Australian School of Business Research Paper No. 2014 ECON 15

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March 12, 2014

Abstract

In this paper we investigate how firms adjust markups across products in response to fluctuations in the real exchange rate. In a theoretical framework, we show that firms increase their markup and producer prices following a real depreciation and that this increase is greater for products with higher productivity, a consequence of local distribution costs. We estimate markups at the market-product-plant level using detailed panel production and cost data from Mexican manufacturing between 1994 and 2007. Exploiting variation in the real exchange rate in the aftermath of the peso crisis in December 1994, we provide robust empirical evidence that plants increase their markups and producer prices in response to a real depreciation and that within-firm heterogeneity is a key determinant of plants' response to exchange rate shocks. We also provide some evidence in favour of a local distribution cost channel of incomplete exchange rate pass-through.

Keywords: multi-product, variable markup, exchange rate pass-through, local distribution cost, Mexico.
JEL Classification: D22, D24, F12, F14, F41, L11.

*We thank Rafael Dix-Carneiro, Nico Voigtländer, Oleg Itshkoki, Esteban Rossi-Hansberg and Saroj Bhattarai for their helpful comments. Special thanks go to Abigail Durán and Gerardo Leyva for granting access to INEGI data at the offices of INEGI in Aguascalientes and to all INEGI employees who provided assistance and answered all questions, in particular to Gabriel Romero, Otoniel Soto and Armando Arallanes. We gratefully acknowledge that this research was financially supported by an Australian Research Council grant to Professor Alan Woodland.

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1 Introduction

Macroeconomic evidence of the impact of exchange rate movements on prices and exports is notoriously weak (Goldberg and Knetter, 1997; Campa and Goldberg, 2005; Obstfeld and Rogoff, 2001; Engel, 2001). Looking at the price and export response at the firm level reveals a much richer picture. Berman et al. (2012) provide strong evidence that high-performance firms react to a depreciation by significantly increasing their producer prices more than low-performance firms. Similar heterogeneity has been observed across products within a multi-product exporter (Chatterjee et al., 2013).

Central to this heterogeneous producer price response of exporters is the heterogeneous response of markups to exchange rate shocks. In response to a real exchange rate depreciation, high-performance firms or products experience a larger increase in markups and this translates into a bigger producer price response. Lack of input data and methodology has limited the empirical analysis of the heterogeneous response of markups to real exchange rate shocks.

In this paper, we estimate markups at the market-product-plant level for multi-product plants, following De Loecker et al. (2012), using detailed panel production and cost data from Mexico between 1994 and 2007. Exploiting huge fluctuations in the multilateral real exchange rate, we document a key heterogeneity in how exporters change their markups. We show that exporters increase their markups in response to a real depreciation and within a plant markups' increase is significantly higher for higher-performance products. This key result is robust across a variety of specifications. We also provide some evidence that this heterogeneous response of markups to real exchange rate shocks is particularly strong in industries with higher local distribution margins, the key channel for incomplete pass-through in our theoretical framework.

Our model is a multi-product version of the heterogeneous firm, variable markup model in a monopolistically competitive setup (Melitz, 2003). The model is an extension of Chatterjee et al. (2013) incorporating imported intermediate inputs. Following Mayer et al. (2014), each multi-product firm is modeled as facing a product ladder, i.e., there is a core product that the firm is most efficient at producing (a firm's "core competency") and the firm is less efficient at producing products further away from it. Variable markups are introduced in the standard monopolistically competitive, CES demand model via local per-unit distribution costs, following Corsetti and Dedola (2005).[1] Within a given firm, optimal markups are higher for products closer to the core competency. We show that in response to a real depreciation, markup and producer-price increases are more pronounced for products closer to the core competency, i.e., those with greater productivity. As discussed in Berman et al. (2012), a similar result will arise in endogenous and variable markup models (Melitz and Ottaviano, 2008; Atkeson and Burstein, 2008), where both a higher productivity at the firm-product level and a real depreciation at the aggregate level weaken the elasticity of demand as perceived by exporters.

We test the model's predictions on rich Mexican product-plant-level panel data, for both domestic and export markets. Spanning the period from 1994 to 2007, during which Mexico experienced a series of major exchange rate fluctuations, the dataset has detailed production and cost information. That allows us to use exchange rate variation as well

[1]There is a significant body of literature that analyses how non-tradable distribution costs affect international pricing decisions (Burstein et al., 2005).

as plant- and product-specific information in order to analyze how plants respond to exchange rate movements. We extend the methodology of De Loecker et al. (2012) to estimate markups at the market-product-plant level.

De Loecker et al. (2012) develop a framework to estimate markups from production data with multi-product firms. Their approach to recovering markups follows De Loecker and Warzynski (2012), the main difference being the use of product-level quantity and price information, rather than firm-level deflated sales. This enables De Loecker et al. (2012) to identify markups for each product-plant-year triplet. We follow De Loecker et al. (2012), but we estimate markups separately for domestic and export markets assuming that inputs are allocated across markets in proportion to sales.[2] Once we obtain markups, we compute marginal costs by dividing the observed prices by the estimated markups.

We find that the responses of markups and producer prices to exchange rate fluctuations are consistent with the theoretical predictions. Our key finding is that the relative position of a product within a firm is a statistically and economically significant determinant of markup and producer-price responsiveness to real exchange rate shocks. This result is robust to different measures of within-firm heterogeneity and to controlling for a rich set of firm and industry characteristics.

Related Literature Our paper is related to several branches of literature. First, our paper contributes to the vast literature on the incomplete pass-through of exchange rate shocks into international prices.[3] A channel of incomplete pass-through into consumer prices often considered in the literature is local distribution costs, as for example in Burstein et al. (2003) and Goldberg and Campa (2010). In our model, the elasticity of producer prices with respect to the exchange rate depends on per-unit local distribution costs. Hence, in our empirical work we allow price responses to vary according to distribution margins, in a manner similar to Goldberg and Campa (2010).

Second, our paper is most directly related to the literature that studies variation in pass-through across heterogeneous firms. This heterogeneity is first documented by Berman et al. (2012), who focus on the role of firm productivity and size. In a multi-product version of their paper, Chatterjee et al. (2013) focus instead on the role of within-firm heterogeneity in productivity as the driver of this variation in pass-through. Given the predominance of multi-product exporters in our data, we also choose to focus on within-firm heterogeneity in productivity.[4] We extend the model in Chatterjee et al. (2013) to incorporate imported intermediate inputs.

In a closely related work, Amiti et al. (2013) focus on heterogeneity in imported input and destination-specific market shares. In our empirical specification, we control

[2]We also check robustness of our results by estimating markups from total sales, but restricting the sample to exporters.

[3]Understanding incomplete pass-through is crucial to policy analysis since the degree of pass-through has both implications for how currency devaluations affect inflation and welfare of firms and consumers. Hellerstein (2008) studies manufacturers' and retailers' pass-through of nominal exchange rate movements in the beer market and estimates a structural econometric model to quantify the extent to which a nominal exchange rate shock affects domestic and foreign firms' profits and consumer surplus.

[4]In our dataset, 60% of plants produce multiple products and they contribute more than two thirds of output. In general, multi-product firms dominate domestic and international commerce: they account for 91% of US manufacturing sales (Bernard et al., 2010) and 98% of the value of US manufacturing exports (Bernard et al., 2007).

for plant-level share of imported materials and within-product export market share to establish our key heterogeneity result. Also, in view of the recent literature on the effect of credit constraints on pass-through at the firm level (Strasser, 2013; Gopinath, 2013), we include additional controls for industry-level financial vulnerability (Manova, 2008) and show that our key results remain robust.

Regarding multi-product firms, our study is similar to Mayer et al. (2014). We adopt their deterministic formulation of product ladders to model within-plant heterogeneity. Bernard et al. (2011) characterize an alternative formulation to a product ladder, in which product-firm specific preferences are stochastic. Our results are independent of whether we use a deterministic or stochastic formulation for product ladders. However, unlike a relatively nascent literature (Eckel and Neary, 2010; Dhingra, 2011; Nocke and Yeaple, 2014; Arkolakis and Muendler, 2011), we do not allow for demand or cost linkages across products within a multi-product firm in our theoretical framework. Similar to De Loecker et al. (2012), our empirical estimation of markups does not make any assumptions regarding the nature of economies of scope within a plant.

On the methodology side, our estimation of markups is based on De Loecker et al. (2012) and De Loecker and Warzynski (2012). They provide an empirical framework in the spirit of Hall (1986) to estimate markups. This approach does not require assumptions on the market structure or demand curves faced by plants, nor assumptions on how plants allocate their inputs across products. We exploit quantity and price information to disentangle markups from quantity-based productivity, and then compute marginal costs by dividing observed prices by the estimated markups.

