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

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Abstract

In this paper I seek to quantify the impact of trade-induced technology adoption on the dramatic increase in the skill premium in Mexico after the unilateral trade liberalization of 1985. To do so, I develop and estimate a structural model of trade and technology adoption with heterogeneous firms in a small open economy. The choice of technology affects the productivity realizations that a firm receives, as well as it's skill-intensity. The model is estimated using a Simulated Method of Moments estimator, and fitted to the Mexican manufacturing sector for the period 1987-1990. The estimates indicate that trade-induced technology adoption can explain about one-sixth of the observed rise of the skill premium in Mexico.

Keywords: Wage inequality, Skill-biased technical change, Structural estimation.
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1 Introduction

Over 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 (Goldberg and Pavcnik, 2007, and Hanson and Harrison, 1999a). 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 proposed by Acemoglu (2003) is based on the stylized fact that firms in developing countries import a significant fraction of their machinery and equipment from skill-abundant developed countries (Eaton and Kortum, 2001). Since the relative supply of skilled workers in developed countries has risen continuously since the 1970s, machinery and equipment (M&E) goods produced there have also become more skill-complementary. Thus, firms in developing countries would tend to become more skill-intense after purchasing sophisticated M&E from abroad. Assuming that the operation of advanced M&E is associated with higher fixed costs of operation (because of more frequent/complex maintenance procedures, for example), a trade liberalization, which increases the potential sales for new and existing exporters can induce the adoption of skill-biased technology embodied in capital equipment, increasing the relative demand for skilled labor and the skill premium. In this way, trade liberalization in an unskilled-labor abundant country can result in an increase in wage inequality.

This paper explores the quantitative importance of the mechanism described above, estimating a structural dynamic model of an open economy with heterogeneous firms. Using plant-level 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 the skill premium. This paper is, to the best of my knowledge, the first attempt to structurally estimate the impact of trade-induced technology adoption on wage inequality.[1]

[1]Krusell et. al. (2000) study the role of falling prices of capital equipment in explaining the increase of wage

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 38% 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 are induced to adopt the more advanced technology. When imports increase, the balanced trade condition implies that the value of exports increases in the same magnitude. The number of high-tech exporting firms in the economy rises (from 29 to 32 percent), while firms in the lower tail of the productivity distribution contract and become less skill-intensive or exit. Finally, firms that were using the advanced technology before liberalization see their total profits fall. Overall, the relative demand for skill increases producing an increase in the skill premium of around 2.4 percent. When the cost of technology adoption is affected by the change in import tariffs, trade liberalization produces a 4.2 percent increase in the skill premium. In this scenario, trade-induced technology adoption can explain about one-sixth of the observed increase in the skill premium in the data.

My model builds on work by Hopenhayn (1992), Melitz (2003) and Yeaple (2005). The model is a dynamic model of industry evolution, where 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, where the mean of the process depends on the technology that a firm chooses to operate. Following Yeaple (2005) firms can choose between two technologies: a "traditional" technology characterized by high marginal costs and low fixed costs, and a "modern technology" that has low marginal costs but requires a high fixed cost of operation[2]. Higher productivity draws increase the relative marginal product of skilled labor, so firms substitute towards skilled labor[3], becoming more skill-intensive. Only high-productivity firms (firms with sufficiently large sales) will find 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

inequality in the US using a structural estimation framework.

[2] 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.

[3] This is the case if skilled and unskilled labor are gross substitutes.

technology[4].

Mexico is one the best case studies to understand the distributional effects of increased trade openness. Mexico went from being a very closed economy to become one of the most open countries in the world (trade as a fraction of GDP has increased from 20 percent in 1980 to 55 percent in 1995 and it 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 it 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 here

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. Moreover, when 'mandated wage' equations (zero-profit conditions derived from HOS) are fitted to the data, their estimates are very imprecise, grossly over-predict wage changes and have very low explanatory power[5]. Other studies that have considered alternative hypotheses for the increase in wage inequality in Mexico include Feenstra

[4] 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). Fernandez (2001) studying in detail the retooling of a food processing plant in the Midwest 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. For developing countries, Bustos (2005), Hanson and Harrison (1999a) and Pavcnik (2003) also find a positive correlation between the use of patents and licensing agreements, spending on computers and software, and skill intensity at the firm level.

