards using more skill-intensive technologies.

Combined with the analysis of the impact of a decrease in barriers to trade, these results highlight the importance of technological diffusion in accounting for increasing skill premia in a developing country. As compared to the previous counterfactual exercise, the change in the skill premium is larger when the technology capital that was produced in the United States is allowed to flow into Mexico via reductions in the distortions to the use of foreign technology by domestic intermediate goods producers. This suggests that previous studies that have focused on domestic technological deepening due to reallocation to more productive firms may be missing an important driver of this deepening, and the subsequent increase in inequality, that follows trade liberalization. I find that when firms in the less developed country are forced to make costly investments in producing their own technology capital, there is very little change in this technology capital following a trade liberalization. On the other hand, when they are able to adopt foreign technologies by integrating into the supply chain of producers in the more advanced country, there is a much larger change in the amount of skill-augmenting technology capital and, therefore, in the skill premium.
**All Barriers to Use of Foreign Capital Erode Completely**  In order to explore the impact of the implementation of an international system of law to protect intellectual property, I move to the extreme case of complete erosion of the barriers to the use of foreign technology capital. In this case, I set tariffs to their observed rates and non-tariff barriers to their post-reform level. This causes the skill premium in Mexico to increase 2.48, a 22% increase in Mexico’s skill premium, which is roughly half of the increase that was observed in the data. Similarly, the United States sees an increase in its skill premium, moving it from 1.14 in the baseline calibration to 1.2, a 5% increase, after the barriers to technology capital are removed. This extreme case serves to highlight the role of the transmission of technology capital in determining the skill premium. If technologies are not transmitted as part of a trade liberalization, we should not expect to observe large increases in the skill premium. This result is related to the findings highlighted in Ripoll (2005) that some liberalizations between developed and developing countries are accompanied by large increases in the skill premium, while others are not. The model suggests that the degree of technology diffusion that accompanies liberalizations is at the heart of this observation.

**Integration Between Two Developed Countries**

In order to highlight the role of the investment channel, I now consider a trade integration between two developed countries, taking as an example the U.S. and Canada. I do a simple experiment, where I set country-specific parameters, such as Canadian TFP relative to U.S. TFP \(A_k = 0.88\), the fraction of the Canadian population with some college education \(\frac{H_k}{H_k + L_k} = 0.25\), and tariffs between the U.S. and Canada to match the data in 1980. I then set the barriers to the use of foreign technology to match exports from the U.S. to Canada and vice versa in 1980. This gives me a skill premium for the United States of 1.25 and for Canada of 1.42. I then eliminate all trade barriers and frictions on the use of foreign technology in 1986, to simulate the Canada-United States Trade Agreement. Although total elimination of these barriers is too extreme of a case to take the magnitudes seriously, I include this exercise to show the qualitative difference in model predictions, especially for trade.

When I reduce trade frictions in this case, the skill premium rises modestly in both countries.\(^{33}\) However, export volume from the U.S. and import volume into the U.S. increase more in this case than in the case of integration with Mexico. This is due to the fact that U.S. producers are more likely to substitute towards using a large volume of Canadian intermediates than they were to substitute towards using a lot of Mexican intermediates. In terms of wage per efficiency unit, the Mexican high-skill worker is more expensive than either the U.S. or the Canadian high-skilled worker and the U.S. technology capital is not as easily used in Mexico as it is in Canada for cost-savings to the final goods producer. Therefore, the final goods producer is more likely to end up indifferent between U.S. and Canadian intermediates than he is to be indifferent between U.S. and Mexican intermediates.

Furthermore, although some firms switch from producing for the domestic final goods producer to producing for the foreign one, the diffusion channel is not the main driver of the increase in the skill premium.

\(^{33}\)The skill premium in the U.S. rises to 1.33 and in Canada rises to 1.52.
because the level of technology capital is similar in both countries to begin with. Instead, the investment channel is very active here. In both countries, adoption causes the return to the final goods producer from investing in technology capital to increase, thus inducing these firms to increase their investments. This drives up the level of technology capital for all final goods producers, increasing the demand for high-skill workers and, therefore, the skill premium.

