Trade, skill-biased technical change and wages in Mexican manufacturing*

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Abstract

This paper analyses the effects of trade liberalisation and skill-biased technical change on the skill premium and the real wages of unskilled and skilled workers in Mexican manufacturing using firm- and industry-level data for 1984-1990. The channel through which technical change occurs is changes in the domestic price of machinery and equipment. The novelty of the paper lies in its strategy for identifying causality, which uses differences across industries over time in the price of machinery and equipment in the US as an instrument for skill-biased technical change. Moreover, by looking at the effects of tariff rates specific to machinery and equipment on the domestic price of machinery and equipment, the paper also finds a causal connection between trade-induced skill-biased technical change and the skill premium. Thus, the paper provides evidence for some recent findings in the literature that link trade liberalisation, skill-biased technical change occurring through technology embodied in machines and increases in the skill premium.
Keywords: trade liberalisation, skill-biased technical change, wage inequality, real wages, Mexico, manufacturing.

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1 Introduction

The last 30 years have witnessed an increase in wage inequality not only in developed countries (Katz and Murphy, 1992; Machin and Van Reenen, 1998), but also in some low-income and many middle-income developing countries (Anderson, 2005; Goldberg and Pavcnik, 2007). This increase in wage inequality – more specifically a rise in the mean wage of skilled workers relative to the mean wage of unskilled workers – mainly reflects a rise in real skilled wages, although in some countries it has been amplified by a stagnation or a fall in the real wages of unskilled workers.

There has been much attention around this rise in inequality. While this attention may be driven by a general aversion to inequality per se based on ethical grounds, the interest in inequality is also linked to the possibility that inequality might affect the way an economy works. The recent debate on whether rising inequality in the US has led to the 2007–2008 financial crisis clearly falls in this second category (Atkinson and Morelli, 2011).

Besides the economic consequences of this increase in inequality, the attention has also fallen on the reasons behind such increase. Several theories have been put forward, mainly based on the observation of two recent phenomena. First, developing countries have become more integrated with the rest of the world, particularly through reductions in tariff rates, quotas and other non-tariff barriers. Traditional trade theory, in particular the Stolper-Samuelson theorem, predicts that the relative wages of skilled workers should decrease in developing countries assuming that they are abundant in unskilled labour. While the widespread rise in the skill premium seems at odds with this traditional trade theory, Wood (1997) points out that Latin American countries, in many of which the rise in the skill premium was marked, were relatively skill abundant when they opened to trade in the 1980s.

Second, since most of the world's technical progress originates in a few rich countries (Schmidt, 2010), which are relatively skill abundant, machinery and equipment, hereafter M&E, tends to be complementary to skill (**?**). When new technologies, such as personal computers, are adopted by firms in developing countries, they are thus likely to increase the relative demand for skilled workers, a process that has been referred to in the literature as *exogenous* skill-biased technical change, hereafter SBTC (see Acemoglu, 2002a;b).

As the debate continues regarding the relative importance of trade liberalisation and SBTC as causes of the rise in the skill premium, a combined hypothesis has been suggested separately by Robbins (2003) and Acemoglu (2002a; 2003) and analysed further in several recent papers (Burstein and Vogel, 2009; Bustos, 2009; Riaño, 2009; Schmidt, 2010; Gallego, 2010). These authors have put forward different models in which, as a country reduces its barriers to trade, firms are able to import new technology embodied in M&E at a lower price, thus inducing the adoption of skill-biased technologies. Through this channel, trade liberalisation can raise the skill premium even in skill-scarce developing countries, a process which can be referred to as *trade-induced* SBTC. Acemoglu (2002b) also suggests that SBTC can be induced by other forms of openness, such as foreign direct investment (FDI) inflows, and other characteristics of the economy, such as labour market institutions.

While consensus is building up on the role played by trade-induced SBTC in the increase in the skill premium (Van Reenen, 2011), the literature is still designing effective strategies to identify the separate effects of SBTC and trade liberalisation on the skill premium and real wages of unskilled and skilled workers within the same analysis, especially in the context of developing countries.

The purpose of this paper is, therefore, to conduct an econometric analysis of wages in the Mexican manufacturing sector in a way that allows the influence of SBTC, measured by the price of M&E relative to the producer price index, and trade liberalisation to be isolated and quantified. It uses firm- and industry-level data for the period 1984-1990 from the *Encuesta Industrial Anual*, Annual Manufacturing Survey, conducted by the Mexican national institute of statistics. The novelty of this work lies in the identification strategy adopted to ensure that the relationships found in the data are of a causal nature – a constant worry in empirical economics.

The identification strategy uses variation across industries over time in the price of M&E relative to the producer price index in the United States (US) as an "external" instrument – not based on the lags of the endogenous variable – for SBTC. Starting with the assumption that most M&E in a developing country, such as Mexico, is imported from more advanced developed countries, the price of M&E in Mexico is estimated to be a function of tariffs specific to M&E and the price of M&E in the US to account for trade-induced SBTC and exogenous SBTC separately. This identification strategy relies on factor immobility across industries, an assumption supported by the descriptive evidence presented.

Decreases in the price of M&E lead to increases in its demand and, thus, its use, particularly by larger firms that invest more in M&E. Assuming equipment-skill complementarity, or at least that M&E is less substitutable with skilled workers than with unskilled workers, an increase in the demand for M&E would lead to an increase in the relative demand for skilled workers, particularly in larger plants and those invest more in M&E. Therefore, relative skilled wages – and real skilled and unskilled wages – are regressed on the price of M&E, interacted with plant size and investments in M&E to account for the heterogeneous effects of SBTC, input and output tariff rates as well as other regressors.

This identification strategy analyses only the effects of trade-induced SBTC that occur through changes in M&E tariffs. However, trade-induced technical change could also happen through output tariff changes. Trade liberalisation could lead to more competition and, thus, innovation in an effort to stay in the market (Gorodnichenko *et al.*, 2010; Bloom *et al.*, 2011). This alternative mechanism will be accounted for in the econometric analysis. Additional regressions will also include more standard plant-level measures of SBTC, i.e., royalties paid on new technologies and M&E imports (see the literature review by Chennells and Van Reenen, 1999).

The paper shows that, after controlling for both plant- and industry-level variables, lower prices of M&E lead to an increase in the skill premium. Also, changes in the price of M&E are affected by changes in the price of M&E in the US and lower tariffs on M&E, thus providing evidence for exogenous and trade-induced SBTC. The results also reveal that trade liberalisation in final goods has a positive and robust effect on unskilled wages. Other effects of trade liberalisation on wages are not robust through the different specifications.

In terms of the magnitude of the estimated effects, SBTC caused by changes in the price of M&E can explain one tenth of the overall increase in the skill premium during the period 1984-1990. This is to be considered a lower-bound estimate since this methodology cannot capture the effects of SBTC and trade liberalisation that are homogeneous across sectors over time.

Mexico has been frequently chosen as a country in which to study the effects of trade liberalisation on wages. Not only did the country go through a substantial trade liberalisation process, with production-weighted average tariffs declining from 28.5 percent in 1985 to 12.5 percent in 1990 (Ten Kate, 1989; 1992) and trade as a fraction of GDP rising from 25 percent to 39 percent during the same period, but also the skill premium increased by almost 30 percent between 1985 and 1994, remaining stable afterwards (Riaño, 2009).

The popularity of the topic, however, does not imply that the literature has been able to address all the issues. A limitation of most previous work on the liberalisation process in Mexico is its focus only on wage inequality, neglecting real wages. Examining real wages as well as relative wages will make possible to differentiate between the effects of alternative measures of SBTC.

Another limitation is the literature's reliance on the Stolper-Samuelson theorem (Hanson and Harrison, 1999; Feliciano, 2001; Esquivel and Rodríguez-López, 2003), which has met some criticism. Hanson and Harrison (1999) argue that the increase in the skill premium can be explained using a HOS framework because the pattern of tariffs before liberalisation was such that unskilled-labour-intensive industries were more protected (Revenga, 1997; Feliciano, 2001). Esquivel and Rodríguez-López (2003) instead use Leamer (1998)'s methodology, which also relies on perfect mobility of all factors across industries, and, in contrast to previous studies, find that trade has tended to reduce relative skilled wages, while SBTC has tended to raise them. However, none of these studies based on the 'mandated wage' approach finds strong evidence for the channel through which the Stolper-Samuelson theorem works in theory, since the correlation between changes in output prices and relative wages at the industry level is extremely low (Riaño, 2009).

Other studies have investigated alternative possible causal connections between greater openness and the increase in wage inequality. Among them, Feenstra and Hanson (1997) argue that FDI towards *maquiladoras*, assembly plants for re-exports, has been the cause of the increase in relative skilled wages after the trade liberalisation of 1985-1987 and Verhoogen (2008) shows that new export opportunities following the 1994 Mexican peso devaluation led to an increase in within-industry wage inequality due to quality upgrading by the most efficient plants.

More recent papers study the links between trade and technology adoption and are, therefore, closely related to this paper. Riaño (2009) develops and estimates a structural model of trade and technology adoption with heterogeneous firms. Firms produce using skilled and unskilled labour and can choose between two technologies: a 'traditional' technology characterised by high marginal costs but low fixed costs, and a 'modern' technology that has low marginal costs but high fixed costs. By identifying plants that purchase imported M&E as using the modern technology, the author estimates the response of technology adoption and the skill premium to a unilateral trade liberalisation of a similar magnitude to the one that took place in Mexico after 1985. Trade liberalisation leads to an increase in the relative demand for skills and an increase in the skill premium of around 2.4 percent. Allowing for the reduced sunk cost of technology adoption due to the falling import tariffs, the impact of trade liberalisation on the skill premium is stronger, raising it by 4.2 percent.

