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Import Variety and Skill Premium in a Calibrated General Equilibrium Model: The Case of Mexico*

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Abstract

It can be theoretically shown that imports of new foreign varieties—an increase in the extensive margin of imports—can be a possible channel for increased skill premium in wages. No past studies, however, have quantified how much of the increase in skill premium can be accounted for by the increase in the extensive margin. This paper formulates a static applied general equilibrium model and then calibrates it to the Mexican input-output matrix for 1987. In the calibrated model, our numerical experiments show that the extensive margin growth in Mexican manufactured imports from the U.S. can account for up to approximately 15 percent of the actual increase in skill premium in Mexico from 1987 to 1994. It indicates that the increase in import variety reinforced the increase in Mexican skill premium that was caused by the Mexican export side.

Keywords: Extensive margin, Import variety, Skill premium, Variety-skill complementarity, Applied general equilibrium, Mexico

JEL Classifications: F12, F16

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1 Introduction

By extending the well-known model of variety trade in intermediate goods advanced by Ethier (1982), it can be theoretically shown that imports of new foreign varieties—an increase in the extensive margin of imports—can be a possible source of an increase in the relative wage of high-skilled to low-skilled workers—the skill premium.[1] An increase in import variety increases the number of inputs used by the final goods and thus widens the gap between the marginal products of high-skilled and low-skilled workers through the variety-skill complementarity.[2] This raises the relative demand and thus relative wage of high-skilled to low-skilled workers and generates the skill premium.

This variety-skill complementarity mechanism is compatible with the spirit of the O-ring model of Kremer (1993), which shows that higher skill workers will use more complex technologies that incorporate more inputs.[3] The mechanism is also compatible with the historical facts in regards to production organization emphasized by Mitchell (2005) if the variety of inputs is interpreted as the variety of tasks which workers need to handle.[4] During the first half of the twentieth century, the spread of mass production required workers to perform a single routine task on the assembly line. On the other hand, during the second half of the century, the introduction of flexible machine tools required workers to handle a wide variety of tasks in each batch. Thus, as the tasks shifted from a single routine task to a wide variety of tasks, the required skill shifted from low skill to high skill.

Hence, this variety-skill complementarity mechanism is intuitively appealing. However, this next poses a quantitative challenge since no past studies have quantified how much of the increase in skill premium is accounted for by the change in the extensive margin.[5] This paper formulates a static applied general equilibrium model and calibrates it to Mexican data for 1987 to quantify the impact of the extensive margin growth in Mexican manufactured imports from the U.S. on the skill premium in Mexico.[6] Here, applied general equilibrium analysis is defined to be the numerical implementation of general equilibrium

[1] Ethier's (1982) model is an intermediate-good version of Krugman's (1979) model of variety trade in final goods.

[2] Kurokawa (2011) formalizes the hypothesis of variety-skill complementarity. Dinopoulos et al. (2009) also link variety trade to wage inequality. Their model, however, modifies the standard one-sector variety-trade model by introducing quasi-homothetic preferences for varieties and non-homothetic technology in the production of each variety, thus relating an increase in the output of each variety—not an increase in the number of variety—to an increase in the relative demand for high-skilled labor by each variety.

[3] Blanchard and Kremer (1997) define the index of complexity which relates the increased number of inputs to more complexity in production processes.

[4] Task-based models (e.g. Grossman and Rossi-Hansberg, 2008; Acemoglu and Autor, 2010) define a skill as a worker's endowment of capabilities for performing various tasks.

[5] Although Kurokawa (2011) has provided several numerical examples to show that the variety-skill complementarity mechanism can be potentially important, it does not produce a more comprehensive quantitative analysis since its purpose is to use a simple model to highlight the existence of such a mechanism.

[6] Due to data constraint, here we use data from 1987. Fortunately, however, Mexico acceded to the General Agreement on Tariffs and Trade (GATT) in 1986 and signed a framework agreement on trade and investment with the U.S. in 1987.

models calibrated to data (Kehoe and Kehoe, 1994; Kehoe and Prescott, 1995).[7]

We use a static applied general equilibrium model which allows us to perform a full-scale calibration.[8] There are two countries and three sectors—primaries, manufactures, and services. While primaries and services are produced under constant returns and perfect competition, manufactures are differentiated goods produced under increasing returns and monopolistic competition. The production of each good uses high- and low-skilled workers, primaries, services, and a variety of manufactures. The technology in each sector displays the variety-skill complementarity mentioned above. Primaries and manufactures are tradable goods, while services are non-tradable goods. In each country, a representative consumer with homothetic preferences consumes these primaries, manufactures, and services. While our model specification is very general, in this paper, we are interested in assessing the impact of the growth in the extensive margin of manufactured imports on the skill premium in Mexico—a small country relative to the U.S. Thus, for our numerical analysis, we specialize the model to a small open economy.

We calibrate our theoretical model to the Mexican input-output matrix for 1987. It is worth noting that as will be shown in the matrix, much of output is services which are non-traded and trade is not balanced in the data, which can be captured by our calibrated model. In this calibrated model, we conduct numerical experiments to see how much of the increase in Mexican skill premium can be accounted for by the extensive margin growth in Mexican manufactured imports from the U.S. Here, the growth in the extensive margin is measured by the growth in what Kehoe and Ruhl (2009) call the "least traded goods." Kehoe and Ruhl classify the set of goods which accounts for only 10 percent of trade as the least traded goods.

Figure 1 plots the 1987-2000 data on the growth in the least traded goods in Mexican manufactured imports from the U.S. for 1987 and on the growth in the relative wage of high-skilled to low-skilled labor in Mexican manufacturing industries.[9] Figure 1 reveals that the least traded goods that account for 10 percent of Mexican manufactured imports from the U.S. in 1987 account for 19.5 percent in 1994. This indicates that over this period, Mexico started importing U.S. manufactured goods that it had not imported before or had imported

[7] See Kehoe and Kehoe (1994) and Kehoe and Prescott (1995) for the discipline and history of applied general equilibrium analysis. While we use it for the Mexican economy, Kehoe et al. (1988) and Kehoe et al. (1995) use a static applied general equilibrium model for the Spanish economy to analyze the impact of the reforms implemented in 1986 to accompany Spain's entry into the European Community (EC).

[8] Our model extends Bergoeing and Kehoe's (2003) applied general equilibrium model by distinguishing high- and low-skilled labor, thus relating an increase in extensive margin into an increase in skill premium.

[9] The data for the least traded goods growth are the Standard International Trade Classification (SITC) (revision 2) 4-digit manufacturing data from the OECD International Trade by Commodities Statistics (ITCS). See Kehoe and Ruhl (2009) for the detailed procedure used to construct Figure 1. The data for the Mexican relative wage is from the *Encuesta Industrial Mensual* (EIM) [Mexican Monthly Industrial Survey] conducted by the *Instituto Nacional de Estadística Geografía e Informática* (INEGI). Here, we use non-production and production workers as an index for high-skilled and low-skilled workers (Berman et al., 1994; Robertson, 2004). We calculate the Mexican relative wage by first calculating the monthly income per person of non-production relative to production labor. The annual average is then produced by averaging this monthly relative wage.

only in small quantities, thus indicating that the variety of Mexican manufactured imports from the U.S. increased. The figure also reveals that the growth in the least traded goods was highly correlated with the growth in the relative wage in Mexico over 1987-2000. In fact, the correlation between these two series was high, 0.926, over the period. As can be seen, the extensive margin of manufactured imports was drastically growing before the North American Free Trade Agreement (NAFTA) was enacted in 1994, and it became stable after the NAFTA. Similarly, the Mexican skill premium was also drastically increasing before the NAFTA and became stable (with a slight decrease) after the NAFTA.[10]

Since our interest is in the impact of an increase in the extensive margin of manufactured imports on rising skill premium, our numerical experiments will focus on the period 1987-1994, when both the extensive margin of manufactured imports and the skill premium were drastically increasing.[11] By restricting ourselves to this period, we give the variety-skill complementarity mechanism a best chance to account for the rising skill premium in Mexico. Specifically, we assess how much of the increase in Mexican skill premium can be accounted for by the extensive margin growth in Mexican manufactured imports from the U.S. over the period. We find that the relative wage of high- to low-skilled labor can increase by up to approximately 6.5 percent if the extensive margin of manufactured imports increases according to the data. Hence, the growth in the extensive margin of manufactured imports over 1987-1994 can raise Mexican skill premium by up to approximately 6.5 percent. On the other hand, the data show that Mexican skill premium increased from 2.021 to 2.899 over 1987-1994, which is a 43.4 percent increase. Thus the results indicate that the extensive margin growth in Mexican manufactured imports from the U.S. can account for up to approximately 15 percent of the change in Mexican skill premium over 1987-1994. We, therefore, illustrate that the extensive margin of manufactured imports is possibly a channel significantly contributing to the increase in wage inequality in Mexico.[12]

Of course, various mechanisms which can explain the increase in Mexican skill premium have been proposed and empirically tested (e.g. Cragg and Epelbaum, 1996; Revenga, 1997; Hanson and Harrison, 1999; Feliciano, 2001; Esquivel and Rodríguez-López, 2003; Robertson, 2004; Verhoogen, 2008).[13] As shown by these past studies, both technological

[10] Esquivel and Rodríguez-López (2003) also show the same movements of Mexican wages. Robertson (2004) argues, using the Mexican Industrial Census, that the Mexican skill premium declined from 1994 to 1998.

