

Multi-product exporters, variable markups and exchange rate fluctuations

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Abstract. In this paper we investigate how firms adjust markups across products in response to fluctuations in the real exchange rate. 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 this increase is greater for products with higher productivity. Thus, we provide direct evidence for the theoretical mechanism of variable markup response behind incomplete and heterogeneous exchange rate pass-through on producer prices. Our empirical methodology allows us to decompose the producer price response to exchange rate shocks into a markup and a marginal cost component using our markup estimates. Using these estimates, we establish that marginal cost at the product-plant level increases more in response to real exchange rate depreciation if the plant has higher share of imported inputs.

JEL Classification: F14, F41.

1. Introduction

The impact of exchange rate movements on prices has important implications for inflation and, hence, for monetary policy. However, macroeconomic evidence of such an impact 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. However, due to the lack of input data and methodology to estimate markups from production data at the product-plant level across heterogeneous sectors of an economy, there is no empirical evidence documenting the heterogeneous response of

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markups to real exchange rate shocks. The primary purpose of this paper is to close this gap by providing such evidence using Mexican data.

In this paper, we follow De Loecker et al. (2016) to estimate markups at the market-product-plant level for multi-product plants using detailed panel production and cost data from Mexico between 1994 and 2007. 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, and hence allows us to use production data for all industries of the Mexican manufacturing sector. Exploiting a series of major fluctuations in the real exchange rate that Mexico experienced in our sample period, this is the first paper to empirically document a key heterogeneity in how exporters change their markups in response to real exchange rate shocks. We show that exporters increase their markups following a real depreciation and that markups within a plant are significantly higher for higher-performance products. This heterogeneous markup response translates into heterogeneity in producer price responses. This key empirical result is robust to different measures of within-firm heterogeneity and to controlling for a rich set of firm and industry characteristics.

We base our theoretical mechanism on a multi-product version of the heterogeneous firm, variable markup model in a monopolistically competitive setup, similar to Chatterjee et al. (2013). 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 extend the model in Chatterjee et al. (2013) to incorporate imported intermediate inputs. The producer price response to a real depreciation is larger than the markup response because of the presence of imported intermediate inputs.

We make several important empirical contributions in the literature that studies variation in exchange rate pass-through across heterogeneous firms (Berman et al., 2012; Chatterjee et al., 2013; Amiti et al., 2014).

First, we estimate markups at the plant-product level for the whole manufacturing sector of Mexico and establish that the relative position of a product within a firm is a statistically and economically significant determinant of the markup and producer-price responsiveness to real exchange rate shocks. Heterogeneity in producer price response was first documented by Berman et al. (2012), who focus on the role of firm productivity and size. Chatterjee et al. (2013) focus instead on the role of within-firm heterogeneity in productivity as the driver of this variation in pass-through in producer prices. Given the predominance of multi-product exporters in our data, we also choose to focus on within-firm heterogeneity in productivity.¹ Our theoretical mechanism behind the heterogeneous producer price response is the heterogeneous response of markups to exchange rate shocks, as in Berman et al. (2012) and Chatterjee et al. (2013). However, unlike previous papers, we take advantage of our detailed input data, similar to that used by De Loecker et al. (2016), and the methodology they recently developed to estimate markups and provide robust empirical evidence in favour of the theoretical mechanism behind heterogeneous producer price pass-through.

¹In 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).

Second, allowing for imported intermediate inputs in production implies that the elasticity of producer price with respect to the real exchange rate is larger than the markup elasticity in proportion to the share of imported intermediate inputs. Therefore, we make further use of our estimation of markups to empirically differentiate the producer price elasticity from the markup elasticity. We find that the elasticity of producer prices with respect to the real exchange rate is larger than the corresponding elasticity of markups by a magnitude roughly equal to the average share of imported intermediate inputs, as predicted by our model.

Third, we can decompose the producer price response to exchange rate shocks into a markup and a marginal cost component using our markup estimates. We find strong evidence that marginal cost increases more in response to real exchange rate depreciation if the plant has a higher share of imported inputs. In a closely related work, Amiti et al. (2014) focus on the decomposition of the producer price response to changes in the real exchange rate into a component due to markup adjustment and another due to marginal cost sensitivity to the real exchange rate. However, the lack of input data does not allow Amiti et al. (2014) to structurally estimate markups and, hence, they rely on imported inputs and destination-specific market shares as sufficient statistics for marginal cost and markup responses. Our approach provides a direct decomposition of the producer price elasticity into markup and marginal cost components and, hence, provides direct evidence for both markup and marginal cost response to exchange rate shocks.

On the methodological side, our estimation of markups is based on De Loecker et al. (2016) and De Loecker and Warzynski (2012). In the spirit of Hall (1986), De Loecker et al. (2016) develop a framework to estimate markups from production and cost data for multi-product plants. 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. (2016) to identify markups for each product-plant-year triplet. In extending De Loecker and Warzynski (2012) to estimate markups for multi-product plants, De Loecker et al. (2016) 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. We follow De Loecker et al. (2016), but we estimate markups separately for domestic and export markets assuming that inputs are allocated across markets in proportion to sales.² To our knowledge, this is the first paper to apply the methodology developed by De Loecker et al. (2016) to study how markups respond to real exchange rate fluctuations. Marin and Voigtländer (2013) use a similar methodology to estimate markups in order to study export-related efficiency gains within plants, and Fan et al. (2015) use it to study the effects of input tariff liberalization on product level markups.

Our paper is also related to the literature on incomplete pass-through into consumer prices due to local distribution costs, as for example in Burstein et al. (2003) and Goldberg and Campa (2010). In the theoretical framework, the elasticity of producer prices with respect to the ex-

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

change 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). We provide some evidence that the 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 this framework. In a similar spirit, Bernini and Tomasi (2015) and Chen and Juvenal (2016) allow for distribution-cost-driven variable markup in their theoretical framework in order to study heterogeneous pricing to market due to quality differentiation.

