Trade, Technology Adoption and the Rise of the Skill Premium in Mexico*

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Abstract

This paper develops and estimates a structural model of trade and technology adoption with heterogeneous firms in a small open economy. In the model, monopolistically-competitive firms produce using two types of labor and face entry/exit, exporting and technology adoption decisions. The choice of technology affects the expected productivity realizations that a firm receives, with modern technologies producing high productivity draws at the expense of a higher per-period fixed cost of operation, in turn affecting the firm's skill-intensity. Furthermore, the existence of a sunk cost of technology adoption makes the firm's problem forward-looking. The model is estimated using a Simulated Method of Moments estimator, and fitted to the Mexican manufacturing sector in 1984, just before Mexico started its trade liberalization reforms. Using the estimates of the structural model, I find that when import tariffs fall by 35 percent, the new steady state skill premium increases by 3.5 percent. When the sunk cost of technology adoption is affected by the import tariff, the response of the skill premium increases to 4.6 percent

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1 Introduction

In the last two decades, middle-income developing countries have become more integrated with the world economy by slashing tariffs and scrapping quotas and other non-tariff barriers to trade. At the same time wage inequality has increased dramatically (see Goldberg and Pavcnik, 2007, for a recent survey), leading public opinion to label the increased trade openness as the main cause of the rise in wage inequality. This fact is at variance with the prediction of the Stolper-Samuelson theorem which states that the real remuneration of unskilled workers should increase in countries relatively abundant in unskilled labor after opening up trade.

An alternative hypothesis suggested by Acemoglu (2002, 2003) is based on the stylized fact that firms in developing countries import a significant share of their machinery and equipment from skill-abundant developed countries (Eaton and Kortum, 2001). As the relative supply of skilled workers in developed countries (in particular in the US) has risen continuously since the 1970s, machinery and equipment (M&E) goods produced there have become more skill-complementary. When a developing country reduces its barriers to trade, it induces the adoption of skill-biased technology embodied in capital equipment. In this way, trade liberalization in an unskilled-labor abundant country can cause an increase in wage inequality. In this paper I explore the interplay between trade openness, technology adoption and the skill premium. I do so by estimating a structural dynamic model of an open economy with heterogeneous firms that make decisions about exporting, technology adoption and the skill intensity of their workforce. Using micro panel data from Mexico's manufacturing sector, I estimate the structural parameters that govern the technology adoption, skill intensity and export decisions for manufacturing firms. I then use my estimated model to quantify the impact of a unilateral trade liberalization on technology adoption and the skill premium.

I build a dynamic model of industry evolution based on Hopenhayn (1992), Melitz (2003) and Yeaple (2005) in which trade may induce the adoption of skill-biased technology. In the model, firms produce using skilled and unskilled labor, and are heterogeneous in their relative productivity of skilled labor. Productivity evolves according to an exogenous stochastic process, but unlike Hopenhayn (1992) or Melitz (2003) the mean of this process depends on the technology that a firm chooses to operate. Following Yeaple (2005) firms can choose between two technologies (or production processes, since I do not include capital in the model): a "traditional" technology characterized by high marginal costs (the result of low productivity draws) but low fixed costs (e.g. a traditional textile loom) and a "modern technology" that has low marginal costs but requires a high fixed cost of operation (e.g. a large-scale automatized sewing machine).[1] Higher productivity draws increase the relative marginal product of skilled labor, so firms substitute towards skilled labor (this is the case if the elasticity of substitution between the two types of labor is greater than one), becoming more skill-intensive. Only high-productivity firms (with sufficiently large sales) will find it optimal to incur the higher per-period fixed cost of operating the modern technology. Hence, modern firms will be larger and more skill-intensive than firms using the traditional technology[2].

Drawing from the literature on investment in physical capital, I assume that technology

[1] My model is similar to Bustos (2005). In her model firms produce using two types of labor, and choose between two technologies characterized by the same trade-off between marginal and fixed cost as in my model. However, her model is static, and assumes that skilled and unskilled workers are perfect complements in production.

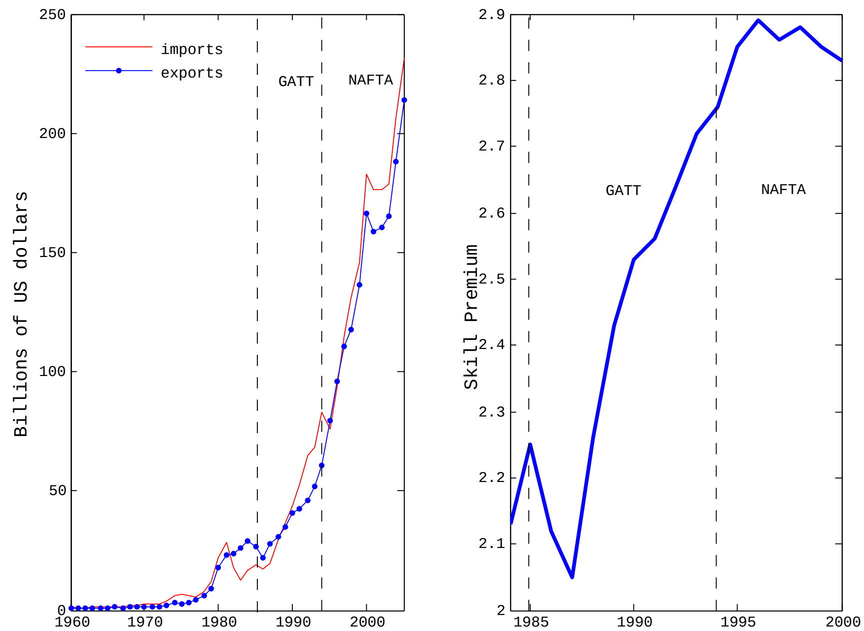
[2] Doms et. al. (1997) observe a set of 17 advanced automation technologies used by manufacturing plants (i.e. numerically controlled machines, robots, programmable controllers, etc.) in a small set of industries (SICs 34-38) in the US. They find a monotonically increasing relationship between the number of technologies used in a plant and the education level of its workforce. They also find that in more technologically advanced plants, non-production workers' share of employment and wage-bill are higher (controlling for size and capital-output ratio). Abowd et. al. (2007) find similar results for a broader sample of firms (including manufacturing, services, wholesale and retail trade) in the US. Fernandez (2001) studies in detail the retooling of a food processing plant in the Midwest. He finds that using a modern automated technology increased the complexity of tasks faced by production workers, and changed the composition of the production workforce in favor of high-skill occupations such as maintenance mechanics and electricians, which in turn commanded the largest increase in real wages, above those observed in the local labor market. For developing countries, Bustos (2005), Hanson and Harrison (1999a) and Pavcnik (2003) also find a positive correlation between the use of advanced technology (i.e. use of patents and licensing agreements, spending on computers and software) and skill intensity at the firm level.

adoption is subject to sunk costs, which will make firms adjust their technology infrequently, so that the persistence of technology choice will be reflected in the skill mix that firms employ. Empirically, I identify plants that purchase imported machinery and equipment (M&E) as using the modern technology described above. Alvarez and Robertson (2004), using data from the 1995 National Survey of Employment, Salaries, Technology, and Training (ENESTYC), document that Mexican firms tend to adopt new advanced production technologies through imports rather than through R&D on-site.

Following Melitz (2003) I assume that exporting is costly. Firms selling abroad incur both a per-period fixed cost and an iceberg transport cost per unit of output. Hence, only high-productivity firms will export. Trade liberalization will affect firms in different ways depending on the firm's technology and productivity. A reduction on the variable cost of trade will increase profits for existing and new exporters. If some of these firms were using the traditional technology previously, the higher volume of sales provides an incentive to incur the higher fixed cost of operation of the modern technology. As more productive firms expand, firms on the lower tail of the productivity distribution contract or exit the market altogether, reallocating workers across firms. These firms suffer a double whammy as import-competition shifts the demand from domestic to imported goods, and the increase in the relative demand for skilled workers pushes up the relative wage of skilled workers increasing costs for all firms.

Mexico is one of the best case studies to understand the distributional effects of increased trade openness. Mexico went from being a very closed economy to one of the most open in the world. Trade as a fraction of GDP has increased from 20 percent in 1980 to 55 percent in 1995 and has kept growing up to 60 percent in 2006. At the same time, the skill premium, defined as the mean wage of skilled workers relative to the mean wage of unskilled workers, increased by almost 30 percent between 1985 and 1994 remaining stable afterwards. These two trends are clearly depicted in Figure 1. To put this in perspective, it took more than twenty five years for a change of similar magnitude in the skill premium to take place in the United States.

Figure 1: Trade Volume and the Rise of the Skill Premium in Mexico



Source: World Bank WDI and INEGI. Exports and imports of manufacturing goods. Skill premium is defined as the mean ratio of non-production to production wages across 2-digit industries.