Riaño's model is similar to Bustos (2009), except that the latter model is static and does not allow for the possibility of cheaper technology due to falling import tariffs. Bustos (2009) estimates the main predictions of her model with firm-level data from Argentina using the reduction in Brazil's import tariff rates as a quasi-natural experiment. The empirical tests reveal that firms, especially large and more productive ones, in industries facing higher reductions in Brazil's tariffs increase their investment in technology faster, as predicted by the model.

The complementarity between imported machines embodying new technologies and skills plays an important role also in a matching model put forward by Csillag and Koren (2011) in which workers with high skills work on imported machines rather than domestic ones because the former are of higher quality even though they are more expensive. The model is consistent the findings, based on Hungarian linked employer-employee data, that workers exposed to imported machines earn higher salaries and the return to schooling is higher on imported machines.

The remainder of the paper is organised as follows. Sections 2 and 3 describe the data used and provide some descriptive evidence of an increase in the relative demand for skilled labour between 1984 and 1990. Section 4 outlines the identification strategy and the econometric specification. This section explains why the price of M&E in the US interacted with the tariff rates on M&E can be used as an instrument for the price of M&E in Mexico, a measure of SBTC. Section 5 presents the results of the regression analysis. Section 6 concludes.

2 Data

The data used in this paper come mainly from the *Encuesta Industrial Anual* (Annual Industrial Survey, EIA), provided by the *Instituto Nacional de Estadistíca y Geografía*, INEGI, the national institute of statistics of Mexico. The database contains information on 3218 manufacturing plants for the period 1984-1990 (for a total of 22526 plant-year observations) and it is by design a balanced panel that covers roughly 80 percent of all manufacturing value added. The data distinguish 129 industries, classified according to the CMAE75 (Clasificación Mexicana de Actividades Económicas, 1975).

The unit of observation in the dataset used is a plant rather than a firm, which may pose problems of identification because firms may re-organise production among the plants they own. Also, it is arguable that the period available is too short to be able to observe any significant relationship between trade, SBTC and wages, but ultimately this is an empirical question.[1]

Omitted from the data are plants with missing information on employment and wage bill of production and non-production workers, some odd observations, entrants and exiters because by construction this is supposed to be a balanced panel and incomplete series (for more information on the EIA and the cleaning procedure see Iacovone, 2008 and Riaño, 2009). Plants belonging to the oil production sector are also eliminated because this sector is fully controlled by the government. The final sample contains 12761 observations, that is, 1823 per year. Table 1 shows the descriptive statistics of

[1]For instance, Bustos (2009) finds a significant relationship between trade-induced SBTC and wages in Argentina using only data for 1992 and 1996.

Table 1: Descriptive statistics

	1986		1990	
	Mean	S.D.	Mean	S.D.
Skill premium	2.06	0.78	2.72	1.55
Real skilled wages (1994 pesos per day)	120.91	53.94	146.43	76.94
Real unskilled wages (1994 pesos per day)	60.84	23.89	58.41	27.98
Price of M&E (Mexico)	1.57	0.45	1.49	0.45
Price of M&E (US)	0.80	0.03	0.78	0.02
Tariff rate on final goods	0.41	0.25	0.15	0.04
Tariff rate on inputs	0.23	0.08	0.11	0.02
Tariff rate on M&E	0.10	–	0.10	–

some of the variables included in the analysis for 1986 and 1990.

The database provides a wide array of information on each individual plant, including information on the total number of blue-collar (or production) workers, whose main activities include machine operation, production supervision, repair, maintenance and cleaning, and white-collar (or non-production) workers, such as managers, administrators, professionals and salesmen, total number of hours worked for each type of worker, total remuneration, production, input use, stock of and investment in different capital goods, expenditures on royalties for the use of new technologies, imports of M&E and materials, value of exports and the state where the plant is located. Variables related to imports and exports are only available from 1986 onwards, therefore the regression analysis focuses on the period 1986–1990.

While the EIA includes information on the percentage of firms' social capital held by foreigners, this variable does not change over time for any of the firms included in the sample. Thus, the direct effects of FDI on the skill premium are identified only through variations across plants. However, the survey does not include *maquiladora* plants, which excludes the possibility of a Feenstra and Hanson (1997) type mechanism. During this period, the Mexican economy also went through a process of privatisation, but the EIA does not include any information on public or private ownership of the plants surveyed (see La Porta and López-De-Silanes, 1999 for the effects of privatisation on productivity in Mexico).

Throughout the paper, skilled wages are measured as the average daily wages for non-production workers, unskilled wages as the average daily wages for production workers and the skill premium, the measure of wage inequality, as the ratio of skilled to unskilled wages. Therefore, the paper distinguishes between skilled and unskilled workers on the basis of occupation rather than education, which is not available in the EIA. The classification of workers into production and non-production groups in order to approximate skilled and unskilled labour respectively is not ideal because skills are better described by classifications based on educational characteristics, as pointed out by Gonzaga *et al.* (2006) and Bustos (2009), and because changes in the skill premium based on occupation may be driven by compositional shifts in the education of workers within the occupation categories. However, this categorisation is very common in the literature because it is often the only one available in firm-level data (Berman *et al.*, 1994; Feenstra and Hanson, 1996; Leamer, 1998; Meschi *et al.*, 2009). Berman *et al.* (1994) also argue that it yields results similar to those obtained using education categories.

The price of M&E in Mexico, alongside the prices of other types of capital, is provided by the INEGI. The following analysis uses the price of M&E relative to the producer price index. The price of M&E in the US, which is also divided by the producer price index, is taken directly from the Bureau of Economic Analysis (BEA). While the price of M&E in Mexico is available for 46 industries according to the CMAE75, the price of M&E in the US is available for 19 industries according to the Standard Industrial Classification. A table of correspondence provided by INEGI is therefore used to match the two industry classifications.

Tariff rates are taken from Ten Kate (1989; 1992). The data available include the Mexican tariff rate specific for M&E, which only varies over time, production-weighted average tariff rates on final goods and tariff rates on inputs, calculated by combining output tariff rates with the input-output tables provided by the INEGI. It should be noted that while tariffs decreased on average throughout this period, they increased slightly after 1988. This is particularly evident for the tariff rate on M&E that decreased down to 3% in 1989, but then increased back to 10% in 1990, the same level as in 1986.

The Herfindahl-Hirschman Index, a measure of concentration at the industry level, is calculated using output value data from the EIA.[2] The degree of unionisation in an industry is calculated as the percentage of workers that belong to a recognised trade union, taken from the National Survey on Household Income and Spending (ENIGH) provided by the INEGI.

3 Descriptive evidence

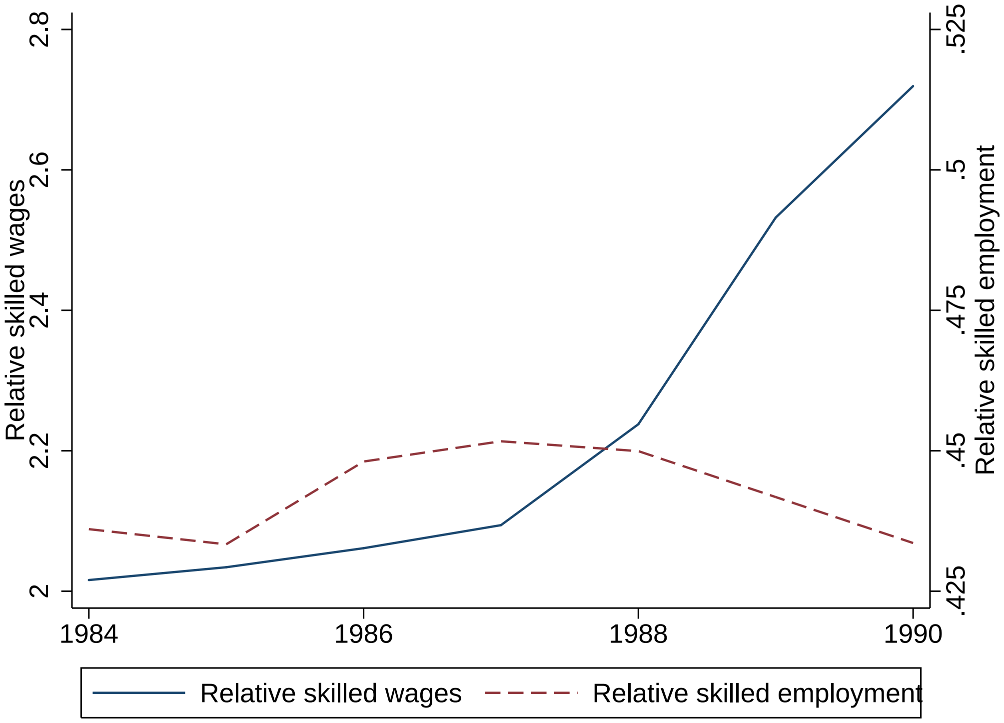
3.1 Trends in the labour market

Figure 1 plots the movement of relative skilled wages (left axis) and relative skilled employment (right axis) between 1984 and 1990. The figure shows that both relative wages and relative employment tended to rise until 1988 – that is, during the rapid trade liberalisation process. Although the increase in relative employment is much more modest, this simultaneous increase in relative wages and relative employment necessarily implies an increase in the relative demand for skilled labour (Meschi *et al.*, 2009). In the period 1988-1990, when tariff rates increased slightly in all sectors, there seems to be an inverse relationship between relative skilled wages and employment. This pattern of relative wages and employment is also consistent with an increase in the relative demand for skilled labour, while it is unlikely that the increase in the relative supply of unskilled labour (see Atkin, 2010) played an important role since the change in relative skilled employment is again small.