Regarding multi-product firms, we allow deterministic product ladders, as in Eckel and Neary (2010) and Mayer et al. (2014), to model within-plant heterogeneity. Bernard et al. (2011) characterize an alternative formulation, in which product-firm specific preferences are stochastic. Our results are independent of whether we use a deterministic or stochastic formulation for product ladders. Unlike a relatively nascent literature (Eckel and Neary, 2010; Dhingra, 2013; 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. However, similar to De Loecker et al. (2016), our empirical estimation of markups does not make any assumptions regarding the nature of economies of scope within a plant.

Finally, our dataset covers a period (1994-2007) marked by huge fluctuations 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.³ Cravino and Levchenko (2015) show that the large Mexican peso devaluation led to further distributional consequences as a result of prices increasing more for people at the bottom of the income distribution. The peso crisis in Mexico 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 (2012), who use 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 the North American Free Trade Agreement (NAFTA). Iacovone et al. (2013) use the same dataset to study the impact of a surge in Chinese exports to Mexico.

The paper is structured as follows. In Section 2, we describe the theoretical model and its predictions. Section 3 discusses the data. The methodology used to estimate 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 provides some concluding remarks.

2. Theoretical Background

Our model is a multi-product version of the heterogeneous firm, variable markup model in a monopolistically competitive setup. It is the same as in Chatterjee et al. (2013) except for the inclusion of imported intermediate inputs. We present a model in which heterogeneous plants in the home country export to a foreign market. As our empirical application uses data from Mexico, we use “home” to refer to Mexican plants. We treat exchange rate movements as

³Our methodology to estimate markups includes controls for quality in order to account for unobserved input price differences (De Loecker et al., 2016). This is particularly relevant for our purposes. Auer 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.

exogenous from the point of view of an individual plant, and analyse how an exchange rate shock affects plants' optimal markup and producer price decisions. Details of the model are presented in the Technical Appendix.

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. Following Eckel and Neary (2010) and 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).⁴

Plants are price takers in the input markets. They combine domestic labour and imported intermediate inputs in a constant elasticity of substitution (CES) production function. Each plant faces a distribution cost incurred in foreign currency for each unit of any product it exports. This cost is meant to capture all expenses associated with delivering the product to a foreign customer after the product has left home. The marginal cost of production depends on productivity of plant-product pairs, while unit cost of distribution does not vary by productivity. Hence, production costs account for a relatively small fraction of total unit costs for more productive product-plant pairs. Consequently, the perceived demand elasticity is lower for more productive product-plant pairs.

Plants set their optimal producer price for each product they export. In this framework, the optimal markup is higher than the usual monopolistic competition markup due to the presence of local distribution costs. Moreover, due to the lower perceived demand elasticity, more productive plants and products charge higher markups.

We can empirically test the following predictions of the model.

Prediction 1: The model shows that markups and producer prices increase with the real exchange rate. Berman et al. (2012), Bergin and Feenstra (2000; 2001; 2009) and Atkeson and Burstein (2008) have similar predictions on markups. The difference in elasticities also provides a direct decomposition of the producer price response into its markup and marginal cost components.

Prediction 2: This response of markups and producer prices is larger for more productive product-plant pairs. Hence, the increase in markups is larger for products closer to core competency, similar to Chatterjee et al. (2013).

Prediction 3: The elasticities of both producer price and markup with respect to the real exchange rate are greater in sectors with higher distribution margins. This follows from our model setup, as in Berman et al. (2012) and Chatterjee et al. (2013).

Prediction 4: The marginal cost elasticity to real exchange rate shocks increases in the share of intermediate inputs that are imported, similar to Amiti et al. (2014).

Our structural estimation of markups and marginal costs allows us to test all four of the above predictions.

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

⁴There is a significant body of literature that analyses how non-tradable distribution costs affect international pricing decisions (Burstein et al., 2005).

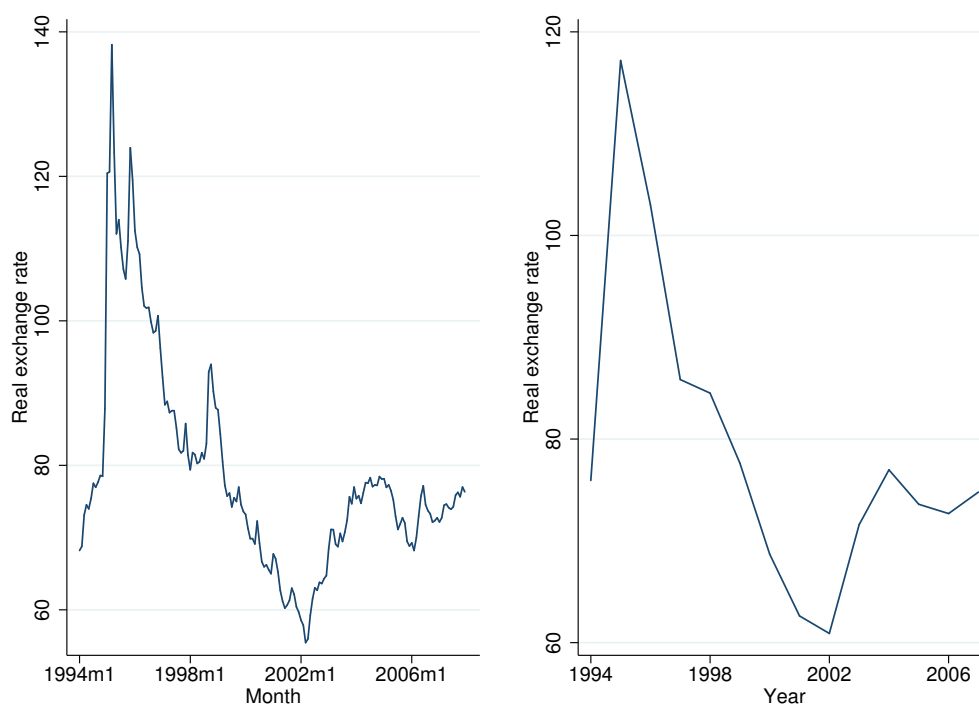


FIGURE 1 Real exchange rate in Mexico
SOURCE: Banco de México, series number SR28.