A large body of literature has studied the relationship between wage inequality and trade openness from the perspective of the Hecksher-Ohlin-Samuelson (HOS) model and one of its main corollaries, the Stolper-Samuelson theorem (Esquível and Rodríguez-López, 2003, Feliciano, 2001, Hanson and Harrison 1999b and Robertson, 2004 for the case of Mexico). However, this approach has not been very successful, as these studies find that the correlation between changes in output prices and relative wages at the industry level is extremely low[3]. Moreover, when 'mandated wage' equations (zero-profit conditions derived from HOS)

[3]The Stolper-Samuelson theorem predicts that changes in the relative price of final goods induced by opening up to trade will shift production toward goods that use the country's abundant factor more intensively. This in turn increases the relative demand for the abundant factor and raising its real reward

are fitted to the data, their estimates are very imprecise, grossly over-predict wage changes and have very low explanatory power[4]. Other studies that have considered alternative hypotheses for the increase in wage inequality in Mexico include Feenstra and Hanson (1997) that examine the role of foreign direct investment, and Verhoogen (2008) which provides evidence that improved exporting opportunities increase within-industry wage dispersion due to quality-upgrading at the plant level.

My model is related to a growing literature that studies the complementarities between investment and the decision to export at the firm level. These papers present evidence for several countries that suggests that exporting and productivity-enhancing investment are complementary actions for a firm.[5] If trade openness does provide a strong incentive for firms to invest and absorb new technologies, then this channel might also be relevant in explaining the rise of the skill premium observed in Mexico and other developing countries. My paper is the first attempt to structurally estimate the impact that trade-induced technology adoption has on wage inequality[6].

Using my econometric model I estimate the response of technology adoption and the skill premium to a unilateral trade liberalization of a similar magnitude to the one that took place in Mexico after 1985 (a 35% reduction in the price of the imported good in the model). I find that only a small fraction of plants in the middle of the productivity distribution find it profitable to switch from technology 1 to 2. When imports increase, the balanced

[4]Attanasio et. al. (2004) and Hanson and Harrison (1999a, 1999b), argue that the increase in the skill premium can be explained using a HOS framework, since the industries that experienced the largest reductions in protection (and which should have experienced the largest changes in relative prices) were predominantly intensive in unskilled labor

[5]Aw et. al. (2007) find a positive and significant correlation between shocks that lead a firm to start exporting and shocks inducing investment in R&D/worker training in the Taiwanese electronics industry. Bustos (2005) finds that new exporters outspend existing exporters and domestic firms in technology-related investment in Argentina. Iacovone and Javorcik (2007) document a higher frequency of investment (in physical capital) spikes for Mexican manufacturing firms that will start exporting within the next two years, and Lileeva and Trefler (2007) find that Canadian plants that were induced to become exporters after the CUSFTA agreement increased their labor productivity and adoption of advanced manufacturing technologies.

[6]Krusell et. al. (2000) study the role of falling prices of capital equipment in explaining the increase of wage inequality in the US using a structural estimation framework

trade condition implies that the value of exports should increase in the same amount. This increases the number of exporting firms in the economy from 25 to 30 percent of all firms due to a terms-of-trade effect. About one third of the new exporting firms used technology 1 in the high-tariffs steady state and decide to start using technology 2 in the post-liberalization steady state. Firms in the lower tail of the productivity distribution will contract and become less skill-intensive (since they just serve the domestic market, and their sales have fallen) or exit. Finally, firms that were using technology 2 before, see their total revenues fall because the fall in domestic profits exceeds the gain in foreign profits. Overall, the relative demand for skill increases producing an increase in the skill premium of around 3.5 percent, about one-tenth of the total increase in the skill premium observed in the data. When the sunk cost of adopting the modern technology is affected by the import tariff, the share of firms using modern technology increases from 28 to 35 percent when the economy is in the new low-tariff steady state, producing a larger response of the skill premium, which now increases by 4.6 percent after trade liberalization. Thus trade-induced skill-biased technology adoption can account for about one sixth of the total increase of the skill premium observed in Mexico. As in many other countries, trade reforms in Mexico took place in a very turbulent time. Other reforms such as the implementation of a large-scale privatization program, and wage-setting arrangements designed to put a brake on inflation may have had a large impact on the skill premium as well. It could also be the case that the availability of new computer-based technologies could have provided a sufficiently large productivity boost, compelling firms to adopt these technologies even in the absence of changes in trade policy.

The paper is organized as follows: section 2 presents a succinct account of Mexico's trade liberalization process and a summary of previous research studying the evolution of wage inequality in Mexico. Section 3 presents the model and discusses its main implications. Section 4 describes the data used for the estimation, looks at the patterns of exporting and defines the proxy for technology adoption used in the estimation. Section 5 presents the estimation method, and discusses the resulting structural parameters. Section 6 presents the results of a counter-factual trade liberalization. Section 7 concludes. Appendix A provides a brief description of the computational algorithm used to compute the stationary equilibrium of the model in section 3, and Appendix B describes the data cleaning procedures used in the paper.

2 Mexico in the 1980s

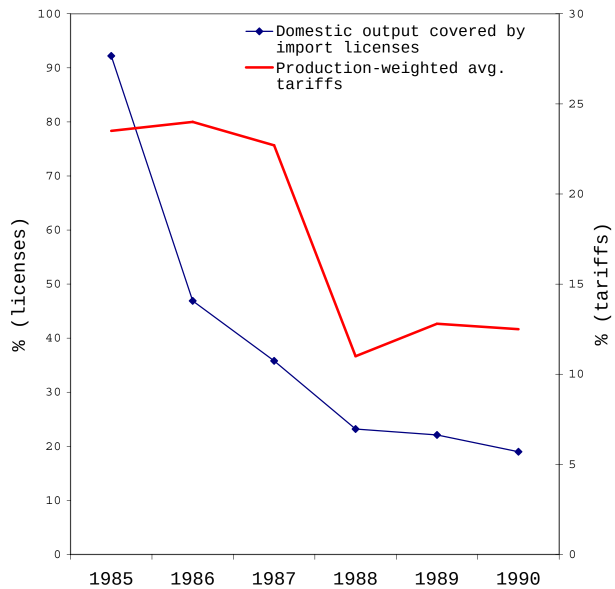
This section describes the main characteristics of the trade liberalization reform pursued by the Mexican government between 1985 and 1987. It also presents a brief account of the evolution of wage inequality in Mexico.

2.1 Mexico's Trade Policy

Mexico, like many Latin American countries, pursued an import-substitution development strategy until the early 1980s. The level and scope of protection of domestic producers against foreign competition were very high even in comparison to other developing economies. At the beginning of the 1980s, Mexico's commercial regime was based on three main instruments: i) an ad-valorem tariff scheme, ii) official minimum prices for custom valuation, and iii) quantitative restrictions that included quotas and import licenses. There is a consensus that import licenses contributed the most to restrict trade flows (Kehoe, 1995, Ten Kate, 1992).

Following a spending spree in the late 1970s fueled by high oil prices and unrestricted bank lending, Mexico found itself in a dire situation as world interest rates began to increase, oil prices to tumble and credit to dry up. The balance-of-payments crisis that ensued led to a collapse of the peso, bank runs and a deep recession (Bergoing et. al., 2002, Lustig, 1998). Trade liberalization (*apertura*) marked the beginning of a series of structural reforms carried out by President Miguel de la Madrid intended to restore the growth of the Mexican

Figure 2: Protection Measures for Manufacturing during the second half of the 1980s



Source: Lustig (1998)

economy. In July 1985, licenses for almost 3,600 tariff items were eliminated. The license coverage ratio fell from 92 to 47 percent between June and December of 1985. Initially, as import licenses were being phased out, the government provided some compensation by increasing tariffs, so that the average tariff went up from 23.5 to 24 percent during 1985. Furthermore, the government devalued the nominal exchange rate by 20 percent, so that the effective rate of protection was still relatively high during the early phase of the reform. In 1986 the maximum tariff rate was reduced to 50 percent, and a four-step calendar was announced that would result in a 0-30 percent tariff scale by October 1988. Moreover, in 1986 Mexico joined the General Agreement on Trade and Tariffs (GATT), deepening its commitment to market-oriented economic environment.