[11] Note that the variety-skill complementarity can be also compatible with the 1994-2000 data in that the skill premium did not show an increasing trend when import variety did not show an increasing trend during the period 1994-2000.

[12] It should be noted that here we look at Mexican trade with the U.S. alone. Our results, however, would be little changed even if Mexican trade with other trade partners of Mexico is also included. This is because Mexico's principal trade partner is by far the U.S., which in 1994 supplied 69 percent of Mexico's imports and attracted 85 percent of its exports. In 1994, Japan provided 6 percent of Mexico's imports, Germany 4 percent, Canada 2 percent, and France 2 percent. Canada was the second largest destination for Mexican products, accounting for 2 percent of exports. Outside the NAFTA, no individual country absorbed more than 2 percent of total Mexican exports.

[13] There are also many notable empirical/quantitative studies on U.S. wage inequality. One set of studies highlights the influence of skill-biased technological change (e.g. Katz and Murphy, 1992; Berman et al.,

change and trade can affect skill premium through different channels. This paper focuses on their effects through the extensive margin of manufactured imports. While many other factors can also potentially cause import variety to increase, Kehoe and Ruhl's (2009) data analysis suggests that the extensive margin growth is primarily driven by these two factors, namely, trade liberalization or structural change, and not by the usual turbulence of business cycles. Thus, in the case of Mexico, the increase in import variety could be a result of trade liberalization in Mexico or of technological change in the U.S. increasing the number of varieties produced there. The results of this paper are independent of these underlying causes of the increase in import variety.[14]

Thus our paper makes the following contributions to the literature on Mexican wage inequality. First, our paper would be the closest and a good complement to Verhoogen (2008). The extensive margin of exports has recently been proven useful in understanding heterogeneous firms export patterns (e.g. Melitz, 2003). Upon application of it, Verhoogen (2008) shows that only the most productive plants in Mexico enter the export market and produce a better-quality good for export than for the domestic market, thus requiring paying high wages to both white-collar and blue-collar employees, but especially to white-collar employees. Thus, while Verhoogen (2008) focuses on the role of the extensive margin of exports in understanding Mexican skill premium, we look at the role of the extensive margin of imports.

Second, we show the possibility that this import variety channel is quantitatively important. It indicates that the increase in import variety reinforced the increase in Mexican skill premium that was caused by the Mexican export side (Verhoogen, 2008). Thus the effects on Mexican skill premium of the extensive margin overall might be more important than believed. Third, from a methodological viewpoint, while static applied general equilibrium models have been used in trade studies, in particular, for analyses of the impact of the NAFTA, ours is a first application to the analysis of Mexican wage inequality.[15]

The rest of this paper is organized as follows. In Section 2, we formulate our static applied general equilibrium model. Section 3 calibrates the model to the Mexican input-output matrix for 1987. Using the calibrated model, we present our numerical experiments

1994; Berman et al., 1998; Katz and Autor, 1999; Krusell et al., 2000). Another set of studies concentrates on the effect of trade (e.g. Borjas and Ramey, 1994; Krugman, 1995; Feenstra and Hanson, 1996; Krugman, 1998; Harrigan and Balaban, 1999; Xu, 2003; Zhu and Trefler, 2005; Burstein and Vogel, 2010). Another set of studies analyzes the relative effect of trade vs. technological change within a unified framework (e.g. Feenstra and Hanson, 1999).

[14] Our exercise avoids the pitfalls pointed out by Deardorff and Hakura (1994) as it can be interpreted as answering either of the following two questions that they suggest are theoretically meaningful: (1) what have been the effects on skill premium of trade liberalization over 1987-1994 through the extensive margin of trade; or (2) what have been the effects in Mexico of increases in product variety in the U.S. over the same period to the extent that they have been transmitted through the increase in the extensive margin of trade.

[15] Kehoe (2005) evaluates the performances of three of the most prominent static applied general equilibrium models used to predict the impact of the NAFTA: the Brown-Deardorff-Stern model of all three North American economies, the Cox-Harris model of Canada, and the Sobarzo model of Mexico. See, for example, Francois and Shiells (1994) for applied general equilibrium models of the impact of the NAFTA.

in Section 4. Finally, Section 5 summarizes main results and mentions future research.

2 The Model

Consider a world in which there are two countries: country 1 and country 2. In each country j, $j = 1, 2$, there are three types of goods, a primary good that is tradable and homogeneous, varieties of a manufactured good that are tradable and differentiated by the firm that produces them, and a service good that is homogeneous and non-tradable. The varieties of the manufactured good are combined to produce a composite manufactured good. Each country j has a given endowment of high-skilled labor and low-skilled labor, H^j and L^j.[16]

A representative consumer in country j solves the problem of maximizing

$$\beta_p \log c_p^j + \beta_m \log c_m^j + \beta_s \log c_s^j, \tag{1}$$

subject to

$$\begin{aligned} q_p^j c_p^j + q_m^j c_m^j + q_s^j c_s^j &\leq w_H^j H^j + w_L^j L^j \\ c_p^j, c_m^j, c_s^j &\geq 0. \end{aligned} \tag{2}$$

Here, c_p^j is the consumption of the primary good and q_p^j is its price; c_m^j is the consumption of the composite manufactured good and q_m^j is its price; c_s^j is the consumption of the service good and q_s^j is its price; and w_H^j and w_L^j are the wages for the high- and the low-skilled labor. The composite manufactured goods is a CES aggregate of different varieties given by

$$c_m^j = \left(\int_{D^w} (c_{mz}^j)^\rho dz \right)^{\frac{1}{\rho}}, \tag{3}$$

where parameter ρ, $\rho < 1$, governs the elasticity of substitution, $1/(1-\rho)$, between any two differentiated varieties in the interval $D^w = [0, n^1 + n^2]$ of the varieties of the manufactured good produced throughout the world. On the other hand, note that the elasticity of substitution between primaries, services, and composite manufactures is 1.

Both the primary and the service good in country j are produced according to constant returns production functions

$$\begin{aligned} y_p^j &= \gamma_p \left[a_p \left\{ b_p (x_{m,p}^j)^\varepsilon + (1-b_p)(H_p^j)^\varepsilon \right\}^{\frac{\mu}{\varepsilon}} + (1-a_p)(L_p^j)^\mu \right]^{\frac{\alpha_{p1}}{\mu}} (x_{p,p}^j)^{\alpha_{p2}} (x_{s,p}^j)^{\alpha_{p3}}, \quad (4) \\ y_s^j &= \gamma_s \left[a_s \left\{ b_s (x_{m,s}^j)^\varepsilon + (1-b_s)(H_s^j)^\varepsilon \right\}^{\frac{\mu}{\varepsilon}} + (1-a_s)(L_s^j)^\mu \right]^{\frac{\alpha_{s1}}{\mu}} (x_{p,s}^j)^{\alpha_{s2}} (x_{s,s}^j)^{\alpha_{s3}}, \quad (5) \end{aligned}$$

[16] It should be noted that by introducing primary and service goods in the present paper, we have generalized Kurokawa's (2011) model that has only manufactured goods produced by high- and low-skilled labor. In addition, we have also allowed trade in final goods which is absent in Kurokawa's model.

where $0 < a_i,\ b_i < 1$, $\gamma_i > 0$, and $0 < \alpha_{ik} < 1$ are sector-specific parameters with $\alpha_{i1} + \alpha_{i2} + \alpha_{i3} = 1$ and $x^j_{h,i}$ refers to factor h used in sector i. The composite manufactured inputs are

$$x^j_{m,p} = \left(\int_{D^w} {x^j_{mz,p}}^\rho dz \right)^{\frac{1}{\rho}} \quad \text{and} \quad x^j_{m,s} = \left(\int_{D^w} {x_{mz,s}}^\rho dz \right)^{\frac{1}{\rho}}. \tag{6}$$

In contrast, the technology for producing manufactured goods exhibits increasing returns to scale because of the presence of fixed costs. Specifically, every manufacturing firm z, $z \in D^w$, has the production function

$$y^j_{mz} = \max \left\{ \gamma_m \left[\begin{array}{c} a_m \left\{ b_m (x^j_{m,mz})^\varepsilon + (1 - b_m) (H^j_{mz})^\varepsilon \right\}^{\frac{\mu}{\varepsilon}} + \\ (1 - a_m) (L^j_{mz})^\mu \end{array} \right]^{\frac{\alpha_{m1}}{\mu}} (x^j_{p,mz})^{\alpha_{m2}} (x^j_{s,mz})^{\alpha_{m3}} - F, 0 \right\}, \tag{7}$$

where as in other sectors $0 < a_m,\ b_m < 1$, $\gamma_m > 0$, $0 < \alpha_{mk} < 1$, and $\alpha_{m1} + \alpha_{m2} + \alpha_{m3} = 1$. Also,

$$x^j_{m,mz} = \left(\int_{D^w} \left(x^j_{mz',mz} \right)^\rho dz' \right)^{\frac{1}{\rho}}, \tag{8}$$

and $F > 0$ is the level of fixed costs in terms of output.