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 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 against the exchange rates of a basket of 111 countries are depicted in Figure 1, which shows the monthly (left-hand panel) and yearly (right-hand panel) movements during the period analysed using data from *Banco de México*.⁵ 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 sample in both surveys includes all plants with more than 100 employees and a deterministic selection of smaller plants based on their ranking within each industry and the level of concentration in that industry (Iacovone, 2008). The micro data used in this paper contain plant-product level sales and quantity data and plant-level input data, similar to De Loecker et al. (2016).

The EIA contains information on 6867 plants in 1994, but this number decreases over time

⁵Data is available online at <http://www.banxico.org.mx/SieInternet/consultarDirectorioInternetAction.do?accion=consultarSeries>, series number SR28, last accessed on June 22, 2016.

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

due to attrition.⁶ It covers roughly 85% 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 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 materials, 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.⁷ We use aggregate price indices provided separately by the INEGI to obtain the quantity of materials 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 average number of products manufactured by any plant, i.e., scope (column 6). While

⁶The EIA was expanded in 2003, after the 2002 industrial census, to 7294 plants.

⁷The variables used to calculate capital stock are existing initial capital stock at book value, available directly in the EIA and 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. See Iacovone (2008) and Caselli and Woodland (2013) for further details.

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

NOTES: Column 1 shows the share of total output of each sector. Column 2 shows the total number of plants surveyed in each sector. Column 3 shows the share of exporting plants within a sector. Column 4 shows the share of exporting plants that are multi-product plants (MPPs) within each sector. Column 5 shows the share of output by multi-product plants within each sector. Column 6 shows the average number of products manufactured by any plant, i.e., scope.

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 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) and the inflation rate in the US, both taken from the FRED database. We focus on the US as it accounts for over 80% of Mexican exports in 2007 according to UN COMTRADE. 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 modelling 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 we estimate markups and marginal costs in a sample of multi-product plants using production data. A more detailed explanation of the estimation procedure is available in the Technical Appendix.

The methodology is derived from De Loecker and Warzynski (2012) and De Loecker et al. (2016) and it has been analysed further in Marin and Voigtländer (2013) and Fan et al. (2015). The approach requires that plants minimise costs and at least one input is adjusted freely (materials), while the other factors show frictions in their adjustment (capital and labour). We rely on the assumption that as long as both multi-product plants and single-product plants produce the same product, they use the same technology. However, we do 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; Akerberg et al., 2006), we assume that productivity is Hicks-neutral and specific to the plant. However, the heterogeneous production capacity of plants across different products is captured in the marginal cost which is allowed to vary across products within a plant. These assumptions are consistent with the theoretical framework described above, as pointed out by De Loecker et al. (2016). They note that the setup in Mayer et al. (2014), from which we derive our own model, matches most closely the underlying structure of their model and that their results are consistent with the predictions in Mayer et al. (2014).

We obtain an expression for markups, derived from a plant's cost minimisation problem. This expression is given by

$$\mu_{ijdt} = \theta_{ijdt}^m (\alpha_{ijdt}^m)^{-1}, \quad (1)$$

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 materials (denoted by superscript m), and α_{ijdt}^m is the expenditure share of revenue spent on materials. In order to estimate markups at the plant-product-market-year level, it is necessary to obtain estimates of the output elasticity and the revenue share of materials at the plant-product-market-year level. Hence, the strategy for estimating markups at the market-product-plant-year level involves two key steps. In the first step of this approach, we obtain estimates of the output elasticity and the revenue share of materials at the plant-year level. In the second step, we estimate input allocation shares across markets and products within plant-year pairs. Finally, we combine estimates from these two steps to obtain estimates of markups at plant-product-market-year level.

Starting with the first step, we can simply calculate the revenue share of materials at the plant-year level from the data available. In order to get unbiased estimates of the output elasticity with respect to materials at the plant-year level, we consider the following general production function for product j of plant i at time t :

$$\ln y_{ijdt} = f_j (\ln c_{ijdt}, \ln \tilde{c}_{ijdt}; \beta) + \omega_{it} + \epsilon_{ijdt}, \quad (2)$$

where 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 (materials 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.⁸ The production function in f_j is assumed to be translog, so that the parameter vector β includes the coefficients on labour, capital and materials, their squares and their interaction terms.⁹

Three key challenges are present when estimating equation (2) given the lack of data for the right-hand side variables, particularly those at the product-plant level. First, there might be a correlation between unobserved productivity shocks and inputs, a typical concern in the literature concerned with production function estimation.

⁸The 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).

⁹The estimated output elasticity on materials for the translog production function is given by: $\hat{\theta}_{ijdt}^m = \hat{\beta}_m + 2\hat{\beta}_{mm}c_{ijdt}^m + \hat{\beta}_{lm}c_{ijdt}^l + \hat{\beta}_{km}c_{ijdt}^k + \hat{\beta}_{lkm}c_{ijdt}^l c_{ijdt}^k$, where superscripts l , k and m stand for labour, capital and materials.

Second, for multi-product plants, De Loecker et al. (2016) 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 materials can result in biased production function estimates. Plants selling higher-quality goods at higher prices tend to face higher prices for their higher-quality inputs (Verhoogen, 2008; De Loecker et al., 2016). This implies that the production function estimation needs to include controls for quality in order to control for unobserved input price differences.¹⁰

In order to tackle the three challenges just presented, we follow De Loecker et al. (2016) and Akerberg et al. (2006) and implement a consistent two-step methodology to estimate the production function in equation (2) at the two-digit sector level.¹¹ In the first stage, we restrict our sample to single-product plants observed for at least three consecutive years and obtain a consistent estimate of expected output. After the first stage, productivity can be computed as the difference between the estimates of equations (2) and expected output. In order to obtain estimates of all production function coefficients, in the second stage we estimate the law of motion for productivity.¹² All coefficients of the production function are then estimated via the generalised method of moments (GMM) using moment conditions that have become standard in the input control literature and that combine the error term from the law of motion for productivity and inputs with different lags depending on the timing of the choice of inputs. The above methodology to estimate the production function makes it possible to obtain estimates of the output elasticity with respect to materials at the plant-year level, based on the estimated parameter vector β .