In extending De Loecker and Warzynski (2012) to estimate markups for multi-product plants, De Loecker et al. (2012) show that a new identification problem arises since multi-product plants do not report how inputs are allocated across products within a plant. To handle this problem, they propose an identification strategy that uses an unbalanced sample of single-product plants since the input allocation problem does not exist in this case. While the exclusion of multi-product plants may lead to a sample selection bias, the unbalanced sample improves the selection problem by including those plants that switch from single-product to multi-product manufacturers in response to productivity shocks. Moreover, a correction for sample selection is introduced by including among the controls for productivity the predicted probability that plants are single-product manufacturers.[5]

Finally, our dataset covers a period (1994-2007) marked by huge flucututations in the real exchange rate in Mexico. Verhoogen (2008) uses the peso crisis and ensuing fluctuations in the real exchange rate as the source of variation to empirically investigate quality-upgrading mechanism linking trade and wage inequality.[6] The peso crisis in Mex-

[5]An alternative approach to estimate markups for multi-product firms relies on estimation of multi-product cost function and exploiting the duality between production and cost functions as done in previous literature (Burgess, 1974; Woodland, 1977a;b; Kohli, 1991). However, the product portfolios in Mexican data are not stable (see Iacovone and Javorcik (2010) for evidence regarding product churning). These frequent changes in product mix require explicitly modeling a firm's decision to add a particular product rather than just accounting for the change from single- to multi-product status. These challenges imply that one would need to introduce additional assumptions on the demand and market structure. This would restrict the estimation of markups to single industries, as is common in the industrial organization side of the literature (Goldberg, 1995).

[6]Our methodology to estimate markups includes controls for quality in order to account for unobserved input price differences (De Loecker et al., 2012). This is particularly relevant for our purposes. Auer

ico in 1994 has also received considerable attention in the international macroeconomics literature (Calvo and Mendoza, 1996; Sachs et al., 1996; Hutchison and Noy, 2006). Also, our paper is related to Iacovone and Javorcik (2010), which uses a similar product-plant level panel dataset from Mexico covering the period 1994-2003 to examine product-level dynamics within multi-product exporters in the context of Mexican trade integration under North American Free Trade Agreement (NAFTA). Iacovone et al. (2013) use the same dataset to study the impact of surge in Chinese exports in Mexico.

The paper is structured as follows. In Section 2, we describe the theoretical model and its predictions. Section 3 presents the data. The methodology used to estimated markups and descriptive statistics of these estimates of markups are presented in Section 4. In Section 5, we present the regression results to corroborate the theoretical predictions of Section 2 and robustness exercises. Section 6 concludes the paper.

2 Theoretical Framework

We present a model in which heterogeneous plants in the home country export to a variety of markets. As our empirical application uses data from Mexico, we use "home" to refer to Mexican plants. Plants can export multiple products to a given market, with the product-plant specific productivity depending on how far the product is from the plant's core expertise. We analyse how an exchange rate shock affects plants' optimal markup and producer price. We treat exchange rate movements as exogenous from the point of view of an individual plant.

2.1 Framework

The representative consumer in the export market has utility

$$U = \left(\int_X x(\varphi)^{1-\frac{1}{\sigma}} d\varphi \right)^{\frac{1}{1-\frac{1}{\sigma}}}, \tag{1}$$

where $x(\varphi)$ is the consumption of product φ in the export market and X denotes the set of traded products. φ also denotes the productivity associated with each product. The elasticity of substitution among products is $\sigma > 1$.

Each plant has one product corresponding to its core competency; this is the product that it is most efficient at producing. The productivity associated with this "core product" is a random draw ω from a common and known distribution $G(\omega)$ with bounded support on $[0, \overline{\omega}]$; each plant is therefore indexed by ω. We use j to denote the rank of the product in increasing order of distance from the plant's core competency, with $j = 0$ referring to the core product. The productivity of a plant with core competency ω in producing product of rank j is given by

$$\varphi(j, \omega) = \omega \lambda_\omega^{-j}, \ \lambda_\omega > 1. \tag{2}$$

and Chaney (2009) show that exchange rate shocks are imperfectly passed through to prices and that the pass-through is greater for low-quality goods than for high-quality goods.

The above expression defines a plant's competency ladder, where λ_ω characterizes the length of the ladder.[7] Products with higher j are further away from the core competency, and the plant is relatively less efficient at producing these products. Plants are price takers in the input markets. They combine domestic labour and imported intermediate inputs in a Cobb-Douglas production function. One unit of imported intermediate inputs is produced using one unit of foreign labour. The unit cost is given by the expression $w^{\varrho}(\varepsilon w^*)^{1-\varrho}$, where w is the wage rate at home, w^* is the wage rate in the foreign country, ε is the nominal exchange rate between home and foreign expressed in the home currency per unit of the foreign currency and ϱ is the share of domestic labour in production. Given the definition of ε, an increase in ε is a depreciation in home's currency. We define $q \equiv \frac{w^*\varepsilon}{w}$ as the real exchange rate between home and export market, such that the unit cost can be rewritten as $wq^{1-\varrho}$.

Each plant faces a distribution cost for each unit of any product it exports. This cost is meant to capture all expenses associated with delivering the product to a customer after the product has left home. Per unit distribution costs in the export market are measured as η units of labour hired in the export market. Because of local distribution costs and imported intermediate inputs, per unit costs depend on both home and foreign wage rates.

Plants also face a fixed cost F in exporting. These fixed costs are the same for all plants and products. In addition, there is an iceberg transport cost $\tau > 1$.

2.2 Optimal pricing

In units of foreign currency, the consumer price of product $\varphi(j, \omega)$ is given by

$$\frac{p\left(\varphi\left(j, \omega\right)\right)\tau}{\varepsilon} + \eta w^*, \tag{3}$$

where $p(\varphi(j, \omega))$ is the producer-price of the good exported expressed in home's currency. The first term corresponds to the good's price at foreign's dock expressed in consumer currency, and the second term captures the distribution cost incurred in the export market. The consumer demand in the export market of this product is

$$x(\varphi) = YP^{\sigma-1}\left(\frac{p(\varphi(j,\lambda))\tau}{\varepsilon} + \eta w^*\right)^{-\sigma}, \tag{4}$$

where Y is the income in the export market and P is the price index in the export market. For a product-plant specific productivity φ, the cost in the home currency of producing $x(\varphi)\tau$ units and selling them in foreign is $\frac{wq^{1-\varrho}x(\varphi)\tau}{\varphi} + F$, which implies exporting profits of

$$\pi(\varphi) = \left(p(\varphi) - \frac{wq^{1-\varrho}}{\varphi}\right)x(\varphi)\tau - F.$$

Given the number of products, maximization of profits from exporting leads to the optimal producer price of

$$p(\varphi) = \frac{\sigma}{\sigma-1}\left(1 + \frac{\eta q^{\varrho}\varphi}{\sigma\tau}\right)\frac{wq^{1-\varrho}}{\varphi} = \mu(\varphi)\frac{wq^{1-\varrho}}{\varphi}, \tag{5}$$

[7] Our main results are independent of whether the length of the ladder λ_ω depends on plant characteristics ω.

where the markup is given by

$$\mu(\varphi) = \frac{\sigma}{\sigma-1}\left(1+\frac{\eta q^{\varrho}\varphi}{\sigma\tau}\right). \tag{6}$$

Note that the markup, $\mu(\varphi)$, is higher than the usual monopolistic competition markup due to the presence of local distribution costs. Also, the markup increases with the real exchange rate and with the product-plant specific productivity level φ.[8] This response of markups implies that producer prices increase following a real depreciation and this increase is larger for more productive product-plant pairs. The elasticity of producer prices with respect to the real exchange rate is given by

$$\frac{\partial \ln p(\varphi)}{\partial \ln q} = (1-\varrho) + \frac{\varrho q^{-1}\eta\varphi}{q^{-\varrho}\sigma\tau + \eta\varphi}, \tag{7}$$

while the elasticity of markups with respect to the real exchange rate is given by

$$\frac{\partial \ln \mu(\varphi)}{\partial \ln q} = \frac{\varrho q^{-1}\eta\varphi}{q^{-\varrho}\sigma\tau + \eta\varphi}. \tag{8}$$

This implies that the difference in the two elasticities is given by the share of imported intermediate inputs in production.

Note that the producer-price and markup elasticities with respect to the real exchange rate are specific to each plant and to each product. In fact, equations (7) and (8) increase in both plant-specific and product-specific productivity. Hence, in response to a real exchange rate devaluation, more productive plants tend to increase prices and markups more than less productive plants. Moreover, multi-product plants increase producer prices and markups to a greater extent for products closer to the core competency than for those further away. Due to the fact that plants are relatively efficient at producing core products as a result of local distribution costs, production costs account for a relatively small fraction of the consumer prices. Consequently, the perceived demand elasticity is lower, which leads to higher markups. This translates into higher price increases for these products as a result of a depreciation.