While figure 1 plots average relative skilled wages, figure 2 plots changes in relative skilled wages at the industry level between 1986 and 1990 against industry-level changes in the price of M&E in the US. The scatter includes 19 industries for which the price of M&E in the US is available. The figure shows that there was a general tendency for relative skilled wages to increase and a general tendency for the price of M&E in the US to decrease. The best fit line suggests that the two variables are negatively correlated. The

[2]The following formula is used to calculated the Herfindahl-Hirschman Index: $hhi_i = \sum_k^n s_{k,i}^2$, where $s_{k,i}$ is the share of firm k in industry i and n is the number of firms in industry i.

Figure 1: Relative skilled wages and employment in Mexican manufacturing



Source: Own calculations based on *Encuesta Industrial Anual*, 1984-1990, INEGI.

econometric analysis below will relate these variables in a more systematic way through changes in the price of M&E in Mexico.

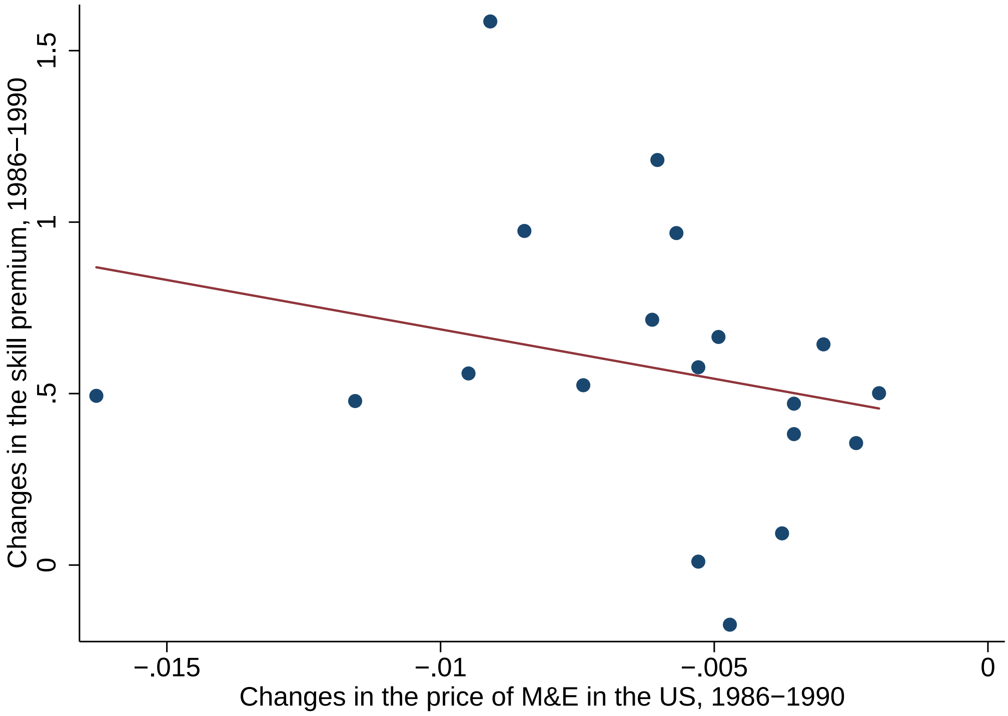
3.2 Decomposition analysis

In order to make a first attempt at understanding the main forces behind the increase in the skill premium documented in the figures above, the aggregate changes in the wage bill share of skilled workers will be split into their between- and within-industry components and, in turn, the within-industry changes can be decomposed into their between- and within-firm components.[3] The wage bill share of skilled workers can be used to distinguish the effects of labour demand from those of labour supply under the assumption that the elasticity of substitution between skilled and unskilled labour is equal to one (Berman and Machin, 2000).

Following Bustos (2007) and Meschi *et al.* (2009), the aggregate increase in the demand for skills may be driven by (a) employment reallocation across industries caused by a trade shift, structural change, changing tastes, or changes in economic policy, or by (b) skill upgrading within industries mainly due to changes in technology, but often also associated with changes in trade policy. The following formula is used to decompose the

[3]The decomposition was also conducted using relative skilled employment, however this provides less clear results because changes in relative skilled employment over this period are negligible.

Figure 2: Changes in relative skilled wages vs. changes in price of M&E in the US



Source: Own calculations based on *Encuesta Industrial Anual*, 1984-1990, INEGI.

total changes in the wage bill share of skilled workers (WS/W):

$$\Delta\left(\frac{WS}{W}\right) = \sum_j \left(\overline{\frac{WS}{W}}\right)_j \Delta\left(\frac{W_j}{W}\right) + \sum_j \Delta\left(\frac{WS}{W}\right)_j \left(\overline{\frac{W_j}{W}}\right)_j, \tag{1}$$

where the subscript j denotes industries or firms, a Δ before a term denotes change over time and a bar over a term denotes average over time.[4] In equation (1), the first term is the between component of skill upgrading, i.e. how much bigger or smaller an industry or firm becomes over time, weighted by time-averaged skill demand. The second term measures the contribution of within variations, weighted by the relative size of industry or firm j. The decompositions are done for the whole 1984-1990 period and for the 1984-1988 and 1988-1990 sub-periods in order to relate the increase in the relative demand for skilled labour more closely to the trade liberalisation process.

Table 2 reports the between and within decompositions of the aggregate change in the wage bill share of skilled labour. The wage bill share of skilled labour increased by 6 percentage points between 1984 and 1990. This increase happened during both sub-periods considered, i.e. 1984-1988 and 1988-1990, and with similar magnitudes.

During all the periods, both between- and within-industry changes are positive and the within-industry changes explain most of the overall change by accounting for about 90 percent of the variation. While the positive between-industry variation implies that

[4]The decomposition analysis is also available at different levels of industrial aggregation, but the additional tables are not included and discussed because the results are similar in magnitude.

Table 2: Decomposition of changes in the wage bill share of skilled labour

	Between	Within	Total
1984-1990			
Industries (19)	0.0054	0.0544	0.0598
Firms (1823)	0.0109	0.0435	0.0544
1984-1988			
Industries (19)	0.0044	0.0282	0.0327
Firms (1823)	0.0072	0.0210	0.0282
1988-1990			
Industries (19)	0.0003	0.0269	0.0272
Firms (1823)	0.0041	0.0228	0.0269

Source: Own calculations based on *Encuesta Industrial Anual*, 1984-1990, INEGI.

there was a reallocation of resources towards more skill-intensive industries, holding skill intensity within industries constant, the positive within-industry variation implies that skill intensity increased within industries, holding industry size constant. When within-industry changes are disaggregated at the firm level, most of the changes are explained by skill upgrading within firms.

The lack of information on entry and exit implies that the reallocations across industries and firms that have occurred through these channels are missed in these calculations. However, since the panel represents 80 percent of manufacturing output, skill upgrading within industries and firms was clearly an important source of the overall increase in the relative demand for skilled labour and the skill premium.

The decomposition analysis shows that not only did skill-intensive industries and firms expand relative to less skill-intensive industries and firms, but also that all industries and firms raised their skill intensity. Traditional trade theory with perfect mobility of workers across industries applied to a developing country abundant in unskilled labour seems to be at odds with this finding. Imperfect mobility of workers seems to fit the results better given the small between-industry changes.

Alternatively, positive within-industry resource reallocations could be explained by trade liberalisation under new trade theory with firm heterogeneity (Melitz, 2003). In models with heterogeneous firms, more productive firms that use skilled workers more intensively find it profitable to scale up their production aimed at the export market at the expense of less productive firms, which may drop out of the market (Vannoorenberghe, 2011; Harrigan and Reshef, 2011). This also implies an increase in the relative demand for skilled labour and positive within-industry changes, however, associated with between-firm changes because not all firms would increase their relative demand for skilled labour.[5]

Positive between-firm changes in the wage bill share of skilled workers could also be observed following the availability of intermediate inputs, facilitated by input tariff reduction, as they could stimulate higher-quality output, particularly in larger firms (Kugler and Verhoogen, 2012). In turn, quality upgrading could increase the demand for skilled workers and, thus, the skill premium (Verhoogen, 2008).

Another hypothesis to explain the large within-industry and within-firm changes is SBTC. As new skill-biased technologies (i.e., M&E) are introduced, due to a decrease in

[5]It should be noted that these models would also predict changes in the relative demand for skilled labour due to firms' exit, which cannot be captured with these data.

their price on international markets or a decrease in tariffs on these inputs, all firms and industries tend to increase their demand for skilled labour, although possibly in different magnitudes, resulting in positive within-industry and within-firm variations.

