The Impact of Exchange Rate Volatility on Plant-level Investment: Evidence from Colombia*

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Abstract

We estimate the impact of exchange rate volatility on firms' investment decisions in a developing country setting. Employing plant-level panel data from the Colombian Manufacturing Census, we estimate a dynamic investment equation using the system-GMM estimator developed by Arellano and Bover (1995) and Blundell and Bond (1998). We find a robust negative impact of exchange rate volatility, constructed either using a GARCH model or a simple standard deviation measure, on plant investment. Consistent with theory, we also document that the negative effect is mitigated for establishments with higher mark-up or exports, and exacerbated for lower mark-up plants with larger volume of imported intermediates.

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1 Introduction

In this paper, we estimate the impact of real exchange rate uncertainty on plant-level investment in the Colombian manufacturing sector. Existing theoretical studies show that uncertainty can affect firm's investment either positively or negatively, depending on the assumptions about adjustment costs (Dixit and Pindyck (1994)), the degree of competition in the industry (Caballero (1991)), as well as risk-aversion (Zeira (1990)). Because the investment-uncertainty relationship is theoretically ambiguous, most studies resort to empirical evaluation to reach conclusions. Previous empirical work on this relationship has considered various dimensions of uncertainty, such as the manager's perception about future demand (Guiso and Parigi (1999)) and share price volatility (e.g., Leahy and Whited (1996), and Bloom et al. (2007)). Here we focus on the impact of real exchange rate volatility on the firm's investment decision. Further, we show that the firm's mark-up, which reflects market power, and international exposure (exports and imports) affect the sensitivity of its investment to exchange rate volatility. Finally, we demonstrate that the impact of volatility on investment differs substantially across manufacturing industries, and it is related to the industry's average mark-up and foreign exposure.

While there is some empirical literature on the impact of exchange rate volatility on investment, there are only a few studies that have considered the mediating role of the firm's mark-up and external exposure, or have documented cross-industry heterogeneity in the impact of exchange rate volatility on investment.[1] Using industry-level data for the U.S., Campa and Goldberg (1995) find that the impact of volatility depends on exposure to foreign markets, but the effect is quantitatively small. In a panel of developing countries, Serven (2003) finds a sizeable negative impact of exchange rate volatility on aggregate investment. Moreover, he also shows that greater trade openness and a weak financial system aggravate the negative impact. Similarly, Fuentes (2006) finds a negative relationship for Chilean manufacturing plants and provides evidence that the relationship is different for importers and non-importers.

In this paper, we analyze four issues. We start by showing that real exchange rate volatility affects firm-level investment adversely in a developing country context. Second, we demonstrate the importance of firm's mark-up in determining the impact of exchange rate volatility on

[1] Additionally, there exists empirical literature on the effects of the exchange rate itself on firm-level performance. For recent examples see Nucci and Pozzolo (2001) and Fung (2008).

investment decisions. The mark-up reflects the firm's market power and depends on industry concentration and import competition, among other factors. A higher mark-up can partially insulate the firm's investment from exchange rate volatility by allowing the firm to absorb some of the fluctuations in its profit margin. Third, we document the role of firm's external exposure in mediating the relationship between real exchange rate volatility and investment. External exposure depends on firm's reliance on foreign markets for exporting output (export exposure) and for importing inputs (import exposure). Since both export exposure and import exposure affect marginal profitability differently, the relative importance of the two channels determines whether openness mitigates or exacerbates the negative effect of exchange rate volatility on investment. Given limited hedging opportunities in developing countries such as Colombia, due, among other reasons, to low financial development, external exposure can potentially be an important factor in determining the impact of exchange rate volatility.[2] Finally, we uncover substantial heterogeneity in the impact of volatility on firm-level investment across different manufacturing industries, and we show that this heterogeneity is related to the average industry mark-up and foreign exposure as theory predicts.[3]

To motivate our empirical investigation, we first present a simple theoretical model where we consider the investment problem of a representative firm which can sell its output at home or abroad, and may import some of its inputs. The theory implies a conventional dynamic investment equation augmented with measures of foreign exposure (export and import channels), and it highlights the importance of the firm's mark-up in determining the sensitivity of the relationship between investment and exchange rate uncertainty. We estimate the implied dynamic investment equation using panel data techniques developed by Arellano and Bover (1995) and Blundell and Bond (1998). An advantage of using plant-level panel data is that it allows us to control for unobservable plant effects that likely affect investment, sales, cash flow, and foreign exposure simultaneously. Our data on Colombian manufacturing plants comes from Colombia's Departamento Administrativo Nacional de Estadistica, and it spans

[2] A related and important issue is the impact of foreign currency exposure, or balance sheet effects, on firm-level investment in the face of exchange rate changes. We cannot investigate foreign currency exposure because balance sheet information is not available in our data set. Echeverry et al. (2003) and Aguiar (2005) are two examples of the growing body of literature that study balance sheet effects for Colombian and Mexican firms, respectively.

[3] Goldberg (1993) finds mixed evidence on heterogeneity of the effect of exchange rate volatility on industry-level investment in the U.S.

the period from 1981 to 1987. Previous work that has employed the plant-level panel data from the Colombian Manufacturing Census includes Roberts and Skoufias (1997), Roberts and Tybout (1997), and Das et al. (2007). Roberts and Skoufias (1997) estimate the long-run demand for skilled and unskilled labor in Colombian manufacturing plants; Roberts and Tybout (1997) quantify the effect of sunk costs associated with export market entry, while Das et al. (2007) estimate a dynamic structural model of export supply for three Colombian manufacturing industries.[4] The data include information on investment, domestic and imported inputs, domestic sales and exports, and purchases and re-sales of capital goods. The availability of plant data on exports and imports allows us to investigate the importance of plant-level foreign exposure in mediating the relationship between investment and exchange rate volatility. Our baseline industry-level measure of real exchange rate uncertainty is constructed using a GARCH process for the exchange rate between the Colombian peso and the currencies of Colombia's trading partners.[5] We construct trade-weighted, 3-digit ISIC industry specific real exchange volatility measures using bilateral exchange rate data from the IMF's International Financial Statistics and industry trade data from the World Bank's Trade and Production database.

We find an economically and statistically significant negative impact of exchange rate volatility on plant-level investment. Our baseline estimates suggest that one standard deviation increase in the real exchange rate volatility reduces investment by 12%. The estimated effect is smaller in magnitude for higher mark-up plants, indicating that they can partially offset the impact of volatility on investment by adjusting their profit margin.[6] We further estimate the sensitivity of the impact of exchange rate volatility by including interaction terms between volatility and export exposure, as well as volatility and import exposure. Consistent with the derived theoretical implications, we show that export exposure reduces the magnitude of the negative effect of exchange rate volatility on investment in all plants. The impact of import

[4]In related work, Goldberg and Pavcnik (2003), Attanasio et al. (2004), and Goldberg and Pavcnik (2005) use household-level data to investigate the impact of the Colombian trade liberalization during the 1980s and 1990s on wage inequality and employment in the informal sector.