The trade liberalization reforms of the 1980s were concluded in 1987 with the enactment of the Economic Solidarity Pact (*Pacto*). The government, business organizations and labor unions agreed to speed up trade reform with the hope that stiffer competition from abroad would help to tame inflation. At the end of the year, the tariff structure was simplified from 16 tariff levels to 5, and a maximum tariff of 20 percent ad-valorem. At this point, the fraction of domestic output covered by import licenses was 23 percent, concentrated in a few key industries (such as petroleum refining, transport equipment and some agricultural commodities) and the production-weighted average tariff was 11 percent. The time path of reductions in tariffs and license coverage is illustrated in Figure 2. Further trade liberalization occurred when Mexico, jointly with the United States and Canada, signed the North American Free Trade Agreement (NAFTA) in December of 1992 and came into effect on January 1st of 1994.

The trade liberalization reforms had a huge impact on the patterns of trade of Mexico. First, the volume of trade has grown by leaps and bounds since 1985 and continues to do so, as is clear in Figure 1. Second, the composition of exports changed radically as oil's share of total exports fell from 75 percent in 1981 to 35 percent in 1990 as its relative price fell and manufactures increased their importance in total exports. Second, non-oil exports rose threefold from 5.5 to 16 billions of dollars between 1981 and 1990. Imports grew even more when the real exchange rate depreciation of 1985-1986 was reversed after 1987 (Ten Kate, 1992). Finally, the importance of the United States as a trading partner became more pronounced as Mexico's share of trade with the US rose from 56 percent in 1982 to 70 percent in 1992. This trend has continued after the implementation of NAFTA in 1994. As of 2006, exports to the US (including *maquiladoras*) account for 85 percent of all Mexican exports, while imports from the US constitute 51 percent of total imports (Banco de Mexico, 2007).

2.2 The Evolution of Wage Inequality in Mexico

Mexico is one of the least egalitarian countries in the world. Although its Gini coefficient fell consistently since the 1960s until the early eighties (Szekely, 1998), this pattern suddenly reversed after the debt crisis and the ensuing economic reforms. The Gini coefficient of wages increased from 0.43 in 1984 to 0.49 in 1992, a 13.9 percent increase in just eight years (Cortez, 2001). Other measures of dispersion show a similar pattern. Cragg and Eppelbaum (1996) report that the average real wage for individuals with some post-secondary schooling increased by almost 70 percent between 1987 and 1993, while it only increased by 8 and 15 percent for workers with some primary and some secondary schooling respectively. The ratio of non-production to production wages in manufacturing, another measure of skill premium, increased from 2.25 in 1988 to 2.75 in 1994 and 2.9 in 1996, remaining roughly constant afterwards[7] Thus, by all accounts, a large and abrupt increase in wage inequality occurred in Mexico in the latter half on the eighties.

The fact that the large increase in the skill premium coincided with the trade liberalization reforms has resulted in a large body of research that addresses possible linkages between increased trade openness and wage inequality in Mexico. At first glance, there is evidence suggesting trade has increased the skill premium. Feliciano (2001) finds that wage dispersion increased more in tradable (manufacturing) than non-tradable sectors (construction, services and government services) and also that changes in wages were more pronounced in industries that suffered the largest reductions in protection. However, trade liberalization was not the only major change taking place in this period. One of the most important components of the *Pacto* was a de-facto freeze of the minimum wage. This, combined with an extensive privatization program and a substantial decline in unionization rates (Cortez, 2001), put downward pressure on real wages for workers at the lower end of the wage distribution, increasing wage inequality.

During this period employment is much more stable than wages. The employment share of manufacturing changed little during the period (on average 31%), and average hours for

[7] This pattern is observed all across the board. Esquível and Rodríguez-López (2003) find that the skill premium increases for 46 out of 49 2-digit industries between 1988 and 1994. I observe the same pattern when comparing 1984 to 1990.

workers with different levels of education remained fairly constant as well (Feliciano, 2001), ruling out important shifts of employment out of the manufacturing sector as a determinant of the evolution of the skill premium. Sánchez-Paramo and Schady (2002) document a 34 percent increase in the relative supply of workers between 1987 and 1999, implying that the relative demand for skilled workers had to increase more than the relative supply[8] to explain the increase in the skill premium. Cragg and Eppelbaum show that skill upgrading took place in both traded and non-traded sectors between 1987 and 1993 and that the returns to skill-intensive occupations such as professionals and administrators experienced the largest increases over the same period, while the wage premia for less educated occupations such as salespersons and transport workers experienced slower growth.

3 Model

In this section I develop a dynamic general equilibrium model of a small open economy in which firms make decisions regarding the adoption of new production technology and participation in international trade. I will use the model to identify the impact of these decisions on the equilibrium level of the skill premium (defined as the wage of skilled workers relative to unskilled workers) after a trade liberalization reform.

3.1 Preferences and Demand

Time is discrete and indexed by $t = 0, 1, 2, \ldots$. The economy is populated by a mass of L individuals, a fraction λ of which are skilled[9]. Each individual is endowed with one unit of time that is supplied inelastically. Individuals are risk-neutral and maximize the expected

[8] this argument has been made before by Katz and Murphy, 1992 and Berman et. al., 1994 in support of skill-biased technical change explaining the increased wage inequality in the US during the 1980s

[9] There are no productivity differences between skilled and unskilled workers. They simply are different factors of production (imperfect substitutes) from the perspective of firms

present discounted value of a consumption aggregate C_t

$$E_0 \sum_{t=0}^{\infty} \beta^t C_t, \quad \beta \in (0,1) \tag{1}$$

Individual income consists of labor income plus distributed profits of domestic firms. The consumption good is a CES aggregate of a continuum of domestically-produced varieties, $q_d(\omega)$ and a single imported variety, q_f,

$$C = \left(\int_{\omega \in \Omega} q_d(\omega)^{\rho} d\omega + q_f^{\rho} \right)^{\frac{1}{\rho}}, \quad \rho \in (0,1), \quad \sigma_c \equiv 1/(1-\rho)$$

where Ω denotes the set of domestically-produced goods. It is assumed that the elasticity of substitution among domestic varieties is the same as the elasticity of substitution between the foreign good and domestic goods. These preferences result in demand functions for variety ω, and for the imported good of the form

$$\begin{aligned} q_d(\omega) &= \left(\frac{Y}{P}\right)\left(\frac{p_d(\omega)}{P}\right)^{-\sigma_c}, \\ q_f &= \left(\frac{Y}{P}\right)\left(\frac{p_f \tau_f}{P}\right)^{-\sigma_c} \end{aligned}$$

where Y is aggregate income, and P is the ideal price index defined as,

$$P = \left[\int_{\omega \in \Omega} p_d(\omega)^{1-\sigma_c} d\omega + (p_f \tau_f)^{1-\sigma_c} \right]^{\frac{1}{(1-\sigma_c)}}$$

I assume that the economy is "small" with respect to the rest of the world in the following sense: consumers can buy the foreign good at a price $p_f \tau_f$, where p_f is the world price of the good (which is set to be the numeraire) and $\tau_f > 1$ is an import tariff. Domestic producers in turn, face a foreign demand schedule $q_x(\omega) = A_x(p_x(\omega))^{-\sigma_c}$ for their variety, where A_x is a parameter. Hence, this economy takes as given the price of imports and the demand schedules for its exports as in Demidova and Rodríguez-Clare (2008).

3.2 Production

Firms operate either a traditional or a modern technology. Let $k \in \{1, 2\}$ index the technology used by a firm, with $k = 1$ denoting the traditional technology and $k = 2$ the modern one. A technology k requires a per-period fixed cost of operation f_k denominated in terms of output. I assume that the fixed cost of operating the modern technology is higher than that of the traditional technology, so $f_1 < f_2$ (this might reflect higher maintenance costs as the complexity of tasks that workers need to perform increases when using advanced technologies. See Fernandez (2001)). The only input in production is labor (skilled and unskilled). Firms produce according to the following production function:

$$q = \left[l^{\alpha} + (zh)^{\alpha}\right]^{\frac{1}{\alpha}}, \quad \sigma_p \equiv \frac{1}{1-\alpha} > 0 \tag{2}$$

where l and h denote unskilled and skilled labor employed by the firm, σ_p is the elasticity of substitution between skilled and unskilled labor, and z is a firm-specific, skill-biased productivity index. Firm's productivity follows an AR(1) processes with a mean $\overline{z}_k$ that depends upon a firm's technology choice

$$\begin{gathered} \log(z_{t+1}) = \overline{z}_k + \phi \log(z_t) + \varepsilon_{t+1}, \quad \varepsilon_{t+1} \sim \mathcal{N}(0, \sigma_{\varepsilon}^2), \\ |\phi| \in (0, 1), \quad \overline{z}_1 < \overline{z}_2 \end{gathered} \tag{3}$$

Technology 2 results in higher productivity realizations on average[10], but requires a higher per-period fixed cost of use relative to technology 1. If a firm wants to start using a different technology, it needs to incur a sunk cost that reflects the costs of retooling and adopting the

[10]Note that I assume that the persistence and variance of innovations are the same for both technologies.

new productive process[11]. One way to think about the sunk cost of adopting the modern technology as the price paid for a new (imported) machine. A firm will keep using this machine for as long its productivity is high enough to cover the fixed cost of operation. The firm may decide to revert to the use of a traditional technology when its productivity falls below a certain threshold. This would be equivalent to scrapping the imported machine at a zero resale value (assuming that there is no sunk cost of switching from technology 2 to 1, as I do in the estimation). Based on this motivation, I will treat plants that start importing machinery and equipment as users of technology 2 in my model.