It should be noted that SBTC could be associated not only with M&E (Krusell *et al.*, 2000; Leonardi, 2007), but also more generally with the availability of intermediate inputs, again facilitated by input tariff reduction, as they could lead to new product introduction (Goldberg *et al.*, 2010). Since new products are related to technological change, product variety expansion could have shifted the demand in favour of skilled labour (Xiang, 2005).

When comparing these findings with those from other middle-income countries, the most striking difference is that in the case of Mexico the between-industry component of the changes in the wage bill share of skilled labour are positive throughout the whole period. This is in contrast with the findings of Gonzaga *et al.* (2006) for Brazil in 1988-1995, Bustos (2007) for Argentina in 1992-1996 and Meschi *et al.* (2009) for Turkey in 1983-1988, which show that these middle-income countries experienced negative between-industry and -firm changes in relative skilled employment or in the wage bill share of skilled labour when they liberalised trade. The present results resemble more closely the findings in Berman *et al.* (1994) for the US, a high-income country relatively abundant in skilled labour. On the other hand, the within-industry and within-firm components of the aggregate change in the relative demand for skilled labour are positive in all these studies, which is consistent with SBTC – both in its exogenous and trade-induced formulations – being pervasive for middle-income countries, as defined by Berman and Machin (2004).

4 Identification strategy and econometric specification

In order to study the effect of trade liberalisation and SBTC on the skill premium, this paper adopts the reduced-form model for wages, suggested by Doms *et al.* (1997),

$$w = w(c,\, o,\, v), \tag{2}$$

where w can be relative skilled wages as well as unskilled or skilled real wages, c is the proxy for SBTC, o represents different measures of trade liberalisation and v stands for other regressors to be included in the regression analysis.

In the baseline specification, SBTC is measured by the industry-level price of M&E. The intuition is that technological improvements biased towards skilled workers may come in the form of a decrease in the domestic price of equipment capital, as proposed by Krusell *et al.* (2000), because of the complementarity between M&E and skilled workers, or at least the lower substitutability of M&E and skilled workers compared to that between M&E and unskilled workers. Moreover, the analysis will look at the heterogeneous effects of M&E by focusing on plant size – since larger plants use M&E more intensively and invest more in M&E – and on whether plants are below or above the median level of investment in M&E throughout the period.

The price of M&E is potentially endogenous since factor prices are determined contemporaneously. Therefore, an instrumental variable (IV) approach is implemented through the use of the system GMM estimator by including both internal instruments, i.e., lagged values of the price of M&E in Mexico, and an external instrument, the price of M&E in the US. The idea is that when the price of M&E decreases in the US exogenously, due for example to the information technology 'revolution', the same is likely to happen to the price of M&E in Mexico because it relies on imports of M&E from the US. In turn, the decrease in the price of M&E increases the demand for it and, assuming that M&E is more complementary with skilled than unskilled workers, leads to SBTC, not only in the US but in Mexico too. Moreover, this paper takes into account trade-induced SBTC by showing in a separate regression that the price of M&E in Mexico is also affected by trade policy via the tariff rate on M&E. When the price of M&E in Mexico is interacted with dummies for plant size, the price of M&E in the US is also interacted with these dummies.

The requirement for any IV approach is that the instrument is both informative and valid. Regarding the informativeness of the instrument, industry-level regressions will show that there is a significant positive relationship between the price of M&E in the US and the price of M&E in Mexico after controlling for the tariff rate on M&E. Moreover, the internal instruments help in addressing any concerns of weak instrumentation. For the instrument to be valid, it must be uncorrelated with the residual in the main equation determining wages. Not only does Leonardi (2007) suggest the validity of the instrument but it also seems unlikely that changes in the price of M&E in the US have any impact on wages in Mexico other than through changes in the price of M&E.

An underlying assumption of this identification strategy to work is that workers cannot move freely across sectors and, if they do so, the movements are random, while they can move more freely across firms within the same sector. If workers were allowed to move across industries, then wages would equal across sectors at all time, which would make it impossible to detect the effects of trade liberalisation and SBTC on wages using changes at the industry level over time. There are several reasons why workers can move more easily across firms within industries than across industries. Labour legislation as well as housing and family ties can severely limit the possibility of labour mobility across sectors in the short and medium run (Goh and Javorcik, 2007). Even in the presence of these constraints, workers are still able to move across firms within industries if sectors are geographically clustered or if workers are required to have industry-specific skills. The descriptive evidence provided in the previous section seems to confirm this short-run labour immobility as it shows that a high percentage of the changes in the relative demand for skilled labour are within industries rather than across them over the 1984-1990 period.

In order to measure trade liberalisation, the analysis includes both input and output tariff rates at the industry level and their interaction, respectively, with the share of exports in total sales and of imported raw materials in total material costs at the firm level. Following the approach by Amiti and Davis (2008) and Amiti and Cameron (2011), the interaction terms are added to analyse whether the effects of trade liberalisation are industry-wide or heterogeneous and affect more firms that import and export.

Even though the 1985-1987 liberalisation process in Mexico was imposed by the external circumstances arising with the debt crisis and its main emphasis was on reducing average tariff rates as well as the dispersion in tariff rates, tariff rates may still be endogenous. In particular, future tariff rates may be correlated with current productivity (Topalova, 2004) or with industries' skill intensity (Revenga, 1997; Feliciano, 2001).

The data show that tariff rates are indeed correlated with past values of productivity – measured using the Levinsohn and Petrin (2003) approach – as well as past values of skilled workers' share in the total number of workers at the industry level. However, the degree of tariff reduction does not depend on any industry characteristic, including the share of skilled workers or productivity, but depends only on the initial tariff level.[6] Thus, extending the approach in Goldberg and Pavcnik (2005), the paper can address the endogeneity of tariffs by using the system GMM estimator since this estimator uses the endogenous variables in differences as instruments for the equations in levels and, viceversa, variables in levels as instruments for the equations in differences.

It should be noted that this identification strategy analyses only the impact of trade-induced SBTC that happen through changes in M&E tariffs, which are supposed to lead to a lower price of M&E. However, trade-induced technical change could also happen through output tariff changes, as these may bring about more competition in the goods market with potential effects on the innovation strategy of firms (Gorodnichenko *et al.*, 2010; Bloom *et al.*, 2011). The inclusion of the Herfindahl-Hirschman Index and the use of the system GMM estimator that allows for this variable to be endogenous and determined by output tariffs, among other factors, implies that this alternative mechanism is accounted for and that the coefficient on the price of M&E only captures trade-induced SBTC occurring through the M&E price channel.

Based on the identification strategy just described, the following equation is to be estimated for relative wages:

$$\begin{aligned}\ln(ws/wu)_{kit} = \alpha_0 + \beta_1 \ln(ws/wu)_{kit-1} + \beta_2 \ln p_{it} * size_{it} + \beta_3 \ln taro_{it} + \\ \beta_4 \ln(taro_{it} * expsh_{kit}) + \beta_5 \ln tari_{it} + \beta_6 \ln(tari_{it} * impsh_{kit}) + \\ \beta_7 \ln(tarme_t * impmesh_{kit}) + \beta_8 X_{kit} + \beta_9 W_{it} + \alpha_t + \alpha_k + \epsilon_{kit},\end{aligned} \tag{3}$$

where ws/wu is the skill premium, p is the price of M&E in Mexico, $size$ indicates a set of dummies for small (no more than 100 employees), medium (between 101 and 250 employees) and large plants (more than 251 employees) defined according to the EIA sample stratification, $taro$ is the tariff rate on final goods, $expsh$ is the share of exports in total sales, $tari$ is the tariff rate on intermediate inputs, $impsh$ is the share of imported materials in total material costs, $tarme$ is the tariff rate on M&E, $impmesh$ is the share of M&E imported, X is a vector of firm-level controls, including the alternative firm-level proxies for SBTC, W is a vector of industry-level controls, α_t represents year fixed effects, α_k represents firm fixed effects, ϵ is the error term, subscript k indexes firms, i industries and t years.

Regarding the firm-level variables to be included in X, the literature review by Chennells and Van Reenen (1999) provides a detailed list. These will be the lagged dependent variable, dummies for firms' size based on total employment, the ratio of total capital to valued added, the share of exports in total sales, the share of materials imported, the share of M&E imported and the share of firms' social capital owned by foreigners, a measure of FDI. Including the lagged dependent variable means that traditional panel data estimators are subject to dynamic panel bias (Roodman, 2009). Given that the number of observations is large, system GMM is a consistent estimator. Moreover, this estimator is able to address the endogeneity issues discussed above through the use of an IV approach with both internal and external instruments.

[6] Results are available upon request.

The additional industry-level variables, W, included in this model are the Herfindahl-Hirschman Index, as proposed by Goh and Javorcik (2007), and the degree of unionisation, a proxy for labour market conditions and the possible difficulties in hiring and firing workers, both of which can have a direct effect on wages (Fairris and Levine, 2004). Through the time dummies, the analysis accounts for economy-wide changes, which include not only exchange rate movements and minimum wage legislation, but also additional effects of trade liberalisation and SBTC that cannot be identified using the present strategy due to some labour mobility. Therefore, the effects of trade liberalisation and SBTC, occurring through the M&E price channel, found in the next section are likely to be lower bound estimates.