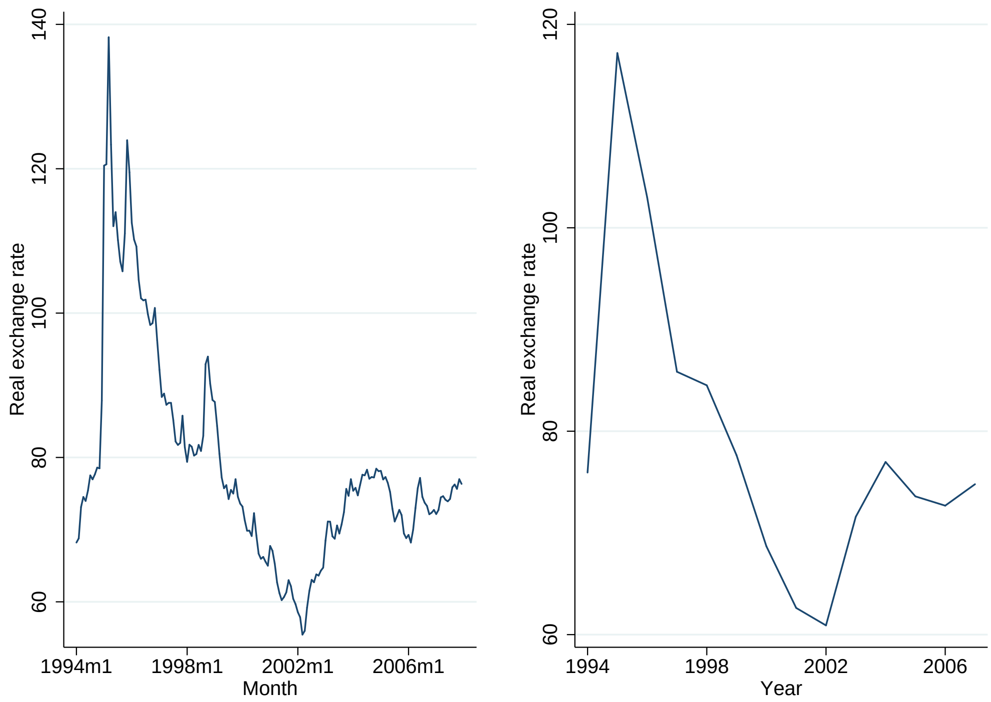
These responses of markups and producer prices to exchange rate movements constitute our key theoretical prediction, which we test in the empirical section. In particular, our main theoretical predictions are that a) producer prices and markups of exporters increase following a real depreciation and b) this increase is larger within plants for products closer to the core competency.

3 Data

This paper uses the large real exchange rate fluctuations that occurred in Mexico between 1994 and 2007 as the exogenous source of variation driving the within-firm changes in product-level producer prices and markups. This period is ideal to study the questions at hand because it covers both the peso crisis of December 1994, which led to a sudden

[8] Berman et al. (2012), Bergin and Feenstra (2000; 2001; 2009) and Atkeson and Burstein (2008) have similar predictions on markups.

Figure 1: Real exchange rate in Mexico



Source: Banco de México.

depreciation of nearly 100%, and the following period in which the Mexican peso steadily appreciated. These large swings in the Mexican peso's real exchange rate are depicted in Figure 1, which shows the monthly (left-hand panel) and yearly (right-hand panel) movements during the period analysed. The data are taken from *Banco de México*. Moreover, there is strong evidence suggesting that the devaluation in 1994 was largely unexpected (Verhoogen, 2008).

Alongside the real exchange rate data, this paper uses plant-level Mexican manufacturing data, collected from the *Instituto Nacional de Estadística y Geografía* (National Institute of Statistics and Geography, INEGI henceforth) and covering the period 1994-2007. The two main datasets used are the *Encuesta Industrial Anual* (Annual Industrial Survey, EIA henceforth), the main survey covering the manufacturing sector, and the *Encuesta Industrial Mensual* (Monthly Industrial Survey, EIM henceforth), a monthly survey that monitors short-term trends.

The EIA contains information on 6867 plants in 1994, but this number decreases over time due to attrition.[9] It covers roughly 85 percent of all manufacturing output value based on information from the industrial census. A few characteristics of the EIA are important to note. First, assembly plants, i.e., "maquiladoras", are excluded from the EIA and their information is collected by a separate survey. Second, the unit of observation of the EIA is a plant, which is described as "the manufacturing establishment where the production takes place" (Iacovone, 2008). Third, each plant is classified in one of the 205 classes of activity based on its principal product, where a class of activity

[9]The EIA was expanded in 2003, after the 2002 industrial census, to 7294 plants.

Table 1: Product codes within the soft drinks industry

Industry number	Product description	Product code number
313050	Soft drinks with “cola” flavour	1
313050	Soft drinks with fruit flavours	2
313050	Other soft drinks	9
313050	Mineral water	11
313050	Purified water	12
313050	Other water	19

or *clase* is the most disaggregated level of industrial classification and is defined at six digits according to the 1994 *Clasificación Mexicana de Actividades y Productos* (Mexican System of Classification for Activities and Products, CMAP henceforth).

The EIA captures variables related to output indicators, inputs and investment. These data make it possible to calculate the value of material, which includes raw materials (domestic and imported), intermediate inputs and energy consumption, as well as the value of capital stock using the perpetual inventory method.[10] We use aggregate price indices provided separately by the INEGI to obtain the quantity of material and capital stock.

The EIM has traditionally been run in parallel with the EIA and covers the same plants. The EIM contains information on the number of workers, their wage bills and number of hours worked by occupation type. Workers are split into white collar (or non-production) and blue collar (or production). The EIM also contains output-related variables, specifically production, total sales and export sales. There are two important things to notice regarding these variables. First, plants are asked to report both values and quantities, thus an implicit average unit price can be calculated. Second, for these variables plants are requested to distinguish each one of their products, so that each one of these variables is reported product by product chosen according to a list given by INEGI for each six-digit class of activity. Table 1 reports an example of how detailed the product-level information is in this data set for the industry “Production of soft drinks and other non-alcoholic beverages”, in which six different products can be identified.

Table 2 highlights a few important characteristics of the dataset by two-digit sector. The table shows the share of total output of each sector (column 1), total number of plants surveyed (column 2), the share of exporting plants (column 3), the share of those plants that are multi-product plants (MPPs) (column 4), the share of output by multi-product plants (column 5) and the number of products manufactured by any plant, i.e. scope (column 6). While sectors differ significantly in their relative sizes and in their propensity to export, it is important to notice that in all sectors a large proportion of plants is made up of multi-product plants (about 58% on average) and that these multi-product plants also account for a large share of total output (about 67% on average). On average, each plant manufactures slightly less than 3 products. The importance of multi-product plants is at the core of this paper, since its focus is on within-plant heterogeneous responses to

[10]The variables used to calculate capital stock are existing initial capital stock at book value, divided into machinery and equipment, construction, land, transportation equipment and other assets, and investment in new and used assets during the year, also divided into the different types of fixed assets. The depreciation rates used are 10% for machinery and equipment, 5.5% for construction and installation, 20% for transportation equipment and 21% for other assets.

Table 2: Descriptive statistics

Sector	Output share	No. plants	Exporting plants	MPPs' plants	MPPs' output	Mean scope
Food, beverages and tobacco	0.30	826	0.13	0.77	0.85	3.37
Textile, wearing apparel and leather	0.06	661	0.21	0.53	0.63	2.62
Wood and wood products	0.01	148	0.10	0.71	0.85	4.21
Paper and paper products	0.04	319	0.13	0.38	0.47	2.21
Chemicals, petroleum, coal products	0.18	789	0.30	0.64	0.81	3.39
Non-metallic mineral products	0.06	281	0.19	0.56	0.61	2.59
Basic metal products	0.08	99	0.38	0.52	0.67	2.01
Machinery and equipment	0.27	800	0.33	0.54	0.53	2.47
All	1.00	3923	0.22	0.58	0.67	2.86

real exchange rate fluctuations.

In addition to the plant-level data, this paper makes use of aggregate data on gross domestic product (GDP) for the United States (US), which accounts for over 80% of Mexican exports in 2007 according to UN COMTRADE data and the inflation rate in the US. Data on distribution margins at the three-digit CMAP industry level, taken from Goldberg and Campa (2010), is also included as a measure of the importance of the distribution costs.

4 Estimation of Markups

4.1 Methodology

The econometric modeling of the impact of exchange rate movements upon prices and markups undertaken in the next section requires information on markups and marginal costs. This subsection describes how markups and marginal costs are estimated in a sample of multi-product plants using production data. A more detailed explanation of the estimation procedure is available in the Appendix.