Thus, in each sector, production requires primaries, services, and a composite good as inputs. The composite input is produced by combining the manufactured good, high-skilled labor, and low-skilled labor with a nested-CES technology, where substitution parameters ε and μ are the same across all sectors. The nested-CES specification allows us to introduce variety-skill complementarity in production in the most natural and parsimonious manner. This is achieved by setting $\varepsilon < \mu$ which makes the varieties of manufactured goods relatively more complementary to high-skilled labor than to low-skilled one.[17]

Let $\tilde{c}^j_{mz}(q^j_m, w^j_H, w^j_L, q^j_p, q^j_s; y_{mz} + F)$ be the solution to the cost minimization problem for manufacturing firm z. As the manufacturing sector produces output using a nested-CES technology with primaries, services, and a composite input made from manufactured good, high-skilled labor, and low-skilled labor as inputs, the cost function can be written in terms of the sub-cost functions as follows:

$$\begin{aligned} \tilde{c}^j_{mz}\left(q^j_m, w^j_H, w^j_L, q^j_p, q^j_s; y_{mz} + F\right) &= \tilde{c}^j_{mz}\left(\tilde{c}^j_{A,m}\left(q^j_m, w^j_H, w^j_L\right), q^j_p, q^j_s; y_{mz} + F\right), \\ &= \tilde{c}^j_{mz}\left(\tilde{c}^j_{A,m}\left(\tilde{c}^j_{B,m}\left(q^j_m, w^j_H\right), w^j_L\right), q^j_p, q^j_s; y_{mz} + F\right), \\ &= \frac{1}{\gamma_m} \left(\frac{\tilde{c}^j_{A,m}}{\alpha_{m1}}\right)^{\alpha_{m1}} \left(\frac{q_p}{\alpha_{m2}}\right)^{\alpha_{m2}} \left(\frac{q_s}{\alpha_{m3}}\right)^{\alpha_{m3}} \left[\begin{array}{c} y_{mz} \\ +F \end{array} \right], \end{aligned} \tag{9}$$

[17] Kurokawa (2011) formalizes the hypothesis of variety-skill complementarity. As mentioned in the introduction, the number of inputs plays a related role in the O-ring model of Kremer (1993), which shows that higher skill workers will use more complex technologies that incorporate more inputs.

where $z \in D^1 = \left[0, n^1\right]$ or $z \in D^2 = \left[n^1, n^1 + n^2\right]$, and the sub-cost functions are

$$\tilde{c}^j_{A,m}\left(q^j_m, w^j_H, w^j_L\right) = \left[a_m^{\frac{1}{1-\mu}} \tilde{c}^j_{B,m}\left(q^j_m, w^j_H\right)^{-\frac{\mu}{1-\mu}} + (1-a_m)^{\frac{1}{1-\mu}} \left(w^j_L\right)^{-\frac{\mu}{1-\mu}}\right]^{-\frac{1-\mu}{\mu}}, \tag{10}$$

$$\tilde{c}^j_{B,m}\left(q^j_m, w^j_H\right) = \left[b_m^{\frac{1}{1-\varepsilon}} \left(q^j_m\right)^{-\frac{\varepsilon}{1-\varepsilon}} + (1-b_m)^{\frac{1}{1-\varepsilon}} \left(w^j_H\right)^{-\frac{\varepsilon}{1-\varepsilon}}\right]^{-\frac{1-\varepsilon}{\varepsilon}}. \tag{11}$$

Thus we can write $\tilde{c}^j_{mz}(.)$ as a linear function of $y_{mz} + F$:

$$\tilde{c}^j_{mz}\left(q^j_m, w^j_H, w^j_L, q^j_p, q^j_s; y_{mz} + F\right) = G^j\left(y_{mz} + F\right), \qquad z \in D^j, \quad j = 1, 2. \tag{12}$$

The firms in the manufacturing sector are monopolistic competitors and face a downward sloping demand curve and manufacturing firm $z \in D^w$ in country j sets its price q^j_{mz} to maximize profits:

$$\max \pi^j_{mz} = q^j_{mz} y_{mz} - G^j\left(y_{mz} + F\right), \tag{13}$$

taking all other prices as given.

Let us derive the demand for each variety z. The demand by the consumer in country j for the domestic variety $z \in D^j$ and the foreign variety $z \in D^{-j}$ is:

$$c^j_{mz} = \left(\frac{q^j_{mz}}{q^j_m}\right)^{-\frac{1}{1-\rho}} \frac{\beta_m\left(w^j_H H^j + w^j_L L^j\right)}{q^j_m}, \qquad z \in D^j, \tag{14}$$

$$c^j_{mz} = \left(\frac{q^{-j}_{mz}}{q^j_m}\right)^{-\frac{1}{1-\rho}} \frac{\beta_m\left(w^j_H H^j + w^j_L L^j\right)}{q^j_m}, \qquad z \in D^{-j}, \tag{15}$$

where q^j_{mz} is the price in country j of variety $z \in D^j$ and q^{-j}_{mz} the price in country $-j$ of variety $z \in D^{-j}$. One can show that q^j_m can be written as an exact consumption-based price index of the prices of individual varieties as follows:

$$q^j_m = \left[\int_{D^j} \left(q^j_{mz}\right)^{-\frac{\rho}{1-\rho}} dz + \int_{D^{-j}} \left(q^{-j}_{mz}\right)^{-\frac{\rho}{1-\rho}} dz\right]^{-\frac{1-\rho}{\rho}}. \tag{16}$$

Hence, the total consumption demand for variety $z \in D^j$ faced by the firm is:

$$\begin{aligned} c^j_{mz} + c^{-j}_{mz} &= \left(\frac{q^j_{mz}}{q^j_m}\right)^{-\frac{1}{1-\rho}} \frac{\beta_m\left(w^j_H H^j + w^j_L L^j\right)}{q^j_m} + \\ &\quad \left(\frac{q^j_{mz}}{q^{-j}_m}\right)^{-\frac{1}{1-\rho}} \frac{\beta_m\left(w^{-j}_H H^{-j} + w^{-j}_L L^{-j}\right)}{q^{-j}_m} \\ &= E q_{mz}^{-\frac{1}{1-\rho}}, \qquad z \in D^j, \quad j = 1, 2, \end{aligned} \tag{17}$$

where

$$E = \frac{\beta_m \left(w_H^j H^j + w_L^j L^j \right)}{(q_m^j)^{-\frac{\rho}{1-\rho}}} + \frac{\beta_m \left(w_H^{-j} H^{-j} + w_L^{-j} L^{-j} \right)}{(q_m^{-j})^{-\frac{\rho}{1-\rho}}}. \tag{18}$$

Thus the total consumption demand varies with price q_{mz}^j with elasticity $-1/(1-\rho)$. One can show that the same holds true for the total input demand by firms for variety $z \in D^j$. Thus the total consumption and input demand for variety z can be expressed as

$$y_{mz} = T q_{mz}^{-\frac{1}{1-\rho}}, \qquad z \in D^j, \quad j = 1, 2, \tag{19}$$

for some constant $T > 0$.

Hence, given the number of varieties, the profit of manufacturing firm z can be rewritten as:

$$\pi_{mz}^j = q_{mz}^j T q_{mz}^{-\frac{1}{1-\rho}} - G^j T q_{mz}^{-\frac{1}{1-\rho}} - G^j F. \tag{20}$$

The first order condition for profit maximization with respect to q_{mz} then gives:

$$q_{mz} = \frac{G^j}{\rho}, \qquad z \in D^j, \quad j = 1, 2. \tag{21}$$

Further, by the zero profit condition for this q_{mz}:

$$\pi_{mz}^j = \frac{G^j}{\rho} y_{mz} - G^j \left(y_{mz} + F \right) = 0, \tag{22}$$

we obtain

$$y_{mz}^j = \frac{\rho}{1-\rho} F, \qquad z \in D^w. \tag{23}$$

Definition 1 *An* ***equilibrium*** *is a vector of prices* q_p^j, q_s^j, q_{mz}^j, w_H^j, w_L^j, *and quantities* c_p^j, c_s^j, c_{mz}^j, y_p^j, y_s^j, y_{mz}^j, $x_{mz,p}^j$, $x_{p,p}^j$, $x_{s,p}^j$, H_p^j, L_p^j, $x_{mz,s}^j$, $x_{p,s}^j$, $x_{s,s}^j$, H_s^j, L_s^j, $x_{mz,mz}^j$, $x_{p,mz}^j$, $x_{s,mz}^j$, H_{mz}^j, L_{mz}^j, $z \in D^j$, $j = 1, 2$, *an interval* $D^w = [0, n^1 + n^2]$, *and a measure of manufacturing firms for each country* $D^1 = \left[0, n^1\right]$ *and* $D^2 = \left[n^1, n^1 + n^2\right]$ *such that*