[5]The results are robust to using other simpler measures of exchange rate volatility, such as the standard deviation of the monthly exchange rate growth.

[6]The mitigating effect of the firm's mark-up is non-linear, i.e., a given increase in market power reduces the magnitude of the negative impact of volatility more for lower mark-up firms than for higher mark-up establishments.

exposure, however, is heterogeneous in the plant's mark-up: it magnifies the negative effect of volatility for low mark-up plants, but it reduces it for high mark-up establishments. Finally, we estimate the model by 2-digit ISIC industry. The results show that, while the impact of exchange rate volatility is negative in 6 out of 7 manufacturing industries, the magnitude of the impact varies considerably. As expected, we find that industries with lower average mark-up, lower average export exposure and higher average import exposure experience larger adverse effects of volatility.

The rest of the paper is organized as follows. Section 2 illustrates theoretically the channels through which exchange rate volatility affects investment. We present the empirical specification of the investment equation and discuss the estimation issues in Section 3. Section 4 describes the Colombian plant-level data we employ and the exchange rate uncertainty measures that we construct. We discuss the results in Section 5. The last section concludes.

2 Simple Model of Investment and Exchange Rate Volatility

To motivate the empirical specification, and to highlight the relationship between exchange rate volatility and investment, we present a simple model. Consider the investment problem of a firm that sells its output in the domestic and foreign markets and imports some of its variable inputs of production. Assume that at the beginning of period t, the firm optimally chooses the level of variable inputs, the output prices it charges in the domestic and foreign markets, and investment before the realization of the exchange rate.[7] Due to a one period time-to-build lag, the new capital resulting from investment becomes productive in the following period.

Let Π_{it} be the maximum profit of firm i obtained by choosing the optimal level of inputs and prices. The firm enters period t with K_{it-1} units of capital and chooses investment I_{it} to maximize the expected present value of current and future profits subject to the standard capital accumulation equation. The maximized value of the expected present value of profits is given by:

[7] For simplicity, we assume that all investment is in domestic capital goods, since in our data we cannot differentiate between investment in domestic or foreign capital goods.

$$V_{it}(K_{it-1}) = \max_{I_{it}} \left\{ \Pi_{it} - G\left(K_{it-1}, I_{it}\right) - I_{it} + \beta_t E_t \left[V_{it+1}(K_{it})\right] \right\} \tag{1}$$

subject to

$$K_{it} = (1-\delta)K_{it-1} + I_{it}, \tag{2}$$

where β_t is the discount factor from period t to period $t+1$, δ is the rate of depreciation, and $G\left(K_{it-1}, I_{it}\right)$ denotes the cost of altering the capital stock which results in a loss of some fraction of investment.[8] The first order conditions of the firm's problem yield the following standard Euler equation:

$$1 + \frac{\partial G\left(K_{it-1}, I_{it}\right)}{\partial I_{it}} = \beta_t E_t \left[\frac{\partial \Pi_{it+1}}{\partial K_{it}} - \frac{\partial G\left(K_{it}, I_{it+1}\right)}{\partial K_{it}} + (1-\delta)\left(1 + \frac{\partial G\left(K_{it}, I_{it+1}\right)}{\partial I_{it+1}}\right)\right], \tag{3}$$

which implies that along the optimal path, the marginal cost of investing in a new unit of capital should be equal to the present discounted value of the marginal return to capital. The marginal return depends on the marginal profitability of capital (net of adjustment costs) and the value of undepreciated capital.

In order to characterize the marginal profitability of capital, we follow Campa and Goldberg (1999) and assume that the firm can sell in the domestic and foreign markets, both of which are imperfectly competitive. Given the demand functions for the consumers at home and abroad, the firm optimally chooses the prices for both markets. Moreover, it optimally chooses the level of domestic and foreign variable inputs, taking the amount of capital at the beginning of the period as given. Hence, at the beginning of each period (before the realization of the exchange rate), each firm i maximizes expected profits conditional on the information available at the beginning of period t:

[8] Note that we are normalizing the price of investment to be one in order to simplify the notation. Since we do not have data on the price of investment goods, we control for it by using plant fixed effects and year fixed effects in the estimation.

$$\Pi_{it} = \max_{p_{it}, p^*_{it}, L_{it}, L^*_{it},} E\left[x_i(p_{it})p_{it} + e_t x^*_i(p^*_{it})p^*_{it} - w_t L_{it} - e_t w^*_t L^*_{it} \mid \Omega_{t-}\right], \tag{4}$$

$$s.t.\ x_{it} + x^*_{it} = F(K_{it-1}, L_{it}, L^*_{it})$$

where $x(p_{it})$ and $x^*(p^*_{it})$ are the product demand functions at home and abroad; p_{it} and p^*_{it} are the product prices charged at home and abroad; e_t is the exchange rate; L_{it} and L^*_{it} are the domestic and foreign inputs with prices w_t and w^*_t, respectively; Ω_{t-} is the information set available at the beginning of period t. The production function, $F(\cdot)$, is homogeneous of degree one.

Using the first order conditions for the optimization problem (4), and the fact that $F(\cdot)$ is homogeneous of degree one, we can differentiate the resulting profit function to obtain the expression for the marginal profitability of capital, which enters equation (3), as:

$$\frac{\partial \Pi_{it}}{\partial K_{it-1}} = E\left[\frac{1}{K_{it-1}}\left(\frac{x_{it}p_{it}}{\psi_i} + e_t\frac{x^*_{it}p^*_{it}}{\psi^*_i} - w_t L_{it} - e_t w^*_t L^*_{it}\right) \mid \Omega_{t-}\right], \tag{5}$$

where ψ_i and ψ^*_i are domestic and foreign mark-ups (price-to-cost margins), that are functions of the price elasticities of demand, η_i and η^*_i: $\psi_i = \frac{\eta_i}{1+\eta_i}$, $\psi^*_i = \frac{\eta^*_i}{1+\eta^*_i}$. To see how exchange rate volatility affects marginal profitability of capital, and to keep the model analytically tractable, assume that the only source of uncertainty is the exchange rate. Further assume that the exchange rate follows a log-normal distribution with mean μ_t and variance σ^2_t, both of which are in the information set, Ω_{t-}. We can rewrite expression (5) as:

$$\frac{\partial \Pi_{it}}{\partial K_{it-1}} = \frac{1}{K_{it-1}}\left[\frac{x_{it}p_{it}}{\psi_i} - w_t L_{it} + \left(\frac{x^*_{it}p^*_{it}}{\psi^*_i} - w^*_t L^*_{it}\right)\exp\left(\mu_t + \frac{\sigma^2_t}{2}\right)\right]. \tag{6}$$