The methodology is derived from De Loecker and Warzynski (2012) and De Loecker et al. (2012) and it has been analysed further in Marin and Voigtländer (2013). The approach requires that plants minimise costs and at least one input is adjusted freely (material), while the other factors show frictions in the adjustment (capital and labour). It relies on multi-product plants manufacturing a particular product using the same technology employed by single-product plants that manufacture that same product. However, it does not impose assumptions regarding the returns to scale and scope, demand and market structure of each industry. For instance, input prices and, therefore, total costs may vary depending on the number of products manufactured. Moreover, following the approach of using inputs to control for unobservables in production function estimations (Olley and Pakes, 1996; Levinsohn and Petrin, 2003; Ackerberg et al., 2006), it assumes that productivity is Hicks-neutral and specific to the plant. These assumptions are consistent with the theoretical framework described above, as pointed out by De Loecker et al. (2012) and Mayer et al. (2014).

The strategy for estimating markups at the market-product-plant-year level involves several steps. Firstly, we obtain an expression for markups, derived from a plant's cost minimisation problem. This expression is given by the following equation:

$$\mu_{ijdt} = \theta_{ijdt}^{m} \left(\alpha_{ijdt}^{m}\right)^{-1}, \tag{9}$$

where μ_{ijdt} is the markup of product j manufactured by plant i at time t and sold at destination d (domestic or export market), θ_{ijdt}^{m} is the output elasticity with respect to material (denoted by superscript m), and α_{ijdt}^{m} is the expenditure share of revenue spent on material.

Data on θ_{ijdt}^{m} and α_{ijdt}^{m} are not readily available. The following step is, thus, to get estimates of the output elasticity with respect to material by estimating production functions at the two-digit sector level using the input control approach in Ackerberg et al. (2006). Since the data do not contain information on the share of inputs by product and market within plant-year pairs, De Loecker et al. (2012) propose to estimate the production function for an unbalanced sample of single-product plants with a correction for sample selection. This way, we obtain estimates of the output elasticity with respect to material at the plant-year level. The error terms of the production function are also retrieved in order to estimate total factor productivity, or simply productivity, at the plant-year level. Separately, we calculate the revenue share of material, also at the plant-year level, from the data available.

Next, we estimate input allocation shares across markets and products within plant-year pairs based on the assumption that these are related to the product revenue share from each market. We combine the output elasticity and revenue share of material at the plant-year level with these input allocation shares to obtain estimates of the output elasticity and revenue share of material at the market-product-plant-year level. This final step allows us to estimate markups according to equation (9).

Additionally, we estimate marginal costs at the market-product-plant-year level by using the following definition of prices

$$p_{ijdt} = \mu_{ijdt} mc_{ijdt}, \tag{10}$$

where p_{ijdt} is the price of the output good and mc_{ijdt} is its marginal cost.

4.2 Markup Estimates

In this subsection, we present descriptive statistics for markups, marginal costs and productivity estimated via the above methodology and we show the presence of heterogeneity across products within plants, our key modelling assumption.

Table 3 shows the mean and median estimates of markups by sector and destination, domestic market in the first two columns and export market in the last two columns. Unlike De Loecker et al. (2012), we estimate markups by market and, thus, report markups separately for the domestic and the export markets. Those observations with markups below the 5th percentile or above the 95th percentile by market and sector are eliminated. Mean markups are generally higher and more dispersed than median markups. There is considerable heterogeneity in median markups across sectors, with four sectors showing median domestic markups below one. Markups in the export market are higher than in the domestic market, particularly in those sectors in which only few plants export, such as the food, beverages and tobacco sector.

Table 3: Estimated markups by market

	Domestic market		Export market	
Sector	Mean	Median	Mean	Median
Food, beverages and tobacco	0.93	0.68	1.60	1.14
Textile, wearing apparel and leather	1.81	1.22	2.06	1.48
Wood and wood products	1.17	0.46	1.38	0.63
Paper and paper products	0.89	0.45	0.87	0.81
Chemicals, petroleum, coal products	2.75	1.76	2.56	1.87
Non-metallic mineral products	2.48	1.13	2.78	1.57
Basic metal products	1.34	1.13	1.80	1.53
Machinery and equipment	0.76	0.45	0.70	0.48
All	1.57	0.84	1.74	1.16

Notes: The table reports the markups estimated by market. The table trims observations with markups that are above and below the 5th and 95th percentiles within each sector and in both domestic and export markets.

Table 4: Correlation between prices, markups, marginal costs and productivity in export market

	Price	Markup	Marginal cost	Productivity
Price	1.00			
Markup	0.17***	1.00		
Marginal cost	0.91***	-0.25***	1.00	
Productivity	-0.59***	-0.22***	-0.49***	1.00

Notes: All variables are expressed in logs. Prices, markups and marginal costs vary at the product-plant level, while productivity varies at the plant level. The table trims observations with markups that are above and below the 5th and 95th percentiles within each sector and in both domestic and export markets. *** indicates coefficients significantly different from zero at 1% level.

The correlation matrix between prices and estimates of markups, marginal costs and productivity in the export market is shown in Table 4. All the correlations are generally consistent with the theoretical model. In particular, as predicted by Mayer et al. (2014) and then also found in the sample of Indian firms by De Loecker et al. (2012), products with higher marginal costs and, thus, further away from the core competency tend to have lower markups. Also, products with higher markups and marginal costs tend to have higher prices and plants with higher productivity tend to have lower prices and marginal costs, but also lower markups. While the last negative correlation does not match the theory and is different from the slightly positive correlation found in De Loecker et al. (2012), the results are reconciled in the next section once the correlation is estimated conditional on other variables.

Table 5 shows the median ratio for both export sales and markups of top to second top product, top to third top product and top to median product, where the product ranking is defined by sales within plant-year pairs. The table shows that, on average, the top most sold product sells more than twice as much as the next most important product and has a markup 20% higher. As we move down the product ladder, the ratio of sales increases by construction, but so does the ratio of markups in a similar way. This large heterogeneity across products within plants is a fundamental feature of the data, which we exploit to explain the effects of real exchange rate fluctuations on producer prices and markups.

Table 5: Relative importance of products in export sales and markups

	Value of exports	Markup of exports
Ratio of top to second top product	2.48	1.20
Ratio of top to third top product	5.10	1.33
Ratio of top to median product	5.19	1.37

Notes: The table trims observations with markups that are above and below the 5th and 95th percentiles within each sector and in both domestic and export markets.

5 Results

5.1 Regression Analysis

In this section, we test our theoretical predictions concerning producer prices and estimated markups in the export market. In particular, our main theoretical predictions are that a) producer prices and markups of exports increase following a real depreciation and b) this increase is larger within plants for products closer to the core competency.

Response of Producer Prices and Markups to the Real Exchange Rate We firstly test whether prices of exports increase following a real depreciation by estimating the following equation:

$$\ln p_{ijt} = \psi_1 \ln RER_t + \psi_2 Z_{ijt} + \psi_3 V_t + \varpi_{ij} + e_{ijt}, \tag{11}$$

where $\ln p_{ijt}$ is the log of the producer price in the export market of product j by plant i at time t, $\ln RER_t$ is the log of the real exchange rate at time t, Z_{ijt} is a vector of plant- and product-plant-level time-variant characteristics, V_t is a vector of characteristics that only vary over time, ϖ_{ij} denotes the product-plant fixed effects and ϵ_{ijt} is an error term. Assuming that the real exchange rate is exogenous for the plant, the theoretical framework above suggests that ψ_1 is positive.

The main purpose of this paper is to empirically examine the responsiveness of markups to changes in the real exchange rate. Thus, we estimate a reduced-form regression equivalent to equation (11) but for markups in the export market:

$$\ln \mu_{ijt} = \varsigma_1 \ln RER_t + \varsigma_2 Z_{ijt} + \varsigma_3 V_t + n_{ij} + \nu_{ijt}, \tag{12}$$

where μ_{ijt} is the markup of export sales for product j of plant i at time t, n_{ij} denotes the product-plant fixed effects and ν_{ijt} is an error term. The theoretical framework above suggests that ς_1 is positive.

In the vector of regressors Z_{ijt}, we include direct controls for productivity and marginal costs estimated through the above methodology and, thus, unlike other papers (e.g., Chatterjee et al., 2013), we do not need to rely on proxies for such variables. In particular, we control for marginal costs in the domestic market at the product-plant-year level as well as plant-level time-variant total factor productivity.