[5] 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

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 strategies for a firm.[6] If trade openness does provide a strong incentive for firms to invest and absorb new technologies, then this channel might also be relevant to explain the rise of the skill premium observed in Mexico and other developing countries. This paper contributes to this literature by attempting to measure the impact of this complementarity between exporting and technology adoption on wage inequality.

The paper is organized as follows: Section 2 presents the model and discusses its main implications. Section 3 describes the data used for the estimation, and presents preliminary evidence of the patterns of the skill premium, exporting and use of advance technology in the data. Section 4 presents the estimation method, and discusses the resulting structural parameters. Section 5 presents the results of a counter-factual unilateral trade liberalization. Section 6 concludes and suggests avenues for future research. An online appendix provides a brief description of the computational algorithm used to compute the stationary equilibrium of the model and the data cleaning procedures.

[6] 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.

2 Model

Preferences and Demand

Time is discrete and labeled $t = 0, 1, 2, \ldots$. The economy is populated by a mass of L individuals, a fraction λ of which are skilled[7]. Each individual is endowed with one unit of time that is supplied inelastically. Individuals are risk-neutral and maximize the expected present discounted value of a consumption aggregate, so $\mathcal{U} = E_0[\sum_{t=0}^{\infty} \beta^t C_t]$, with $\beta \in (0, 1)$. 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,

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

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 imported consumption good and $\tau_f > 1$ is an iceberg transportation cost. Domestic producers in turn, face a

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

foreign demand schedule $q_x(\omega) = A_x(p_x(\omega))^{-\sigma_c}$ for their own variety, where the size of the foreign market, 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 (2009).

Production

Firms are monopolistic competitors with market power in the good they sell but are price-takers in the labor market. They can 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. Technology k requires a per-period fixed cost of operation f_k denominated in units of output that need to be produced but cannot be sold. 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 as documented by Fernandez (2001). The only input in production is labor, skilled and unskilled. Firms produce according to the following production function:

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

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,

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

Technology 2 results in higher productivity realizations on average[8], 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

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

needs to incur a sunk cost that reflects the costs of retooling and adopting the new productive process[9].

This characterization of technology results in a trade-off for firms between marginal cost and the fixed cost of operating a given technology. The higher productivity realizations that result 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. How responsive will skill intensity be 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 an 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.

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 problem regarding technology adoption. I describe the static problem first.

Static Problem

Incumbent firms can sell their output in the domestic market alone or they can export some of 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 (again, denominated in units of output) 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, which can differ from τ_f. Since production exhibits constant-returns-to-scale, firms independently maximize the profits from domestic and foreign sales. Given the CES preferences, firms set their prices at the usual constant markup over marginal cost.

Every period a firm compares the potential profits from exporting with the participation cost in

[9] 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.

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 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:

$$\begin{aligned} \pi_d(k,z) &= YP^{\sigma_c - 1}\left[\left(\frac{\sigma_c}{\sigma_c - 1}\right) mc(k,z)\right]^{1-\sigma_c}, \\ \pi_x(k,z) &= A_x\left[\left(\frac{\sigma_c}{\sigma_c - 1}\right) \tau_x mc(k,z)\right]^{1-\sigma_c}, \\ \pi(k,z) &= \pi_d(k,z) + \max\bigl\{\pi_x(k,z) - f_x mc(k,z), 0\bigr\}. \end{aligned} \tag{4}$$

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

$$\min_{l,h} w_l l(k,z) + w_h h(k,z) \tag{5}$$

$$\text{s.t.:}$$

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

where $q(k,z)$ denotes total output produced by the firm: domestic and foreign sales in addition to appropriate fixed costs of operation, exporting and potentially the sunk cost of switching from technology 1 to 2.