1. *Given the prices, the consumption plans* c_p^j, c_{mz}^j, c_s^j *solve the utility maximization problem of consumer* j*;*

2. *Given factor prices, the production plans (including the factor demands) for the primary and service good satisfy the conditions for zero profit and cost minimization;*

3. *Given factor prices and demand, price* q_{mz}^j *and production plans (including the factor demands) of the manufacturing firm* z *in country* j *maximize profits and minimize costs;*

4. *Every manufacturing firm* $z \in D^w$ *earns zero profits;*

5. *The markets for goods clear,*

$$\sum_{j=1}^{2}\left(c_p^j + x_{p,p}^j + x_{p,s}^j + \int_{D^j} x_{p,mz}^j dz\right) = \sum_{j=1}^{2} y_p^j, \tag{24}$$

$$c_s^j + x_{s,p}^j + x_{s,s}^j + \int_{D^j} x_{s,mz}^j dz = y_s^j,\ j = 1,2, \tag{25}$$

$$\left[\begin{array}{c} c_{mz}^j + x_{mz,p}^j + x_{mz,s}^j + \int_{D^j} x_{mz,mz'}^j dz' + \\ \left(c_{mz}^{-j} + x_{mz,p}^{-j} + x_{mz,s}^{-j} + \int_{D^{-j}} x_{mz,mz'}^j dz'\right) \end{array}\right] = y_{mz}^j,\ j = 1,2; \tag{26}$$

6. *The factor markets clear,*

$$H_p^j + \int_{D^j} H_{mz}^j dz + H_s^j = H^j, \quad j = 1,2, \tag{27}$$

$$L_p^j + \int_{D^j} L_{mz}^j dz + L_s^j = L^j, \quad j = 1,2; \tag{28}$$

7. *The number of available varieties for consumption is the number of varieties produced,*

$$D^w = D^1 \cup D^2.$$

3 Calibration of the Model

In the previous section, we have laid out the model in the two-country setting. We, however, are interested in assessing the impact of the growth in the extensive margin of manufactured imports on the skill premium in Mexico—a small country relative to the U.S. Thus, in our simulations, we will concentrate on the small open economy case. Therefore, we will omit country superscripts from this section onwards. The details of solving the model are standard and have been relegated to Appendix A.

We calibrate the model to the input-output matrix for Mexico for the year 1987 to test the ability of the model to account for the rise in skill premium in Mexico over the period 1987-1994. The choice of 1987 comes from data constraint. However, this is not a serious limitation since Mexico acceded to the GATT in 1986 and signed a framework agreement on trade and investment with the U.S. in 1987.

3.1 Data

The input-output matrix for Mexico for 1987 is given in Appendix B. This matrix contains the information on the factor costs in each sector ($X_{h,i}$) where i stands for sector and h stands for the factor; the value of output for each sector, Y_i; the value of exports and imports for each sector, EX_i and IM_i; and the value of consumption of each good, C_i. All of the steps to construct this input-output matrix and the sources of the data are shown in Appendix B. Note that we do not have data on the break-up of the cost share of labor

between low-skilled and high-skilled labor for the primary and service sectors for Mexico.[18] In the benchmark simulations, we assume the share to be the same as in the manufacturing sector. In an alternative scenario, we use the break-up for Chile for 1992.

As shown in the matrix, much of output is services which are non-traded, and trade is not balanced in the data. We can also see that the gross value added in each sector equals its factor payments

$$Y_i = \sum_h X_{h,i}, \qquad i = p, m, s, \tag{29}$$

and that the total use of each good equals its net supply

$$\sum_k X_{i,k} + C_i = Y_i + IM_i - EX_i \qquad i = p, m, s. \tag{30}$$

3.2 Calibration

We begin our calibration by choosing the values of the three substitution parameters in the model, ρ, μ, and ε. The parameter ρ governs the elasticity of substitution, $1/(1-\rho)$, among varieties. Recall that the elasticity of substitution between the primaries, the services, and the manufactures is already set to 1. We set $\rho = 19/29$, which means that the elasticity of substitution among varieties, $1/(1-\rho)$, is 2.9. This is in accordance with evidence on the elasticity of substitution across varieties of intermediate goods estimated by Klenow and Rodríguez-Clare (1997).[19]

Parameters μ and ε set the elasticity of substitution between the varieties and low-skilled labor and between the varieties and high-skilled labor, respectively. Due to the uncertainty about these elasticities, we set μ and ε as free parameters. Here, as a benchmark case, we choose the elasticity of substitution for low-skilled labor to be 2 and for high-skilled labor to be 0.5.[20] This implies $\mu = 1/2$ and $\varepsilon = -1$. In Section 4.2, we will do an extensive sensitivity analysis for a variety of values of μ and ε and report the range for skill premium rather than a point estimate. Therefore, the choice of benchmark values of these two substitution parameters does not affect the results that we report.

We next calibrate the rest of the model's parameters to match the input-output matrix

[18] As will be noted in footnote 30 in Section 4.3, though the *Encuesta Nacional de Empleo Urbano* (ENEU) [National Urban Employment Survey] conducted by the INEGI has data for the primary and service sectors in Mexico, unfortunately it is not consistent with the data that we use for skill premium and input-output matrix.

[19] Klenow and Rodríguez-Clare (1997)'s estimate, though based on Costa Rican data, is in line with estimates of substitutability in the trade and industrial organization literatures (see Feenstra, 1995).

[20] Although our focus is on variety-skill complementarity, it is worth noting that a number of studies report evidence on capital-skill complementarity. For example, see Griliches (1969), Berndt and Christensen (1974), Fallon and Layard (1975), and Brown and Christensen (1981). As Krusell et al. (2000) document, the majority of the estimates for the elasticity of substitution between low-skilled labor and capital lie between 0.5 and 3 whereas most estimates of the elasticity of substitution between high-skilled labor and capital are below 1.2, and as they note, "several are near zero." This capital-skill complementarity hypothesis was first formalized by Griliches (1969). Goldin and Katz (1998) document the importance of capital-skill complementarity during the period 1909-1929. Lindquist (2005) has recently replicated the research by Krusell et al. (2000) for Sweden.

for Mexico for 1987. We begin this calibration by setting

$$E = C_p + C_m + C_s. \tag{31}$$

Further, given that there are productivity parameters in the production functions, we can only normalize all domestic goods prices to 1, i.e., we set

$$q_p = q_m = q_s = 1. \tag{32}$$

Further, we can also independently set the wage rates. Hence, without loss of generality, let[21]

$$w_L = w_H = 1. \tag{33}$$

The calculation of $\beta's$ is straightforward in our case

$$\beta_i = \frac{C_i}{E}, \qquad i = p, s, m. \tag{34}$$

For factor h, define the cost share of that factor in sector i as $\theta_{h,i}$ and denote by $\mathbf{w}_h$ the price of factor $h = p, s, m, L, H$.[22] Then, from the demand functions derived above, we get

$$\theta_{h,i}\left(q_m, w_H, w_L, q_p, q_s\right) = \frac{\mathbf{w}_h x_{h,i}\left(q_m, w_H, w_L, q_p, q_s\right)}{\tilde{c}_i\left(q_m, w_H, w_L, q_p, q_s\right)}. \tag{35}$$

Then, $b_i's$ can be solved from the following equations

$$\frac{\theta_{m,i}}{\theta_{H,i}} = \frac{X_{m,i}}{X_{H,i}}, \qquad i = p, s, mz. \tag{36}$$

Each of these equations has only one unknown, b_i. Note that here we are using the fact that

$$\frac{X_{m,mz}}{X_{H,mz}} = \frac{X_{m,m}}{X_{H,m}}. \tag{37}$$

Similarly, $a_i's$ solve the following equations

$$\frac{\theta_{m,i} + \theta_{H,i}}{\theta_{L,i}} = \frac{X_{m,i} + X_{H,i}}{X_{L,i}}, \qquad i = p, s, mz. \tag{38}$$

Recall, as we do not have data on the break-up of the cost share of labor between low-skilled and high-skilled labor for the primary and service sectors, in the benchmark calibration we set $\theta_{H,i}/\theta_{L,i} = \theta_{H,m}/\theta_{L,m}$, $i = p, s$.[23]

[21] It does not matter how big w_H is in relation to w_L. Normalizing prices/wages at one only changes the units of goods and labor, but does not change the results in terms of percent changes.

[22] For example, $w_m = q_m$, $w_p = q_p$, and $w_s = q_s$.

[23] In Section 4.3, for the primary and service sectors, we will use the break-up in Chile in 1992.