Equation (6) demonstrates how the exchange rate volatility can affect investment through the marginal profitability of capital. First, exchange rate volatility has an impact on marginal profitability through export sales: for a given level of foreign sales, x^*_{it}, exchange rate volatility, σ^2_t, raises marginal profitability. Hence, higher export sales stimulate investment. On the other hand, for a given level of imported inputs, L^*_{it}, higher volatility reduces marginal profitability and hence depresses investment. Note that in reality, other sources of uncertainty, in addition to exchange rate volatility, may also affect the firm's investment decision (see, for example, Guiso and Parigi (1999), Leahy and Whited (1996), and Bloom et al. (2007)). Hence, the relationship between profitability, external exposure, and exchange rate volatility is likely to be more complex than the one suggested by equation (6).[9]

Further, equation (6) reveals an additional important factor that mediates the relationship between investment and exchange rate volatility. The firm's mark-up, ψ_i^*, which is closely linked to the degree of competition in the destination market as well as the industry structure, plays an important role in determining the sensitivity of investment to exchange rate volatility. The higher the monopoly power of the firm, the higher the firm's mark-up.[10] A higher mark-up will reduce the sensitivity of investment to exchange rate uncertainty by allowing the firm to absorb some of the impact of exchange rate volatility. Moreover, volatility may affect the marginal profitability of capital by altering competitors' prices and by changing the domestic demand for the firm's product. The higher the import competition a firm faces, the more important this channel becomes.

To characterize the investment Euler equation fully, we need to specify a functional form for the adjustment cost, $G(K_{t-1}, I_t)$. As an example, we adopt the standard convex adjustment cost assumption:

$$G(K_{t-1}, I_t) = \frac{b}{2}\left(\frac{I_t}{K_{t-1}} - c\right)^2 K_{t-1}, \tag{7}$$

where b and c are parameters. We obtain the fully-parameterized Euler equation by substituting equation (6) and the partial derivatives of the adjustment cost function in equation (7) into equation (3). Not surprisingly, this produces a non-linear equation in the variables of interest. In order to simplify the interpretation of the coefficients and to obtain an equation that can be used as the basis for our empirical specification, we linearize the Euler equation using a

[9] Also note that, the implications we derive in equation (6) showing how export exposure and import exposure affect the sensitivity of investment to exchange rate volatility result from the specific assumptions about the production, demand and cost functions. The results may differ with the particular choices of functional forms. For example, assuming sunk costs of investment, Darby et al. (1999) theoretically show that exchange rate uncertainty depresses investment only above a certain volatility threshold.

[10] For example, assuming a Dixit-Stiglitz demand aggregator, $x_{it}^* = Y_t^*\left(\frac{p_{it}^*}{p_t^*}\right)^{\eta_i^*}$, where the price elasticity of demand is given by $|\eta_i^*| > 1$, the Lerner index of monopoly power is equal to -$\frac{1}{\eta_i^*}$. The higher the monopoly power (the more inelastic the demand), the higher the mark-up, $\psi_i^* = \frac{\eta_i^*}{\eta_i^*+1}$.

first-order Taylor approximation around the steady state. After linearizing and rearranging the terms, we obtain the following investment equation:

$$\frac{I_{it}}{K_{it-1}} = E_t\left[\phi_0 + \phi_1\beta_t + \phi_2\frac{I_{it+1}}{K_{it}} + \phi_3\frac{S_{it+1}}{K_{it}} - \phi_4\frac{Z_{it+1}}{K_{it}} + \phi_5\frac{S^*_{it+1}}{K_{it}} - \phi_6\frac{Z^*_{it+1}}{K_{it}} + \phi_7\mu_{t+1} + \phi_8\sigma^2_{t+1}\right] \tag{8}$$

where S_{it+1} is the value of total sales $(x_{it+1}p_{it+1} + x^*_{it+1}p^*_{it+1})$, S^*_{it+1} is the value of exports $(x^*_{it+1}p^*_{it+1})$, Z_{it+1} is total costs $(w_{t+1}L_{it+1} + w^*_{t+1}L^*_{it+1})$, and Z^*_{it+1} is the cost of imported inputs $(w^*_{t+1}L^*_{it+1})$. The ϕ's are functions of the structural parameters of the model (see the Appendix for the details of the Taylor approximation and the expressions for the ϕ's).[11] Equation (8), which presents the first-order approximation of the model, shows that the investment process depends on the discount factor, future investment, expected total and foreign sales, expected total costs and imported input costs, as well as the expected mean and variance (volatility) of the exchange rate.

3 Empirical Investment Equation and Estimation

The theoretical framework in Section 2 motivates the relationship between investment and exchange rate volatility, and it also highlights other important determinants of investment. One can extend the model to allow for more complex adjustment costs and additional constraints imposed on the firm. Each new assumption would give rise to a different structural relationship. Because our main goal is to estimate the impact of exchange rate volatility on investment, instead of focusing on the structural process, we estimate a reduced form investment equation which takes equation (8) as its basis.[12]

We start by estimating the following baseline specification (9) which focuses on the main effect of exchange rate volatility on investment. In order to address some of the econometric issues in estimating the empirical relationship between investment and exchange rate volatility, we modify equation (8) in a number of ways to obtain the following baseline dynamic investment

[11] Note that the coefficient on exchange rate volatility, ϕ_8, depends on the steady state values of the mark-up (ψ), exports (S^*), and imports (Z^*).

[12] Bond and Van Reenen (2008) provide a review of the empirical literature that uses firm- or plant-level data to estimate an investment equation. They note that the reduced form models can be interpreted as representing an empirical approximation to the underlying investment process.

equation:

$$\frac{I_{ijt}}{K_{ijt-1}} = \alpha_1 \frac{I_{ijt-1}}{K_{ijt-2}} + \alpha_2 \frac{S_{ijt}}{K_{ijt-1}} + \alpha_3 \frac{S_{ijt-1}}{K_{ijt-2}} + \alpha_4 \frac{C_{ijt}}{K_{ijt-1}} + \alpha_5 \frac{C_{ijt-1}}{K_{ijt-2}} + + \alpha_6 \Delta e_{jt} + \alpha_7 ev_{jt} + \upsilon_i + \eta_t + \varepsilon_{ijt}, \tag{9}$$

where $\frac{I_{ijt}}{K_{ijt-1}}$ is the investment rate for plant i in industry j in year t, $\frac{S_{ijt}}{K_{ijt-1}}$ and $\frac{C_{ijt}}{K_{ijt-1}}$ are the plant's total sales and cash flow, respectively, normalized by its capital stock. The term Δe_{jt} denotes the annual difference in the logarithm of the real exchange rate for industry j, and ev_{jt} denotes the exchange rate volatility measure for that industry as constructed in the next section.