In the second step of this approach, we estimate input allocation shares across markets and products within plant-year pairs. In this step, we initially follow De Loecker et al. (2016) and solve for each plant-year pair a system of $J + 1$ equations. The system of equations for each plant-year pair is 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. In addition, to estimate markups by market, we assume that the input allocation share between the product sold domestically and that sold

¹⁰On the other hand, the Mexican industrial survey provide wages at the plant-level, implying that no adjustment is needed for quality of labour.

¹¹The sectors included are: Food, beverages and tobacco; Textile, wearing apparel and leather; Wood 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.

¹²We describe full details of our production function estimation, our regression to obtain expected output and the law of motion for productivity, in the Technical Appendix.

TABLE 3
Estimated export markups by plant size

Quartile	Total sales		Workers		Capital	
	Mean	Median	Mean	Median	Mean	Median
1st quartile	2.21	1.27	2.23	1.40	2.30	1.35
2nd quartile	2.29	1.38	2.45	1.41	2.65	1.43
3rd quartile	2.70	1.44	2.58	1.43	2.63	1.43
4th quartile	2.87	1.48	2.88	1.38	2.62	1.39
All	2.57	1.41	2.57	1.41	2.57	1.41

NOTES: The table reports the export markups estimated by the quartile in which plants fall according to their total sales, number of workers and quantity of capital. The table trims observations with markups that are below the 5th and above the 95th percentiles within each sector and in both domestic and export markets.

abroad is same as the product revenue share from each market. We combine the output elasticity and revenue share of materials at the plant-year level obtained from the first step with these input allocation shares to obtain estimates of the output elasticity and revenue share of materials at the market-product-plant-year level. This final step allows us to estimate markups according to equation (1).

Once we have estimated markups, we can calculate marginal costs at the market-product-plant-year level by using the following definition of prices

$$p_{ijdt} = \mu_{ijdt} \cdot mc_{ijdt}, \quad (3)$$

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 plants and across products within plants.

We estimate markups and marginals costs at the product-plant-year level for both domestic and export markets. In order to better understand the relative importance of markups and marginal costs in explaining prices, we calculate the share of prices accounted for by markups and marginal costs. On average, 25 % of prices can be attributed to markups, while the remaining 75 % is explained by marginal costs.

To get a sense of the magnitude and distribution of the markups, Table 3 shows the mean and median markup estimates in the export market and how these markups change by plant size. Plant size is defined by plants' total sales, number of employees and quantity of capital. Lower quartiles indicate smaller plants that employ fewer workers and less capital. The table clearly shows that larger plants have on average larger markups in a rather consistent way. The overall mean and median markups in the export market are 2.57 and 1.41. These values are in the same order of magnitude as those estimated by De Loecker et al. (2016). Although not shown in Table 3, we also observe significant heterogeneity in estimated markups across sectors and markets. These results are available upon request.

It is also important to examine how markups differ by the level of competition across product-year pairs. In order to measure competition in the domestic market, we use three different measures. First, the concentration ratio of the top five plants for each product is measured as the sum of the domestic market shares of the five largest plants producing each product. Second, the Herfindahl-Hirschman Index (HHI) is a standard measure of concentration and is defined as $hhi_{jt} = \sum_i ms_{ijt}^2$, where ms is the domestic market share of plant i in product j at

TABLE 4
Estimated domestic markups by level of competition

Quartile	CR5		HHI		Entropy	
	Mean	Median	Mean	Median	Mean	Median
1st quartile	2.01	1.13	1.70	1.12	1.62	1.12
2nd quartile	2.20	1.14	2.36	1.18	2.26	1.19
3rd quartile	2.23	1.20	2.24	1.20	2.32	1.22
4th quartile	2.25	1.17	2.39	1.14	2.49	1.13
All	2.17	1.16	2.17	1.16	2.17	1.16

NOTES: The table reports the domestic markups estimated by the quartile in which products fall according to three different measures of competition, the concentration ratio of the top five plants (CR5, first column), the Herfindahl-Hirschman Index (HHI, second column) and the Entropy measure (third column). The table trims observations with markups that are below the 5th and above the 95th percentiles within each sector and in both domestic and export markets.

TABLE 5
Relative importance of products in export sales and markups

	Value of exports	Markup of exports
Ratio of top to second top product	2.52	1.11
Ratio of top to third top product	5.10	1.14
Ratio of top to median product	5.28	1.24

NOTES: The first row shows the median ratio of top to second top product for both export sales (column 1) and markups (column 2), the second row shows the median ratio of top to third top product and the third row shows the median ration of top to median product. Product ranking is defined by sales within plant-year pairs. The table trims observations with markups that are below the 5th and above the 95th percentiles within each sector and in both domestic and export markets.

time t . Third, the entropy measure captures the extent to which output is skewed towards the largest producers and is defined as $entropy_{jt} = \sum_i ms_{ijt} \ln ms_{ijt}$. Product-markets characterised by higher values of all three measures exhibit more concentration and, thus, less competition, leading to higher producers' markups. Table 4 shows the mean and median markup estimates in the domestic market and how these markups change by level of competition in the same domestic market. Lower quartiles indicate less concentrated and more competitive product-markets. The table clearly shows that more competitive product-markets have on average lower markups, with the main exception being for median markups and the fourth quartile according to all three measures.

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 in value as the next most important product and has a markup that is 11% 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.