This characterization of technology results in a trade-off for firms between marginal cost (which depends inversely on productivity) and the fixed cost of operating a given technology. The higher productivity realizations that come from using technology 2 will make a firm larger (in terms of employment) and also more skill-intensive, provided that skilled and unskilled labor are gross substitutes (Doms et. al., 1997, Hanson and Harrison, 1999a and Pavcnik, 2003 among others find a positive correlation between size and the employment share of non-production workers). The responsiveness of skill intensity to productivity shocks crucially depends on how substitutable skilled and unskilled workers are in production. If the elasticity of substitution between the two types of labor is very high, even small productivity shocks will result in large changes in the relative demand for skilled workers at the firm level. At the aggregate level this will also imply that the skill premium will be highly responsive to aggregate shifts of the relative labor demand for skilled labor.

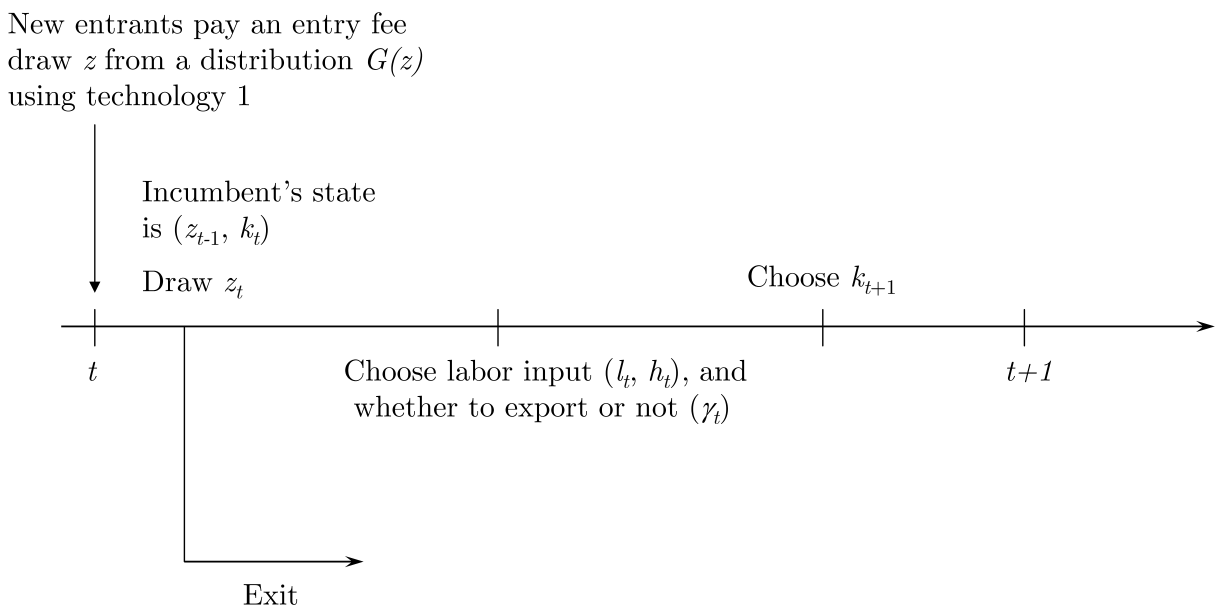
Firms are monopolistically competitive, with market power in the good they sell, but they are price-takers in the labor market. Hence, the unit cost function for a firm is,

$$mc = \left[w_l^{1-\sigma_p} + \left(\frac{w_h}{z} \right)^{1-\sigma_p} \right]^{\frac{1}{1-\sigma_p}} \tag{4}$$

[11] This representation of the innovation decision is similar in spirit to the one used by Costantini and Melitz (2007) where firms face a one-time opportunity to obtain a high productivity draw which has long-lasting effects on productivity. On the other hand, in Atkenson and Burnstein (2007) firms repeatedly invest in *R&D* controlling the drift of a geometric Brownian motion process that governs productivity.

which is decreasing in firm-specific productivity, z. The firm's decision problem can be partitioned in a static profit maximization, in which a firm chooses optimal price(s) to charge, its labor input and whether or not to export. and a dynamic decision regarding technology adoption. I describe the static problem first. Figure 3 describes the sequence of actions that take place in the model.

Figure 3: Sequence of Actions



Static Problem

Incumbent firms can sell their output at home or they can export it, although exporting is costly. A firm that in a given period decides to sell abroad faces two costs: 1) A (per-period) fixed cost f_x of participating in the export market (denominated in terms of output as in Yeaple (2005)) and 2) variable costs that take the form of iceberg transportation costs, so that for one unit of a good to arrive at its final destination, $\tau_x > 1$ units must be shipped. Since production exhibits constant-returns-to-scale, firms independently maximize the profits from domestic and foreign sales. Therefore, firms set their prices at the usual constant markup over marginal cost

$$p_d = \left(\frac{\sigma_c}{\sigma_c - 1}\right) mc, \tag{5}$$

$$p_x = \tau_x p_d$$

Every period, a firm compares the potential profits from exporting with the participation cost in order to decide whether to export or not. Let $\gamma \in \{0, 1\}$ denote the firm's export decision (with $\gamma = 1$ meaning that the firm is exporting in the current period). The solution to this problem is a cutoff rule for productivity, z_x. Firms with current productivity z_t above the cutoff will export. As soon as their productivity falls below z_x, they stop. Hence, only the most productive firms will export. Given γ, static profits net of exporting costs for Home firms are

$$\pi_d(k, z) = Y P^{\sigma_c - 1} \left[\left(\frac{\sigma_c}{\sigma_c - 1}\right) mc(k, z)\right]^{1-\sigma_c},$$

$$\pi_x(k, z) = A_x \left[\left(\frac{\sigma_c}{\sigma_c - 1}\right) \tau_x mc(k, z)\right]^{1-\sigma_c},$$

$$\pi(k, z) = \pi_d(k, z) + \max\big\{\pi_x(k, z) - f_x mc(k, z), 0\big\} \tag{6}$$

Finally, the firm's input demand is obtained by solving the following program taking the vector of wages (w_l, w_h) as given

$$\min_{l,h} w_l l(k, z) + w_h h(k, z) \tag{7}$$

s.t.:

$$\left[l^\alpha + (zh)^\alpha\right]^{\frac{1}{\alpha}} = q_d(k, z) + \gamma(k, z) q_x(k, z)$$

Dynamic Problem

A firm starts period t with a given technology k_t, and a productivity level z_{t-1}; these are its state variables. At the beginning of the period, the firm draws z_t and decides whether to continue producing or not (we normalize the scrap value to zero). Let $\chi(k,z) \in \{0,1\}$ denote the exit policy rule (where $\chi(k,z) = 1$ denotes exit). An incumbent firm that stays in the market produces, decides whether to export or not, and finally chooses the technology that it will use in period $t+1$. The dynamic programming problem of the firm is given by:

$$V(k,z) = \max\{0, V^C(k,z)\} \tag{8}$$

$$\begin{aligned} V^C(k,z) = \max\Big\{ & \pi(k,z) - f_k mc(k,z) + \beta \int_{z'} Q_k(z,z')V(k,z')dz' \;, \\ & \pi(k,z) - [f_k + S_{\tilde{k}}]mc(k,z) + \beta \int_{z'} Q_{\tilde{k}}(z,z')V(\tilde{k},z')dz' \Big\} \end{aligned} \tag{9}$$

where $S_{\tilde{k}}$ is the sunk cost that a firm has to pay when switching from technology k to $\tilde{k}$[12] and $Q_k(z,z')$ is the transition density for productivity when using technology k. As I mentioned before, it is assumed that technology 2 requires a higher per-period fixed cost of operation than technology 1, that is $f_1 < f_2$. The solution to this problem produces two policy rules: for technology, $\mathcal{K}(k,z) \in \{1,2\}$, characterized by two productivity cutoffs, $z_{\text{out}} < z_{\text{in}}$ and exit, $\chi(k,z) \in \{0,1\}$, which is also characterized by a productivity cutoff $z_{\text{exit}}(k)$, below which firms decide to exit the market. A firm currently using technology 1 will start using technology 2 if its current productivity draw exceeds z_{in}. However, a firm that already operates technology 2 will continue to use it even if its productivity falls below z_{in}, since it takes into account the option value of receiving higher productivity draws in the future without having to pay the adoption cost S_2.