Since our dataset does not disaggregate exports by destination, it is not possible to include time fixed effects in the above regressions and also identify the coefficient on the real exchange rate. We, therefore, include in vector V_t a set of regressors to control for economy-wide time-variant characteristics. In particular, we control for US GDP, the

Table 6: Producer price and markup responsiveness to real exchange rate

Dependent variable	*Log price*	*Log markup*
Log Real Exchange Rate	0.61***	0.19***
	(0.03)	(0.03)
Log Marginal Cost	0.15***	-0.61***
	(0.03)	(0.02)
Log Total Factor Productivity	-0.05***	0.01
	(0.01)	(0.01)
Product-plant fixed effects	yes	yes
Aggregate-level controls	yes	yes
No of obs.	22583	22583
R^2 (within)	0.38	0.48
F statistic	705.08	102.12

Notes: The dependent variable is the log of the price of exports in column 1 and the log of the markup of exports in column 2. The aggregate-level controls include logged US GDP and its squared term, the inflation rate in the US and its squared term as well as a time trend variable and its squared term. Standard errors clustered at the plant level are shown in parentheses. *** indicates coefficients significantly different from zero at 1% level.

main export market for Mexican goods, and its squared term, the inflation rate in the US and its squared term as well as a time trend variable and its squared term.

Table 6 reports the results concerning the responsiveness of producer prices (column 1) and markups (column 2) to the real exchange rate, corresponding to equations (11) and (12). As in all the following tables, standard errors in parentheses are clustered at the plant level in order to allow the unobserved errors to be correlated across products and over time within each plant.[11] The two regressions are significant as a whole and the within R-squared is respectively 0.38 and 0.48.

The results confirm the predictions of our theoretical framework. The coefficient estimate for log real exchange rate is positive and significantly different from zero in both regressions. The elasticity of producer price with respect to the real exchange rate is estimated to be 0.61, while the elasticity of markup with respect to the real exchange rate is equal to 0.19. Thus, an increase in the real exchange rate, i.e., a real depreciation, increases markups and, consequently, producer prices in Mexican pesos.

The difference between the estimated elasticity of producer price and that of markup is 0.42. As predicted by the model in Section 2, this difference is of the same order of magnitude as the average share of imported material inputs, calculated in this sample to be approximately equal to 0.3.

Given the estimated producer price elasticity, the exchange rate pass-through to import prices in foreign currency is 0.39, before the further attenuation caused by local distribution costs. This is lower than the exchange rate pass-through estimated by Chatterjee et al. (2013) for Brazilian firms and Berman et al. (2012) for French firms, respectively equal to 0.77 and 0.92. However, it is similar to the exchange rate pass-through elasticity of 0.4 estimated by Campa and Goldberg (2005) for the US.

We also find that products with higher marginal costs in the domestic market tend to have higher prices and lower markups in the export market and that, even after controlling

[11] We also test the sensitivity of our results by using bootstrapped standard errors, also clustered at the plant level. All the following results go through both qualitatively and quantitatively and are available upon request.

for the effects of marginal costs, plants with higher productivity tend to have lower prices and higher markups. However, this last result is not statistically significant.

Heterogeneous Response in Producer Prices and Markups In order to test the model's second prediction, i.e., whether the increase in producer prices and markups following a real depreciation is larger within plants for products closer to the core competency, we follow Chatterjee et al. (2013) and estimate the following reduced-form regression for producer prices in the export market:

$$\ln p_{ijt} = \vartheta_1 \ln RER_t + \vartheta_2 \ln RER_t \times Ladder_{ijt} + \vartheta_3 Z_{ijt} + \vartheta_4 V_t + \upsilon_{ij} + u_{ijt}, \tag{13}$$

where $Ladder_{ijt}$ is a variable that indicates the relative position of product j among all products sold abroad by plant i at time t, υ_{ij} denotes the product-plant fixed effects and u_{ijt} is an error term. The theoretical framework above suggests that the coefficient ϑ_1 on the real exchange rate remains positive after the inclusion of *Ladder* as a regressor, while ϑ_2 is negative. That is, it is expected that the positive impact of the real exchange rate on prices is lower for products further away from plants' core competency.

Unlike Chatterjee et al. (2013), in this paper we can also test the responsiveness of markups to changes in the real exchange rate. Thus, we estimate a reduced-form regression equivalent to equation (13) but for markups in the export market:

$$\ln \mu_{ijt} = \zeta_1 \ln RER_t + \zeta_2 \ln RER_t \times Ladder_{ijt} + \zeta_3 Z_{ijt} + \zeta_4 V_t + o_{ij} + \upsilon_{ijt}, \tag{14}$$

where o_{ij} denotes the product-plant fixed effects and υ_{ijt} is an error term. As for the previous equation, the theoretical framework above suggests that ζ_1 remains positive, while ζ_2 is negative.

We measure the variable indicating the ladder based on the volume of exports of each product within each plant-year pair. For any plant-year pair, the product that is most sold abroad is the core product ($r = 0$), the second most sold product is the next to the core product ($r = 1$), and so on. Four different measures of ladder are used in this paper: log ranking is the logged ranking of export sales of all product within plant-year pairs, with lower ranks associated with products with higher export sales; core/non-core is an indicator variable for whether a product is not the product with highest export sales in each plant-year pair, i.e., it is not the core product; top/bottom is an indicator variable for whether a product is below the median ranking of export sales within each plant-year pair; and first/second is an indicator variable for whether a product is the second most sold product within each plant-year pair, i.e., it is the same as core/non-core but any only the first and second ranked products are included.

Table 7 reports the results concerning the responsiveness of producer prices to the real exchange rate along the product ladder, corresponding to equation (13). Each of the four columns correspond to a different specification using a different measure of the ladder variable. All four regressions are significant as a whole and the within R-squared values are between 0.38 and 0.42.

The results confirm the predictions of our theoretical framework. The coefficient estimate for log real exchange rate remains positive, equal to 0.61, and significantly different from zero in all four specifications. This implies that an increase in the real exchange rate, i.e., a real depreciation, increases producer prices of core products in the Mexican pesos.

Table 7: Producer price responsiveness to real exchange rate by product ranking

	Log Ranking	Core/Non-core	Top/Bottom	First/Second
Log Real Exchange Rate	0.61***	0.61***	0.61***	0.61***
	(0.03)	(0.03)	(0.03)	(0.03)
Log Real Exchange Rate *	-0.02***			
Log Ranking	(0.00)			
Log Real Exchange Rate *		-0.02***		
Core/Non-core		(0.00)		
Log Real Exchange Rate *			-0.01***	
Top/Bottom			(0.00)	
Log Real Exchange Rate *				-0.01***
First/Second				(0.00)
Log Marginal Cost	0.13**	0.12**	0.12**	0.16***
	(0.06)	(0.06)	(0.06)	(0.06)
Log Real Exchange Rate *	0.01	0.01	0.01	0.00
Log Marginal Cost	(0.01)	(0.01)	(0.01)	(0.01)
Log Total Factor Productivity	-0.05***	-0.05***	-0.05***	-0.05***
	(0.01)	(0.01)	(0.01)	(0.01)
Product-plant fixed effects	yes	yes	yes	yes
Aggregate-level controls	yes	yes	yes	yes
No of obs.	22583	22583	22583	17566
R^2 (within)	0.39	0.38	0.38	0.42
F statistic	340.19	1192.79	860.05	376.51

Notes: The dependent variable is the log of the price of exports. The aggregate-level controls include logged US GDP and its squared term, the inflation rate in the US and its squared term as well as a time trend variable and its squared term. Standard errors clustered at the plant level are shown in parentheses. ** and *** indicate coefficients significantly different from zero at 5 and 1% level respectively.

The coefficient estimate for the interaction between log real exchange rate and each of the four ladder variables is always negative and significantly different from zero. This implies that the within-plant responsiveness of producer prices to the real exchange rate is lower for products further away from plants' core competency. In the main specification where log ranking is used as the ladder variable, the point estimate of -0.02 is somewhat smaller than the point estimate of -0.04 found for Brazilian firms (Chatterjee et al., 2013) and it implies that the producer price of the third-highest ranked product increases by 1% less than that of the second-highest ranked product in response to a real depreciation.

The table also shows that the responsiveness of producer prices to the real exchange rate does not depend on products' marginal costs in the domestic market, since the coefficient on the interaction variable between log real exchange rate and log marginal cost is not statistically different from zero in all four specifications. Additional specifications, not included in the table, show that the interaction term between log real exchange rate and log total factor productivity is not statistically significant.

Markups' response to the real exchange rate is shown in Table 8, where again each of the four columns correspond to a specification using one of the four ladder variables. All four regressions are significant as a whole and the within R-squared values are between 0.45 and 0.49.