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. Let $\chi(k,z) \in \{0,1\}$ denote the exit policy rule, where $\chi(k,z) = 1$ denotes exit. If a firm decides to exit the market, it obtains a scrap value of zero and stays out of the market forever. An incumbent firm that decides to stay in the market, produces, decides whether to export or not, and finally chooses the technology that it will operate in period $t+1$. The dynamic programming problem of the firm is given by:

$$V(k,z) = \max\{0, V^C(k,z)\}. \tag{6}$$

$$V^C(k,z) = \max\Bigg\{\pi(k,z) - f_k mc(k,z) + \beta \int_{z'} Q_k(z,z')V(k,z')dz' \;\; , \\ \pi(k,z) - [f_k + S_{\tilde{k}}]mc(k,z) + \beta \int_{z'} Q_{\tilde{k}}(z,z')V(\tilde{k},z')dz' \Bigg\}.$$

where $S_{\tilde{k}}$ is the sunk cost that a firm has to pay when switching from technology k to $\tilde{k}$[10] 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.

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 $G(z)$, 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 $V^E = \int_z V(1,z)dG_E(z) - mc(1,z)S_E$, since I assume that all entrants start using technology 1, so they will tend to be smaller than incumbent firms.

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

Stationary Equilibrium Definition

A recursive competitive equilibrium for the model consists of a value function for firms $V^C(k,z)$, a 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: (i) $V^C(k,z)$ solves the dynamic problem of the firm. Decision rules are optimal; (ii) labor demand equals labor supply for both types of workers; (iii) the flow of entrants balances the flow of exiting firms; (iv) equilibrium good prices are consistent with the aggregate price index P; (v) aggregate income Y equals aggregate profits plus total labor income; (vi) Free entry and (vii) 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, then all firms that become exporters have first to 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 such as 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 domestic firms face when selling abroad falls, total profits for exporting firms increase, providing an incentive to adopt technology 2 if they still have not done it, as the higher fixed cost of operation can be spread over a higher volume of sales. In a 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 contract or exit the market altogether.

If on the other hand, what happens is that the economy pursues a unilateral trade liberalization which reduces 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. The reduction in profits causes smaller, unskilled worker-intensive firms to contract and exit. However, some firms in the middle of the productivity distribution are induced to export, thus maintaining balanced trade. Some of these new exporters will also adopt technology 2 and become more skill-intensive.

3 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 the online Appendix), I have a balanced panel of 1,913 plants for the period 1984-1990. For each plant I 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 Imported Technology

Empirically, I identify plants that purchase imported machinery and equipment (M&E) as using the modern technology described above[11]. Similar definitions of technology adoption have also been used by Huggett and Ospina (2001) and Kasahara (2001). Table 1 shows how export participation and the use of imported machinery and equipment (M&E) 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 for the whole economy shown in Figure 1. In 1986, 66 percent of

[11] 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.

the plants served only the domestic market and did not import any machinery and equipment, by the 1990, this group comprised 42 percent of the sample. At the same time, the number of plants that both export and use imported machinery doubled. The number of plants that export but do not import M&E increased by just 8 percent. Although the barriers faced by Mexican exporters were relatively low and did not change much during this period, one of the components of the macroeconomic stabilization program of 1985 was a 46 percent depreciation of the nominal exchange rate, which in turn resulted in depreciation of the real exchange rate of over one hundred percent, providing a tremendous boost for exports. At the same time, by the end of 1987 the price of machinery and equipment relative to consumer prices experienced a 30 percent fall which persisted until the Tequila crisis of 1994. This trend is very similar to what has been documented in the United States by Krusell et. al. (2000), but was also reinforced by a 55 percent tariff reduction.

Table 1 here

Relative Employment and Wages

Table 2 shows the evolution of mean employment and hourly wages over the sample period. Between 1984 and 1990, the hourly remuneration for skilled workers increased by 20 percent, with most of the increase happening after 1988. Wages for unskilled workers fell by 7 percent over the same period. The two trends put together result in an increase in the skill premium of 31 percent in just six years, or a rate of growth of 4.6 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 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 17 percent, and white and blue-collar employment increase both by 13 percent. 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 increased by 15 percent.