[12] In the estimation I assume that firms do not need to pay any adoption cost when switching from technology 2 to 1, that is, $S_1 = 0$

Every period there is a continuum of ex-ante identical potential entrants. The only barrier to entry is a sunk entry cost S_E (denominated in terms of output). When potential entrants pay the sunk entry cost, they draw their initial value of z from a common distribution $G_E(z)$, which is assumed to be log-normal with mean $\mu_E - \sigma_\varepsilon^2/[2(1-\phi^2)]$ and variance $\sigma_\varepsilon^2/(1-\phi^2)$. The value of entry, net of entry costs is:

$$V^E = \int_z V(1,z)dG_E(z) - mc(1,z)S_E \tag{10}$$

I assume that all entrants start using technology 1, so they will be on average smaller than incumbent firms as empirical evidence suggests.

3.3 Stationary Equilibrium Definition

A recursive competitive equilibrium for the model consists of a value function for firms $V^C(k,z)$, list of decision rules for pricing $\{p_d(k,z), p_x(k,z)\}$, exporting $\gamma(k,z)$, labor demand $\{l(k,z), h(k,z)\}$, exit $\chi(k,z)$ and technology adoption $\mathcal{K}(k,z)$; a post entry/exit distribution of firms across technologies and productivity $\mu(k,z)$ and a set of aggregate variables: aggregate income Y, ideal price index P, mass of incumbents M and entrants M_E and a vector of wages $\{w_l, w_h\}$ such that:

1. $V^C(k,z)$ solves the dynamic problem of the firm. Decision rules are optimal.
2. Labor demand equals labor supply for both types of workers
3. The flow of entrants balances the flow of exiting firms
4. Equilibrium good prices are consistent with the aggregate price index P
5. Aggregate income Y equals aggregate profits plus total labor income
6. Free entry

7. Balanced trade

Discussion

Several combinations of technology use and exporting status are possible depending on the relative position of these cutoffs in the productivity distribution (for instance, if the productivity cutoff for exporting is too high, it might be the case that all firms that become exporters have to first adopt technology 2). As firms with high productivity levels tend to export and use the modern technology, simulations of the model show that intermediate states (exporting using technology 1 or not exporting using technology 2) are not very persistent – firms quickly become high-tech exporters or low-tech domestic producers.

When the variable cost of trade that firms face when selling abroad falls, sales for exporting firms (both existing and new) increase. This proves an incentive to adopt technology 2 as the higher fixed cost of operation can be spread over a higher volume of sales. In a new stationary equilibrium with lower trade costs, the share of firms using the modern technology increases. Firms using technology 2 become larger and more skill-intensive at the expense of firms that use technology 1, which will contract or exit the market altogether.

If the economy pursues a unilateral trade liberalization (which would reduce the price that consumers pay for the imported good), the demand for the imported good rises (at the expense of the demand for domestic goods), reducing domestic profits for all firms. Qualitatively, the response of firms will be similar to that when exporting prospects improve: smaller, unskilled worker-intensive firms will contract and exit, while the most productive firms expand, as these firms reshuffle their sales from the domestic to the foreign market (in this way maintaining balanced trade). From an empirical perspective it is important to notice the differences between the two scenarios. In a large number of cases, when developing countries pursue trade liberalization reforms they do so in a unilateral fashion. At the same time, their exporters do not experience significant changes in the level of tariffs they face (since most of their exports are directed towards developed countries where tariffs are very low). This is certainly the case for Mexico[13], and for several Latin American countries as well. Quantitatively I find that since the response of exports is smaller after a unilateral liberalization, fewer firms adopt technology 2 and the skill premium rises by a smaller amount than in the first case.

4 Data

The data used in the paper comes from the *Encuesta Industrial Anual* (Annual Manufacturing Survey) produced by the *Instituto Nacional de Estadísticas, Geografía, e Información* (INEGI), the Mexican government statistical agency. After cleaning the data (the exact procedure is described in Appendix B), I have a balanced panel of 1,913 plants for the period 1984-1990. For each plant we have information on the total number of *obreros* (blue-collar workers whose main activities include machine operation, production supervision, repair, maintenance and cleaning) and *empleados* (white-collar workers such as managers, administrators, professionals and salesmen), total number of hours worked for each type of worker, total remuneration, production, input use, investment in capital goods (including machinery and equipment imports) and exporting status (from 1986 onwards).

Exporting and Use of Foreign Technology

Table 1 shows how export participation and the use of imported machinery and equipment (M&E) and materials experienced a dramatic increase over the second half of the 1980s. The patterns of openness for the manufacturing sector mirror the behavior of the aggregates

[13] The NBER trade database shows that, from 1970 to 1992, Mexico's annual average trade share with countries that were clearly relatively skill abundant was greater than 90 percent throughout the period, including the United States and Canada (69 percent), Europe (16 percent), and Japan, Australia, and New Zealand (5 percent).

for the whole economy shown in Figure 1. In 1986, 66 percent of the plants serve only the domestic market and do not import any machinery and equipment, by the 1990, this group comprises 42 percent of the sample. At the same time, the number of plants that both export and use imported machinery doubles. The number of plants that export but do not import M&E increases by just 8 percent.

Table 1: Openness at the Plant Level

	1986	1990	% change
Fraction of exporting plants	22.8	35.9	57.4
Mean exports/sales	24.7	26.8	8.5
Fraction of plants importing M&E	22.6	37.3	64.9
Expenditure in imported M&E[a]	5.3	9.9	85.5
Fraction of plants importing materials	33.5	50.6	51.1
Expenditure in imported materials[b]	8.0	12.9	60.8

[a]As a fraction of total expenditure in Machinery and Equipment
[b]As a fraction of total expenditure in materials

As has been noted by the literature studying plant-level investment patterns (e.g Cooper and Haltiwanger, 2006), there is a great deal of inaction and spikes in investment rates: for 52 percent of the observations, the gross investment rate falls below 1 percent of the book value of capital stock, while at the same time, for 6 percent of plant-year observations an investment rate above 25 percent of the value of capital stock is observed. More importantly, 78 percent of these investment spikes involve the purchase of imported M&E. Hence, I identify a plant that *starts* importing machinery and equipment as adopting technology $k = 2$ in my model[14] (similar definitions of technology adoption have been used by Huggett and Ospina (2001) and Kasahara (2001)).

[14]Ideally knowing how important is imported M&E in the capital stock would be allow me to better identify the plants that are using more advanced technologies, however this information is unavailable in my sample. Other indicators of use of advanced technology such as the use of advanced manufacturing technology and automatized processes are included in the ENESTYC survey which is available after 1992

Relative Employment and Wages

Between 1984 and 1990, the hourly remuneration for skilled workers increased by 24 percent, with most of the increase happening after 1988. Wages for unskilled workers fell by 17 percent in the same period. The two trends put together result in an increase in the skill premium (the relative wage of skilled workers) of 30 percent in a matter of just of five years, or a rate of growth of 4.47 percent per year, a dramatic rise in the skill premium. Importantly, the rise of the skill premium was not concentrated in a handful of industries, it took place across the board. The skill premium (measured as the ratio of the mean non-production worker wage relative to the mean production-worker wage) increased for 115 out 127 4-digit industries between 1984 and 1990.

The pattern of employment is surprisingly stable during the period of study. In the sample, total employment increases by 11 percent, and white and blue-collar employment increase by 8 and 6 percent respectively. The mean employment share of non-production workers (a measure of skill intensity) remains stable at around 30 percent during the sample period. However, the wage-bill share of non-production workers increases by 15 percent.

5 Estimation

The model presented in section 3 is estimated on a balanced panel of 1,913 Mexican manufacturing plants for the period 1984-1990. I am treating 1984 as a pre-liberalization stationary equilibrium of the model. The model is set to fit the size distribution of plants in the pre-liberalization steady state, since productivity differences in the model, are directly reflected in size (employment) differences. Other features that the model seeks to match are the frequency and intensity[15] of exporting, use of imported technology, and differences in skill intensity between exporting and non-exporting plants.

[15] measured as the mean fraction of revenues accrued from exporting

There is a set of parameters that are determined out of the estimation routine. The discount factor β is set equal to 0.939 to match the average real interest rate (based on Certificados de la Tesoreria de la Federacion a 28 dias, CETES) for the period 1982-2006, of 6.46 percent. The fraction of skilled workers in the economy is set equal to the mean share of non-production employment in 1984, 0.301. Given the CES demand system used, the ratio of domestic revenues to total variable cost is constant across firms, and equal to the markup charged by firms. The mean of this ratio for 1984 is 1.407, which implies a demand elasticity $\sigma_c = 3.451$. The price of the imported good faced by consumers τ_f is set to 1.55. This is higher than the production-weighted average tariff imposed for manufacturing imports in 1984 (23.5 percent) but takes into account the broad licensing requirements that were in place at the time which are considered the most binding barrier to trade. The variable cost of exporting for Mexican firms is set to match the average U.S. tariff on dutiable goods imported from Mexico in 1984, 5 percent. Table 2 summarizes the parameter values fixed outside the estimation. Finally, the size of the economy L is normalized to 1,000.