The correlation matrix between prices and estimates of markups, marginal costs and productivity in the export market is shown in Table 6. 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. (2016), 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, while plants with higher

TABLE 6

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

	Price	Markup	Marginal cost	Productivity
Price	1.00			
Markup	0.12***	1.00		
Marginal cost	0.93***	-0.25***	1.00	
Productivity	-0.45***	0.00	-0.44***	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 below the 5th and above the 95th percentiles within each sector and in both domestic and export markets. *** indicates coefficients significantly different from zero at the 1% level.

productivity tend to have lower prices and marginal costs as well as higher markups. However, the last correlation between markups and productivity is not statistically different from zero, which is not unexpected given that the former are estimated at the product-plant-year level while the latter is estimated at the plant-year level. Moreover, the correlation becomes positive and significant when we control for other factors, as in Table 7.

5. Results

5.1. Regression Analysis

In this section, we test our theoretical predictions concerning producer prices and markups in the export market. In particular, our main theoretical predictions are that 1) producer prices and markups of exports increase following a real depreciation and 2) this increase is larger within plants for products closer to the core competency. Moreover, we also test the predictions that 3) the elasticities of both producer prices and markups with respect to the real exchange rate are greater in sectors with higher distribution margins and 4) the marginal cost elasticity with respect to real exchange rate shocks is an increasing function of the share of imported intermediate inputs.

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

$$\ln p_{ijt} = \psi_1 \ln RER_t + \psi_2 Z_{ijt} + \psi_3 V_t + \varpi_{ij} + e_{ijt}, \quad (4)$$

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 e_{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, i.e., a real depreciation leads to an increase in producer prices.

The mechanism behind the positive producer price response to increases in the real exchange rate is the positive response of markups to such real exchange rate increases. The first main contribution of this paper is, thus, to empirically examine the responsiveness of markups to changes in the real exchange rate. In order to test this mechanism, we estimate a reduced-form regression equivalent to equation (4) but with markups in the export market as the dependent variable:

$$\ln \mu_{ijt} = \varsigma_1 \ln RER_t + \varsigma_2 Z_{ijt} + \varsigma_3 V_t + n_{ij} + \nu_{ijt}, \quad (5)$$

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, i.e., a real depreciation leads to an increase in markups.

As markups are estimated with the procedure described in Section 4, we correct for potential heteroskedasticity caused by the use of an estimated dependent variable. Thus, all markup regressions are estimated via feasible GLS with weights given by the inverse of each observation's standard error conditional on the covariates.

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. To correct for the potential measurement error caused by the fact that marginal cost and total factor productivity are estimated in the preceding analysis, we follow De Loecker et al. (2016) and, in all regressions, we instrument for these two regressors with one-year lags of these two variables.

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, since the US is the main export market for Mexican goods, we control for 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.

Table 7 reports the results concerning the responsiveness of producer prices (column 1) and markups (column 2) to the real exchange rate, corresponding to equations (4) and (5). As in all of 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. The two regressions are significant as a whole, as indicated by the high F statistics values, and the within R-squared is respectively 0.25 and 0.88.

The results confirm the predictions of our theoretical framework with regards to the relationship between markups and the real exchange rate. The coefficient estimate for the log of the 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 0.29, while the elasticity of markup with respect to the real exchange rate is equal to 0.06. Thus, an increase in the real exchange rate, i.e., a real depreciation, increases markups and, consequently, producer prices in Mexican pesos.¹³

Given the estimated producer price elasticity, the estimate for the exchange rate pass-through to import prices in foreign currency is 0.71, before the further attenuation caused by local distribution costs. This is only slightly 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 higher than the exchange rate pass-through elasticity of 0.4 estimated by Campa and Goldberg (2005) for the US based on industry-level data. Our estimate also differs from Fitzgerald and Haller (2014), who find that, conditional on prices changing and local currency pricing, the price elasticity with respect to the real exchange rate is equal to one in a sample of Irish exporters. Based on their estimation and assuming constant relative marginal costs within product-plant pairs across markets, they can claim that the

¹³These basic results follow through when we restrict the sample to single-product plants that do not rely on the multi-product plant methodology by De Loecker et al. (2016) to estimate markups. Additional results are available upon request. Obviously, we cannot check the role of within-plant heterogeneity with only single-product plants.

TABLE 7
 Producer price and markup responsiveness to real exchange rate

<i>Dependent variable</i>	<i>Log price</i>	<i>Log markup</i>
Log Real Exchange Rate	0.29*** (0.04)	0.06*** (0.01)
Log Marginal Cost	0.20*** (0.04)	-0.64*** (0.01)
Log Total Factor Productivity	-0.04* (0.02)	0.04*** (0.01)
Product-plant fixed effects	yes	yes
Aggregate-level controls	yes	yes
No of obs.	16820	16820
R ² (within)	0.25	0.88
F statistic	271.83	912.51
First-stage F statistic	415.70 / 344.48	52.61 / 60.42

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. In all regressions, marginal cost and total factor productivity are instrumented by the lagged values of marginal cost and total factor productivity. In each column, the first one of the first-stage F statistics refers to the marginal cost and the second one to the total factor productivity. The markup regression (column 2) is estimated via feasible GLS with weights given by the inverse of each observation's standard error conditional on the covariates. 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 the 10 and 1% level respectively.

ratio of the markup in the foreign market relative to the home market changes one-for-one with the real exchange rate, a very particular form of pricing-to-market.

The difference between the estimated elasticity of producer prices and that of markups is 0.23 and the Wald test rejects the hypothesis that this difference is statistically equal to zero ($\chi^2 = 326.84$). An implication of the difference in the estimated elasticity of producer prices and that of markups is that it provides us with an alternative and direct method, compared to the indirect method employed by Amiti et al. (2014), to decompose the real exchange rate pass-through into markup and marginal cost components. The results suggest that one fifth of the real exchange rate pass-through is due to changes in markups and four fifths are due to changes in marginal costs.