Table 2 here

Across the size distribution of plants, both exporters and plants importing M&E are about 18 percent more skill-intensive than domestic plants that do not use imported capital, and this premium remains stable throughout the sample period for exporters while declining slightly for plants importing machinery. Moreover, similarly to the findings of Bustos (2005) and as predicted by the model in Section 2, new exporters show skill-upgrading before entering the export market[12], while the plants that stop exporting shift their employment towards non-skilled workers, as can be seen in Figure 2.

Figure 2 here

4 Estimation

The model presented in section 2 is estimated on a balanced panel of 1,913 Mexican manufacturing plants for the period 1984-1990, from the manufacturing survey described in section 3. I consider the period 1987-1990 as a post-liberalization stationary equilibrium of the model. The model is set to fit the size distribution of plants in the steady state with low import tariffs, since in the model productivity differences are directly reflected in size (employment) differences. Other features that the model intends to match are the frequency and intensity[13] of exporting, use of imported technology, differences in skill intensity between exporting and non-exporting plants and the entry rates into exporting and use of imported technology[14].

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

[12] Controlling for time and industry-specific variation and differences in the capital stock.

[13] Measured as the mean fraction of revenues accrued from exporting

[14] One problem that I face in the estimation 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.

obtained. Using these policy rules, I simulate the behavior of a large number of plants, creating S[15] simulated panel datasets $\{D^s_{it}(\boldsymbol{\theta})\}$. Taking averages over these simulations, I construct a vector of simulated moments, $\hat{\mathbf{m}}(\boldsymbol{\theta}) = \frac{1}{S}\sum_{s=1}^{S}\mathbf{m}(D^s_{it}(\boldsymbol{\theta}))$.

The estimated vector of parameters minimizes the log-differences between a set of simulated and sample moments:

$$\hat{\boldsymbol{\theta}} = \arg\min_{\boldsymbol{\theta}\in\Theta} \Psi = (\log(\hat{\mathbf{m}}(\boldsymbol{\theta})) - \log(\mathbf{m}))'[(1 + 1/S)\hat{\Sigma}]^{-1}(\log(\hat{\mathbf{m}}(\boldsymbol{\theta})) - \log(\mathbf{m})). \tag{7}$$

where $\mathbf{m}$ is the vector of moments calculated directly from the data, and $\hat{\Sigma}$ is the estimated optimal weighting matrix[16]. The objective function results from a complicated dynamic programming problem, hence is not smooth and presents multiple local minima. In order to deal with these issues, I use a stochastic pattern search algorithm to solve the problem in equation 7.

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[17] 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, 0.311. 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 the post-liberalization period is 1.379, which implies a demand elasticity $\sigma_c = 3.634$. The price of the imported good faced by consumers τ_f is set to 1.05. The variable cost of exporting for Mexican firms is set to match the average U.S. tariff on dutiable goods imported from Mexico, 5 percent. Table 3 summarizes the parameter values fixed outside the estimation. Finally, the size of the economy L is normalized to 1,000.

Table 3 here

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

[16]The details on how the optimal weighting matrix is estimated can be found on Appendix **??**.

[17]Based on *Certificados de la Tesoreria de la Federacion a 28 días*, CETES bonds.

This leaves the following 12 parameters to be estimated by MSM:

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

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, and σ_p is the elasticity of substitution between skilled and unskilled labor.

Table 4 reports the moments used in the estimation. The first set of moments is based on the size distribution of plants in the post-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 premium 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 M&E in steady state.

Table 4 here

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 large, 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 employment dispersion 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.

A set of dynamic moments allows 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.

Point Estimates

Table 5 report the point estimates produced by the model. All the parameters with the exception of the elasticity of substitution are statistically significant. The elasticity of substitution between skilled and unskilled workers is estimated to be 1.41, although is not very precisely estimated as the other parameters in the model, it falls in 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.

Table 5 here

The difference on average productivity for the two technologies is statistically significant. Plants that become sufficiently productive to start operating the modern technology become significantly bigger and more skill-intensive. On average, plants using technology 2 are 82 times larger than their counterparts using the high-marginal cost technology, and account for most of the dispersion of the size distribution.