Table 2: Calibrated Parameters

Parameter	**Value**
β	0.939
σ_c	3.451
τ_f	1.55
τ_x	1.05
λ	0.301
L	1,000

The structural parameters of the model are estimated using a method of simulated moments (MSM) estimator. Given a vector of parameters $\boldsymbol{\theta}$, the stationary equilibrium of the model is solved and policy rules for employment, exporting, exiting and technology adoption $\{l^*, h^*, \gamma^*, \chi^*, \mathcal{K}^*\}$ are obtained. Using these policy rules, I simulate the behavior of a large number of plants, creating a simulated panel dataset $\{D_{it}^s(\boldsymbol{\theta})\}$. Taking averages over these simulations, I construct a vector of simulated moments,

$$\hat{\mathbf{m}}(\boldsymbol{\theta}) = \frac{1}{S} \sum_{s=1}^{S} m(D_{it}^{s}(\boldsymbol{\theta}))$$

where S is the number of simulation repetitions[16]. The estimated vector of parameters minimizes the distance between a set of simulated and sample moments. More formally,

$$\hat{\boldsymbol{\theta}} = \arg\min_{\boldsymbol{\theta} \in \Theta} \Psi = (\hat{\mathbf{m}}(\boldsymbol{\theta}) - \mathbf{m})' W (\hat{\mathbf{m}}(\boldsymbol{\theta}) - \mathbf{m}) \tag{11}$$

where $\hat{\mathbf{m}}(\boldsymbol{\theta})$ is the vector of moments calculated directly from the data, and W is a conformable positive definite matrix of weights[17]. The objective function results from simulations of a complicated dynamic programming problem, hence is likely to be neither smooth nor concave. In order to deal with these issues, I use a stochastic variant of the Nelder-Mead simplex algorithm to solve the problem in equation 11.

The following 12 parameters are estimated by MSM

$$\theta \equiv \{\overline{z}_1, \overline{z}_2, \phi, \sigma_{\varepsilon}^2, f_1, f_2, S_2, A_x, f_x, \mu_E, S_E, \sigma_p\} \tag{12}$$

Where $(\overline{z}_1, \overline{z}_2, \phi, \sigma_z^2)$ determine the stochastic process for firm-specific productivity, (f_1, f_2, S_2) are the fixed cost of operating and adopting each technology, A_x is the size of the foreign market, f_x is the fixed cost of participating in the export market in each period, μ_E is the mean of the distribution from which entrants draw their initial productivity, S_E is the sunk cost of starting a new firm, and σ_p is the elasticity of substitution between skilled and unskilled labor.

Table 5 reports the moments I use in the estimation. The first set of moments charac-

[16]The estimation procedure uses $S = 50$

[17]Note that the number of parameters to be estimated has to be less than or equal to that the number of moments used

Table 3: Data Moments

Pre-Liberalization (1984)	**Value**	**Dynamic Moments**	**Value**
Mean fraction of exporting firms	0.231	Corr(export$_t$, export$_{t-1}$)	0.862
Mean exports/sales ratio	0.218	Corr (skill share$_t$, skill share$_{t-1}$)	0.939
Std skill share of employment	0.167	Mean adoption rate imported technology	0.072
Mean skill share, exporters	0.353	Mean entry rate into exporting	0.033
Mean skill share, non-exporters	0.294		
Mean entry rate	0.110		
Mean log(total employment)	4.791		
Std log(total employment)	1.235		
Mean log(total employment), entrants	2.868		
Std log(total employment), entrants	0.866		
Mean log(total employment), exiters	2.270		
Std log(total employment), exiters	0.866		
Mean fraction of firms using imported technology	0.226		
Std log(non-production employment)	1.394		
Std log(production employment)	1.236		
Mean log(total employment), exporters	5.304		
Std log(total employment), exporters	1.198		
Fraction of plants with 0-30 employees	0.713		
Fraction of plants with 30-100 employees	0.209		
Fraction of plants with 100-500 employees	0.051		

terize the size distribution of plants in the pre-liberalization steady state. In the model, all productivity differences will be reflected in size (employment) differences. Fixed costs f_k and and the intercepts of the productivity processes, $\overline{z}_k$ will affect the average size of incumbent firms, since higher fixed costs and higher productivity realizations will result in larger firms in equilibrium. The difference between $\overline{z}_1$ and $\overline{z}_2$ and f_1 and f_2 will be determined by the difference in skill-intensity and size between exporting and non-exporting plants (due to selection effects the largest firms become exporters), as well as by the share of firms importing foreign M&E in steady state.

The parameters governing the decision to export (A_x, f_x) are pinned down by the frequency and intensity of exporting: a larger foreign market induces more firms to export, and also leads exporters to sell a larger share of their output abroad. A higher f_x, on the other hand, reduces the number of firms engaged in exporting activities but increases the share of exports in total revenues as the fewer firms that find profitable to export will seek to spread the large fixed cost over a larger volume of sales.

The elasticity of substitution between skilled (non-production) and unskilled (production) workers determines the responsiveness of skill-intensity to productivity innovations (given that labor supply is fixed in the model). If σ_p is too big, firms that draw good productivity shocks become very large and highly skill-intensive, while firms that suffer bad draws will shrink and employ a large share of unskilled workers. Matching the share of plants in different size bins, and the standard deviation of log employment will help me to identify σ_p. The relative size of entrants and the mean entry rate (which will be identical to the exit rate in the stationary equilibrium) determine μ_E and S_E.

The second set of moments comprises dynamic moments calculated from the entire panel, not just the pre-liberalization cross-section. These moments allow me to identify the root of the auto-regressive process governing productivity which in turn will affect the persistence of skill-intensity which is very high in the data. If productivity is highly persistent, in my model this would result in a highly persistent skill-intensity across firms (for a given elasticity of substitution), with large changes taking place only when firms switch technology. The dispersion of the size distribution helps me to identify the variance of productivity shocks. Finally, the sunk cost of adopting technology 2 will be identified by the share of firms importing technology in the cross-section and the mean rate at which plants start importing M&E.

My estimation strategy suffers two drawbacks: first, since I only have one year of data before trade liberalization occurred, I use the entire panel to compute dynamic moments that will be used to identify the persistence of the stochastic process for productivity, and the rate at which plants start adopting foreign technology, even though the observed behavior during these years is probably reflecting the transition dynamics towards a new steady state with lower trade protection. The second problem is the fact that I do not observe entry and exit of plants in my sample. To circumvent this problem, I used a dataset constructed by the Inter-American Development Bank from administrative records collected by the *Instituto Mexicano del Seguro Social* (IMSS) for the period 1994-2000. From this dataset, I obtain the relative sizes of entering and exiting plants as well as the mean entry rate used in the estimation.

Preliminary Estimates

Table 4 reports the point estimates produced by the model using the identity matrix to weigh moments[18]. The elasticity of substitution between skilled and unskilled workers is estimated to be 1.40. This estimate falls in the middle of the range of estimates obtained for the US (between 1 and 2.2) estimated from macroeconomic data, and is very close to the preferred estimate found by Katz and Murphy (1992), 1.42. which is widely used in several

[18]Using the identity matrix provides consistent, but not efficient estimates. Standard errors are not yet available.

studies on the evolution of wage inequality in the US. The fixed cost of operation accounts for 25 percent of total labor cost. Costantini and Melitz (2007) calibrate the fixed cost of operation in their model so that firms devote 20 percent of their labor cost to overhead, based on results from Bustos (2005), assuming that all non-production workers are devoted to overhead. Exporters pay on average 12 percent of their foreign revenues as a per-period cost to serve the market. Firms that decide to start using technology 2 in the next period incur an adoption cost equivalent to 48 percent of their current revenues at the time of switching.

Given the estimated size of the foreign market and the fixed cost of exporting, the exporting cutoff is higher than the technology adoption cutoff. Hence all exporting firms are users of technology 2, suggesting a conscious preparation to export as suggested by Iacovone and Javorcik (2007). The model predicts that when firms start importing M&E, their skill-intensity (the share of skilled workers in total employment) increases by 31 percent (from 0.29 to 0.38) on impact.