Note first that while the baseline specification (9) includes only total sales, which proxy for the future profitability of capital, we introduce both exports and imported inputs in a latter specification that augments equation (9). Higher total sales are expected to increase investment, since they signal higher profitability. Second, following Fazzari et al. (1988), it is common practice to include cash flow as a proxy for financing constraints, which arise due to capital market imperfections. In the absence of financing constraints, internal sources of funds, such as cash flow, should not affect investment, since the firm can smooth investment behavior via external capital markets. As capital market imperfections are more prevalent in emerging markets, cash flow can be an important determinant of investment for Colombian firms.[13] Empirically, cash flow is constructed as the difference between sales and costs, adjusted for taxes and depreciation.[14] Because costs and cash flow are highly correlated, we include only cash flow in the specification in order to minimize collinearity problems.[15] Third, to allow for serial correlation in sales and cash flow, we include the current as well as the lagged values of those variables. We also include the lagged investment rate to control for the autocorrelation that may arise due to adjustment costs.

The specification in equation (9) also includes plant specific fixed effects, υ_i, that capture

[13] Examples of previous work that have shown the importance of financing constraints for investment in developing countries include Jaramillo et al. (1996), Harrison and McMillan (2003), and Love (2003).

[14] In terms of our notation, $C_{ijt} = S_{ijt} - Z_{ijt} - tax + depreciation$.

[15] The results including costs in addition to sales and cash flow are similar to those reported in the following sections, and they are available upon request.

the time-invariant plant-level determinants of investment, as well as year effects, η_t, that capture aggregate economy-wide fluctuations. To the extent that the discount factor is common to all the firms, and depends on macroeconomic factors such as the interest rate, β_t will be absorbed in the time effects. However, firms in different industries might have different discount factors depending, for example, on the working capital and borrowing needs. In order to allow for heterogeneous effects of the interest rate on investment, in some specifications, we additionally include interaction terms between the interest rate and a full set of industry dummies.[16] Finally, the error term, ε_{ijt}, is assumed to be i.i.d with $E(\varepsilon_{ijt}) = 0$.

Based on the implications of our theoretical framework, and following the empirical example of Campa and Goldberg (1995), we augment the baseline specification (9) in two important ways. First, to check how the impact of exchange rate volatility on investment depends on the firm's mark-up, ψ_i, we include an interaction term between the mark-up and volatility, $\psi_i * ev_{jt}$.[17] Moreover, we also consider an alternative specification that includes additional interaction terms between the mark-up and all of the firm specific right-hand side controls (investment, sales, and cash flow) in order to examine the differences in the importance of firm-level investment determinants between low and high mark-up establishments. In general, we expect investment to be less sensitive to changes in these variables as mark-up rises, because the higher the mark-up, the easier it is for firms to absorb changes without altering investment.

Second, we explicitly recognize that exchange rate volatility may have different impact on plants with greater exposure to foreign markets. While export exposure, χ_i^{exp}, captures the importance of foreign sales, import exposure, χ_i^{imp}, captures firm's reliance on imported inputs (see Section 4 for the exact definition and construction of the exposure measures). Hence, we also estimate the following augmented specification:

[16]We use eight 2-digit ISIC industries - Table 7 reports the names of the seven main industries. The one not listed in Table 7 is "Other manufacturing".

[17]Note that we cannot construct empirically two separate mark-ups for the domestic and foreign market. The data only allow us to compute one mark-up, which in essence is a weighted average of the two. Henceforth, we use ψ_i to refer to this mark-up.

$$\frac{I_{ijt}}{K_{ijt-1}} = \alpha_1 \frac{I_{ijt-1}}{K_{ijt-2}} + \alpha_2 \frac{S_{ijt}}{K_{ijt-1}} + \alpha_3 \frac{S_{ijt-1}}{K_{ijt-2}} + \alpha_4 \frac{C_{ijt}}{K_{ijt-1}} + \alpha_5 \frac{C_{ijt-1}}{K_{ijt-2}} + \quad (10)$$
$$+ \alpha_6 \Delta e_{jt} + \alpha_7 ev_{jt} + \alpha_8 \chi_i^{exp} * ev_{jt} + \alpha_9 \chi_i^{imp} * ev_{jt} + \upsilon_i + \eta_t + \varepsilon_{ijt},$$

which includes interaction terms between the exchange rate volatility and export exposure, $\chi_i^{exp} * ev_{jt}$, as well as exchange rate volatility and import exposure, $\chi_i^{imp} * ev_{jt}$.

We estimate the dynamic investment equations (9) and (10) using the *system-GMM estimator* of Arellano and Bover (1995) and Blundell and Bond (1998). This estimator for panel data sets with short time dimension addresses the potential biases that arise from the correlation between the plant fixed effects, υ_i, and the lagged dependent variable, $\frac{I_{ijt-1}}{K_{ijt-2}}$, as well as the endogeneity of sales, $\frac{S_{ijt}}{K_{ijt-1}}$, and cash flow, $\frac{C_{ijt}}{K_{ijt-1}}$. The system-GMM estimator combines the first-difference equations, whose regressors are instrumented by their lagged levels, with equations in levels, whose regressors are instrumented by their first-differences.[18] We treat all of the plant specific variables as endogenous, and use lagged values dated $t-2$ and $t-3$ as the GMM-type instruments.[19] To this instrument set, we add lagged exchange rate and lagged exchange rate volatility in all the specifications. The full set of instruments can be found at the end of each table. We employ and report the Sargan-Hansen tests of overidentification to test for the validity of our instruments.[20]

4 Data

4.1 Colombian Plant-level Data

To identify the impact of exchange rate volatility on investment, we use the Colombian manufacturing Census annual plant-level data from 1981 to 1987. This is the same panel previously

[18]The *system-GMM estimator* builds on the *difference-GMM estimator* of Arellano and Bond (1991), which uses only the differenced equations, instrumented by the lagged levels of the regressors. If the regressors are persistent, then their lagged levels are shown to be weak instruments. See Arellano and Bover (1995) and Blundell and Bond (1998) for more details. To avoid this drawback of the *difference-GMM estimator*, we opt for the *system-GMM estimator*.

[19]In some of the specifications lagged values dated $t-2$ were shown to be invalid instruments using the Sargan-Hansen tests of overidentification. In those cases, only the lagged values dated $t-3$ are used as instruments.

[20]All the estimations and tests were done using the *xtabond2* command in Stata 9.2.

used in Roberts and Skoufias (1997), and it includes all manufacturing establishments with at least 10 employees. The data were originally collected by the Colombian Statistical Institute (Departamento Administrativo Nacional de Estadistica, DANE), and it is described in detail in Roberts and Tybout (1996). An establishment is not necessarily a single-plant firm; however, most Colombian firms operate only one plant (Das et al. (2007)). For each establishment, the survey collects data on production, value added, sales, employment, wages, exports, investment, and a small number of other plant characteristics. Plant's capital stock is constructed using the perpetual inventory method, and cash flow is calculated as the after tax operating profits plus deprecation.[21] All plants are classified into 8 2-digit ISIC (International Standard Industrial Classification, revision 2) industries, and then further subdivided into 28 3-digit ISIC industries.