An additional reduced-form equation is estimated in order to determine how much of the variation in the price of M&E in Mexico, is due to exogenous SBTC, measured by the price of M&E in the US, and trade-induced SBTC, measured by the tariff rate specific to M&E. This is necessary because system GMM does not report the results of this type of regression, which is equivalent to the first-stage regression in a simpler two-stage least squares estimation. The equation to be estimated is as follows:

$$\ln p_{it} = \gamma_0 + \gamma_1 \ln pus_{it} + \gamma_2 \ln(tarme_t + 1) + \gamma_3 W_{it} + \eta_i + \nu_{it}, \tag{4}$$

where pus is the price of M&E in the US, W represents additional industry-level regressors also included in equation (3), η_i are industry fixed effects and ν is the error term. Year fixed effects are not included because they would not make it possible to identify the coefficient on the tariff rate specific to M&E. However, in order to show that the coefficient on the M&E-specific tariff rate is not simply picking up a time trend, an alternative specification that includes year fixed effects is also estimated.

A simple variation of equation (3) can be estimated to look at real skilled and unskilled wages. This yields

$$\begin{aligned}\ln ws_{kit} = \alpha_0 &+ \beta_1 \ln ws_{kit-1} + \beta_2 \ln p_{it} * size_{it} + \beta_3 \ln taro_{it} + \\ &\beta_4 \ln(taro_{it} * expsh_{kit}) + \beta_5 \ln tari_{it} + \beta_6 \ln(tari_{it} * impsh_{kit}) + \\ &\beta_7 \ln(tarme_t * impmesh_{kit}) + \beta_8 X_{kit} + \beta_9 W_{it} + \alpha_t + \alpha_k + \epsilon_{kit}\end{aligned} \tag{5}$$

$$\begin{aligned}\ln wu_{kit} = \alpha_0 &+ \beta_1 \ln wu_{kit-1} + \beta_2 \ln p_{it} * size_{it} + \beta_3 \ln taro_{it} + \\ &\beta_4 \ln(taro_{it} * expsh_{kit}) + \beta_5 \ln tari_{it} + \beta_6 \ln(tari_{it} * impsh_{kit}) + \\ &\beta_7 \ln(tarme_t * impmesh_{kit}) + \beta_8 X_{kit} + \beta_9 W_{it} + \alpha_t + \alpha_k + \epsilon_{kit},\end{aligned} \tag{6}$$

where ws stands for real skilled wages and wu for real unskilled wages.

5 Econometric analysis

5.1 Results for the skill premium

Table 3 presents the baseline results for the skill premium based on the estimation of equation (3) via system GMM. The Wald tests show that all regressions are significant as a whole, while the AR(1) and AR(2), the Arellano-Bond tests for serial correlation of the residuals, detect only first-order serial correlation and reject the hypothesis of higher-order serial correlation. Therefore, the system GMM estimator can use the first

Table 3: The effects of trade and SBTC on the skill premium

Dep. var.: $\ln(ws/wu)$	(1) M&E price	(2) Plant-size interactions	(3) Trade variables	(4) Both M&E and trade	(5) Additional controls
Log skill premium (-1)	0.53	0.53	0.55	0.55	0.54
	(0.03)***	(0.03)***	(0.03)***	(0.03)***	(0.03)***
Log M&E price	-0.08	0.17		0.06	0.05
	(0.04)*	(0.14)		(0.08)	(0.09)
Log M&E price *		-0.23		-0.14	-0.13
Size (101-250)		(0.11)**		(0.07)**	(0.07)**
Log M&E price *		-0.27		-0.16	-0.15
Size (>251)		(0.13)**		(0.08)**	(0.09)*
Log input tariffs			-0.04	-0.04	-0.02
			(0.02)	(0.02)**	(0.01)
Log input tariffs *			0.00	0.02	0.08
Share input imports			(0.09)	(0.09)	(0.09)
Log output tariffs			0.02	0.02	0.02
			(0.01)*	(0.01)*	(0.01)**
Log output tariffs *			-0.19	-0.16	-0.16
Share exports			(0.11)	(0.12)	(0.12)
Log M&E tariffs *			-0.04	-0.02	-0.03
Share M&E imports			(0.03)	(0.03)	(0.03)
Log FDI					0.17
					(0.08)**
Size dummies	no	yes	no	yes	yes
Input/export shares	no	no	yes	yes	yes
Other firm-level controls	no	no	no	no	yes
Industry-level controls	no	no	no	no	yes
Year fixed effects	yes	yes	yes	yes	yes
No. obs.	9115	9115	9115	9115	9115
Wald test	1291.68***	1360.46***	2319.92***	2048.59***	2887.80***
AR(1)	-18.03***	-17.72***	-15.66***	-15.45***	-15.76***
AR(2)	-0.03	-0.01	-1.35	-1.34	-1.29

Notes: The regressions are estimated via system GMM. The dependent variable is the log of the skill premium in all regressions. Robust standard errors in parentheses are clustered at the industry level. One, two and three asterisks indicate coefficients significantly different from zero at 10%, 5% and 1% level respectively.

and higher-order lags of the dependent variable as instruments. While the Hansen test of overidentifying restrictions does not reject the null of hypothesis of exogeneity of instruments in all the specifications, the Sargan test of overidentifying restrictions fails. Moreover, the difference-in-Hansen test does not reject the exogeneity of the price of M&E in the US as an instrument by itself. These tests, which are not reported, should not be relied upon too faithfully because the Hansen-type tests are weakened by many instruments and the Sargan test is prone to weakness (Roodman, 2009) and it tends to become more significant as the number of observations grows large (Meschi *et al.*, 2009), as in this analysis.

Moving on to the different specifications reported, column 1 includes only the lagged dependent variable, the log of the price of M&E and year fixed effects. The coefficient on the lagged values of the skill premium is always positive and with a coefficient less than one. The coefficient on the log of the price of M&E in Mexico is negative and significant at the 10% level. Decreases in the price of M&E lead to increases in the skill premium, thus confirming the hypothesis that technical change coming through M&E favours skilled workers.

Column 2 tests whether the effects of SBTC coming through changes in the price of M&E are heterogeneous depending on the size of the plant. This second specification also includes dummy variables for plant size. The coefficient on the price of M&E is now positive but not significant, thus implying that the price of M&E has no effect on the skill premium in small plants. However, the price of M&E has a significantly negative effect on the skill premium in medium- and large-sized plants. Joint tests of significance show that all three coefficients are jointly different from zero. This implies that SBTC measured through changes in the price of M&E is more important in larger plants, thus confirming the important role of firm heterogeneity in recent models of technical change and trade.

Regarding the magnitude of the coefficients related to the price of M&E, a 10% decrease leads to an increase in the skill premium by approximately 1% in larger plants, but no effect on smaller plants. This implies that SBTC coming through the variation in the price of M&E across industries can account for one tenth of the overall increase in the skill premium during the 1986-1990 period. The magnitude of the effect is similar in the following specifications.

Column 3 drops the price of M&E and adds the log of input tariffs, the log of output tariffs, their interactions with the shares of intermediate input imported and sales exported respectively and the interaction of the tariff rate on M&E with the share of M&E that is imported. This specification also adds these shares separately. The only variable that has an effect on the skill premium is the log of output tariffs, albeit only at the 10% significance level. The joint test of significance for the output tariff and its interaction with the share of sales exported shows that the effect of output tariffs is heterogeneous. While the positive coefficient on the output tariff variable suggests that trade liberalisation in final goods has a negative effect on the skill premium, this effect dies off quickly and becomes positive as firms export larger shares of their sales.

The price of M&E and its interaction with plant size dummies and all trade-related variables are added in the same specification in column 4. The results from the previous two columns do not change qualitatively, with the exception of the coefficient on input tariffs that is now significant at the 5% level. The negative coefficient implies that decreases in input tariffs tend to increase the skill premium, which contrasts with the results in Amiti and Cameron (2011) for Indonesia. While this could be due to the fact that Mexico is more skill-abundant than Indonesia, it should be noted that this result is not robust since it does not carry through all specifications.

Additional firm-level and industry-level controls are added in column 5. In particular, the log of FDI, defined as the share of firms' social capital held by foreigners, is included in this specification. The skill premium is larger in plants with at least some foreign ownership, which implies that FDI is a significant contributor towards the increase in wage inequality. The inclusion of these additional variables does not, however, affect the statistical significance of the point estimates on the price of M&E and its interaction and the trade-related variables, which only tend to decrease slightly.

Table 4: The determinants of the price of M&E in Mexico

Dep. var.: Log M&E price			
	(1) US price and tariff	(2) Industry controls	(3) Year fixed effects
Log M&E price in US	0.84	0.69	-0.39
	(0.32)***	(0.34)**	(1.88)
Log M&E tariffs	0.85	1.17	
	(0.26)***	(0.50)***	
Industry fixed effects	yes	yes	yes
Industry-level controls	no	yes	yes
Year fixed effects	no	no	yes
No. obs.	276	276	276
R-squared	0.80	0.80	0.81
F-test	15.11***	7.68***	7.93***

Notes: The regressions are estimated via fixed effects. The dependent variable is the log of the price of M&E in Mexico in all regressions. Robust standard errors in parentheses are clustered at the industry level. One, two and three asterisks indicate coefficients significantly different from zero at 10%, 5% and 1% level respectively.