Table 4: Parameter Estimates

Parameter	**Point Estimate**
$\overline{z}_1$	-0.010
$\overline{z}_2$	0.031
ϕ	0.914
σ_{ε}^2	0.244
f_1	12.233
f_2	86.910
S	75.452
A_x	0.455
f_x	44.727
μ_E	1.218
S_E	19.743
σ_p	1.400
Ψ	1.766

Table 5 shows how well the model performs fitting the data. The model does a good job matching several features of the size distribution of Mexican manufacturing plants. In particular, the overall mean of the size distribution, the relative size of entrants, exiters and exporters, the share of exporters and their export intensity closely fit the data. The estimates result in entrants and exiters being smaller than incumbents, and exporters being considerably larger than non-exporters.

The model is less successful matching the second moments of the size distribution. The standard deviation of log employment of entrants and exiters are much smaller than what I observe in the data. This could be due to the fact that the only source of randomness is the productivity process, making it hard to match the standard deviation of log employment for different groups of firms. This is especially relevant for exiting firms. Since there is no random "death shock", only very small firms choose to get out of the market, resulting in too little dispersion in their size.

The model closely matches the skill intensity of exporters, but underestimates that of non-exporters. This is due to the fact that firms only have two technologies to choose from. Given the magnitude of the estimated fixed costs, and the fact that firms find it optimal first to adopt technology 2 before starting exporting, results in too large of a difference in skill intensity between these two types of firms. The share of firms importing M&E (using technology 2) is slightly over-predicted. The high sunk cost of technology adoption implies a high option value of continuing to use technology 2, resulting in a large number of firms using technology 2 in steady state.

Looking at the dynamic moments, it is clear that the high persistence of the stochastic process for productivity allows me to match the high persistence of exporting status and skill-intensity across firms. The lower predicted persistence and higher entry rate into exporting reflect the fact there are no sunk costs to enter foreign markets. There is no option value of remaining an exporter when productivity falls below the level that induced the firm to start exporting. The existence of a sunk technology adoption cost results in a higher persistence

Table 5: Goodness of Fit

Pre-Liberalization (1984)	Data	Simulated	**Dynamic Moments**	Data	Simulated
Mean fraction of exporting firms	0.231	**0.257**	Corr(export$_t$, export$_{t-1}$)	0.862	**0.758**
Mean exports/sales ratio	0.218	**0.232**	Corr (skill share$_t$, skill share$_{t-1}$)	0.939	**0.892**
Std skill share of employment	0.167	**0.074**	Mean adoption rate imported technology	0.072	**0.040**
Mean skill share, exporters	0.353	**0.349**	Mean entry rate into exporting	0.033	**0.080**
Mean skill share, non-exporters	0.294	**0.191**			
Mean entry rate	0.110	**0.083**			
Mean log(total employment)	4.791	**4.617**			
Std log(total employment)	1.235	**1.195**			
Mean log(total employment), entrants	2.868	**2.846**			
Std log(total employment), entrants	0.866	**0.437**			
Mean log(total employment), exiters	2.270	**2.508**			
Std log(total employment), exiters	0.866	**0.555**			
Mean fraction of firms using imported technology	0.226	**0.279**			
Std log(non-production employment)	1.394	**1.574**			
Std log(production employment)	1.236	**1.100**			
Mean log(total employment), exporters	5.304	**5.550**			
Std log(total employment), exporters	1.198	**0.723**			
Fraction of plants with 0-30 employees	0.713	**0.655**			
Fraction of plants with 30-100 employees	0.209	**0.242**			
Fraction of plants with 100-500 employees	0.051	**0.078**			

of skill intensity and a lower entry technology adoption rate.

6 Trade Liberalization

Given the estimates obtained from fitting the model to the pre-liberalization Mexican manufacturing data, I can now ask what would happen to technology adoption and the skill premium after trade liberalization. In order to capture the experience of Mexico in the second half of the 1980s, I will look at a reduction of the foreign price of 35% (that is, τ_f falls from 1.55 to 1.05).[19] The results of this experiment are presented in Table 6.

Table 6: Unilateral Trade Liberalization

Statistic	**Benchmark**	**35% reduction in τ_f**	**35% reduction in τ_f, affecting S_2**
Aggregate income (Y)	100	85.09	85.21
Price index (P)	100	84.07	89.69
Price of foreign consumption good (τ_f)	155	105	105
Mass of incumbent firms (M)	100	98.62	99.37
Skill premium (w_h/w_l)	2.525	2.612	2.635
Fraction of plants using foreign tech.	0.279	0.319	0.353
Fraction of exporting plants	0.257	0.308	0.332

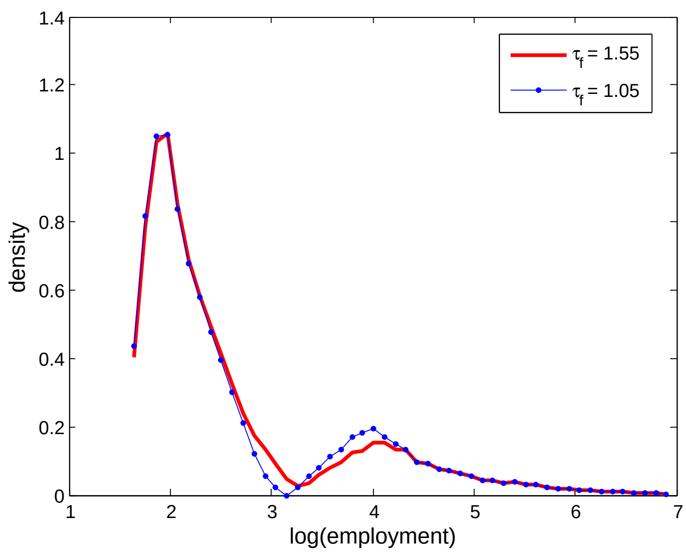
The reduction in the price of the foreign good boosts the domestic demand for imports and has a direct effect on the aggregate price index, which falls 15 percent. The reduction in the price index has a negative effect on domestic profits. This in turn reduces the equilibrium mass of firms in the market by approximately 2 percent. Exit takes place at the lower end of the productivity distribution and workers employed by these firms reallocate to larger and more skill-intensive firms. This is a pro-competitive effect. Aggregate income falls as average

[19]Notice that the iceberg transportation cost for Mexican producers is not being affected by the unilateral trade liberalization.

profits are lower in the post-liberalization steady state.

The balanced trade condition implies that as the value of imports rises, so does the value of exports. the exporting cutoff falls due to a terms-of-trade effect, providing an incentive for firms to enter the foreign market. Out of these new exporters, 31 percent choose to start using technology 2. Firms that start using foreign technology in the trade liberalization steady state increase their total revenues by 78 percent, while firms that were already using the modern technology and become exporters experience a decrease in total revenues of 9 percent (of course, firms that remain producing for the domestic market are the most affected, as their revenues fall 13 percent on average). Figure 4 shows that the main difference in the size distribution of firms happens in the middle, as the new users of modern technology move towards the right of the size distribution. This is a similar conclusion to the findings of Lileeva and Trefler (2007) that only firms with moderate pre-CUSFTA value-added per worker experienced significant gains in productivity as a result of productivity-enhacing investment activities.

Figure 4: Size Distribution after Trade Liberalization



Overall, a unilateral trade liberalization decreases profits for a large number of firms in the economy, so that the use of modern technology increases by just 4 percentage points. This modest increase results in a 3.5 percent rise of the skill premium, far lower from what is observed in the data. Allowing the sunk cost of technology adoption to be affected by the price of imported goods (i.e purchasing a foreign piece of equipment subject to an import tariff, resulting in a technology adoption cost $\tau_f S_2$) produces similar results qualitatively. From a quantitative standpoint, the number of exporters and high-tech firms is higher (relative to the benchmark experiment) in the post-liberalization steady state, producing a stronger response of the skill premium which now rises by 4.6 percent, or about one-sixth of the observed increase of the skill premium in the Mexican manufacturing sector.

7 Concluding Remarks

This paper estimates a structural model of trade and technology adoption with heterogeneous firms aimed at understanding the extraordinary rise of the skill premium in Mexico after the inception of an ambitious trade liberalization process. Several mechanisms have been proposed that link changes in the degree of trade openness to changes in wage inequality, but only with limited success. This paper studies the hypothesis that trade-induced adoption of skill-intensive technologies could be behind the increase in inequality. Previous research has lent support to this view by finding that new exporters exhibit higher rates of investment, and growth in productivity than domestic firms and continuing exporters. My model does a good job matching several key characteristics of the Mexican manufacturing sector, and produces sensible estimates of the parameters that govern technology adoption. However, my estimates suggest that the import-competition effect alone does not provide a sufficiently large push of the relative demand for skilled labor to explain the rise of the skill premium that took place in Mexico since the mid 1980s.