The exchange rate policy in Colombia for the sample period, 1981-87, was characterized by a crawling peg. In that period the Colombian Peso depreciated over 30 percent in real terms, and manufacturing exports rose (see Jaramillo et al. (1999)). There is substantial heterogeneity, however, across industries in the number of trading partners as well as export destinations – for example, certain fabrics are exported mainly to nearby partners in South America, while leather products are mostly sold to Europe and the United States.[22] Table 1 presents the 15 largest trading partners, with the United States, Japan, Germany and Venezuela at the top of the list. Note that the plant-level data do not contain any information on the plant's or industry's export destinations and import partners. We obtain industry-level exports and imports from the World Bank's Trade and Production Database.[23] We employ this data set to compute partners' trade shares, and use them to construct the industry-level exchange rate volatility (3-digit ISIC) measures, as we describe in the next subsection. Bilateral exchange rate data come from the IMF's International Financial Statistics (IFS).[24]

Because firms with high market power can absorb some of the fluctuations in exchange rate volatility by adjusting their profit margins instead of altering their investment behavior, we check if investment in firms with higher price-cost margins is less sensitive to exchange rate

[21]See Liu (1993) for detailed description of the construction of the capital measure in this data set.

[22]Colombia exports merchandize in every single 3-digit ISIC industry. Industries with the largest volumes of exports are Petroleum Refineries, Food, Textiles and Industrial Chemicals.

[23]The World Bank's Trade and Production Database is available on-line at http://www.worldbank.org.

[24]IFS is available on-line at http://www.imfstatistics.org.

volatility. To proxy for plants' market power, we use the information provided in the panel to construct plant-level mark-ups. Following Campa and Goldberg (1999), the average mark-up, ψ_i, for plant i (average over the sample period from 1981 to 1987) is defined as[25]:

$$\psi_i = \frac{\text{value of sales}_i + \Delta\text{inventories}_i}{\text{payroll}_i + \text{cost of materials}_i}. \tag{11}$$

Similarly, to test how firm's foreign exposure affects investment, we compute measures of export and import exposure: average export fraction of sales, and average fraction of total costs from imported inputs, including intermediates, raw materials, and labor costs of foreign employees. Table 2 presents the summary statistics. Only about 15 percent of all plants export a positive fraction of their sales[26], and about 34 percent import intermediates or raw materials.[27]

4.2 Exchange Rate Volatility Measures

Previous research has employed a number of different exchange rate volatility measures, although there is still no consensus on which one is the most appropriate (Clark et al. (2004)). The choice is driven by a number of factors including, among others, the time horizon considered (short-run vs. long-run). Often, the volatility measure incorporates some variant of the standard deviation of the difference in the annual or monthly exchange rate (see, for example, Frankel and Wei (1993); Rose (2000); Cho et al. (2002); Clark et al. (2004); Tenreyro (2007)). Such measures reflect the unconditional, realized volatility. To capture exchange rate uncertainty ex ante, we employ a GARCH process (Engle (1982); Bollerslev (1986)) to model the conditional exchange rate variance. The GARCH specification accommodates for the heavy tails of the distribution of exchange rate changes, and it allows us to model their variance as time dependent. Many researchers have employed a GARCH model to construct measures for exchange rate volatility – examples include Baillie and Bollarslev (1989), Pozo (1992), Arize et al. (2000), Clark et al. (2004), Wang and Barett (2007), and Kandilov (2008).

We allow for maximum flexibility by estimating a GARCH model for each year of our

[25]This mark-up measure is a positive transformation of the mark-up measure of Domowitz et al. (1986), mk, where the measure defined in (11) is equal to $\frac{1}{1-mk}$. We use the average mark-up rather than a contemporaneous measure in order to avoid endogeneity issues in the estimation.

[26]We consider a plant an exporter if its exports are positive in at least two consecutive years.

[27]Using a smaller sample of public Colombian manufacturing firms for the 1995-2001 period, Echeverry et al. (2003) report that the average share of exports in total revenue for their sample is about 8 percent.

sample. Because we have a large sample of trading partners, it is computationally cumbersome to estimate a separate GARCH(1,1) specification for the exchange rate process of each trading partner. Instead, we follow Clark et al. (2004), and we group the exchange rate data into two categories – exchange rates between Colombia and developed countries and exchange rates between Colombia and developing nations. We estimate the GARCH (1,1) process separately for each of the two categories of countries for every year from 1981 to 1987 using monthly data on exchange rates for that category from the previous five years. The resulting measure of exchange rate volatility reflects medium- to long-run volatility. More formally, for a given year t, t = 1981, 1982, ..., 1987, we estimate two versions of the following GARCH (1,1) model (one for each of the two categories of exchange rates):

$$\begin{aligned} 100\Delta \ln e_{kzm} &= \psi_0 + \xi_{kzm} \\ \xi_{kzm} \mid I_{zm-1} &\sim N(0, h_{zm}) \\ h_{zm} &= \delta_0 + \delta_1 \xi^2_{kzm-1} + \delta_2 h_{zm-1}, \end{aligned} \tag{12}$$

where e_{kzm} is the real exchange rate between country k and Colombia in month m = 1, 2, ..., 12, of year $z = t - 1, \ldots, t - 5$. We estimate 14 (= 7 years * 2 categories of exchange rates) different GARCH (1,1) models. As in Clark et al. (2004), we use the last estimated conditional standard deviation of each country pair (divided by 100) as the approximation of the conditional volatility, ev^c_{kt}, at the beginning of the next period. For example, the conditional volatility for 1985 is the estimated conditional standard deviation for December 1984 in the GARCH (1,1) model using data from January 1980 to December 1984.

We construct our preferred measure of exchange rate volatility, ev^c_{kt}, using the real exchange rate as in Arize et al. (2000), Cho et al. (2002), and Kandilov (2008). Some previous studies have used the nominal rate instead (e.g., Tenreyro (2007)), but we choose the real rate because, theoretically, profits are affected by both the nominal exchange rate and prices (of traded goods) (see Maskus (1986)). For most industrial as well as some developing economies, there is little difference between the real and the nominal exchange rate volatility because prices are sluggish. However, differences arise in countries with high inflation episodes, such as Argentina and Brazil during the 1980s, when nominal exchange rate volatility is higher than the real rate volatility.

A second measure of exchange rate volatility that we construct reflects the unconditional, realized volatility as in Clark et al. (2004), as well as Tenreyro (2007). Formally, for a given year t, $t = 1981, 1982, \ldots, 1987$:

$$ev^{u}_{kt} = St.Dev. \left[\ln e_{kz,m} - \ln e_{kz,m-1} \right], \; m = 1, 2, ..., 12; \; z = t-5, ..., t-1. \tag{13}$$

We use the conditional, ev^{c}_{kt}, and the unconditional, ev^{u}_{kt}, bilateral exchange rate volatility measures to construct the industry-specific volatility measures. The two industry-specific measures behave very similarly – the correlation between them is 0.61.