5.2 Disentangling trade-induced and exogenous SBTC

Table 4 reports the estimation results for equation (4). This equation is equivalent to the first-stage regression in a two-stage least squares estimation and it is necessary to see how the price of M&E in Mexico varies with the price of M&E in the US, to be considered a measure of exogenous SBTC, and the tariff rate specific to M&E, a measure of trade-induced SBTC, since system GMM does not report the results of this regression. The caveat is that this equation only captures the effects of exogenous and trade-induced technical change that happen through changes in the price of M&E.

The first column of table 4 shows the results including only the log of the price of M&E in the US, the log of M&E tariffs and industry fixed effects. Both the price of M&E in the US and the tariff rate on M&E affect positively the price of M&E in Mexico, with coefficients statistically significant at the 1% level. Both coefficients are statistically not different from one, which corresponds to a perfect pass-through of foreign prices and tariffs to the domestic price of M&E.

Column 2 adds other industry-level regressors, in order to match the variables included in the estimation of equation (3). The coefficients on the main variables of interest change slightly, yet they both remain statistically different from zero but not different from one.

The specifications in the first two columns do not add year fixed effects because their inclusion would prevent to identify the coefficient on the tariff rates on M&E since this variable does not change across industries but only over time. In order to make sure that changes in tariff rates on M&E do not simply capture a time trend, column 3 estimates equation (4) with year fixed effects instead of tariff rates on M&E. In this specification, the coefficient on the price of M&E in the US becomes negative and insignificant, which is unlikely given the importance of imports of equipment capital, especially from the US, for the Mexican economy. Therefore, changes in the price of M&E in Mexico are caused by changes in the price of M&E in the US and changes in the tariff rates on M&E, with the latter having a slightly larger effect than the former on the Mexican M&E price.

Table 5: The effects of trade and SBTC on skilled and unskilled wages

Dep. var.	$\ln ws$	$\ln ws$	$\ln wu$	$\ln wu$
	(1) Plant-size interactions	(2) Additional controls	(3) Plant-size interactions	(4) Additional controls
Log skilled wage (-1)	0.66	0.61		
	(0.02)***	(0.03)***		
Log unskilled wage (-1)			0.57	0.57
			(0.03)***	(0.03)***
Log M&E price	-0.31	0.04	-0.28	-0.00
	(0.19)*	(0.08)	(0.15)*	(0.08)
Log M&E price *	0.17	-0.12	0.19	-0.01
Size (101-250)	(0.14)	(0.08)	(0.11)*	(0.07)
Log M&E price *	0.18	-0.19	0.23	-0.05
Size (>251)	(0.16)	(0.09)**	(0.15)	(0.10)
Log input tariffs		-0.01		0.01
		(0.01)		(0.01)
Log input tariffs *		0.01		-0.10
Share input imports		(0.09)		(0.06)*
Log output tariffs		-0.00		-0.03
		(0.01)		(0.01)**
Log output tariffs *		-0.26		-0.14
Share exports		(0.13)**		(0.14)
Log M&E tariffs *		-0.01		0.01
Share M&E imports		(0.02)		(0.02)
Log FDI		0.43		0.30
		(0.08)***		(0.08)***
Size dummies	yes	yes	yes	yes
Input/export shares	no	yes	no	yes
Other firm-level controls	no	yes	no	yes
Industry-level controls	no	yes	no	yes
Year fixed effects	yes	yes	yes	yes
No. obs.	9115	9115	9115	9115
Wald test	2492.41***	4732.51***	2114.00***	4885.48***
AR(1)	-19.07***	-14.28***	-17.88***	-13.65***
AR(2)	1.27	0.01	0.60	0.59

Notes: The regressions are estimated via system GMM. The dependent variable is the log of real skilled wages in columns 1 and 2 and the log of real unskilled wages in columns 3 and 4. Robust standard errors in parentheses are clustered at the industry level. One, two and three asterisks indicate coefficients significantly different from zero at 10%, 5% and 1% level respectively.

5.3 Results for real skilled and unskilled wages

Table 5 shows four regressions, in which the dependent variable is either real skilled wages (first two columns) or real unskilled wages (last two columns). In all the regressions, the estimator used is system GMM. The first and third columns correspond to the specification in column 2 of table 3, while the second and fourth columns report the same specification as in column 5 of table 3, but with skilled and unskilled wages as the dependent variables. All specifications are significant overall, as shown by the Wald tests, and only first-order serial correlation is detected by the AR(1) and AR(2) tests.

Starting with the regressions for real skilled wages, column 1 shows that the price of M&E has a negative effect on the real wage of skilled workers in all firms since the interaction terms of the M&E price with the dummies for plant size are not significant. However, when all the other regressors are included, as in column 2, skilled wages turn out to be affected negatively the price of M&E only in larger plants, which is equivalent to the results for the skill premium in table 3. This implies that decreases in the price of M&E tend to increase real skilled wages in medium- and large-sized plants.

Regarding the other coefficients, the lagged dependent variable, in the specifications for both real skilled and real unskilled wages, is always positive and significant, with a coefficient less than one. Plants in which foreigners have a stake tend to pay higher skilled wages and exporting plants in industries that decreased output tariffs also tend to pay higher wages.

The results are different for real unskilled wages. Column 3 shows that decreases in the price of M&E tend to increase real unskilled wages, but more so in smaller plants. However, the statistical significance of these point estimates does not hold when other important regressors are included, as in column 4. This specification shows that the variables related to the price of M&E are not significant, while the log of the share of firms' social capital held by foreigners is positive and highly significant. The coefficient is smaller than that on the same variable in the regression for real skilled wages, which is consistent with the positive effect of foreign ownership on the skill premium. Some of the coefficients attached to the trade-related variables are also statistically significant. In particular, plants that import intermediate inputs and that belong to industries that decreased input tariffs tend to pay higher real unskilled wages. Decreases in output tariffs also lead to industry-wide increases in real unskilled wages.

5.4 Robustness checks

This section presents some robustness checks for the results presented above, starting with the regressions for the skill premiium. Table 6 shows that the results presented in table 3, particularly the specification in column 5 considered to be the baseline, are robust across specifications.

One of the main concerns is that measure of technical change used, the price of M&E is not robust to the inclusion of firm-level measures of technical change. Column 1 includes the amount of money spent on royalties for the use of new technologies to measure technical change, as in Bustos (2007; 2009), instead of the price of M&E. The coefficient on technology expenditures through royalties is positive and significant, albeit only at the 10% level, and the significance of the point estimates on the variables included is not altered. Column 2 uses imports of M&E, as in Riaño (2009), as a measure of technical change. The coefficient on M&E imports is not statistically different from zero. All three measures of technical change, i.e., the price of M&E, technology expenditures and M&E imports, are included in the specification in column 3. As before, decreases in the price of M&E lead to increases in the skill premium, but only in larger plants. Additionally, higher technology expenditures through royalties are also associated with a higher skill premium. As a further robustness check, the coefficients on the price of M&E and its interaction with plant size dummies do not change significantly when expenditures on royalties and M&E imports are also interacted with plant size dummies. Results are available upon request.

The reason why M&E imports do not affect the skill premium is that this variable ex-

Table 6: The effects of trade and SBTC on the skill premium – robustness checks

Dep. var.: ln(ws/wu)	(1) Royalties expenditures	(2) M&E imports	(3) All SBTC measures	(4) No foreign firms	(5) State-year fixed effects
Log skill premium (-1)	0.54	0.54	0.54	0.54	0.54
	(0.03)***	(0.03)***	(0.03)***	(0.03)***	(0.03)***
Log M&E price			0.05	0.16	0.05
			(0.03)	(0.11)	(0.08)
Log M&E price *			-0.14	-0.19	-0.13
Size (101-250)			(0.07)**	(0.10)*	(0.07)**
Log M&E price *			-0.15	-0.23	-0.14
Size (>251)			(0.09)*	(0.11)**	(0.09)*
Log royalties	0.09		0.10		
expenditures	(0.05)*		(0.05)**		
Log M&E imports		0.01	0.02		
		(0.03)	(0.03)		
Log input tariffs	-0.02	-0.02	-0.02	-0.01	-0.02
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)**
Log input tariffs *	0.12	0.12	0.09	0.18	0.08
Share input imports	(0.08)	(0.09)	(0.09)	(0.14)	(0.09)
Log output tariffs	0.03	0.03	0.02	0.02	0.03
	(0.01)***	(0.01)***	(0.01)**	(0.01)**	(0.01)**
Log output tariffs *	-0.14	-0.14	-0.14	-0.05	-0.21
Share exports	(0.11)	(0.11)	(0.11)	(0.13)	(0.11)*
Log M&E tariffs *	-0.04	-0.04	-0.03	-0.01	-0.03
Share M&E imports	(0.03)	(0.03)	(0.03)	(0.04)	(0.03)
Log FDI	0.32	0.34	0.16		0.14
	(0.11)***	(0.12)***	(0.08)**		(0.08)*
Size dummies	yes	yes	yes	yes	yes
Input/export shares	yes	yes	yes	yes	yes
Other firm-level controls	yes	yes	yes	yes	yes
Industry-level controls	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	no
State-year fixed effects	no	no	no	no	yes
No. obs.	9115	9115	9115	6380	9115
Wald test	2327.70***	2073.64***	2831.90***	1631.17***	3.88e+09***
AR(1)	-15.76***	-15.84***	-15.73***	-14.15***	-15.91***
AR(2)	-1.30	-1.31	-1.27	-1.74	-1.52

Notes: The regressions are estimated via system GMM. The dependent variable is the log of the skill premium in all regressions. Robust standard errors in parentheses are clustered at the industry level. One, two and three asterisks indicate coefficients significantly different from zero at 10%, 5% and 1% level respectively.

cludes purchases of imports via other domestic firms (e.g., specialised importers). Moreover, the design even of domestically produced M&E is heavily influenced by that of imported M&E and of M&E used abroad, which domestic producers copy either under license (for which they pay royalties) or by making something similar. Therefore, imported M&E is important, both in itself and as a model for local producers to copy, but it is not the whole of the new technology story. Expenditures on royalties for new technologies are also not able to wholly capture technical change because they exclude the possibility of technology embodied in M&E, which is particularly important in developing countries.