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 estimate the following reduced-form regression for producer prices in the export market:

$$\ln p_{ijt} = \vartheta_1 \ln RER_t + \vartheta_2 \ln RER_t \times Ladder_{ijt} + \vartheta_3 Z_{ijt} + \vartheta_4 V_t + v_{ij} + u_{ijt}, \quad (6)$$

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 , v_{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 an increase in the real exchange rate on prices is lower for products further away from plants' core competency.

The heterogeneous responsiveness of markups to real exchange rate shocks constitutes the core mechanism behind the heterogeneous producer price response to such exchange rate

TABLE 8
 Producer price responsiveness to real exchange rate by product ranking

	Log Ranking	Core/Non-core	Top/Bottom	First/Second
Log Real Exchange Rate	0.30*** (0.05)	0.30*** (0.05)	0.30*** (0.05)	0.31*** (0.05)
Log Real Exchange Rate *	-0.021*** (0.006)			
Log Real Exchange Rate *		-0.015*** (0.005)		
Log Real Exchange Rate *			-0.014*** (0.004)	
Log Real Exchange Rate *				-0.010** (0.005)
Log Marginal Cost	0.20*** (0.04)	0.20*** (0.04)	0.20*** (0.04)	0.24*** (0.06)
Log Total Factor Productivity	-0.04* (0.02)	-0.04* (0.02)	-0.04* (0.02)	-0.03 (0.02)
Product-plant fixed effects	yes	yes	yes	yes
Aggregate-level controls	yes	yes	yes	yes
No of obs.	16820	16820	16820	13168
R ² (within)	0.25	0.25	0.25	0.27
F statistic	96.87	66.39	105.22	96.66
First-stage F statistic	403.69 / 344.16	412.73 / 344.24	405.85 / 343.68	278.65 / 215.63

NOTES: The dependent variable is the log of the price of exports. In all regressions, marginal cost and total factor productivity are instrumented by the lagged values of marginal cost and total factor productivity. In each column, the first one of the first-stage F statistics refers to the marginal cost and the second one to the total factor productivity. 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 the 10, 5 and 1% level respectively.

shocks. The second main contribution of this paper is to empirically test this mechanism. Thus, we estimate a reduced-form regression equivalent to equation (6) but for markups in the export market:

$$\ln \mu_{ijt} = \zeta_1 \ln RER_t + \zeta_2 \ln RER_t \times Ladder_{ijt} + \zeta_3 Z_{ijt} + \zeta_4 V_t + o_{ij} + v_{ijt}, \quad (7)$$

where o_{ij} denotes the product-plant fixed effects and v_{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. This implies that the positive impact of an increase in the real exchange rate on markups is lower for products further away from plants' core competency.

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: 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 only the first- and second-highest ranked products are included.

Table 8 reports the regression results corresponding to equation (6). Each of the four

TABLE 9
Markup responsiveness to real exchange rate by product ranking

	Log Ranking	Core/Non-core	Top/Bottom	First/Second
Log Real Exchange Rate	0.06*** (0.01)	0.07*** (0.01)	0.07*** (0.01)	0.07*** (0.01)
Log Real Exchange Rate * Log Ranking	-0.013*** (0.001)			
Log Real Exchange Rate * Core/Non-core		-0.011*** (0.001)		
Log Real Exchange Rate * Top/Bottom			-0.012*** (0.001)	
Log Real Exchange Rate * First/Second				-0.010*** (0.001)
Log Marginal Cost	-0.64*** (0.01)	-0.64*** (0.01)	-0.63*** (0.01)	-0.57*** (0.02)
Log Total Factor Productivity	0.04*** (0.01)	0.04*** (0.01)	0.04*** (0.01)	0.04*** (0.01)
Product-plant fixed effects	yes	yes	yes	yes
Aggregate-level controls	yes	yes	yes	yes
No of obs.	16820	16820	16820	13168
R ² (within)	0.88	0.90	0.89	0.83
F statistic	1031.88	3257.47	1802.79	339.45
First-stage F statistic	43.70 / 62.37	43.30 / 59.41	20.74 / 94.74	18.59 / 41.03

NOTES: The dependent variable is the log of the markup of exports. In all regressions, marginal cost and total factor productivity are instrumented by the lagged values of marginal cost and total factor productivity. In each column, the first one of the first-stage F statistics refers to the marginal cost and the second one to the total factor productivity. All regressions are estimated via feasible GLS with weights given by the inverse of each observation's standard error conditional on the covariates. 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 the 1% level.

columns correspond to a different specification of the ladder variable. All four regressions are significant as a whole and the within R-squared values are between 0.25 and 0.27.

The results confirm the predictions of our theoretical framework. The coefficient estimate for the log of the real exchange rate remains positive, between 0.30 and 0.31 depending on which ladder variable is used, 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 Mexican pesos.

The coefficient estimate for the interaction between the log of the 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 the log of the ranking is used as the ladder variable, the point estimate of -0.021 is somewhat smaller than the point estimate of -0.04 found for Brazilian firms (Chatterjee et al., 2013). Considering that the size of the main effect is 0.3, this is an economically significant coefficient as it implies that the producer price of the third-highest ranked product increases by 3% less than that of the second-highest ranked product in response to a real depreciation.

The response of markups to the real exchange rate is shown in Table 9, 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 0.83 and 0.90.

TABLE 10
Responsiveness to real exchange rate: the role of distribution margins

<i>Dependent variable</i>	<i>Log price</i>	<i>Log markup</i>
Log Real Exchange Rate *	0.10***	0.009***
Log Distribution Margin	(0.02)	(0.003)
Log Real Exchange Rate *	-0.007***	-0.005***
Log Distribution Margin * Log Ranking	(0.002)	(0.001)
Log Marginal Cost	0.20***	-0.64***
	(0.04)	(0.01)
Log Total Factor Productivity	-0.04*	0.04***
	(0.02)	(0.01)
Product-plant fixed effects	yes	yes
Aggregate-level controls	yes	yes
No of obs.	16820	16820
R ² (within)	0.25	0.89
F statistic	222.11	2133.17
First-stage F statistic	404.80 / 344.52	45.68 / 43.31

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. In all regressions, marginal cost and total factor productivity are instrumented by the lagged values of marginal cost and total factor productivity. In each column, the first one of the first-stage F statistics refers to the marginal cost and the second one to the total factor productivity. The markup regression (column 2) is estimated via feasible GLS with weights given by the inverse of each observation's standard error conditional on the covariates. 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 the 10 and 1% level respectively.