The fixed cost of operation accounts on average for 33 percent of total labor cost. Although there are no other studies that estimate these fixed costs to compare the plausibility of the estimates, Costantini and Melitz (2007) calibrate the fixed cost of operation in their model so that plants devote 20 percent of their labor cost to overhead, assuming that all non-production workers are devoted to overhead, based on results from Bustos (2005). Exporters pay on average 5 percent of their foreign revenues as a per-period cost to serve the world market. However, since the fixed cost of exporting is denominated in units of output, the smaller new exporters pay on average 11 percent of their exporting revenues.

Given the estimated size of the foreign market and the fixed cost of exporting and using technology 2, a firm that breaks into world markets adopts the modern technology immediately. Iacovone and Javorcik (2007) present evidence of frequent investment spikes and skill upgrading for plants that will start exporting in the next two years in the Mexican manufacturing sector. The implication in terms of the labor force composition is that for the plants that start importing M&E, their skill-intensity almost doubles on impact.

Firms that decide to start using technology 2 in the next period incur an adoption cost equivalent to twice their current revenues at the time of switching. Since plants that start using the modern technology always start exporting at the same time, they become 6 times bigger in terms of employment with total revenue 60 times larger on impact.[18]

Table 6 shows how the model fits the data. The overall difference between the empirical and simulated moments is about 0.09 log-points, and in fact, this difference for several moments is smaller than 5 percent. 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 share of exporters and their export and skill-intensity close fit the data. The simulated size distribution is also very close to the data, although the model slightly overestimates the share of large plants.

Table 6 here

The main shortcoming of the model is its inability to match the dispersion of the size distribution and the size premium of exporters. As pointed out by Armenter and Koren (2009) models with

[18] By the construction of the model, all exporting firms sell the same share of output in foreign markets, about 21 percent in the benchmark estimation. Therefore, all new exporters experience a great boost to their total revenues upon entry.

fixed costs to export have a very hard time matching both the share of exporting plants and the relative size of exporters. Since only one third of the plants in the sample export, the sizeable fixed cost needed to match this moment results in exporters that are too large. In the data, exporters are about twice as big as non-exporters, while in the simulated model they are 82 times larger. This mismatch is also manifested in the skill intensity premium for exporters, since in the model there is a monotonic relationship between size and skill intensity. Although the skill intensity for exporters is closely fitted, non-exporting plants are 58 percent less skill-intensive than in the data. In a similar fashion, the combination of high fixed costs of using the modern technology and fixed costs to participate in the export market that are necessary to match the share of these type of plants in the data, result in an extremely high dispersion of size in the simulated model, almost six times larger than in the data. The fact that the only source of uncertainty in the model is idiosyncratic productivity, which at the same time is highly persistent, contributes to this discrepancy.

Looking at the dynamic moments, the high persistence of the stochastic process for productivity allows me to match the high persistence of exporting status and skill-intensity across firms quite closely. 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 staying a exporter when productivity falls below the level that induced the firm to start exporting.

The high fixed costs of using the modern technology and exporting together with the highly persistent productivity process produce a size distribution with a relatively high mean size (311 workers) and a high share of small plants (about 71 percent of plants have 30 workers or less). Almost all large plants are high-tech exporters and the majority of plants are non-exporters and new entrants (which by assumption enter the market using technology 1) which face a high probability of exiting the market soon[19].

[19] In fact, contrary to the findings of the empirical literature on industry evolution, the model generates exiting plants that are slightly bigger than new entrants. The size difference between the two is not statistically significant.

5 Trade Liberalization

Using the estimates from the previous section, I can now perform a counterfactual analysis and ask what would happen to technology adoption and the skill premium prior to the trade liberalization. In order to capture the experience of Mexico in the second half of the 1980s, I will look at an increase in the foreign price of 38% (that is, τ_f rises from 1.05 to 1.55).[20] The results of this experiment are presented in Table 7. This increase in τ_f is bigger than the change in the production-weighted average tariff for manufacturing imports that took place after liberalization, but intends to take into account the broad licensing requirements that were in place at the time, which are considered the most binding barrier to trade.