On the one hand, my model does not capture other plausible forces affecting wage inequality in Mexico, such as the wage freeze produced by the *Pacto* and the persistent fall in unionization rates triggered by the privatization program, that compressed the bottom of the wage distribution. Yet there are some features that my model could incorporate that could help bridge the gap between its predictions and the observed increase in the skill premium. In particular, an important extension is to include an aggregate stochastic process for the exchange rate. As it stands, my model does not take into account the large depreciation that the real exchange rate experienced between 1985 and 1988. As Verhoogen (2008) has been pointed out, movements in exchange rates can often dwarf changes in tariffs. The real exchange rate depreciation provides a big boost for firms to become exporters and adopt the modern technology, thus generating a stronger response of the skill premium.

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A Computational Algorithm

This section describes the computational algorithm used to compute the stationary equilibrium of my model.

(i) Let $\boldsymbol{\theta}$ denotes the vector of parameters to be estimated, and $\boldsymbol{\theta_{ne}}$ the vector of parameters calibrated outside the model.

$$\begin{gathered}\boldsymbol{\theta} = [\overline{z}_1, \overline{z}_2, \phi, \sigma_\varepsilon^2, f_1, f_2, S, A_x, f_x, \mu_E, S_E, \sigma_p]_{12\times 1}, \\ \boldsymbol{\theta_{ne}} = [\beta, \lambda, \sigma_c, L, \tau_f, \tau_x]_{6\times 1}\end{gathered} \tag{13}$$

let θ^0 be the initial guess for the estimated parameters.

(ii) The state variables for a firm are: 1) technology $k \in \{1, 2\}$ and 2) the idiosyncratic productivity index, z^k. I assume that z^k can take values in a grid $Z^k \equiv \{z_1^k, \ldots, z_N^k\}$. The stochastic process for the idiosyncratic productivity shock is approximated using the method proposed by Tauchen (1986). This produces two sets of grids $Z^1 \equiv \{z_1^1, \ldots, z_N^1\}$ and $Z^2 \equiv \{z_1^2, \ldots, z_N^2\}$ and associated transition matrices $Q_1(z, z')$ and $Q_2(z, z')$.

(iii) Given an initial guess for the aggregate macroeconomic variables in the model,

$$X \equiv [P, Y, M, w_l, w_h],$$

firms solve their static problem choosing optimal prices in each market (domestic and foreign), labor demand for each type of worker and whether to export or not, and static profits $\pi(k, z)$ are calculated.

(iv) Running through all points in the state space $i_k = 1, 2$ and $i_z = 1, \ldots, N$ solve the firm's dynamic programming problem using value function iteration. Iterate over equation (9) until $\|v^\ell - v^{\ell-1}\| < \mathsf{tol}$, where ℓ indexes iterations over the value function, and $\mathsf{tol} = 1e - 4$ is the convergence criterion. This step yields a value function $v(k, z)$, a policy rule for technology adoption $\mathcal{K}(k, z)$, and a policy rule for exiting, $\chi(k, z)$.

(v) Given the policy functions for technology adoption and exiting, and the transition matrix for productivity, construct a transition matrix P of size $(2N \times 2N)$ that gives the conditional probability of visiting state (i'_k, i'_z) next period for incumbent firms with current state is (i_k, i_z). Finally, compute the invariant distribution associated with P, $\tilde{\mu}(k, z)$.

(vi) Define M_E as the mass of potential entrants that can start producing in a given period. In a stationary equilibrium, the flow of successful entrants should exactly balance the flow of exiting firms. Given the distribution of incumbents $\tilde{mu}(k, z)$, we can solve for M_E:

$$M_E = \frac{M\tilde{\mu}(k, z)'\chi(k, z)}{G_E(z)'(1 - \chi(1, z))}$$

and we can also define the post entry/exit distribution of firms across technologies and productivity, $\mu(k,z)$:

$$\mu(k,z) = \tilde{\mu}(k,z)'(1-\chi(k,z)) + \left(\frac{M_E}{M}\right) G_E(z)'(1-\chi(k,z))$$

(vii) Compute the market clearing conditions: 1) labor market clearing, 2) consistency of the aggregate price index, 3) consistency of aggregate income, 4) net value of entry equal to zero, and 5) balanced trade:

$$\frac{h(k,z)}{l(k,z)} - \frac{\lambda}{(1-\lambda)} = 0, \qquad \text{(Labor Market Clearing)}$$

$$P = \left[M\mu(k,z)' p_d(k,z)^{1-\sigma_c} + \tau_f^{1-\sigma_c} \right]^{\frac{1}{1-\sigma_c}}, \qquad \text{(Aggregate Price Index)}$$

$$Y = M\mu(k,z)'\pi(k,z) \ + L[\lambda w_h + (1-\lambda) w_l], \qquad \text{(Aggregate Income)}$$

$$G_E(z)' \cdot v(1,z) - mc(k,z) S_E = 0, \qquad \text{(Free Entry)}$$

$$M\mu(k,z)'[\gamma(k,z) r_x(k,z)] - Y \left(\frac{\tau_f}{P}\right)^{1-\sigma_c} = 0, \qquad \text{(Balanced Trade)}$$

a vector $X^* \equiv [P^*, Y^*, M^*, w_l^*, w_h^*]$ that solves the system of equations defined above characterizes the stationary equilibrium of this economy. In the computer code, the function `mktclear` receives as inputs the vector of initial parameters $\boldsymbol{\theta^0}$, and the initial guess for the macroeconomic variables X. The program solves the static and dynamic problems of the firm, finds the stationary distribution of the economy, and produces the vector of market clearing conditions, Ψ such that $X^* = \arg\min \|\Psi(X)\|$

(viii) Armed with the policy rules for labor demand, exporting, technology choice, entry and exit, generate $S = 50$ simulated panels of firms. Starting with a given number of incumbent firms, $N_{inc} = 50$, with $N_{ent} = (M_E/M)N_{inc}$ potential entrants every period. Using these simulations, compute a vector of simulated moments (averaged across simulations), of size $r > 12$ (the number of parameters to estimate) and minimize the loss function 11

B *Encuesta Industrial Anual*: Cleaning Procedure

The *Encuesta Industrial Anual* (Annual Manufacturing Survey) is produced by the *Instituto Nacional de Estadísticas, Geografía, e Información* (INEGI), the Mexican government statistical agency. The data contains information on 3,218 manufacturing plants for the period 1984-1990 (for a total of 22,526 plant-year observations) and it is by design a balanced panel that covers roughly 80 percent of cumulative value-added. The sample design is deterministic. Plants with more than 100 employees are included automatically. Plants are ranked according to total value of production and are added to the sample until the set of the selected plants covers approximately 85 percent of the respective classs (4-digit industry) output value. Furthermore, whenever the normal sampling procedure implies that more than 120 plants need to be surveyed to reach the 85 percent threshold, the number of plants surveyed is kept to a maximum of 120; on the other hand if the 85 percent threshold is reached by covering less than 15 plants, then all the plants are included. For more information about the Encuesta Industrial Anual see Iacovone (2008)

The survey contains information on inputs used by manufacturing plants (labor split into production and non-production workers, raw materials, intermediate inputs, energy consumption), and output indicators such as value of production, value of sales, inventory, revenues derived from industrial services like maquila and non-industrial services. The original sample did not have information on the value of imported materials or machinery and equipment and export revenues. However from 1986 onwards this information is available following a World Bank project aimed at collecting exporting information for plants covered by the EIA. The cleaning procedure for the sample follows Grether (1996):

(i) An observation is eliminated if one of the following variables is non-positive: total employment, number of non-production workers, number of production workers, total wage-bill, value-added[20] and gross value of output. This resulted in the elimination of 1,550 plant-year observations.

(ii) Elimination of odd observations: observations for which the annual growth rate of total employment was above 300 percent on absolute value; annual growth rate of total remuneration above 1,000 percent in absolute value; annual growth rate of total value of production above 1,000 percent in absolute value; annual growth rate of energy consumption above 2,500 percent in absolute value and annual growth rate of expenditure on materials above 2,500 percent in absolute value. This resulted in the elimination of 5,973 plant-year observations.

(iii) Elimination of incomplete series: plants that were discarded in at least one year for the reasons mentioned above were discarded for all the other years as well. This resulted in the elimination of 848 plant-year observations.

[20]corrected by maquiladora flows, i.e value-added + income from maquila services − expenditure on maquiladora services

(iv) Entry and exit: Some plants are recorded as entrants or exiters even though the sample is supposed to be closed. This resulted in the elimination of 317 plant-year observations.

(v) Maquila plants: Plants for which revenues from maquila services were more than 10 percent of total revenues. This resulted in the elimination of 447 plant-year observations.

The final sample contained 13,391 observations (that is, 1,913 per year).