As predicted by the theoretical framework, the results in Table 9 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 variable is estimated to be positive, equal to approximately 0.07, 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 the log of the real exchange rate and any of the four ladder variables. The point estimate in the main specification, using the log of the ranking as the ladder variable, is -0.013. Considering that the size of the main effect is about 0.07, this is an economically significant coefficient as it implies that markups increase by about 7% less for third-highest ranked product relative to the second-highest ranked product when the real exchange rate depreciates.

Local Distribution Cost Channel In order to test more directly the local distribution cost channel for incomplete pass-through, Table 10 shows two additional specifications – one for producer prices and the other for markups. In these specifications, the log of the real exchange rate and its interaction with the log of the ranking are both interacted with the variable denoted as the 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 10 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

TABLE 11
Marginal cost responsiveness to real exchange rate

	Aggregate controls	Year fixed effects
Log Real Exchange Rate	0.34*** (0.02)	
Import Share (t-1)	-0.72*** (0.16)	-0.83*** (0.13)
Log Real Exchange Rate *	0.18***	0.20***
Import Share (t-1)	(0.04)	(0.03)
Log Total Factor Productivity	-0.29*** (0.02)	-0.29*** (0.02)
Product-plant fixed effects	yes	yes
Aggregate-level controls	yes	no
Year fixed effects	no	yes
No of obs.	16820	16820
R ² (within)	0.65	0.62
F statistic	2606.27	1141.24
First-stage F statistic	259.74	278.29

NOTES: The dependent variable is the log of the marginal cost of exports. In all regressions, total factor productivity is instrumented by the lagged values of total factor productivity. All regressions are estimated via feasible GLS with weights given by the inverse of each observation's standard error. 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 the 1% level.

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).

Marginal Cost and the Imported inputs Channel We now explore the role of imported intermediate inputs in mitigating the effect of real exchange rate changes on producer prices. We provide direct evidence of the mechanism by Amiti et al. (2014) and investigate whether the marginal cost elasticity with respect to the real exchange rate is increasing in the share of intermediate inputs that are imported. In order to do so, we estimate the following reduced-form regression for marginal cost in the export market:

$$\ln mc_{ijt} = \iota_1 \ln RER_t + \iota_2 \ln RER_t \times impsh_{i,t-1} + \iota_3 W_{it} + \iota_4 V_t + \chi_{ij} + \varepsilon_{ijt}, \quad (8)$$

where $impsh_{i,t-1}$ is the share of materials that is imported for plant i at time $t - 1$ and W_{it} is a vector of plant-level time-variant characteristics. We follow Amiti et al. (2014) and use the lagged values of the share of imported materials to reduce endogeneity problems. In the vector of regressors W_{it} , we include the lag of the share of imported materials and total factor productivity to control for time-variant plant-level characteristics. The theoretical framework provided above and the mechanism by Amiti et al. (2014) suggest that the coefficient ι_2 on the interaction between the real exchange rate and the share of imported intermediate inputs is positive.

Table 11 reports the results concerning the responsiveness of marginal cost to the real exchange rate and the share of imported materials, corresponding to equation (8). Column 1 corresponds to a specification in which we add the log of the real exchange rate and the aggregate-level controls. As we are mainly interested in the coefficient on the interaction between the log

of the real exchange rate and the share of imported materials, we provide a second specification in column 2 as a robustness check in which we add year fixed effects and, thus, the log of the real exchange rate by itself and the aggregate-level controls are dropped. Both regressions are significant as a whole, as indicated by the high F statistics values, and the within R-squared lies between 0.62 and 0.65.

The results confirm the theoretical predictions and the mechanism by Amiti et al. (2014). An increase in the real exchange rate, i.e., a real depreciation, leads to an increase in marginal cost, as indicated by the positive and statistically significant coefficient on the log of the real exchange rate. Moreover, plants with a greater share of imported materials exhibit a larger increase in marginal costs following a real depreciation, as indicated by the positive and statistically significant coefficient on the interaction variable between the log of the real exchange rate and the share of imported intermediate inputs.

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 the log of the ranking as the ladder variable.

Table 12 presents a robustness check for the heterogeneous responsiveness of producer price (column 1) and that of markups (column 2) to the real exchange rate related to the mechanism by Amiti et al. (2014). In Table 11, we provided direct evidence that the marginal cost elasticity with respect to the real exchange rate depends on the share of imported intermediate inputs. Here, we check that this mechanism is already accounted for in our price and markup specifications. Thus, we add to the specification in equations (6) and (7) the share of imported materials and the market share at the product-plant-year level as well as their interactions with the log of the real exchange rate. Our results are robust to the inclusion of these additional regressors, as shown by an examination of the parameter estimates. Contrary to the results in Amiti et al. (2014), these additional variables are not generally significant, with the exception of the product market share and its interaction with the log of the real exchange rate in the markup equation.¹⁴ The reason is that in our specifications we control directly for marginal cost, while in Amiti et al. (2014) the share of imported materials indirectly proxies for the responsiveness of marginal cost to the real exchange rate.

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 equations (6) and (7), including the lagged values of log marginal cost and total factor productivity, and 6-digit-industry-level dummies. In the first stage, 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 the time-invariant log of the ranking interacted with log of the 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

¹⁴However, given that the value of the log of the real exchange rate is between four and five, the effect of changes in the product market share on markups is close to zero in total.