As predicted by the theoretical framework, the results in Table 8 provide empirical evidence that the response of producer prices to the real exchange rate is due to a qualitatively equivalent responsiveness of markups. The coefficient on the real exchange rate

Table 8: Markup responsiveness to real exchange rate by product ranking

	Log Ranking	Core/Non-core	Top/Bottom	First/Second
Log Real Exchange Rate	0.19***	0.18***	0.18***	0.15***
	(0.03)	(0.03)	(0.03)	(0.03)
Log Real Exchange Rate *	-0.04***			
Log Ranking	(0.01)			
Log Real Exchange Rate *		-0.02***		
Core/Non-core		(0.00)		
Log Real Exchange Rate *			-0.02***	
Top/Bottom			(0.00)	
Log Real Exchange Rate *				-0.02***
First/Second				(0.00)
Log Marginal Cost	-0.64***	-0.65***	-0.65***	-0.64***
	(0.05)	(0.05)	(0.05)	(0.05)
Log Real Exchange Rate *	0.01	0.01	0.01	0.02**
Log Marginal Cost	(0.01)	(0.01)	(0.01)	(0.01)
Log Total Factor Productivity	0.01	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)
Product-plant fixed effects	yes	yes	yes	yes
Aggregate-level controls	yes	yes	yes	yes
No of obs.	22583	22583	22583	17566
R^2 (within)	0.49	0.48	0.48	0.45
F statistic	94.73	90.93	92.00	60.54

Notes: The dependent variable is the log of the markup of exports. The aggregate-level controls include logged US GDP and its squared term, the inflation rate in the US and its squared term as well as a time trend variable and its squared term. Standard errors clustered at the plant level are shown in parentheses. **, *** indicate coefficients significantly different from zero at 5 and 1% level respectively.

variable is estimated positive, between 0.15 and 0.19 depending on which ladder variable is used, and significantly different from zero. Therefore, when the exchange rate depreciates, markups go up and so do producer prices in Mexican pesos.

Moreover, the within-plant response of markups is lower for products further away from plants' core competency, as implied by the negative and significantly different from zero coefficient on the interaction term between log real exchange rate and any of the four ladder variables. The point estimate in the main specification using log ranking as the ladder variable is -0.04. This implies that markups increase by about 2% less for third-highest ranked product relative to the second-highest ranked product when the real exchange rate depreciates. This is an economically significant coefficient considering that the coefficient on the real exchange rate variable is 0.19.

With regards to the other coefficients, products with higher marginal costs tend to have lower markups, while the effect of plant-level productivity is positive but statistically insignificant. The response of markups to the real exchange rate does not depend on products' marginal costs, since the coefficient on the interaction variable between log real exchange rate and log marginal cost is not statistically different from zero in three of the four specifications and only significant at the 5% level in the last specification.

Local Distribution Cost Channel In order to test more directly the local distribution cost channel for incomplete pass-through, Table 9 shows two additional specifications, one for producer prices and the other for markups. In these specifications, log real exchange

Table 9: Responsiveness to real exchange rate: the role of distribution margins

Dependent variable	*Log price*	*Log markup*
Log Real Exchange Rate * Log Distribution Margin	0.21*** (0.01)	0.06*** (0.01)
Log Real Exchange Rate * Log Distribution Margin * Log Ranking	-0.01*** (0.00)	-0.01*** (0.00)
Log Marginal Cost	0.11* (0.06)	-0.65*** (0.05)
Log Real Exchange Rate * Log Marginal Cost	0.01 (0.01)	0.01 (0.01)
Log Total Factor Productivity	-0.05*** (0.01)	0.01 (0.01)
Product-plant fixed effects	yes	yes
Aggregate-level controls	yes	yes
No of obs.	22583	22583
R^2 (within)	0.38	0.49
F statistic	4404.79	93.93

Notes: The dependent variable is the log of the price of exports in column 1 and the log of the markup of exports in column 2. The aggregate-level controls include logged US GDP and its squared term, the inflation rate in the US and its squared term as well as a time trend variable and its squared term. Standard errors clustered at the plant level are shown in parentheses. *, *** indicate coefficients significantly different from zero at 10 and 1% level respectively.

rate and its interaction with log ranking are both interacted with log distribution margin, a 3-digit-industry-level measure that captures the components of the consumer price that are not included in the producer price. The inclusion of these interactions enables us to determine whether the responses of prices and markups to changes in the real exchange rate are affected by the distribution margins.

The estimates in Table 9 lead to two main results. First, the results do not change qualitatively compared to the previous two tables. A real depreciation leads to higher markups and producer prices, and within plants these increases are smaller for products further away from plants' core competency. Second, across industries, both effects are larger in industries facing higher distribution margins. This provides support for the local distribution cost channel of incomplete pass-through (Burstein et al., 2003; Goldberg and Campa, 2010).

5.2 Robustness Checks

This subsection checks for the robustness of our key result, i.e., within-plant heterogeneity in the responsiveness of producer prices and markups to changes in the real exchange rate, in a variety of specifications. In all specifications shown below, we use log ranking as the ladder variable.

Table 10 presents two robustness checks for the responsiveness of producer price (the first two columns) and that of markups (the last two columns) to the real exchange rate. Following Amiti et al. (2013), we expand on the specification above by including the share of material imported at the plant-year level, its interaction with log real exchange rate, the market share at the product-plant-year level and its interaction with log real exchange rate. All the previous results are robust to the inclusion of these additional regressors, as shown by an examination of the parameter estimates in the first and third

Table 10: Responsiveness to real exchange rate: robustness checks

Dependent variable	*Log price*		*Log markup*	
	Import & market share	Excluding 1994	Import & market share	Excluding 1994
Log Real Exchange Rate	0.61***	0.38***	0.15***	0.09*
	(0.05)	(0.06)	(0.05)	(0.05)
Log Real Exchange Rate * Log Ranking	-0.02***	-0.02***	-0.04***	-0.04***
	(0.00)	(0.00)	(0.01)	(0.01)
Log Marginal Cost	0.12**	0.10*	-0.65***	-0.66***
	(0.06)	(0.06)	(0.05)	(0.05)
Log Real Exchange Rate * Log Marginal Cost	0.01	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)
Log Total Factor Productivity	-0.05***	-0.05***	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)
Import Share	0.35		0.49	
	(0.29)		(0.31)	
Log Real Exchange Rate * Import Share	-0.08		-0.11	
	(0.07)		(0.07)	
Product Market Share	-0.17		-0.55**	
	(0.26)		(0.24)	
Log Real Exchange Rate * Product Market Share	0.05		0.13**	
	(0.06)		(0.06)	
Product-plant fixed effects	yes	yes	yes	yes
Aggregate-level controls	yes	yes	yes	yes
No of obs.	22583	21245	22583	21245
R^2 (within)	0.39	0.26	0.49	0.50
F statistic	289.78	140.99	72.43	102.32

Notes: The dependent variable is the log of the price of exports in columns 1 and 2 and the log of the markup of exports in columns 3 and 4. The aggregate-level controls include logged US GDP and its squared term, the inflation rate in the US and its squared term as well as a time trend variable and its squared term. Standard errors clustered at the plant level are shown in parentheses. * ** and *** indicate coefficients significantly different from zero at 10, 5 and 1% level respectively.

columns. Contrary to the results in Amiti et al. (2013), these additional variables are not generally significant, except for product market share and its interaction with log real exchange rate in the regression for markups but then only at the 5% level. The reason is that in our specifications we control directly for marginal cost, while in Amiti et al. (2013) the share of imported material proxies for the responsiveness of marginal cost to the real exchange rate.

The other robustness check shown in the second and fourth columns of Table 10 involves dropping the observations for year 1994. This year might constitute an outlier or might yield non-linearities given the large increase in the real exchange rate that occurred between 1994 and 1995. An examination of the parameter estimates in the second and fourth columns of Table 10 reveal that our previous results are generally robust to the exclusion of data for 1994.

Another robustness check that we conduct is to correct for the possibility of sample selection bias caused by the fact that not all plants export all products at all times and that this decision is endogenous. We adopt a Heckman (1979) two-stage procedure that consists in first estimating a probit selection equation for whether a product-plant-year triplet is exported. We include among the controls all variables used in estimating

Table 11: Responsiveness to real exchange rate: sample selection correction

Dependent variable	*Log price*	*Log markup*
Log Real Exchange Rate	0.39***	0.09*
	(0.06)	(0.05)
Log Real Exchange Rate *	-0.02***	-0.04***
Log Ranking	(0.00)	(0.00)
Log Marginal Cost	0.09	-0.67***
	(0.06)	(0.05)
Log Real Exchange Rate *	0.01	0.01
Log Marginal Cost	(0.01)	(0.01)
Log Total Factor Productivity	-0.05***	0.01
	(0.01)	(0.01)
Inverse Mills Ratio	-0.01*	-0.02***
	(0.01)	(0.01)
Product-plant fixed effects	yes	yes
Aggregate-level controls	yes	yes
No of obs.	20773	20773
R^2 (within)	0.26	0.50
F statistic	56.17	89.24

Notes: The dependent variable is the log of the price of exports in column 1 and the log of the markup of exports in column 2. The aggregate-level controls include logged US GDP and its squared term, the inflation rate in the US and its squared term as well as a time trend variable and its squared term. Standard errors clustered at the plant level are shown in parentheses. * and *** indicate coefficients significantly different from zero at 10 and 1% level respectively.

equations (13) and (14) and 2-digit-sector-level dummies. Instead of using product-plant fixed effects, we include time-invariant average product-level marginal costs, time-invariant average plant-level productivity and a fifth-order polynomial of time-invariant log ranking interacted with log real exchange rate. In order to identify the coefficients in the main estimating equation, the exclusion restriction is generated by including the lagged value of the indicator variable in the first stage. In the second stage, we include the Inverse Mills Ratio based on the first-stage predicted values. As shown in Table 11, which presents the stage-two parameter estimates, the results are robust to the sample selection correction.