Table 7 here

Moving from a low to a high import tariff steady state has a direct effect on the aggregate price index, which rises 21 percent. This has a positive effect on domestic profits and aggregate income which increases by 16 percent, resulting in an increase in the average plant size of about one percent. When the economy moves from a high to a low tariff regime the equilibrium mass of firms in the market falls by approximately 2 percent. Exit takes place at the lower end of the productivity distribution and workers employed on these firms reallocate to larger and more skill-intensive firms. This is a pro-competitive effect that would occurs after trade liberalization.

The balanced trade condition implies that as the value of imports falls, so does the value of exports. The exporting cutoff increases, thus reducing the share of exporting plants by 12 percent when import competition is less intense. The plants that remain exporting are larger and more skill-intensive (12 and 3 percent respectively), although they sell a smaller share of their output abroad. The reduction in exporting plants also is accompanied by a reduction in the fraction of plants importing M&E. The fall in the share of high-tech plants is smaller, hence in the high-tariff equilibrium there will be a very small fraction of high-tech non-exporters.

[20] Notice that the iceberg transportation cost for Mexican producers remains the same.

When moving from a high to a low-tariff steady state, some firms that produced for the domestic market only, find profitable to become exporters when domestic revenues fall due to import competition. The main difference in the size distribution of firms occurs in the middle, as the new users of modern technology move towards the right of the size distribution, as can be seen in Figure 3. 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-enhancing investment activities.

Overall, a unilateral trade liberalization decreases profits for a large number of firms in the economy, therefore, the use of modern technology increases by just one percentage point. This modest increase in turn, results in a 2.46 percent rise of the skill premium, far 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 change in number of exporters and high-tech firms is larger relative to the benchmark experiment, producing a stronger response of the skill premium which now rises by 4.2 percent, about one-sixth of the total increase in the skill premium observed in the data.

6 Concluding Remarks

This article presents a structural empirical 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 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 than domestic firms and continuing exporters and also that they are the ones that benefit the most in terms of productivity change. 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. The results of my estimation suggest that the import-competition effect result from trade liberalization does not provide a sufficiently large push of the relative demand for skilled labor (by means of a significantly adoption of modern technology) to explain the rise of the skill premium that we observed in Mexico since the mid 1980s.

Future work on the impact of trade openness on wage inequality would benefit greatly from using data from the National Survey of Employment, Salaries, Technology, and Training (ENESTYC) to construct more refined measurements of advanced manufacturing technology utilization. This would enable researchers to better identify how the labor force composition of a firm changes when specific technologies are introduced in the workplace. Another interesting area for future research is the transitional dynamics of wage inequality after trade liberalizations. Work on this area should aim to explain why the skill premium increase so rapidly after Mexico joined the GATT while remaining stable when it joined NAFTA and its volume of trade almost tripled. Understanding the evolution of wage inequality is particulary interesting since similar patterns are observed in several developing countries such as Argentina, Chile and Colombia. Structural empirical models of these dynamics should help to further our understanding of the factors determining wage inequality.

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Table 1: Trade 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

Own calculations. Source: *Encuesta Industrial Anual* (Annual Manufacturing Survey), Mexico, 1984-1990, INEGI.

Table 2: Employment and Relative Wages

	1984	1990	% change
Employment			
Production	201.8	228.9	13.4
Non-production	86.7	98.4	13.4
Hourly wages			
Production	28.7	26.7	-6.8
Non-production	56.1	67.5	20.2
Skill premium	2.10	2.76	31.4

Own calculations. Source: *Encuesta Industrial Anual* (Annual Manufacturing Survey), Mexico, 1984-1990, INEGI.

Table 3: Calibrated Parameters

Parameter	**Description**	**Value**
β	Discount factor	0.939
σ_c	Elasticity of substitution, consumption	3.634
τ_f	Post-liberalization import tariff	1.05
τ_x	Export tariff	1.05
λ	Share of skilled workers	0.311
L	Size of Labor force	1,000

Table 4: Moments used for Estimation (Data)