6.4 Sensitivity Analysis

The key parameters in the model are those governing the importance of technology capital in production, \( \alpha \), and governing substitutability between high- and low-skill components of production, \( \sigma \). Figures 7a and 7b display the percent change in Mexico’s skill premium for various values of these two parameters. Recall that the baseline value for \( \alpha \) is 0.15 and this allows the model to account for about a 15% increase in the skill premium, which is about 29% of the total increase in the skill premium experienced in Mexico over the time period of interest. Changing the value of \( \alpha \) has a large impact on these results. For example, increasing the value of \( \alpha \) such that technology capital is very important in production (\( \alpha = 0.99 \)), serves to increase the skill premium in Mexico by over 100%, whereas setting \( \alpha \) very low (\( \alpha = 0.01 \)) results in a skill premium that is essentially unchanged following the liberalization. This is intuitive; the size of \( \alpha \) governs the relative importance of technology capital in production and, therefore, the extent to which technology impacts the skill premium. If technology capital is very important in production, lowering barriers to its diffusion should have a large impact on the skill premium, whereas when technology is relatively unimportant, we are moving towards the H-O case explored in the previous section. Turning now to Figure 7b, we can see that, again, the model results are somewhat sensitive to the value of \( \sigma \), but in this case, they do not vary dramatically. The calibrated value of \( \sigma \) is 1.51, which is in the middle of values that have been estimated in the literature on the substitutability of high- and low-skilled labor. Here, \( \sigma = 1 \) would be the case of Cobb-Douglas production,
whereas $\sigma = 2$ would be perfect substitutes where high-skilled inputs $(Z^a h^{1-a})$ are very substitutable for low-skilled inputs. As we move from the case that both high- and low-skilled inputs are necessary for production to a case with perfect substitutes, the impact of the policy change on the skill premium increases by 5 percentage points. Again, this is intuitive. As the two types of workers become less substitutable for one another, any increase in demand for high-skilled workers will also impact the demand for low-skilled workers, thereby increasing the wages of both types of workers. If the two groups are perfect substitutes, an increase in high-skilled inputs substitutes for low-skilled inputs, thereby increasing the relative wage of the high-skilled workers.

7 Conclusion

In this paper, I show that diffusion of technology capital is an important component of the impact that a trade liberalization has upon relative wages. 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. 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 occurs as part of integrated supply chains, the increase in the skill premia in Mexico is in part attributable to the diffusion of non-rival technology from the United States to Mexico. The model predicts that, while changes in tariffs have some impact upon the skill premium in Mexico, the primary driver of the increase in the skill premium is the inflow of foreign technologies due to improved IP protections. Studies that assume that there are existing, more advanced technologies within a liberalization country that may be adopted once trade liberalization occurs, therefore, may be overestimating the impact of these liberalizations upon skill upgrading and the skill premium. Ignoring the source of newly adopted technologies and assuming that all countries have access to the same set of technologies shuts down an important distinction across trade liberalizations. For a liberalization between a developing and developed country, this assumption may lead to the prediction of larger increases in the skill premium than actually occur, while in the case of liberalization between two advanced economies, it may lead to the underestimation of the effects of that liberalization on skill upgrading and, therefore, the skill premium.

The model embeds the standard Heckscher-Ohlin forces and when I completely shut down the importance of technology capital in production, I find the standard prediction of a falling skill premium in Mexico and a rising skill premium in the United States. Allowing for trade in technology overturns this result because it allows for technology diffusion to 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 adoption of stronger 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.
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 (2017), among others, show that reallocation across firms can have an impact on inequality. Allowing for this feature in the current framework would allow me to use more of the plant-level data to test the accuracy of the model. Moreover, it would allow the study of 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 would 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 countries that invest in it. It demonstrates 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

(2005): “INTERNATIONAL TRADE: Mexico’s Maquiladora Decline Affects U.S.–Mexico Border Communities and Trade; Recovery Depends in Part on Mexico’s Actions,” Discussion paper, United States General Accounting Office.