Recent papers document variation in exchange rate pass-through across firms due to credit constraints (Strasser, 2013; Gopinath, 2013). To allow for this possibility, we interact the real exchange rate with two time-invariant industry characteristics that capture financial vulnerability (Manova, 2008). These two variables are external financial dependence (Rajan and Zingales, 1998) and asset tangibility (Braun, 2003). Results are shown in the first and third columns of Table 12, which also control for time-variant industry characteristics (average capital-labour ratio and average skill intensity). Alternatively, it is possible to include industry-year fixed effects to control for changes over time at the industry level, as in the second and fourth columns of Table 12. However, under this specification, it is not possible to identify the coefficients on the real exchange rate and on variables varying across industries and time, but only the coefficient on the interaction term between the real exchange rate and the ladder variable. Under all these specifications, within-firm heterogeneity continues to remain a key feature of how plants respond to real exchange rate movements.

As a last check, we estimate equations (13) and (14) with the inclusion of one lag in

Table 12: Responsiveness to real exchange rate: industry-level controls

Dependent variable	*Log price*		*Log markup*	
	Industry-level & controls	Industry-year fixed effects	Industry-level & controls	Industry-year fixed effects
Log Real Exchange Rate	0.44***		-0.13*	
	(0.07)		(0.08)	
Log Real Exchange Rate * External Financial Dependence	0.02		0.10	
	(0.09)		(0.09)	
Log Real Exchange Rate * Asset Tangibility	0.54**		0.97***	
	(0.22)		(0.23)	
Log Real Exchange Rate * Log Ranking	-0.02***	-0.02***	-0.04***	-0.04***
	(0.00)	(0.01)	(0.01)	(0.01)
Log Marginal Cost	0.14**	-0.01	-0.63***	-0.77***
	(0.06)	(0.06)	(0.05)	(0.07)
Log Real Exchange Rate * Log Marginal Cost	0.00	0.03*	0.01	0.03**
	(0.01)	(0.02)	(0.01)	(0.02)
Log Total Factor Productivity	-0.05***	-0.04***	0.01	0.02
	(0.01)	(0.01)	(0.01)	(0.01)
Product-plant fixed effects	yes	yes	yes	yes
Aggregate-level controls	yes	yes	yes	yes
Industry-level controls	yes	no	yes	no
Industry-year fixed effects	no	yes	no	yes
No of obs.	22583	22583	22583	22583
R^2 (within)	0.39	0.49	0.49	0.59
F statistic	142.95	378.82	71.47	204.45

Notes: The dependent variable is the log of the price of exports in columns 1 and 2 and the log of the markup of exports in columns 3 and 4. The aggregate-level controls include logged US GDP and its squared term, the inflation rate in the US and its squared term as well as a time trend variable and its squared term. The industry-level controls include the average capital-labour ratio and the average ratio of the number of white- to blue-collar workers. Standard errors clustered at the plant level are shown in parentheses. * ** and *** indicate coefficients significantly different from zero at 10, 5 and 1% level respectively.

the real exchange rate and its interaction with the ladder variable and, separately, with the inclusion of a quadratic term for the real exchange rate to examine the possibility of non-linearities. Our results remain robust to the additional specifications and to the calculation of long-run responses when the lag of the real exchange rate is included. All results are available upon request.

6 Conclusion

Understanding the determinants of exchange rate pass-through is crucial to many issues faced by policymakers. For example, the degree of exchange rate pass-through has implications for how currency devaluations affect inflation and, hence, for the conduct of monetary policy. Furthermore, it may also have important effects on the welfare of exporting firms, importing firms, and consumers. In particular, understanding the degree of exchange rate pass-through may help us understand how firms set prices and how they react to shocks.

In this paper, we present a theoretical mechanism to explain how multi-product plants adjust markups and prices in response to exchange rate fluctuations. When there is a real depreciation, plants increase their markups and producer prices. The increase in producer prices is larger due to imported intermediate inputs. Moreover, plants increase markups and producer prices more for products with higher productivity, a consequence of local distribution costs.

This key heterogeneity in the response of producer prices to a real exchange rate depreciation has been documented previously by Chatterjee et al. (2013). In this paper we go one step further in documenting heterogeneity in response of markups to real exchange rate shocks. Specifically, we estimate market-specific markups for multi-product plants from detailed product-plant level panel data from Mexico between 1994 and 2007 following De Loecker et al. (2012). Exploiting variation in the real exchange rate in the aftermath of the peso crisis in December 1994, we document that plants increase their markups and producer prices in response to a real depreciation and that within-firm heterogeneity is a key determinant of plants' response to exchange rate shocks. We also document that the increase in producer prices is larger than that of markups by a magnitude similar to the average share of imported intermediate inputs, as predicted by the model.

The role of imported intermediate inputs has recently caught the attention of the exchange rate pass-through literature (Amiti et al., 2013). Potentially, imported intermediate inputs can account for further heterogeneity across products within plants due to differences in quality, which may, in turn, lead to differences in exchange rate pass-through (Auer and Chaney, 2009). This is an important avenue for future research.

Acknowledgments

We thank Rafael Dix-Carneiro, Nico Voigtländer, Oleg Itshkoki, Esteban Rossi-Hansberg and Saroj Bhattarai for their helpful comments. Special thanks go to Abigail Durán and Gerardo Leyva for granting access to INEGI data at the offices of INEGI in Aguascalientes and to all INEGI employees who provided assistance and answered all questions, in particular to Gabriel Romero, Otoniel Soto and Armando Arallanes. We gratefully acknowledge that this research was financially supported by an Australian Research Council grant to Professor Alan Woodland.

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Appendix: Methodology to estimate markups

This appendix describes in detail how markups and marginal costs at the market-product-plant-year level are estimated in a sample of multi-product plants using production data. The methodology described below is derived from De Loecker and Warzynski (2012) and De Loecker et al. (2012) and it involves several steps. Firstly, we obtain an expression for markups from a plant's cost minimisation problem, in which markups are equal to the output elasticity with respect to the flexible input, i.e., material, divided by the expenditure share of revenue spent on material. Next, we need to get estimates of these two variables. The output elasticity at the plant-year level is derived after estimating a production function using the input control approach in Ackerberg et al. (2006) for an unbalanced sample of single-product plants. On the other hand, the revenue share of material at the plant-year level can be calculated directly from data. The last step involves the estimation of input allocation shares by destination and product within plant-year plants. Combined with the output elasticity and revenue share of material at the plant-year level, the input allocation shares make it possible to get estimates of the output elasticity and revenue share of material and, in turn, markups, all at the market-product-plant-year level. Finally, marginal costs are estimated by dividing prices by markups.

Looking at the methodology step-by-step, we firstly obtain an expression for markups derived from the first order condition of a plant's cost minimisation problem with respect to material. This expression is given by the following equation:

$$\mu_{ijdt} = \theta^m_{ijdt} \left(\alpha^m_{ijdt}\right)^{-1}, \tag{15}$$

where $\mu_{ijdt} \equiv \frac{p_{ijdt}}{mc_{ijdt}}$ is the markup of product j manufactured by plant i at time t and sold at destination d, i.e. domestic or export market, p_{ijdt} is the price of the output good, mc_{ijdt} is the marginal cost, superscript m stands for material, $\theta^m_{ijdt} \equiv \frac{\partial \ln y_{ijdt}}{\partial \ln c^m_{ijdt}}$ is the output elasticity with respect to material, c^m_{ijdt}, $\alpha^m_{ijdt} \equiv \frac{w^m_{it} c^m_{ijdt}}{p_{ijdt} y_{ijdt}}$ is the revenue share of material, y_{ijdt} is the quantity of output and w^m_{it} is the price of material.