To build the industry-specific (3-digit ISIC) measures, we weight the bilateral volatility measures by the partner's trade share in the industry. More formally, let ev_{jt} denote the exchange rate volatility in (3-digit ISIC) industry j in year t:

$$ev^{GARCH}_{jt} = \sum_{k} TradeShare_{jk} * ev^{c}_{kt}, \tag{14}$$

where $TradeShare_{jk}$ is

$$\frac{1}{T} \sum_{t} \frac{M_{jkt} + X_{jkt}}{\sum_{k} M_{jkt} + X_{jkt}},$$

and M_{jkt} denotes imports from country k to Colombia in industry j, in year t, and similarly, X_{jkt} denotes exports from Colombia to country k in industry j, in year t. Finally, ev^{c}_{kt} is the conditional exchange rate volatility in year t between the Colombian Peso and country k's currency. We consider Colombia's 29 largest trading partners, each with an industry trade share (bilateral industry trade as a share of total industry trade) of at least 5 percent. This group of partners captures more than 75 percent of Colombia's total trade. Note that the trade shares are fixed over time – they are averaged (within an industry) across the sample time period. Hence, variation in ev^{GARCH}_{jt} over time comes only from changes in exchange rate volatility and not from fluctuations in partners' trade shares. To check for robustness, we also construct a second measure of the industry-specific exchange rate volatility, ev^{StDev}_{jt}, which uses the unconditional exchange rate volatility ev^{u}_{kt} from (13) in place of ev^{c}_{kt} in equation (14).

The summary statistics in Table 2 show that the two measures of real exchange rate volatility appear very similar in terms of their first and second moments (mean and standard deviation). Table 3 presents the average (over the sample period) of the two measures of real exchange rate volatility, ev_{jt}^{GARCH} and ev_{jt}^{StDev}, and the change in these measures from the beginning of the sample period in 1981 to the end in 1987 for all of the 3-digit ISIC industries. Generally, exchange rate volatility increases towards the end of the sample period, but there is substantial heterogeneity across industries in both the average value and the magnitude of the increase in volatility. Finally, using formula (14), we also compute the (3-digit ISIC) industry exchange rate, e_{jt}, where in place of ev_{kt}^{c}, we use the level of the exchange rate in year t between the Colombian Peso and country k's currency, e_{kt}.

5 Results

The results from our baseline specification (9), which estimates the impact of exchange rate volatility on investment in the Colombian manufacturing sector, are reported in Table 4. In this first set of results, we evaluate the average impact of exchange rate volatility on all manufacturing establishments. In subsection 5.2, we document the importance of the firm's market power as proxied by the size of the firm's mark-up in mediating the effects of exchange rate volatility on investment. In subsection 5.3, we show how the impact of exchange rate volatility can be amplified or mitigated by the degree of the firm's external exposure. Finally, in subsection 5.4 we demonstrate that the impact of volatility on investment differs substantially across 2-digit ISIC industries, and it is related to the industry's average mark-up and foreign exposure as theory suggests.

5.1 Main Effects of Exchange Rate Volatility on Investment

Column (1) of Table 4 presents the results from our baseline specification (9) using the GARCH measure of exchange rate volatility, ev_{jt}^{GARCH}. The estimates reveal that volatility has a large, negative, and statistically significant impact on investment. The estimated coefficient of -0.629 (standard error = 0.166) implies that one percent increase in the conditional volatility,

ev_{jt}^{GARCH}, leads to a 0.39 percent decrease in investment.[28, 29] Alternatively, one standard deviation reduction in volatility (0.04, see Table 2) will raise investment by 12 percent. Column (3) of Table 4 reports the results from our baseline specification (9) employing the standard deviation measure of exchange rate volatility, ev_{jt}^{StDev}. Consistent with our findings using the GARCH measure, the coefficient on ev_{jt}^{StDev} in column (3) is negative and statistically significant at -0.372 (0.171), and it implies that one percent increase in volatility leads to a 0.18 percent decline in investment.

Among the firm-specific determinants of investment, as expected, lagged investment and lagged sales have estimated coefficients that are, while small in magnitude, positive and significant in both columns (1) and (3) of Table 4. The coefficient on current sales, while also small in magnitude, is estimated to be negative, which is surprising. We, however, show in the next subsection that this coefficient is actually positive and significant for lower mark-up firms. The estimated coefficients on both current and lagged cash flow are small and not statistically significantly different from zero either in specification (1) or specification (3).

Note that while we do not explicitly control for the effect of the interest rate in specifications (1) and (3), it is implicitly subsumed in the year dummies, which are included in order to account for any aggregate economy-wide shocks common to all industries.[30] In specifications (2) and (4) of Table 4, we go a step further and allow for a heterogeneous impact of the interest rate across industries by including interaction terms between the interest rate and a full set of 2-digit industry dummies.[31] An F-test for joint significance of all interest rate interactions indicates that they are all jointly significant in both columns (2) and (4) of Table 4. The estimates in column (2) are similar to their counterparts in column (1). The impact of (the GARCH measure of) exchange rate volatility increases slightly in magnitude when we allow for differences in the impact of the interest rate across industries – the implied elasticity of investment with respect to the conditional volatility, ev_{jt}^{GARCH}, is now -0.47. Using the standard deviation measure, ev_{jt}^{StDev}, in column (4), the impact of volatility on investment is

[28]The elasticity of the investment rate, $\frac{I_{ijt}}{K_{ijt-1}}$, with respect to the (GARCH measure of) exchange rate volatility, ev_{jt}^{GARCH}, at the sample means is -0.629*0.13/0.21=-0.39.

[29]We compute robust standard errors with the Windmeijer (2005) small sample correction.

[30]Year dummies are jointly significant (p-values$\leq$0.000) in all of the specifications.

[31]Data on Colombian interest rate (discount rate) come from the IMF's International Financial Statistics.

also estimated to be larger when we allow for heterogeneity in the impact of the interest rate. The implied elasticity in this case is -0.52.

All four specifications in Table 4 are supported by the tests of overidentifying restrictions, for which the Hansen test statistics fail to reject the validity of the instrument sets (the p-values are 0.267, 0.226, 0.285, and 0.247, respectively).[32] Moreover, the tests for serial correlation, which are applied to the residuals in the first differenced equations ($\Delta\varepsilon_{ijt}$), show that we can reject the null-hypothesis of no first-order serial correlation, but cannot reject the null-hypothesis of no second order serial correlation.[33] The fact that the errors only have first order autocorrelation confirms the validity of instruments dated $t-2$ and $t-3$.