In the specifications reported so far, the share of foreign capital in each firm, a measure of FDI, has been included to account for the differential skill premium in foreign firms. However, the demand for labour in foreign firms may differ from domestic firms because of the relationship with the parent firm (Amiti and Cameron, 2011). Column 4 excludes from the sample any firm that is partially or wholly owned by foreigners. The coefficients on all variables remain similar in magnitude and their significance does not change.

Works by Hanson (1997) and Chiquiar (2008) suggest that the regional dimension is important in determining wage and the return to skill in Mexico. Therefore, column 5 controls for state-year fixed effects to isolate the impact of STBC from the differential impact of market access. The coefficients on the price of M&E and its interaction with plant size remain similar in magnitude and their significance does not change either. Interestingly, the coefficient on input tariffs turns significant at the 5% level. The negative sign implies that decreases in input tariffs are associated with increases in the skill premium. The coefficient on output tariffs is still positive and significant, while the coefficient on its interaction with the share of exports is negative and significant. Thus, trade liberalisation in final goods tends to decrease the skill premium, but this effect may turn positive in larger plants.

Table 7 presents some robustness checks for the specifications using real skilled wages (first two columns) or real unskilled wages (last two columns) as the dependent variable.

Column 1 includes three different measures of SBTC, i.e., the price of M&E with its interaction with plant size dummies, expenditures on royalties and M&E imports. The coefficients on the price of M&E and its interactions remain similar in magnitude and their significance does not change. The coefficient on expenditures on royalties is positive and highly significant, while that on M&E is not significant. Column 3 presents the same specification using real unskilled wages as the dependent variable. As before, the price of M&E does not affect real unskilled wages, but expenditures on royalties have a positive and significant effect on real unskilled wages.

These results suggest that larger plants in industries in which the price of M&E decreased pay higher real skilled wages, but plants that spend more on royalties for the use of new technologies pay higher skilled and unskilled wages. Thus, the M&E and royalties for technology licenses represent different types of technical change. In particular, M&E seem to be associated with a technology that favours skilled labour in larger plants, while expenditures on royalties seem to be a technology that is either complementary with both, although to different degrees, or more generally that increases the productivity of both types of labour.

Columns 2 and 4 include state-year fixed effects to account for time-variant unobservables at the regional level that may have affected wages. The results presented so far are robust to this specification. The coefficients related to the price of M&E remain similar in magnitude and their significance does not change, with the exception of the negative coefficient on the interaction between the price of M&E and medium-sized plants that becomes significant at the 10% level and the .

The trade-related variables are not affected by these robustness checks, with the exception of the coefficient on the interaction between input tariffs and the share of inputs imported in the specification using real unskilled wages as the dependent variables and state-year fixed effects. This coefficients remains negative and of similar magnitude, but it becomes insignificant.

Table 7: The effects of trade and SBTC on skilled and unskilled wages – robustness checks

Dep. var.	$\ln ws$	$\ln ws$	$\ln wu$	$\ln wu$
	(1) All SBTC measures	(2) State-year fixed effects	(3) All SBTC measures	(4) State-year fixed effects
Log skilled wage (-1)	0.60	0.61		
	(0.03)***	(0.03)***		
Log unskilled wage (-1)			0.57	0.56
			(0.03)***	(0.03)***
Log M&E price	0.04	0.03	-0.00	-0.01
	(0.07)	(0.06)	(0.08)	(0.08)
Log M&E price *	-0.13	-0.12	-0.01	-0.01
Size (101-250)	(0.08)	(0.07)*	(0.07)	(0.06)
Log M&E price *	-0.20	-0.18	-0.06	-0.05
Size (>251)	(0.09)**	(0.08)**	(0.09)	(0.09)
Log royalties	0.18		0.09	
expenditures	(0.05)***		(0.04)**	
Log M&E imports	0.04		0.03	
	(0.03)		(0.03)	
Log input tariffs	-0.01	-0.02	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)
Log input tariffs *	0.01	0.02	-0.10	-0.08
Share input imports	(0.08)	(0.09)	(0.06)*	(0.05)
Log output tariffs	-0.00	-0.00	-0.03	-0.03
	(0.01)	(0.01)	(0.01)**	(0.01)***
Log output tariffs *	-0.22	-0.33	-0.10	-0.16
Share exports	(0.12)*	(0.13)**	(0.13)	(0.14)
Log M&E tariffs *	-0.02	-0.02	0.01	0.01
Share M&E imports	(0.02)	(0.02)	(0.02)	(0.02)
Log FDI	0.42	0.36	0.30	0.27
	(0.08)***	(0.07)***	(0.08)***	(0.08)***
Size dummies	yes	yes	yes	yes
Input/export shares	yes	yes	yes	yes
Other firm-level controls	yes	yes	yes	yes
Industry-level controls	yes	yes	yes	yes
Year fixed effects	yes	no	yes	no
State-year fixed effects	no	yes	no	yes
No. obs.	9115	9115	9115	9115
Wald test	6992.10***	9.59e+08***	5204.53***	2.86e+08***
AR(1)	-14.25***	-14.33***	-13.69***	-14.22***
AR(2)	0.04	-0.05	0.58	0.65

Notes: The regressions are estimated via system GMM. The dependent variable is the log of real skilled wages in columns 1 and 2 and the log of real unskilled wages in columns 3 and 4. Robust standard errors in parentheses are clustered at the industry level. One, two and three asterisks indicate coefficients significantly different from zero at 10%, 5% and 1% level respectively.

6 Conclusion

This paper analyses and quantifies the effects of SBTC, both exogenous and trade-induced, that occur through changes in the price of M&E and trade liberalisation using data at the plant level in Mexican manufacturing from 1984 to 1990. The novelty of this work lies in the identification strategy adopted, based on using both internal instruments, i.e. lagged values of the endogenous variables, and an external instrument, the price of M&E in the US, for the price of M&E in Mexico. This strategy ensures that the relationships found in the data are of a causal nature.

The results show that the effects of both exogenous and trade-induced SBTC – caused by changes in the price of M&E – on the skill premium are of statistical and economic significance. Changes in the price of equipment in the US and in tariff rates on M&E can explain about one tenth of the increase in the skill premium during the period considered. Given the identification strategy adopted, this is to be considered a lower bound estimate of the effects of SBTC on the skill premium.

The evidence presented is, therefore, consistent with the idea that, as the price of equipment decreases, due to exogenous technical progress abroad or a decline in tariffs, the demand for it increases, particularly in large plants that invest more in M&E, as predicted by recent models with heterogeneous firms. The increase in the demand for M&E in larger plants leads to an increase in the relative demand for skilled workers and, thus higher relative and real skilled wages in larger plants due to complementarity. These results are confirmed when the regressions use different firm-level measures of SBTC, including expenditures on royalties for new technologies. The evidence also points towards a specific-factors model in which workers have both general and sector-specific skills.

References

Acemoglu, D. (2002a). 'Directed Technical Change', *Review of Economic Studies*, vol. 69, no. 4, pp. 781–809.

Acemoglu, D. (2002b). 'Technical Change, Inequality, and the Labor Market', *Journal of Economic Literature*, vol. 40, no. 1, pp. 7–72.

Acemoglu, D. (2003). 'Patterns of Skill Premia', *Review of Economic Studies*, vol. 70, no. 2, pp. 199–230.

Amiti, M. and Cameron, L. (2011). 'Trade Liberalization and the Wage Skill Premium: Evidence from Indonesia', C.E.P.R. Discussion Papers, CEPR Discussion Papers, no. 8382.

Amiti, M. and Davis, D. R. (2008). 'Trade, Firms, and Wages: Theory and Evidence', C.E.P.R. Discussion Papers, CEPR Discussion Papers, no. 6872.

Anderson, E. (2005). 'Openness and inequality in developing countries: A review of theory and recent evidence', *World Development*, vol. 33, no. 7, pp. 1045–1063.

Atkin, D. (2010). 'Endogenous Skill Acquisition and Export Manufacturing in Mexico', Yale University.

Atkinson, A. B. and Morelli, S. (2011). 'Economic crises and Inequality', United Nations Development Programme (UNDP), Human Development Research Papers, no. HDRP-2011-06.

Berman, E., Bound, J. and Griliches, Z. (1994). 'Changes in the Demand for Skilled Labor within U.S. Manufacturing: Evidence from the Annual Survey of Manufactures', *The Quarterly Journal of Economics*, vol. 109, no. 2, pp. 367–397.

Berman, E. and Machin, S. (2000). 'Skill-Based Technology Transfer around the World', *Oxford Review of Economic Policy*, vol. 16, no. 3, pp. 12–22.