The $\alpha_i^{\prime}s$ are easy to calculate as well

$$\alpha_{i1} = \frac{X_{m,i}+X_{H,i}+X_{L,i}}{Y_i}, \quad i=p,s,mz, \tag{39}$$

$$\alpha_{i2} = \frac{X_{p,i}}{Y_i}, \quad i=p,s,mz, \tag{40}$$

$$\alpha_{i3} = \frac{X_{s,i}}{Y_i}, \quad i=p,s,mz. \tag{41}$$

With all goods prices (q_p, q_m, q_s) and factor prices (w_H, w_L) normalized to 1, factor costs equal factor demands, and it is easy to calibrate γ_p and γ_s by using the production functions $(4-5)$ in which the only remaining unknown is γ_i. Furthermore, by labor market clearing, the supply of low-skilled and high-skilled labor is simply equal to the factor payments of each labor.

$$L = \sum_{i=p,m,s} X_{L,i}, \tag{42}$$

$$H = \sum_{i=p,m,s} X_{H,i}. \tag{43}$$

3.2.1 Remaining Calibration

To complete the calibration we still need to find values for

$$q_{mz},\ q_{mz^*},\ \gamma_m,\ n,\ n^*, x_{mz},\ x_{mz^*}. \tag{44}$$

We begin with the composite of the domestic traded varieties which can be expressed as

$$\bar{x}_{mz} = \frac{Y_m - EX_m}{\bar{q}_{mz}} = \frac{Y_m - EX_m}{n^{-\frac{1-\rho}{\rho}} q_{mz}}, \tag{45}$$

which in turn yields[24]

$$x_{mz} = \frac{\bar{x}_{mz}}{n^{\frac{1}{\rho}}} = \frac{Y_m - EX_m}{n q_{mz}}. \tag{46}$$

Similarly,

$$x_{mz^*} = \frac{\bar{x}_{mz^*}}{(n^*)^{\frac{1}{\rho}}} = \frac{IM_m}{n^* q_{mz^*}}. \tag{47}$$

Since varieties are aggregated using a CES aggregator, it is easy to see from $(14-15)$ or $(A.9-A.10)$ that the relative demand for the domestic and foreign varieties is

$$\frac{x_{mz}}{x_{mz^*}} = \left(\frac{q_{mz}}{q_{mz^*}}\right)^{-\frac{1}{1-\rho}}. \tag{48}$$

[24] We could have obtained this directly using symmetry.

Further, from the price index of the manufactured good $(A.12)$, we have

$$q_m = \left[n q_{mz}^{-\frac{\rho}{1-\rho}} + n^* q_{mz^*}^{-\frac{\rho}{1-\rho}} \right]^{-\frac{1-\rho}{\rho}}, \tag{49}$$

which can be simplified using (48). For this, we use (48) to obtain

$$\frac{n q_{mz} x_{mz}}{n^* q_{mz^*} x_{mz^*}} = \frac{n}{n^*} \left(\frac{q_{mz}}{q_{mz^*}} \right)^{-\frac{\rho}{1-\rho}} = \frac{Y_m - EX_m}{IM_m}, \tag{50}$$

which can be used to write (49) as

$$\begin{aligned} q_m &= (n^*)^{-\frac{1-\rho}{\rho}} q_{mz^*} \left[\left\{ \frac{n}{n^*} \left(\frac{q_{mz}}{q_{mz^*}} \right)^{-\frac{\rho}{1-\rho}} \right\} + 1 \right]^{-\frac{1-\rho}{\rho}} \\ &= (n^*)^{-\frac{1-\rho}{\rho}} q_{mz^*} \left[\frac{Y_m - EX_m}{IM_m} + 1 \right]^{-\frac{1-\rho}{\rho}}. \end{aligned} \tag{51}$$

Finally, we impose the normalization

$$n + n^* = 100, \tag{52}$$

and calibrate the ratio of varieties produced in Mexico and the U.S.

$$\frac{n}{n^*} \tag{53}$$

using the employment data. It can be shown that in the model, the ratio n/n^* equals the ratio of the total labor compensations in the Mexican and U.S. manufactures $(X_{H,m} + X_{L,m})/(X^*_{H,m} + X^*_{L,m})$, which is approximately 3/97 in the data for 1987.

It is possible to solve (21), $(46-48)$, and $(51-53)$ for q_{mz}, q_{mz^*}, γ_m, n, n^*, x_{mz}, and x_{mz^*}. In order to complete the calibration of the model, we check the calibration by ensuring that all markets actually clear. The resulting calibration of the model is summarized in Table 1, and Table 2 lists the initial steady state values of the key variables.

4 Extensive Margin and Skill Premium

We have calibrated the static applied general equilibrium model to the Mexican economy. In the calibrated model, we quantitatively evaluate the ability of the variety-skill complementarity mechanism to account for the rise in skill premium in Mexico over the period 1987-1994. To do so, we change the number of foreign varieties—the extensive margin of manufactured imports—in the calibrated model as in the Mexican data from 1987 to 1994.

Here, as we have seen in Figure 1, the growth in the extensive margin is measured by the

growth in what Kehoe and Ruhl (2009) call the "least traded goods."[25] Kehoe and Ruhl classify the set of goods which accounts for only 10 percent of trade as the least traded goods. As shown in Figure 1, the least traded goods that account for 10 percent of Mexican manufactured imports from the U.S. in 1987 account for 19.5 percent in 1994, which is a 95 percent increase in the extensive margin of manufactured imports. This indicates that over this period, Mexico started importing U.S. manufactured goods that it had not imported before or had imported only in small quantities, thus indicating that the variety of Mexican manufactured imports from the U.S. increased.

It is worth noting that the method by Kehoe and Ruhl (2009) used in our paper for measuring the extensive margin is different from methods used in the few previous studies of the extensive margin. Hummels and Klenow (2005) and Broda and Weinstein (2006), for example, classify a good as not traded if the value of trade is zero, and Evenett and Venables (2002) classify a good as not traded if its yearly value of trade is less than or equal to 50,000 1985 U.S. dollars, regardless of the country to be studied.[26] In Kehoe and Ruhl's definition of a non-traded good, on the other hand, goods with very small but non-zero amounts of trade can also be considered, and the actual dollar value of the 10 percent cutoff can differ across countries. Thus non-traded goods in a country are determined based on the relative importance of goods in the country's trade. In fact, this country-variant method by Kehoe and Ruhl has been widely used. Mukerji (2009) and Sandrey and van Seventer (2004), for example, use the method to measure the extensive margin of trade as does our paper.

Before presenting the results, here we briefly sketch the procedure for solving for the new equilibrium. To obtain the new values of q'_{mz^*}, q'_{mz}, n', q'_s, q'_m, w'_H, w'_L, y'_p, and y'_s, we solve zero profit conditions $(A.11)$ for the primary and the service sectors; the profit maximization condition (21) for a representative domestic variety; the price index (49) for the domestic composite manufactured good, q_m; market clearing conditions $(42-43)$ for the two types of labor; the market clearing condition for the non-traded service good (25); the consumer's budget constraint $(A.2)$; and the market clearing condition for a representative foreign variety (26). In the consumer's budget constraints, total net exports adjust freely in the new equilibrium.

4.1 Numerical Experiment - Extensive Margin and the Skill Premium

In this experiment, as mentioned above, we increase the number of foreign varieties n^* by 95 percent as in the Mexican data over 1987-1994. Thus it is anticipated that the increased availability of varieties would raise the demand for the high-skilled labor relative

[25] Klenow and Rodríguez-Clare (1997) measure import variety by the number of countries from which a given product is imported.

[26] According to Kehoe and Ruhl (2009), there is no absolute concept of zero in trade statistics. For example, export shipments from the U.S. (import shipments to the U.S.) are, in general, required to be reported only if the value of the shipment is greater than 2,500 U.S. dollars (2,000 U.S. dollars). A good could have trade with a number of shipments smaller than this limit and be reported as having zero trade. The minimum reporting level tends to vary across countries.

to that of the low-skilled labor since the high-skilled labor is more strongly complementary to varieties than the low-skilled labor. This, in turn, will lead to the rise in the wage of the high-skilled labor relative to that of the low-skilled labor—the skill premium. In other words, the increase in the available number of foreign varieties will lower the price of the composite manufactured input, which in turn will raise the relative wage of the high-skilled labor through the variety-skill complementarity mechanism.

This indeed is the case as shown by the new equilibrium for the year 1994 in Table 2. The number of imported varieties n^* rises from 97 to 189.15, which is a 95 percent increase in the number of foreign varieties. The price index of the composite manufactured good falls from 1 to 0.8952. As a result, we can see that the wage of the high-skilled labor increases from 1 to 1.0377 and that of the low-skilled labor decreases from 1 to 0.9972. Thus the relative wage w_H/w_L increases from 1 to 1.0406, which is a 4.06 percent increase.

Other changes in the equilibrium are also worth noting. While q_{mz^*} does not change in the new equilibrium, q_{mz} does fall, in this case, from 1.9422 to 1.8947. While the number of imported varieties n^* increases, the quantity of each imported variety x_{mz^*} actually falls from 4.17 to 3.34. This is an interesting and important point in variety-trade models emphasized by Ethier (1982). When the increased number of varieties become available, it is optimal to spread existing imports over these varieties to gain from the diversity of inputs. However, this also reduces the price of the composite input which then increases its usage. This increase in usage tends to mitigate the fall in quantity of each imported variety but does not completely offset it.