The data available do not contain information on the output elasticity and the revenue share of material at the market-product-plant-year level. It is, therefore, necessary to obtain estimates of these two variables. In order to get unbiased estimates of the output elasticity with respect to material, we consider the following general production function for product j of plant i at time t:

$$\ln y_{ijdt} = f_j \left(\ln c_{ijdt}, \ln \tilde{c}_{ijdt}; \beta\right) + \omega_{it} + \epsilon_{ijdt}, \tag{16}$$

y_{ijdt} is market-product-level physical output, c_{ijdt} and $\tilde{c}_{ijdt}$ are the unobserved market-product-level vectors of inputs deflated using respectively plant-level prices (labour) and aggregate price indices (material and capital), β is the parameter vector to be estimated in order to calculate the output elasticities, ω_{it} is the plant-level productivity term that is observable by the plant but not by the econometrician and ϵ_{ijdt} is an error term that is unobservable to both the plant and the econometrician.[12] The production function in

[12] The use of physical output eliminates potential biases caused by the use of deflated sales data and usually found in the literature estimating production functions (Marin and Voigtländer, 2013).

f_j is assumed to be translog, so that the parameter vector β includes the coefficients on labour, capital and material, their squares and their interaction terms.[13]

Three key challenges are present when estimating equation (16) given the data available. First, there might be a correlation between unobserved productivity shocks and inputs, a typical concern in the literature concerned with production function estimation. Following Ackerberg et al. (2006), this bias can be removed by using a perfectly variable input, such as material, to proxy for unobserved productivity. Identification comes from the assumption that material is perfectly invertible in productivity, i.e. the demand for material is strictly monotonic in productivity and productivity is the only unobservable entering the demand for material, and from the assumptions regarding the timing of the decisions on the quantity used of each input. In particular, Ackerberg et al. (2006) assume that capital is chosen before labour and both are chosen before the productivity shock, while material is chosen when the plant learns its productivity.[14]

Second, for multi-product plants, De Loecker et al. (2012) show that a new identification problem arises since multi-product plants do not report how inputs are allocated across products within a plant. To remove this bias, they propose an identification strategy that uses an unbalanced sample of single-product plants since the input allocation problem does not exist in this case. While the exclusion of multi-product plants may lead to a sample selection bias, the unbalanced sample improves the selection problem by including those plants that switch from single-product to multi-product manufacturers in response to productivity shocks. Moreover, to account for the fact that the productivity threshold determining a firm's decision to switch from being single-product to multi-product and viceversa may be correlated with the inputs, a correction for sample selection is introduced by estimating the predicted probability that plants are single-product manufacturers and by including this predicted probability among the controls for productivity.

Third, the use of aggregate price indices for capital and material can result in biased production function estimates. When inputs are deflated based on aggregate price indices, plants that use inputs of different quality and prices will show up as plants using different quantity of inputs and with different productivity, even though they produce the same level of output and their productivity is actually the same. Therefore, plants selling higher-quality goods at higher prices tend to face higher prices for their higher-quality inputs (Verhoogen, 2008; De Loecker et al., 2012). This implies that the production function estimation needs to include controls for quality in order to control for unobserved input price differences.[15]

In order to tackle the three challenges just presented, we follow De Loecker et al. (2012) and Ackerberg et al. (2006) and implement a consistent two-step methodology to estimate the production function in equation (16) at the two-digit sector level.[16] In

[13] The estimated output elasticity on material for the translog production function is given by: $\hat{\theta}^m_{ijdt} = \hat{\beta}_m + 2\hat{\beta}_{mm}c^m_{ijdt} + \hat{\beta}_{lm}c^l_{ijdt} + \hat{\beta}_{km}c^k_{ijdt} + \hat{\beta}_{lkm}c^l_{ijdt}c^k_{ijdt}$, where superscripts l, k and m stand for labour, capital and material.

[14] In contrast, Olley and Pakes (1996) and Levinsohn and Petrin (2003) assume that the choice of labour is made when the plant learns its productivity, which creates a collinearity problem according to the critique by Ackerberg et al. (2006).

[15] On the other hand, the Mexican industrial survey provide wages at the plant-level, implying that no adjustment is needed for quality of labour.

[16] The sectors included are: Food, beverages and tobacco; Textile, wearing apparel and leather; Wood

the first stage, we restrict our sample to single-product plants observed for at least three consecutive years and a consistent estimate of expected output is obtained from the following regression:

$$\ln y_{it} = \phi_t \left(\ln c_{it}, \ln \tilde{c}_{it}, z_{it}, h_{it}\right) + \epsilon_{it}. \tag{17}$$

The function ϕ is approximated by a fourth-order polynomial in inputs, vector z that includes variables affecting the demand for material, the chosen proxy for unobserved productivity, and vector h that includes the controls for quality.[17]

After the first stage, productivity can be computed as the difference between the estimates of equations (16) and (17):

$$\hat{\omega}_{it} = \hat{\phi}_{it} - \hat{f}\left(c_{it}, \tilde{c}_{it}; \tilde{\beta}\right) - h_{it}\tilde{\gamma}, \tag{18}$$

for any vectors $\tilde{\beta}$ and $\tilde{\gamma}$, the vector of coefficients attached to the controls for quality and that are not of direct interest in this analysis.

In order to obtain estimates of all production function coefficients included in vectors β and γ, in the second stage we estimate the law of motion for productivity. This is given by:

$$\hat{\omega}_{it} = g_{t-1}\left(\hat{\omega}_{it-1}, \delta^{\kappa}_{it-1}, \delta^{\chi}_{it-1}, \hat{s}_{it-1}\right) + \xi_{it}, \tag{19}$$

where δ^{κ}_{it-1} and δ^{χ}_{it-1} are respectively lagged export and import dummies, $\hat{s}_{it-1}$ is the lagged predicted probability of remaining a single-product plant,[18] ξ_{it} is the productivity innovation, which is observed after capital and labour are chosen and at the same time as material is chosen, and the function g is approximated by a fourth-order polynomial.

After the estimation of the law of motion for productivity, the productivity innovation ξ is computed as the residual term. All coefficients of the production function are then estimated via generalised method of moments (GMM) using moment conditions that have become standard in the input control literature:

$$\mathbb{E}\left(\xi_{it}\left(\beta, \gamma\right)\mathbf{B}_{it}\right) = 0, \tag{20}$$

where the vector $\mathbf{B}$ contains lags of all the variables in the translog production function and the current values of labour and capital in the corresponding interactions appearing in the translog production function as well as additional variables, including lagged output prices, lagged product market share, their interactions with lagged and current capital and lagged material. These variables are valid instruments since labour and capital are chosen

and wood products; Paper and paper products, printing and publishing; Chemicals, petroleum, coal, rubber and plastic products; Non-metallic mineral products; Basic metal products; Fabricated metal products, machinery and equipment, and other manufacturing.

[17] Vector z includes output prices, product market shares, indicators for whether a plant exports and imports, product and time dummies, and vector h includes output prices, product market shares, and their interactions with capital and material.

[18] The predicted probability of remaining a single-product plant is estimated via a probit that regresses a dummy variable equal to 1 if a plant remains single-product and 0 if it switches to being multi-product between t and $t+1$ conditional on the information set, i.e. labour, capital, material, product price, dummies for exporting and importing, and product and year fixed effects.

before the current shock to productivity is observed and are therefore not immediately affected by it, while material is affected immediately by the productivity shock.

The above methodology to estimate the production function makes it possible to obtain estimates of the output elasticity with respect to material at the plant-year level, based on the estimated parameter vector β. It is also possible to calculate the revenue share of material at the plant-year level from the available data. However, in order to obtain estimates of the output elasticity and revenue share of material at the market-product-plant-year level, we need one last step, which involves the estimation of input allocation shares across markets and products within plant-year pairs.

These input allocation shares can be seen in equation (15). In this equation, c_{ijdt}^{m} is unobserved, but can be estimated by noticing that $\ln c_{ijdt}^{m} = \rho_{ijt} + \rho_{ijdt} + \ln c_{it}^{m}$, where $\rho_{ijt} = \ln c_{ijt} - \ln c_{it}$ is product j's input cost share and $\rho_{ijdt} = \ln c_{ijdt} - \ln c_{ijt}$ is destination d's product input cost share and these cost shares are equal for all inputs. To estimate ρ_{ijt} and ω_{it} for multi-product plants, we initially follow De Loecker et al. (2012) and solve for each plant-year pair a system of $J+1$ equations made up of J equations for the bias in the error term of the product-level production function due to the missing information on input allocation shares across products, where J is the number of products in each plant-year pair, and one equation stating that the sum of input cost shares at the plant-year level is 1. On the other hand, to estimate ρ_{ijdt}, we depart from De Loecker et al. (2012), who do not estimate markups by market, and assume that the amount of inputs used to manufacture a specific quantity of a product sold to either the domestic or the export market is the same. Thus, the input allocation share between the product sold domestically and that sold abroad is estimated as the product revenue share from each market.

After all these steps, we obtain estimates of the output elasticity, θ_{ijdt}^{m}, and revenue share of material, α_{ijdt}^{m}, at the market-product-plant-year level, which make it possible to estimate markups at the market-product-plant-year level according to equation (15). Finally, after having estimated markups, marginal costs are estimated by dividing prices by markups.