Appendix

This appendix provides additional data details, as well as additional parameter values not reported in the main text.

Data Details and Additional Empirical Evidence

In this section, I provide details of the data and additional evidence for my proposed mechanism, including a case study of one particular company in the automotive industry, as well as additional econometric analysis in order to show that my results are robust to alternative specifications.

Details of the Plant-Level Data

First, I show the variation in the plant-level data that is being used for identification in the empirical analysis. Figures 8a and 8b show the distribution of plants across production values. This distribution looks similar to what others have documented for the U.S., with many small plants and a few very large one. Figures 9a and 9b display the distribution of plants across number of employees. Again, there are many plants with less than 1000 employees and a few who employ many.

Next, I turn to the distribution of plants across skill intensities, which I present in Figure 10. Following the extant literature, I define skill intensity as the fraction of employees that are white collar. The median skill intensity is about 0.34. I have plotted skill intensities across all years here, though the distribution varies some across time. In particular, the distribution moves slightly to the right over time, as plants begin to produce more skill intensively. This shift is not dramatic, however.
In Figure 11, the distribution across 4-digit industry codes is provided. These are expressed as the Mexican classification of industries that was in use at the time that the data was gathered, the CMAP classification. The CMAP codes and their corresponding names are available upon request.

In Table 7 reports fraction of plants that are exporters vs. non-exporters and that are fully domestically owned vs. partially (or wholly) foreign owned. The majority of plants are fully domestically owned and do not export. Again, I have pooled these numbers across all years and the fraction of exporters increases between 1986 to 1990 from 16% to 25.1%.

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Table 7: Exporter and MNC Status

Figure 9: Number of Employees across Plants

Figure 10: Skill Intensities
Trade and Technology Transfer: A Case Study of an Auto Plant

As an example of the transfer of technology capital, I now turn to a case study of one company’s vertical integration of its supply chain, including a plant in Northern Mexico, conducted by Shaiken and Herzenberg (1987). This particular plant was partially owned by an undisclosed American auto manufacturer to make engines and engine parts for cars that would be exported, in keeping with Mexican regulations that required that a large proportion of output from foreign-owned plants be produced for export. The case study consists of interviews with both production and non-production workers, and it directly compares the Mexican plant with its U.S. counterpart in terms of production techniques, technology used, management practices, and the quality and quantity of output. The Mexican plant was a brand new facility, which utilized some of the most advanced production technologies available at the time of its construction, and it was built to compete with the most successful engine plants in the world.

The study finds that the Mexican plant was able to achieve efficiency comparable to that of the U.S. plant, due in large part to its utilization of technology capital that was the same across the two locations. The company invested significant resources in training the Mexican workers to operate state of the art machinery and to manage operations according to the company’s best practices. The case study details how supply chains served as a way to transfer blueprints for the production of parts, technology embedded in intermediate parts and in machines, best practices for efficient production, and organizational capital, such as worker training programs. These types of technology capital impacted production and non-production workers differentially. One place that this is evident is in the worker training programs implemented by the company. Non-production workers, such as technicians, had to acquire many skills that were not part of their previous skill sets. In order to do so, there were task certification programs, in-plant and on-the-job training programs and apprenticeships, and even trips to tool suppliers in the United States, all to ensure that the technicians understood how to maintain the plant. Production workers also received training, but to a lesser extent.