Post-Liberalization (1987-1990)	**Value**
Mean fraction of exporting firms	0.317
Mean exports/sales ratio	0.213
Std. skill share of employment	0.175
Mean skill share, exporters	0.347
Mean entry rate	0.110
Mean total employment	311.76
Std total employment	461.70
Mean total employment, entrants	17.85
Mean total employment, exiters	15.564
Mean fraction of firms using foreign technology	0.222
Mean total employment, exporters	504.93
Correlation(export$_t$, export$_{t-1}$)	0.862
Correlation (skill share$_t$, skill share$_{t-1}$)	0.937
Mean adoption rate imported technology	0.053
Mean entry rate into exporting	0.039
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

Own calculations. Source: *Encuesta Industrial Anual* (Annual Manufacturing Survey), Mexico, 1984-1990, INEGI, and Job Flows in Latin America dataset, Inter-American Development Bank (2004).

Table 5: Parameter Estimates

Parameter	**Point Estimate**
Mean productivity tech. 1 ($\overline{z}_1$)	0.050
	(0.003)
Mean productivity tech. 2 ($\overline{z}_2$)	0.109
	(0.005)
Root productivity process (ϕ)	0.952
	(0.012)
Variance productivity innovations (σ_ε^2)	0.278
	(0.073)
Fixed cost of using tech. 1 (f_1)	91.409
	(2.354)
Fixed cost of using tech. 2 (f_2)	568.53
	(30.242)
Sunk cost of adopting tech. 2 (S)	65.093
	(14.881)
Foreign market size (A_x)	910.23
	(0.892)
Fixed cost of exporting (f_x)	48.726
	(0.045)
Mean productivity, entrants (μ_E)	1.226
	(0.0187)
Sunk cost of entry (S_E)	4.234
	(1.555)
Elasticity of substitution (σ_p)	1.410
in production	(0.952)
Value objective function (Ψ)	0.0926

Standard errors in parenthesis.