The effect on skill premium of the extensive margin growth in manufactured imports seems to be small compared to the data. The data show that the Mexican skill premium increased from 2.021 to 2.899 during the period 1987-1994, which is a 43.4 percent increase. Thus the extensive margin growth in Mexican manufactured imports from the U.S. accounts for approximately 9.4 percent of the change in Mexican skill premium over 1987-1994. It should be noted that here we have looked at Mexican trade with the U.S. alone. Our results, however, would be little changed even if Mexican trade with other trade partners of Mexico is also included. This is because Mexico's principal trade partner is by far the U.S., which in 1994 supplied 69 percent of Mexico's imports and attracted 85 percent of its exports.

It should be also noted that one of the most salient characteristics of the Mexican economy is *maquiladoras*. This export-processing sector imports intermediate inputs and then assembles them into final goods in a similar way as modeled in this paper. In fact, our assumption (manufactured imported inputs and high-skilled workers are complements) can be compatible with the observations in *maquiladoras* emphasized by Feenstra and Hanson (1997): both the imports from the U.S. and the demand for high-skilled workers increased in *maquiladoras*.[27]

[27] Of course, low-skilled workers would be used more intensively than high-skilled workers in *maquiladoras*, but it is still possible that the demand for high-skilled workers increases more than that for low-skilled workers (complementarity). In fact, our experiments successfully capture both the intensity and the complementarity.

4.2 Sensitivity Analysis

The results obviously depend on the values of the two substitution parameters in the model, ε and μ. We thus do an extensive sensitivity analysis for a variety of values of ε and μ and report the range for skill premium rather than a point estimate. Given the uncertainty about these elasticities, the sensitivity analysis can test the robustness of our quantitative results. It can also provide an estimate of the upper bound on the amount of rise in skill premium in Mexico that can be accounted for by the extensive margin growth in Mexican manufactured imports from the U.S.

Recall that the benchmark numerical experiment in Section 4.1 has set $\varepsilon = -1$ and $\mu = 1/2$. This means that the elasticity of substitution between the varieties and high-skilled labor, $1/(1-\varepsilon)$, is 1/2 and that between the varieties and low-skilled labor, $1/(1-\mu)$, is 2.

Here, we do our sensitivity analysis for two sets of value of ε and μ so that the two elasticities of substitution take extreme values. Table 3 reports the results of the numerical experiment in which $\varepsilon = -3$ and $\mu = 3/4$, that is, the elasticity of substitution between the varieties and high-skilled labor is 1/4 and that between the varieties and low-skilled labor is 4. The rise in skill premium is still small but is stronger (a 5.17 percent increase) compared to the benchmark case (the 4.06 percent increase). We can now account for 11.9 percent of the actual rise in skill premium.

In Table 4, we further increase the difference in the elasticities by letting $\varepsilon = -9$ and $\mu = 9/10$; the elasticity of substitution between the varieties and high-skilled labor is 1/10 and that between the varieties and low-skilled labor is 10. As we can see, the results indicate that the skill premium now increases slightly more (a 5.49 percent increase). We can now account for 12.7 percent of the actual rise in skill premium.

Qualitatively, these results are as expected. A more negative value of ε (a smaller elasticity of substitution between the varieties and high-skilled labor) and a greater value of μ (a greater elasticity of substitution between the varieties and low-skilled labor) are accompanied by a larger increase in skill premium. Quantitatively, however, all of these increases (4.06, 5.17, and 5.49 percent) do not make a significant difference in that they are around 10 percent of the actual increase of 43.4 percent. In fact, it can be shown that in our numerical experiments, the upper bound for the increase in skill premium is approximately 13 percent of the actual increase of 43.4 percent. However, the choice of elasticities of substitution may make a greater difference when the rise in skill premium is initially more significant in the benchmark case.

It is worth noting that besides the manufacturing sector, the service sector also expands whereas the primary sector shrinks when the elasticity of substitution between the varieties and high-skilled labor is small ($\varepsilon = -3$ and -9).

4.3 Sectoral Variation in Skill Intensity of Employment and Skill Premium

In the previous sections, we might have underestimated the increase in skill premium due to the increase in the extensive margin of manufactured imports. In the new equilibrium, manufacturing and service sectors can expand at the expense of the primary sector. There is overwhelming evidence that manufacturing and service production is more skill intensive than the production of primaries (see Atolia, 2007).[28] In fact, recent evidence in Bussolo et al. (2002) indicates that the service sector is the most skill-intensive sector followed by the manufacturing.[29] The upshot of these facts is that as manufactures and services expand, their resulting resource allocation further raises the relative demand of high-skilled labor through the Heckscher-Ohlin mechanism.

Due to lack of data on the skill intensity of employment in the primary and service sectors for Mexico, we have so far assumed the skill intensity to be the same as in manufacturing.[30] However, as the above discussion shows, this is not an innocuous assumption and might lead us to underestimate the effect of the growth in the extensive margin of manufactured imports on skill premium. The only virtue of this assumption is that it does not demand any additional data. It can, however, be argued that this virtue is also its weakness since it forces us to ignore evidence available on sectoral differences in skill intensity, albeit from other similar countries.

To rectify this shortcoming of the previous analysis, in this subsection we allow sectoral differences in the skill intensity of employment. In particular, we use the evidence in Bussolo et al. (2002) on the skill intensity of employment in Chile for 1992.[31] They provide the sectoral break-up of employment into seven categories. We present results for two different ways of aggregating these categories into high- and low-skilled employment.

In the first case, we aggregate workers by their skill level: managers and professionals, technicians, administrative workers, and skilled blue collar workers comprise the high-skilled

[28] Atolia (2007) shows, using numerical simulations, that the rise in wage inequality in Latin America can be rationalized as a short-run response to trade liberalization. See also Robbins (1996) for discussions on increased skill premium in Latin America.

[29] Note, this implies that by assuming the skill intensity of employment to be the same as the manufacturing sector for all sectors, we have not overestimated the overall skill intensity of employment in the economy. In fact, besides being the most skill-intensive sector, the service sector is also the biggest, accounting for almost half of the total output of the economy.

[30] Note that though the ENEU conducted by the INEGI has data for the primary and service sectors in Mexico, unfortunately it is not consistent with the data that we use for skill premium and input-output matrix. While our data use a non-production/production classification, the ENEU data use a post-secondary/no post-secondary classification. In fact, the share of non-production employment in the manufacturing sector is 30 percent in our data, but the share of post-secondary in the manufacturing sector is 12 percent in the ENEU data. On the other hand, the data in Bussolo et al. (2002), though Chilean data, classify workers by skill level, and the share of skilled workers in the manufacturing sector is 28 percent in the Bussolo et al. data. Thus, the Bussolo et al. data, though from Chile, are more consistent with our data.

[31] Table 2 in their paper summarizes the structural features of the Chilean economy. They report the shares of gross output, value-added, total demand, trade flows, and employment for 24 sectors and three aggregate macro-sectors (primary, manufactures and services). These shares are calculated using the Social Accounting Matrix for Chile in Alonso and Roland-Holst (1995).

category; commerical and service workers, un-skilled blue collar workers, and informal workers comprise the low-skilled. With this classification, the ratio of (share of) high-skilled workers in the primary sector to the manufacturing sector is 11/28. The number for the service sector is 32/28. We recalibrate the model taking these sectoral skill intensity variations into account.

In the recalibrated model, the change is that as shown in Table 5, the growth in the extensive margin of manufactured imports over 1987-1994 gives rise to a 3.94 percent increase in skill premium for the benchmark values of $\varepsilon = -1$ and $\mu = 1/2$, which is slightly smaller than the 4.06 percent change in the absence of sectoral variations in skill intensity. This 3.94 percent increase is 9.1 percent of the actual 43.4 percent increase. In fact, by doing a sensitivity analysis it can be shown that the upper bound of the increase in skill premium is approximately 14 percent of the actual rise.

In the first case, the classification of the workers as high- and low-skilled is not the same across all sectors. We have followed the skill classification of Bussolo et al. (2002) for the primary and service sectors, whereas for the manufacturing sector, we have used nonproduction-production classification based on Mexican data. To avoid this problem, in the second case, we aggregate employment in the primary and service sectors according to the white and blue collar classification of Bussolo et al. (2002) which corresponds more closely to the nonproduction-production classification. As a result, now the ratios of high-skilled workers in primaries and services are 22/48 and 49/48. In the recalibrated model, as shown in Table 6 the skill premium now increases by 4.17 percent for the bencmark values of $\varepsilon = -1$ and $\mu = 1/2$. This number (4.17 percent) is 9.6 percent of the actual observed rise in skill premium. In fact, by doing a sensitivity analysis it can be shown that the upper bound of the increase in skill premium is approximately 15 percent of the actual rise in this second case.

Thus the above results indicate that in the previous sections, we have slightly underestimated the increase in skill premium due to lack of data on the skill intensity of employment in the primary and service sectors for Mexico.

5 Conclusion

The main purpose of this paper has been to quantitatively evaluate the ability of the variety-skill complementarity mechanism to account for the rise in skill premium in Mexico over the period 1987-1994. The results of our numerical experiments indicate that the extensive margin growth in Mexican manufactured imports from the U.S. has the capability of accounting for up to approximately 15 percent of the change in Mexican skill premium during this period. Here, we have illustrated the possibility that the growth in the extensive margin of manufactured imports can significantly contribute to the increase in Mexican skill premium, indicating that the increase in import variety reinforced the increase in Mexican

skill premium that was caused by the Mexican export side (Verhoogen, 2008).