Another example of the transfer of technology capital is the modification of the production line layout. Figure (12a) shows the standard layout for a production line, where each circle with a cross in it represents a worker and each rounded solid box is a machine that needs to be operated. Figure (12b) displays the new
layout used by the company. As can be seen by examining the areas enclosed with the dotted blue lines, in the standard layout each worker is in charge of two machines, whereas in the new layout, each worker is in charge of three machines. This changes the mix of workers necessary in the plant; because each production worker is now operating more machines, all else equal, fewer production workers are required. However, because this may lead to more breakdowns on the line, there are more technicians (non-production workers) required. The technology in this production line modification augments the skilled non-production workers and substitutes for the unskilled production workers. In general, this case study serves to highlight the role of integrated supply chains in transferring skill-augmenting technology capital across borders.

**Empirical Evidence**

Here, I supplement the evidence in the main text relating technology transfer, as measured by royalty payments, to changes in the demand for skill by analyzing the share of labor expenditure on skilled workers as the dependent variable, instead of the skill premium. I implement the same two stage least squares approach as in the main text. In particular, the following equation is estimated via two stage least squares:

$$\left( \frac{w_H}{w_L} \right)_{ijt} = \alpha + \beta_1 \ln (\text{roy}_{ijt} + 1) + \beta_2 \ln (\tau_{ijt}^e) + \beta_3 \ln (\tau_{ijt}^i) + \beta_4 \left( \ln (\tau^m_{ijt}) * \frac{\text{Exp}Y_{ijt}}{\text{MC}_{ijt}} \right) + \beta_5 \left( \ln (\tau^m_{ijt}) * \frac{\text{ImpM&E}_{ijt}}{\text{MC}_{ijt}} \right) + \beta_6 X_{ijt} + \gamma_i + T_t + \epsilon_{ijt},$$

(22)

where \( \left( \frac{w_H}{w_L} \right)_{ijt} \) is the plant-level ratio of high-skilled payroll to low-skilled payroll, \( \ln (\text{roy}_{ijt} + 1) \) are predicted plant-level royalty payments, and \( \tau_{ijt}^e, \tau_{ijt}^i, \tau^m_{ijt} \) are tariffs on exports, imports, and machinery and equipment, respectively. All data is the same as was used in the main text. Following the analysis done in the main text, export, import and machinery and equipment tariffs are interacted with the export share of total sales \( \left( \frac{\text{Exp}Y_{ijt}}{\text{MC}_{ijt}} \right) \), share of material costs that are imported \( \left( \frac{\text{ImpM&E}_{ijt}}{\text{MC}_{ijt}} \right) \), and the share of machinery and equipment that is imported \( \left( \frac{\text{ImpM&E}_{ijt}}{\text{MC}_{ijt}} \right) \), respectively. \( X_{ijt} \) controls for plant-level variation in number of employees (a proxy for size), initial skill intensity, ratio of capital to value added, capital share owned by foreign entities (foreign direct investment), and the shares of exports to total sales, materials imported, and machinery and equipment. Industry- and time-fixed effects (\( \gamma_i \) and \( T_t \)) are also included.

Table 8 reports the baseline results from estimating Equation 22 via OLS (Columns 1 and 2) and by
two-stage least squares (Columns 3 and 4). The results here mirror those in the primary text, with royalties having a large and statistically significant correlation with the skill premium, while tariffs do not have a statistically significant direct effect on the skill premium once royalty payments are included in the analysis.

Firm-Level Analysis

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Plant-level controls? Yes Yes Yes Yes - -
Industry-level controls? No No No No Yes Yes
Industry Fixed Effects? Yes Yes Yes Yes No Yes
Time Fixed Effects? Yes Yes Yes Yes Yes Yes


R^2 0.677 0.673 0.650 0.649 0.780 0.885
N 10,865 10,865 10,865 10,865 10,865 640 1,295

Table 8: Skill Premium and Liberalization

Standard errors in parentheses. * denotes significance at the 10% level, ** significance at the 5% level, and *** significance at the 1% level.

Additional Parameter Values

In Table 9, I report the values for \( \theta \), the vector of parameters governing skill intensity, as well as the tariff rates used in the pre- and post-reform periods.
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Table 9: Parameter Values