5.2 Exchange Rate Volatility and Mark-up

The theoretical framework in Section 2 illustrates the importance of the firm's mark-up in determining the impact of exchange rate volatility – investment in a firm with higher market power should be less sensitive to volatility. The mark-up depends on the industry concentration and import competition, as well as other industry specific factors. In the following specification, we explicitly test if firms with higher market power experience smaller negative effects of exchange rate volatility. To this end, we augment our baseline specification (9) to include an interaction term between the exchange rate volatility measure, ev_{jt}^{GARCH}, and the mark-up measure, ψ_i. Henceforth, we employ the conditional (GARCH) exchange rate volatility, ev_{jt}^{GARCH}, as our preferred volatility measure. The results are presented in Table 5. As expected, in column (1), the estimated coefficient on the interaction term is positive at 0.052 (0.032). It implies that the magnitude of the impact of exchange rate volatility is about 10 percent smaller for a firm with a mark-up that is two standard deviations (1.02 = 2*0.51) above the average mark-up of 1.39 (see Table 2). The estimated coefficient on the interaction term is marginally statistically insignificant at the 10 percent level, implying that there maybe a non-linear mark-up effect that we have not properly captured with the simple linear interaction

[32]The validity of the excluded instruments is also confirmed by the Kleibergen and Paap (2006) test of underidentification, for which the null hypotheses of underidentification is strongly rejected (p-values$\leq$0.000) for all of the specifications. Further, in all specifications, the validity of OLS against the GMM alternative was strongly rejected (p-values$\leq$0.000) by the Hausman specification test.

[33]Assuming that the residuals, ε_{ijt}, in equation (9) are i.i.d, we expect $\Delta\varepsilon_{ijt}$ in the first-differenced equations to have first order autocorrelation.

in column (1).

To accommodate for possible non-linearities, in column (2), we include an additional squared (in the mark-up) interaction term, $ev_{jt} * \psi_i^2$. The estimates strongly support the existence of a non-linear (in the mark-up) effect. Both the linear and the squared terms are economically and statistically significant tracing the increasing portion of a downward-open parabola, indicating that the magnitude of the negative impact of exchange rate volatility declines with mark-up faster at lower levels of the mark-up. The estimates in column (2) imply that the impact of exchange rate volatility, ev_{jt}^{GARCH}, is -0.744 for firms with mark-up that is two standard deviations below the average, while it is only -0.543 for firms with the average mark-up. For firms with mark-ups that are two standard deviations above the average, the magnitude of the impact of volatility, while still significant, is even smaller at -0.416. These coefficients imply elasticities of investment with respect to exchange rate volatility of -0.46 and -0.26, for firms with mark-ups that are two standard deviations bellow and two standard deviations above the average, respectively. While both estimates are economically significant, the magnitude of the negative impact of exchange rate volatility on investment in firms with negligible market power (-0.46) is almost twice as large as the magnitude of the same impact in firms with considerable market power (-0.26). These results are in line with findings in Campa and Goldberg (1995), and confirm the theoretical prediction that the high mark-up firms are better able to insulate their investment from exchange rate volatility.

Because the effects of the firm-level covariates (sales and cash flow, as well as lagged investment, sales, and cash flow) are also likely to differ across firms with varying degree of market power, we next further augment our specification to include interactions between these firm-level covariates and the mark-up. The results, which are presented in column (3) of Table 5, demonstrate that there is a difference in the implied investment dynamics between firms with high market power and those with low market power. As expected, the coefficients on sales and lagged sales are positive and negative respectively for low mark-up firms, implying that the impact of sales growth on investment is positive. This positive impact of sales disappears almost entirely for the average mark-up firm. Similarly, the estimates reveal that the positive impact of cash flow is larger (in magnitude) for firms with lower market power than it is for firms with higher mark-ups, for which the impact is negative. The positive impact of cash flow on investment reflects the importance of internal funds for investment especially in low mark-up firms which tend to be more financially constrained.[34] The coefficient on lagged cash flow is estimated to be negative, yielding a positive impact of the growth in cash flow (given the positive coefficient on cash-flow). While the estimated effect of cash flow reported in column (3) is suggestive of the existence of financing constraints for firms with lower market power in the Colombian manufacturing sector, it cannot be considered conclusive because the estimated coefficients are not statistically significantly different from zero.

5.3 External Exposure Results

As we discussed in Section 2, the impact of exchange rate volatility can be amplified or mitigated, especially in the absence of hedging opportunities, by the degree of firm's external exposure. Export exposure should in theory mitigate the adverse effect of exchange rate volatility on investment, while import exposure should aggravate it. To examine how external exposure affects the impact of exchange rate volatility on plant investment, we estimate specification (10), which augments our baseline equation (9) with interaction terms between the respective measure for exposure (export or import exposure) and the exchange rate volatility. We include both measures of exposure, export (χ_i^{exp}) and import (χ_i^{imp}) exposure, in the same specification. While export exposure captures the importance of foreign revenues, import exposure focuses on the cost aspect of openness.

The results from specification (10) are presented in column (1) of Table 6. The main volatility effect is again negative and statistically significant at -0.559 (0.187). As expected, the interaction term between exchange rate volatility, ev_{jt}^{GARCH}, and export exposure, χ_i^{exp}, is positive and statistically significant, indicating that higher export exposure mitigates the adverse impact of exchange rate volatility. The estimates imply that the elasticity of investment with respect to exchange rate volatility for a firm with export exposure that is two standard deviations (= 2*0.11) above the average exposure of 0.02 is -0.29, while the elasticity for a firm

[34] In a similar empirical work, Harrison and McMillan (2003) find a negative impact of cash-flow on both domestic and foreign investment in the Ivory Coast. As discussed in Bond and Meghir (1994) and Harrison and McMillan (2003), when the firm can obtain the necessary financing, cash-flow will be negatively correlated with investment, since high cash-flow will imply a low marginal adjustment cost of investment, given that adjustment costs are increasing in investment, as in equation (7).

with the average export exposure is about 17 percent lower at -0.34. This finding is similar to the results in Campa and Goldberg (1995), who find that, in general, volatility stimulates investment as the export share of the industry rises.

Contrary to expectations, the interaction term between exchange rate volatility and import exposure is positive. The estimated coefficient of 0.543 (0.149) in column (1) of Table 6 implies that a higher import share mitigates the volatility for the average plant. As we demonstrated in the previous subsection (5.2), however, the firm's mark-up plays a key role in mediating the relationship between exchange rate volatility and investment. This leads us to expect that the volatility mitigating effects of import exposure may not be homogeneous in the firm's mark-up. In column (2) of Table 6 we investigate how the size of the firm's mark-up changes the import exposure effect on the volatility-investment relationship. The estimates show that for firms with low mark-up, as expected, higher import exposure intensifies the negative impact of volatility, by making costs harder to predict. For firms with higher market power, on the other hand, the larger the fraction of imported inputs, the smaller the adverse impact of exchange rate volatility.[35] The mitigating effect of imports for the high mark-up firms might arise if larger share of imported inputs is correlated with higher productivity, which partially insulates the firm's investment decisions from exchange rate volatility. Alternatively, firms with higher market power, which are generally larger producers, may be entering into longer-term contracts with foreign suppliers, and by doing so they are able to reduce the impact of exchange rate volatility they face.