TABLE 12

Responsiveness to real exchange rate: import and market share

<i>Dependent variable</i>	<i>Log price</i>	<i>Log markup</i>
Log Real Exchange Rate	0.32*** (0.07)	0.03*** (0.01)
Log Real Exchange Rate *	-0.022***	-0.014***
Log Ranking	(0.006)	(0.001)
Log Marginal Cost	0.20*** (0.04)	-0.64*** (0.01)
Log Total Factor Productivity	-0.04* (0.02)	0.04*** (0.01)
Import Share (t-1)	0.29 (0.37)	0.07 (0.09)
Log Real Exchange Rate *	-0.07	-0.02
Import Share (t-1)	(0.08)	(0.02)
Product Market Share (t-1)	-0.06 (0.36)	-0.39*** (0.06)
Log Real Exchange Rate *	0.01	0.08***
Product Market Share (t-1)	(0.08)	(0.01)
Product-plant fixed effects	yes	yes
Aggregate-level controls	yes	yes
No of obs.	16820	16820
R ² (within)	0.25	0.94
F statistic	47.04	6043.97
First-stage F statistic	405.33 / 345.44	18.04 / 70.86

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. In all regressions, marginal cost and total factor productivity are instrumented by the lagged values of marginal cost and total factor productivity. In each column, the first one of the first-stage F statistics refers to the marginal cost and the second one to the total factor productivity. The markup regression (column 2) is estimated via feasible GLS with weights given by the inverse of each observation's standard error conditional on the covariates. 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 the 10 and 1% level respectively.

predicted values. As shown in Table 13, 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 14, 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 14. 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 robustness check, we estimate equations (6) and (7) with the inclusion of one lag in the real exchange rate and its interaction with the ladder variable and, separately, with

TABLE 13
 Responsiveness to real exchange rate: sample selection correction

<i>Dependent variable</i>	<i>Log price</i>	<i>Log markup</i>
Log Real Exchange Rate	0.21*** (0.06)	0.02** (0.01)
Log Real Exchange Rate *	-0.019***	-0.012***
Log Ranking	(0.005)	(0.001)
Log Marginal Cost	0.17*** (0.04)	-0.65*** (0.01)
Log Total Factor Productivity	-0.02 (0.02)	0.04*** (0.01)
Inverse Mills Ratio	-1.15*** (0.30)	-0.48*** (0.06)
Product-plant fixed effects	yes	yes
Aggregate-level controls	yes	yes
No of obs.	16794	16794
R ² (within)	0.26	0.92
F statistic	17.51	1711.72
First-stage F statistic	959.97 / 410.23	33.86 / 188.18

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. In all regressions, marginal cost and total factor productivity are instrumented by the lagged values of marginal cost and total factor productivity. In each column, the first one of the first-stage F statistics refers to the marginal cost and the second one to the total factor productivity. The markup regression (column 2) is estimated via feasible GLS with weights given by the inverse of each observation's standard error conditional on the covariates. 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 the 5 and 1% level respectively.

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. It may also have important effects on the profitability 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 employ 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.

The main contribution of this paper is to provide robust empirical evidence in favour of heterogeneity in the response of markups to real exchange rate shocks. This key heterogeneity is the mechanism behind heterogenous producer price pass-through, as documented previously by Chatterjee et al. (2013). Specifically, we directly estimate market-specific markups for multi-

TABLE 14
 Responsiveness to real exchange rate: industry-level controls

<i>Dependent variable</i>	<i>Log price</i>		<i>Log markup</i>	
	Industry-level & controls	Industry-year fixed effects	Industry-level & controls	Industry-year fixed effects
Log Real Exchange Rate	0.14 (0.09)		-0.22*** (0.02)	
Log Real Exchange Rate *	0.17 (0.12)		0.10*** (0.02)	
External Financial Dependence				
Log Real Exchange Rate *	0.35 (0.25)		0.79*** (0.05)	
Asset Tangibility				
Log Real Exchange Rate *	-0.022***	-0.020***	-0.013***	-0.013***
Log Ranking	(0.006)	(0.006)	(0.001)	(0.001)
Log Marginal Cost	0.20*** (0.04)	0.18*** (0.04)	-0.63*** (0.01)	-0.64*** (0.01)
Log Total Factor Productivity	-0.04* (0.02)	-0.06** (0.02)	0.04*** (0.01)	0.04*** (0.01)
Product-plant fixed effects	yes	yes	yes	yes
Aggregate-level controls	yes	no	yes	no
Industry-level controls	yes	no	yes	no
Industry-year fixed effects	no	yes	no	yes
No of obs.	16820	16820	16820	16820
R ² (within)	0.25	0.37	0.88	0.90
F statistic	166.34	1.8e+9	770.64	1408.54
First-stage F statistic	398.27 / 342.96	292.57 / 242.64	70.58 / 65.79	47.72 / 57.07

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. In all regressions, marginal cost and total factor productivity are instrumented by the lagged values of marginal cost and total factor productivity. In each column, the first one of the first-stage F statistics refers to the marginal cost and the second one to the total factor productivity. The markup regressions (columns 3 and 4) are estimated via feasible GLS with weights given by the inverse of each observation's standard error conditional on the covariates. 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 the 10, 5 and 1% level respectively.

product plants from detailed product-plant level panel data from Mexico between 1994 and 2007 following De Loecker et al. (2016). 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.

Another contribution of our paper is that we provide a direct way to decompose the real exchange rate pass-through into separate markup and marginal cost components. An alternative method to decompose the real exchange rate pass-through has been proposed by Amiti et al. (2014), who rely on sufficient statistics based on market shares and imported intermediate inputs in order to estimate such components. We 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. We also find direct evidence that the marginal cost elasticity to real exchange rate shocks increases in the share of imported intermediate inputs.

In this paper, we make a significant contribution in emphasising the role of variable markups to explain heterogeneous exchange rate pass-through while abstracting from the endogenous choice of quality. Potentially, quality differences can account for further heterogeneity in markups and marginal costs across products within plants and lead to differences in exchange

rate pass-through (Auer and Chaney, 2009; Auer et al., 2014; Bernini and Tomasi, 2015; Chen and Juvenal, 2016). This is an important avenue for future research.

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