It may be noted that while the increase in the extensive margin of manufactured imports is large, the rise in wage inequality in Mexico is modest in our experiments. A factor causing this modesty is that in our model, the marginal products of both high- and low-skilled labor rise due to the increased number of inputs, but the former rises disproportionately more than the latter. Thus the relative demand for high- to low-skilled labor does not rise as much, thereby mitigating the rise in wage inequality.

Looking forward, we can say that this paper's methodology can be used to derive further quantitative implications. First, this paper has focused on the case where Mexico is a small open economy. We can also extend our model to a two-country model.

Second, our model can be directly applied to countries other than Mexico. We can calibrate our model to the input-output data for other countries and then quantify the effects of the growth in the extensive margin of manufactured imports on skill premium in each of them.

Third, this paper has focused on the extensive margin of manufactured imports. It would also be interesting to introduce tariffs into the model and then exogenously change the tariffs to change the intensive margin of manufactured imports—the import volumes of existing foreign varieties—in the model as in available data.

Finally, it would also be interesting to extend our model to a heterogeneous firm trade model. It may provide further insights on the rise in wage inequality due to the heterogeneous use of increasing import varieties.

Appendix A - Solving the Model

To solve the model, we begin with the consumer's problem.

Consumption

With the Cobb-Douglas utility function, the consumer's optimal decision is to spend a constant fraction β_i of his income on good $i = p, m, s$. Thus utility maximization yields the following demand functions for the consumption of the different goods:

$$c_i\left(q_i, E\right) = \frac{\beta_i E}{q_i}, \qquad i = p, m, s, \tag{A.1}$$

where E is the total consumption expenditure and q_i is the price of good i. From (2), we have that the consumption expenditure equals the wage income. However, with an eye on calibration to data wherein a country may not have the balanced current account, we allow for net exports (NX) and E to be given by

$$E = w_H H + w_L L - NX. \tag{A.2}$$

Accordingly, in the demand for each individual variety in $(14 - 15)$, $w_H H + w_L L$ is replaced by E.

Production

Turning to the production, we start with the primary and service sectors. Similar to (9), we can write the cost functions for the primary and service sectors as

$$\begin{aligned}
\tilde{c}_i\left(q_m, w_H, w_L, q_p, q_s; y_i\right) &= \tilde{c}_i\left(\tilde{c}_{A,i}\left(q_m, w_H, w_L\right), q_p, q_s; y_i\right) \\
&= \tilde{c}_i\left(\tilde{c}_{A,i}\left(\tilde{c}_{B,i}\left(q_m, w_H\right), w_L\right), q_p, q_s; y_i\right) \\
&= \frac{1}{\gamma_i}\left(\frac{\tilde{c}_{A,i}\left(q_m, w_H, w_L\right)}{\alpha_{i1}}\right)^{\alpha_{i1}}\left(\frac{q_p}{\alpha_{i2}}\right)^{\alpha_{i2}}\left(\frac{q_s}{\alpha_{i3}}\right)^{\alpha_{i3}} y_i,
\end{aligned} \tag{A.3}$$

where

$$\begin{aligned}
\tilde{c}_{A,i}\left(q_m, w_H, w_L\right) &= \left[a_i^{\frac{1}{1-\mu}} \tilde{c}_{B,i}\left(q_m, w_H\right)^{-\frac{\mu}{1-\mu}} + \left(1 - a_i\right)^{\frac{1}{1-\mu}} w_L^{-\frac{\mu}{1-\mu}}\right]^{-\frac{1-\mu}{\mu}}, \\
\tilde{c}_{B,i}\left(q_m, w_H\right) &= \left[b_i^{\frac{1}{1-\varepsilon}} q_m^{-\frac{\varepsilon}{1-\varepsilon}} + \left(1 - b_i\right)^{\frac{1}{1-\varepsilon}} w_H^{-\frac{\varepsilon}{1-\varepsilon}}\right]^{-\frac{1-\varepsilon}{\varepsilon}},
\end{aligned} \tag{A.4}$$

and, $i = p, s$.

Using these cost functions, it is easy to derive the input demands using Shephard's

lemma. For example, the demand of primaries is

$$x_{p,i}\left(q_m, w_H, w_L, q_p, q_s; y_i\right) = \frac{\partial \tilde{c}_i}{\partial q_p} = \frac{\alpha_{i2}\tilde{c}_i}{q_p}, \qquad i = p, s, \tag{A.5}$$

$$x_{p,mz}\left(q_m, w_H, w_L, q_p, q_s; y_{mz} + F\right) = \frac{\partial \tilde{c}_{mz}}{\partial q_p} = \frac{\alpha_{m2}\tilde{c}_{mz}}{q_p}, \tag{A.6}$$

where the numerator is the factor payment to the primaries for the relevant good or variety, and the demand for service input is

$$x_{s,i}\left(q_m, w_H, w_L, q_p, q_s; y_i\right) = \frac{\partial \tilde{c}_i}{\partial q_s} = \frac{\alpha_{i3}\tilde{c}_i}{q_s}, \qquad i = p, s, \tag{A.7}$$

$$x_{s,mz}\left(q_m, w_H, w_L, q_p, q_s; y_{mz} + F\right) = \frac{\partial \tilde{c}_{mz}}{\partial q_s} = \frac{\alpha_{m3}\tilde{c}_{mz}}{q_s}, \tag{A.8}$$

Similarly, we can derive the demand for low-skilled labor $\left(L_i\left(q_m, w_H, w_L, q_p, q_s; y_i\right)\right)$ and high-skilled labor $\left(H_i\left(q_m, w_H, w_L, q_p, q_s; y_i\right)\right)$ and that of the composite manufactured input $\left(x_{m,i}\left(q_m, w_H, w_L, q_p, q_s; y_i\right)\right)$ by differentiating the cost function with respect to w_L, w_H, and q_m. Finally, the input demand for a particular variety z of manufactures is

$$x_{mz,i} = \left(\frac{q_{mz}}{q_m}\right)^{-\frac{1}{1-\rho}} x_{m,i}, \qquad i = p, s, \tag{A.9}$$

$$x_{mz,mz} = \left(\frac{q_{mz}}{q_m}\right)^{-\frac{1}{1-\rho}} x_{m,mz}. \tag{A.10}$$

The condition for profit maximization by the firms producing varieties has already been derived (see (21)).[32] Profit maximization by firms implies that in the primary and service sectors, price equals marginal cost which also equals the unit cost

$$q_i = \frac{1}{\gamma_i}\left(\frac{\tilde{c}_{A,i}\left(q_m, w_H, w_L\right)}{\alpha_{i1}}\right)^{\alpha_{i1}}\left(\frac{q_p}{\alpha_{i2}}\right)^{\alpha_{i2}}\left(\frac{q_s}{\alpha_{i3}}\right)^{\alpha_{i3}}, \qquad i = p, s. \tag{A.11}$$

Production and Use of Manufactures

The maximization problem for a firm manufacturing a particular variety has already been solved in Section 2. We now proceed to further derive the aggregate variables for the manufacturing sector or good. For this we begin by imposing symmetry in the manufacturing sector so that the price of all domestic varieties and hence their quantities produced as well as domestically used are all the same. Similarly, the price and quantities used of the imported varieties are the same as well.

Let n be the number of domestic varieties and n^* be the number of foreign varieties. Further, let x_{mz} be the quantity of a representative variety that is domestically used and

[32] Even though the country is small, every firm producing a variety z of manufactured good possesses marketing power and faces same elasticity of demand in domestic and foreign markets. So, equation (21) still applies.

similarly define x_{mz^*}. Then we can write the price (q_m) of the composite manufactured good that is used in production and for consumption as a use- or consumption-based price index

$$q_m = \left[n q_{mz}^{-\frac{\rho}{1-\rho}} + n^* q_{mz^*}^{-\frac{\rho}{1-\rho}} \right]^{-\frac{1-\rho}{\rho}}. \tag{A.12}$$

It is instructive to rewrite this index as a combination of the price indices for the domestic and foreign varieties

$$q_m = \left[\bar{q}_{mz}^{-\frac{\rho}{1-\rho}} + \bar{q}_{mz^*}^{-\frac{\rho}{1-\rho}} \right]^{-\frac{1-\rho}{\rho}}, \tag{A.13}$$

where

$$\bar{q}_{mz} = n^{-\frac{1-\rho}{\rho}} q_{mz}, \tag{A.14}$$

is the price index for the domestically produced varieties and

$$\bar{q}_{mz^*} = (n^*)^{-\frac{1-\rho}{\rho}} q_{mz^*} \tag{A.15}$$

is the price index for the foreign produced varieties. The corresponding quantity indices for their *use* in the domestic economy are

$$\bar{x}_{mz} = n^{\frac{1}{\rho}} x_{mz}, \tag{A.16}$$

$$\bar{x}_{mz^*} = (n^*)^{\frac{1}{\rho}} x_{mz^*}. \tag{A.17}$$

Appendix B - Benchmark 1987 Mexican Data Set

The following is the input-output matrix for 1987 that is used to calibrate the model to the Mexican economy. All the numbers in the matrix are in millions of U.S. dollars. The steps following the matrix show the procedure for the construction of the input-output matrix and the sources of the data.