Berman, E. and Machin, S. (2004). 'Globalization, Skill-Biased Technological Change and Labour Demand', in E. Lee and M. Vivarelli (eds.), *Understanding Globalization, Employment and Poverty Reduction*, New York: Palgrave Macmillan, pp. 39–66.

Bloom, N., Draca, M. and Reenen, J. V. (2011). 'Trade Induced Technical Change? The Impact of Chinese Imports on Innovation, IT and Productivity', Centre for Economic Performance, LSE, CEP Discussion Papers, no. dp1000.

Burstein, A. and Vogel, J. (2009). 'Globalization, Technology, and the Skill Premium', Columbia University.

Bustos, P. (2007). 'The Impact of Trade on Technology and Skill Upgrading: Evidence from Argentina', CREI, Universitat Pompeu Fabra.

Bustos, P. (2009). 'Trade Liberalization, Exports and Technology Upgrading: Evidence on the Impact of MERCOSUR on Argentinean Firms', CREI, Universitat Pompeu Fabra, Economics Working Papers, no. 1173.

Chennells, L. and Van Reenen, J. (1999). 'Has technology hurt less skilled workers? A survey of the micro-econometric evidence', Institute for Fiscal Studies, IFS Working Papers, no. W99/27.

Chiquiar, D. (2008). 'Globalization, regional wage differentials and the Stolper-Samuelson Theorem: Evidence from Mexico', *Journal of International Economics*, vol. 74, no. 1, pp. 70–93.

Csillag, M. and Koren, M. (2011). 'Machines and machinists: Capital-skill complementarity from an international trade perspective', Center for Firms in the Global Economy, CeFiG Working Papers, no. 13.

Doms, M., Dunne, T. and Troske, K. R. (1997). 'Workers, Wages, and Technology', *The Quarterly Journal of Economics*, vol. 112, no. 1, pp. 253–90.

Esquivel, G. and Rodríguez-López, J. A. (2003). 'Technology, trade, and wage inequality in Mexico before and after NAFTA', *Journal of Development Economics*, vol. 72, no. 2, pp. 543–565.

Fairris, D. and Levine, E. (2004). 'Declining union density in Mexico, 1984-2000', *Monthly Labor Review*, vol. 127, no. 9, pp. 10–17.

Feenstra, R. C. and Hanson, G. H. (1996). 'Globalization, Outsourcing, and Wage Inequality', *American Economic Review*, vol. 86, no. 2, pp. 240–45.

Feenstra, R. C. and Hanson, G. H. (1997). 'Foreign direct investment and relative wages: Evidence from Mexico's maquiladoras', *Journal of International Economics*, vol. 42, no. 3-4, pp. 371–393.

Feliciano, Z. (2001). 'Workers and Trade Liberalization: The Impact of Trade Reforms in Mexico on Wages and Employment', *Industrial and Labor Relations Review*, vol. 55, no. 1, pp. 95–115.

Gallego, F. (2010). 'Skill Premium in Chile: Studying Skill Upgrading in the South', Instituto de Economia, Pontificia Universidad Católica de Chile, Documentos de Trabajo, no. 377.

Goh, C.-c. and Javorcik, B. S. (2007). 'Trade Protection and Industry Wage Structure in Poland', in A. Harrison (ed.), *Globalization and Poverty*, Chicago, IL: University of Chicago Press, pp. 337–372.

Goldberg, P. K., Khandelwal, A. K., Pavcnik, N. and Topalova, P. (2010). 'Imported Intermediate Inputs and Domestic Product Growth: Evidence from India', *The Quarterly Journal of Economics*, vol. 125, no. 4, pp. 1727–1767.

Goldberg, P. K. and Pavcnik, N. (2005). 'Trade, wages, and the political economy of trade protection: evidence from the Colombian trade reforms', *Journal of International Economics*, vol. 66, no. 1, pp. 75–105.

Goldberg, P. K. and Pavcnik, N. (2007). 'Distributional Effects of Globalization in Developing Countries', *Journal of Economic Literature*, vol. 45, no. 1, pp. 39–82.

Gonzaga, G., Menezes Filho, N. and Terra, C. (2006). 'Trade liberalization and the evolution of skill earnings differentials in Brazil', *Journal of International Economics*, vol. 68, pp. 345–367.

Gorodnichenko, Y., Svejnar, J. and Terrell, K. (2010). 'Globalization and Innovation in Emerging Markets', *American Economic Journal: Macroeconomics*, vol. 2, no. 2, pp. 194–226.

Hanson, G. H. (1997). 'Increasing Returns, Trade and the Regional Structure of Wages', *Economic Journal*, vol. 107, no. 440, pp. 113–33.

Hanson, G. H. and Harrison, A. (1999). 'Trade liberalization and wage inequality in Mexico', *Industrial and Labor Relations Review*, vol. 52, no. 2, pp. 271–288.

Harrigan, J. and Reshef, A. (2011). 'Skill Biased Heterogeneous Firms, Trade Liberalization, and the Skill Premium', National Bureau of Economic Research, Inc, NBER Working Papers, no. 17604.

Iacovone, L. (2008). 'Exploring Mexican Firm-Level Data', University of Sussex.

Katz, L. F. and Murphy, K. M. (1992). 'Changes in Relative Wages, 1963-1987: Supply and Demand Factors', *The Quarterly Journal of Economics*, vol. 107, no. 1, pp. 35–78.

Krusell, P., Ohanian, L. E., Ríos-Rull, J.-V. and Violante, G. L. (2000). 'Capital-Skill Complementarity and Inequality: A Macroeconomic Analysis', *Econometrica*, vol. 68, no. 5, pp. 1029–1054.

Kugler, M. and Verhoogen, E. (2012). 'Prices, Plant Size, and Product Quality', *Review of Economic Studies*, vol. 79, no. 1, pp. 307–339.

La Porta, R. and López-De-Silanes, F. (1999). 'The Benefits Of Privatization: Evidence From Mexico', *The Quarterly Journal of Economics*, vol. 114, no. 4, pp. 1193–1242.

Leamer, E. (1998). 'In search of Stolper-Samuelson linkages between international trade and lower wages', in S. Collins (ed.), *Imports, Exports and the American Worker*, Washington, DC: Brookings Institution, pp. 141–202.

Leonardi, M. (2007). 'Firm heterogeneity in capital-labour ratios and wage inequality', *Economic Journal*, vol. 117, no. 518, pp. 375–398.

Levinsohn, J. and Petrin, A. (2003). 'Estimating Production Functions Using Inputs to Control for Unobservables', *Review of Economic Studies*, vol. 70, no. 2, pp. 317–341.

Machin, S. and Van Reenen, J. (1998). 'Technology And Changes In Skill Structure: Evidence From Seven OECD Countries', *The Quarterly Journal of Economics*, vol. 113, no. 4, pp. 1215–1244.

Melitz, M. J. (2003). 'The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity', *Econometrica*, vol. 71, no. 6, pp. 1695–1725.

Meschi, E., Taymaz, E. and Vivarelli, M. (2009). 'Trade, Technology and Skills: Evidence from Turkish Microdata', Friedrich-Schiller-University Jena, Max-Planck-Institute of Economics, Jena Economic Research Papers in Economics, no. 2009-097.

Revenga, A. (1997). 'Employment and Wage Effects of Trade Liberalization: The Case of Mexican Manufacturing', *Journal of Labor Economics*, vol. 15, no. 3, pp. S20–43.

Riaño, A. (2009). 'Trade, Technology Adoption and the Rise of the Skill Premium in Mexico', University of Nottingham.

Robbins, D. (2003). 'The Impact of Trade Liberalization upon Inequality in Developing Countries – A Review of Theory and Evidence', International Labour Organization, ILO Working Paper, no. 13.

Roodman, D. (2009). 'How to do xtabond2: An introduction to difference and system GMM in Stata', *Stata Journal*, vol. 9, no. 1, pp. 86–136.

Schmidt, G. (2010). 'Technology Choice and International Trade', Kiel Institute for the World Economy, Working Papers, no. 1600.

Ten Kate, A. (1989). 'Notas sobre la apertura comercial de México, experiencias y lecciones', *Ensayos Sobre Política Económica*, vol. 15, no. 6, pp. 95–111.

Ten Kate, A. (1992). 'Trade Liberalization and Economic Stabilization in Mexico: Lessons of Experience', *World Development*, vol. 20, no. 5, pp. 659–672.

Topalova, P. (2004). 'Trade Liberalization and Firm Productivity: The Case of India', IMF, Working Papers, no. 04/28.

Van Reenen, J. (2011). 'Wage inequality, technology and trade: 21st century evidence', *Labour Economics*, vol. 18, no. 6, pp. 730–741.

Vannoorenberghe, G. (2011). 'Trade between symmetric countries, heterogeneous firms, and the skill premium', *Canadian Journal of Economics*, vol. 44, no. 1, pp. 148–170.

Verhoogen, E. A. (2008). 'Trade, Quality Upgrading, and Wage Inequality in the Mexican Manufacturing Sector', *The Quarterly Journal of Economics*, vol. 123, no. 2, pp. 489–530.

Wood, A. (1997). 'Openness and Wage Inequality in Developing Countries: The Latin American Challenge to East Asian Conventional Wisdom', *World Bank Economic Review*, vol. 11, no. 1, pp. 33–57.

Xiang, C. (2005). 'New Goods and the Relative Demand for Skilled Labor', *The Review of Economics and Statistics*, vol. 87, no. 2, pp. 285–298.