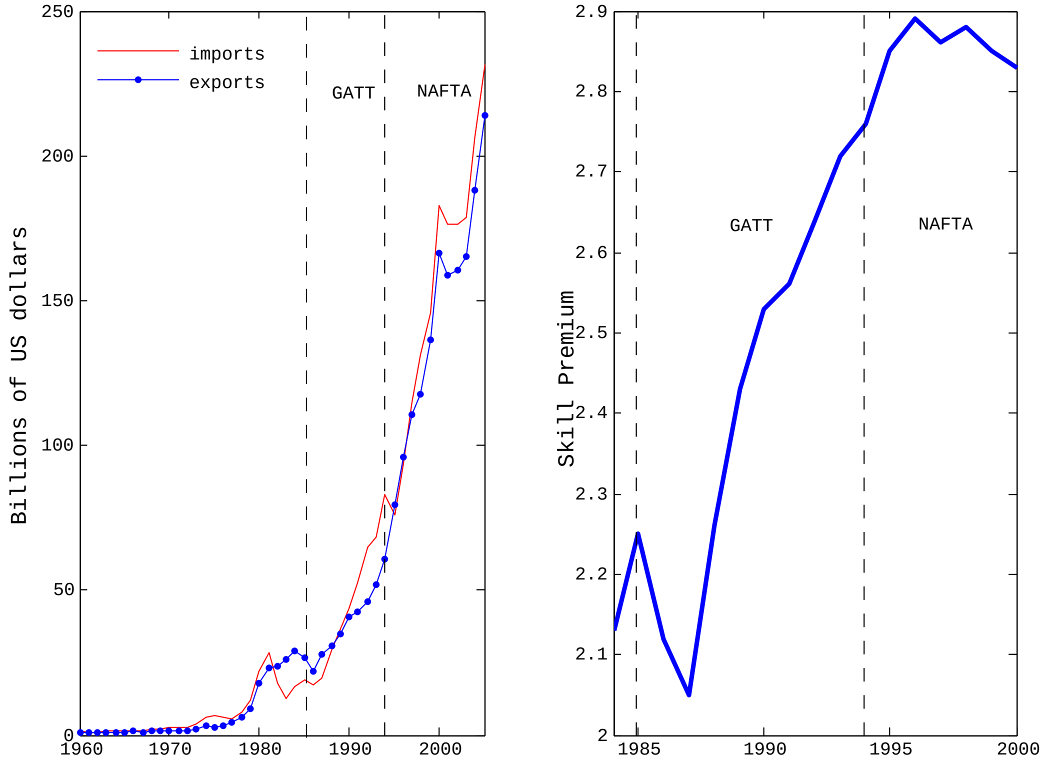
Table 6: Goodness of Fit

Post-Liberalization (1987-1990)	**Data**	**Simulated**	**log-difference**
Share of exporting plants	0.317	**0.327**	0.014
Mean exports/sales ratio	0.213	**0.223**	0.018
Std. skill share of employment	0.175	**0.120**	0.164
Skill share, exporters	0.347	**0.345**	0.002
Mean entry rate	0.110	**0.005**	1.280
Mean total employment	311.76	**380.81**	0.087
Std. log(total employment)	461.70	**2,548.45**	0.742
Mean total employment, entrants	17.85	**19.17**	0.030
Mean total employment, exiters	15.564	**21.54**	0.141
Share of plants using imported M&E	0.222	**0.327**	0.169
Mean total employment, exporters	504.93	**1,111.76**	0.343
Corr. (export$_t$, export$_{t-1}$)	0.862	**0.785**	0.046
Corr. (skill share$_t$, skill share$_{t-1}$)	0.937	**0.908**	0.041
Mean adoption rate imported M&E	0.039	**0.043**	0.084
Mean entry rate into exporting	0.033	**0.043**	0.047
Share of plants with 0-30 employees	0.713	**0.708**	0.003
Share of plants with 30-100 employees	0.209	**0.140**	0.172
Share of plants with 100-500 employees	0.051	**0.086**	0.229

Table 7: Unilateral Trade Liberalization

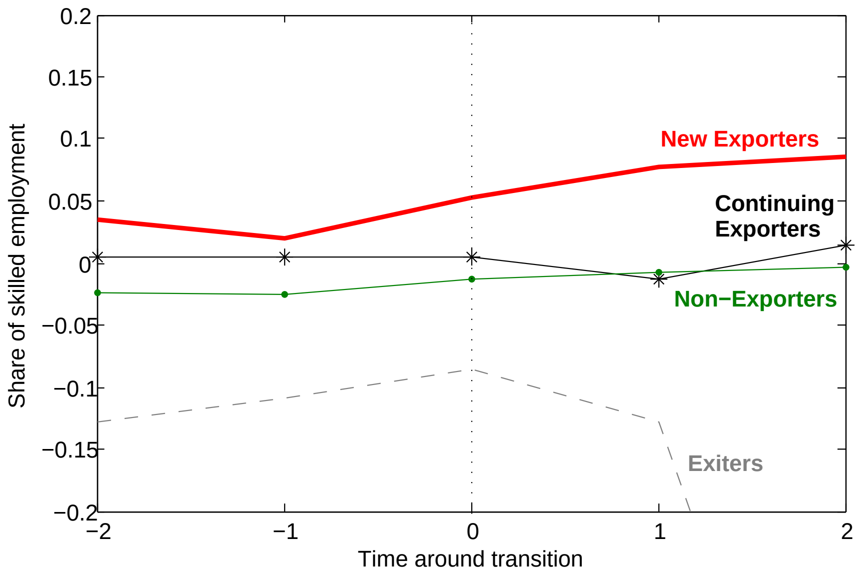
Statistic	**Benchmark** $\tau_f = 1.05$	**High tariff** $\tau_f = 1.55$	**High tariff affecting** S_2
Aggregate income (Y)	100	116.10	118.02
Price index (P)	100	120.91	124.10
Price of foreign consumption good (τ_f)	105	155	155
Mass of incumbent firms (M)	100	101.23	102.50
Skill premium (w_h/w_l)	6.871	6.701	6.584
Share of plants using imported M&E	0.329	0.319	0.274
Share of exporting plants	0.329	0.292	0.262

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.

Figure 2: Skill-Intensity Trajectories Around Entry into Export Market



The figure depicts the residual of regressing the share of non-production employment at the plant level on the log of capital stock, time and 4-digit industry-specific dummies around entry into the export market.

Figure 3: Size Distribution after Trade Liberalization