	Primaries	Manufactures	Services	Total
$X_{p,i}$	2,712	13,485	1,533	17,730
$X_{m,i}$	2,836	23,704	15,939	42,479
$X_{s,i}$	1,190	8,355	14,874	24,419
H_i	9,131	17,068	37,414	63,613
L_i	10,756	20,106	44,075	74,937
Y_i	26,625	82,718	113,835	223,179
C_i	4,643	38,793	89,416	132,853
NX_i	4,252	1,446	0	5,698
EX_i	6,626	13,643		
IM_i	2,374	12,197		

Step 1. Intermediate input and total production. This 1987 matrix is constructed from the 1980 input-output table provided by the INEGI.

Step 2. Labor compensation. $Y_i - X_{p,i} - X_{m,i} - X_{s,i}$ in each sector. The compensation is then distributed into H_i and L_i according to the INEGI's EIM: $w_H H / w_L L = 4185/4930$ in 1987.

Step 3. Net exports to the U.S. of primaries and manufactures. Source: The International Trade Administration.

Step 4. Consumption. Get from $Y_i - C_i - X_{i,p} - X_{i,m} - X_{i,s} = NX_i$. This consumption C corresponds to $c + i + g+$net exports to the rest of the world except the U.S.

Notes

1. 1 peso = 1000 old pesos.
2. The nominal exchange rate in 1987 = 1.37818 MXP/USD. Source: The International Financial Statistics (IFS).

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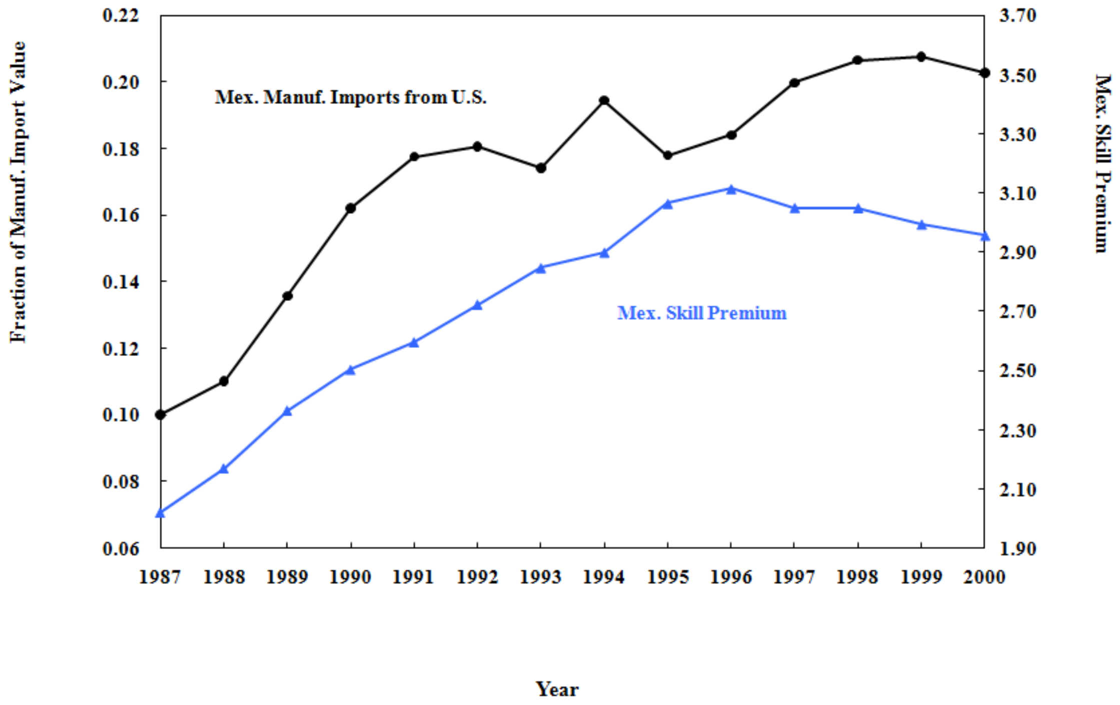

Figure 1: Least traded goods growth in Mexican manufactured imports from U.S. and Mexican skill premium, 1987-2000.

Preference parameters		
$\beta_p = 0.035$	$\beta_s = 0.673$	$\beta_m = 0.292$
Technology: CES aggregator parameters		
$b_p = 0.088$	$b_s = 0.154$	$b_m = 0.659$
$a_p = 0.569$	$a_s = 0.591$	$a_m = 0.665$
$\varepsilon = -1$	$\mu = \frac{1}{2}$	$\rho = \frac{19}{29}$
Technology: productivity parameters		
$\gamma_p = 3.688$	$\gamma_s = 3.697$	$\gamma_m = 3.697$
Technology: cost shares		
$\alpha_{p1} = 0.853$	$\alpha_{p2} = 0.102$	$\alpha_{p3} = 0.045$
$\alpha_{s1} = 0.856$	$\alpha_{s2} = 0.013$	$\alpha_{s3} = 0.131$
$\alpha_{m1} = 0.736$	$\alpha_{m2} = 0.163$	$\alpha_{m3} = 0.101$
Endowments		
$L = 74936.415$	$H = 63613.585$	
Manufactured varieties		
$F = 7472.059$		
$n = 3$	$n^* = 97$	
$q_{mz} = 1.9422$	$q_{mz^*} = 30.1432$	
$x_{mz} = 11,855$	$x_{mz^*} = 4.17$	

Table 1: The parameterization of the model.

	Initial equilibrium	New equilibrium
$\varepsilon = -1, \mu = 1/2$	1987	1994
n	3	3.1705
n^*	97	189.15
x_{mz}	11,855	10,187
x_{mz^*}	4.17	3.34
q_{mz}	1.9422	1.8947
q_{mz^*}	30.1432	30.1432
q_m	1	0.8952
q_p	1	1
q_s	1	0.9955
w_H	1	1.0377
w_L	1	0.9972
w_H/w_L	1	1.0406
y_p	26,625	26,786
y_s	113,835	113,713
y_m	82,718	85,284

Table 2: The results for the benchmark numerical experiment with epsilon = -1 and mu = (1/2).

	Initial equilibrium	New equilibrium
$\varepsilon = -3, \mu = 3/4$	1987	1994
n	3	3.1577
n^*	97	189.15
x_{mz}	11,855	10,226
x_{mz^*}	4.17	3.36
q_{mz}	1.9421	1.8960
q_{mz^*}	30.1432	30.1432
q_m	1	0.8971
q_p	1	1
q_s	1	0.9956
w_H	1	1.0431
w_L	1	0.9918
w_H/w_L	1	1.0517
y_p	26,625	23,923
y_s	113,835	115,857
y_m	82,718	84,992

Table 3: The results for the numerical experiment with epsilon = -3 and mu = (3/4).

$\varepsilon = -9, \mu = \frac{9}{10}$	Initial equilibrium 1987	New equilibrium 1994
n	3	3.1637
n^*	97	189.15
x_{mz}	11,855	10,210
x_{mz^*}	4.17	3.35
q_{mz}	1.9422	1.8952
q_{mz^*}	30.1432	30.1432
q_m	1	0.8961
q_p	1	1
q_s	1	0.9959
w_H	1	1.0451
w_L	1	0.9907
w_H/w_L	1	1.0549
y_p	26,625	24,843
y_s	113,835	115,128
y_m	82,718	85,122

Table 4: The results for the numerical experiment with epsilon = -9 and mu = (9/10).

$\varepsilon = -1, \mu = \frac{1}{2}$	Initial equilibrium 1987	New equilibrium 1994
n	3	3.1724
n^*	97	189.15
x_{mz}	11,855	10,145
x_{mz^*}	4.17	3.38
q_{mz}	1.9422	1.9061
q_{mz^*}	30.1432	30.1432
q_m	1	0.8991
q_p	1	1
q_s	1	1.0048
w_H	1	1.0459
w_L	1	1.0063
w_H/w_L	1	1.0394
y_p	26,625	27,735
y_s	113,835	112,975
y_m	82,718	85,848

Table 5: The results for the benchmark numerical experiment with sectoral variations in skill intensity: the first case.

$\varepsilon = -1, \mu = \frac{1}{2}$	Initial equilibrium 1987	New equilibrium 1994
n	3	3.1730
n^*	97	189.15
x_{mz}	11,855	10,142
x_{mz^*}	4.17	3.38
q_{mz}	1.9422	1.9065
q_{mz^*}	30.1432	30.1432
q_m	1	0.8992
q_p	1	1
q_s	1	1.0043
w_H	1	1.0476
w_L	1	1.0057
w_H/w_L	1	1.0417
y_p	26,625	27,583
y_s	113,835	113,095
y_m	82,718	85,881

Table 6: The results for the benchmark numerical experiment with sectoral variations in skill intensity: the second case.