5.4 Results by Industry

Theoretical studies have shown that the degree of competition, foreign exposure, returns to scale, and adjustment costs are important factors in determining the direction and magnitude of the impact of uncertainty on investment (e.g., Caballero (1991), and Dixit and Pindyck (1994)). All of these factors differ across industries, generating heterogeneity in the impact of exchange rate volatility on investment. To document this heterogeneity and to relate it to the variables that are central to our investigation – the mark-up and foreign exposure – we

[35] In their investigation with industry-level U.S. manufacturing data, Campa and Goldberg (1995) also provide some evidence that the effect of import exposure on the impact of exchange rate volatility depends on the mark-up.

estimate our baseline specification separately for each of the seven 2-digit ISIC manufacturing industries.[36]

The results are presented in Table 7. We focus our attention on the impact of exchange rate volatility in each of the seven industries, and as such, to conserve space, we only report the coefficient on ev_{jt}^{GARCH}. While a few of the industry specific coefficients are similar to the aggregate coefficient of -0.629 (0.166) in column (1) of Table 4, there is substantial heterogeneity. For example, the impact of exchange rate volatility on plant-level investment for firms in Fabricated metal products is close to twice the size of the aggregate impact (-1.151 vs. -0.629). On the other hand, while not statistically significantly different from zero, the volatility impact is estimated to be actually positive, at 0.972 (2.144), for firms in Non-metallic mineral products. All of these results show that while the overall aggregate impact of exchange rate volatility on investment is negative, it varies considerably by industry.

In the previous two subsections, 5.2 and 5.3, we showed that the effect of volatility depends on both mark-up and external exposure. In what follows, we demonstrate that the average industry mark-up and external exposure (both export and import) can help rationalize the industry specific estimates of the impact of exchange rate volatility presented in the first column of Table 7. For example, note that the Non-metallic mineral products industry has the largest average industry mark-up (see the second column of 7) and the lowest import exposure index of all 7 industries. Given that higher mark-up tends to reduce the magnitude of the negative impact of volatility and lower import exposure also exerts downward pressure on the magnitude of the volatility impact (in theory for all firms, and in practice at least in firms with lower market power), it is not surprising that this industry does not seem to experience large negative effects of exchange rate volatility on investment. At the other end of the spectrum, consider the Fabricated metal products industry – it has the lowest average industry export exposure and the highest import exposure. Given our earlier theoretical framework and empirical findings, it is then, not too surprising that this industry experiences the largest adverse effects of exchange rate volatility on investment. More generally, consider the partial correlations (at the bottom of

[36]Note that fitting the investment equation by industry allows for maximum flexibility in estimating the impacts of all right-hand side variables, whose effects are now allowed to differ by industry. See Table 7 for the names of the seven 2-digit ISIC industries. We ignore the rather small industry "Other manufacturing" because it is not a well-defined, homogeneous group.

Table 7) between the industry specific effect of volatility and the three channels through which volatility may affect investment – the mark-up, export exposure, and import exposure. In line with our earlier theoretical arguments and empirical results, these correlations demonstrate that industries with lower average mark-up, lower average export exposure, or higher average import exposure also have lower coefficient on the exchange rate volatility, i.e., they experience larger adverse impact of volatility on investment.

6 Conclusion

Researchers have investigated the effects of exchange rate volatility on economic outcomes ever since the collapse of the Bretton Woods System in the 1970s, when previously fixed exchange rates among major currencies were allowed to float. Recent progress in econometrics and availability of micro-level data allow us to shed more light on the impact of volatility on plant-level behavior. In this paper, we use manufacturing Census data from Colombia to assess the impact of real exchange rate volatility on plant investment. We estimate a dynamic investment equation using panel data techniques developed by Arellano and Bover (1995) and Blundell and Bond (1998), as well as a GARCH process to model exchange rate volatility. One advantage of using micro-level as opposed to industry-wide panel data is the opportunity to control for time-invariant unobservable plant characteristics that affect establishments' investment decisions.

We find a strong negative and statistically significant impact of real exchange rate volatility on plant investment. Our baseline results imply that one standard deviation reduction in volatility leads to a 12 percent increase in investment. As predicted by theory, we also demonstrate that the impact of volatility is larger in establishments with lower mark-up. We further show that the firm's external exposure to export and import markets affects the impact of volatility. Higher exports mitigate the impact, while a larger fraction of imported inputs exacerbates the adverse effects of exchange rate volatility on investment for low mark-up firms. Finally, our results suggest that the impact of volatility differs substantially across industries, and it is related to the industry's average mark-up and external exposure.

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Theoretical Appendix

The fully-parameterized non-linear investment equation we obtain when we substitute equation (6) and the partial derivatives of the adjustment cost function in equation (7) into equation (3) is:

$$\beta_t E_t \left\{ \frac{b}{2} \left(\frac{I_{it+1}}{K_{it}} \right)^2 + (1-\delta) b \frac{I_{it+1}}{K_{it}} + \frac{1}{K_{it}} \left[\frac{x_{it+1} p_{it+1}}{\psi_i} - w_{t+1} L_{it+1} + \left(\frac{x^*_{it+1} p^*_{it+1}}{\psi^*_i} - w^*_{t+1} L^*_{it+1} \right) \exp\left(\mu_{t+1} + \frac{\sigma^2_{t+1}}{2} \right) \right] \right\}$$
$$= b \frac{I_{it}}{K_{it-1}} + \left[(1-\delta)(1-bc) - \frac{bc^2}{2} \right] \beta_t + (1-c).$$

First we take a first-order Taylor approximation of the non-linear equation above around the steady state values of the variables. Second we define total sales as S_{it}=$x_{it+1}p_{it+1} + x^*_{it+1}p^*_{it+1}$, and the value of foreign sales as S^*_{it+1}=$x^*_{it+1}p^*_{it+1}$. Similarly, we define total costs as $Z_{it+1} = w_{t+1}L_{it+1} + w^*_{t+1}L^*_{it+1}$, and the cost of imported inputs as $Z^*_{it+1} = w^*_{t+1}L^*_{it+1}$. Rewriting the sales and the cost variables in terms of S_{it}, S^*_{it+1}, Z_{it+1} and Z^*_{it+1}, we obtain equation (8) in the text:

$$\frac{I_{it}}{K_{it-1}} = E_t \left[\phi_0 + \phi_1 \beta_t + \phi_2 \frac{I_{it+1}}{K_{it}} + \phi_3 \frac{S_{it+1}}{K_{it}} - \phi_4 \frac{Z_{it+1}}{K_{it}} + \phi_5 \frac{S^*_{it+1}}{K_{it}} - \phi_6 \frac{Z^*_{it+1}}{K_{it}} + \phi_7 \mu_{t+1} + \phi_8 \sigma^2_{t+1} \right].$$

The expressions for the coefficients in terms of the structural parameters and the steady-state values of the variables are:

$$\phi_0 = -\beta \left[\tfrac{I}{K} + \tfrac{1}{2} \left(\tfrac{I}{K} \right)^2 + \left(\tfrac{S^*}{\psi K} - \tfrac{Z^*}{K} \right) \exp\left(\mu + \tfrac{\sigma^2}{2} \right) \left(\mu + \tfrac{\sigma^2}{2} \right) - \tfrac{(1-\delta)(1-bc)}{b} + \tfrac{c^2}{2} + \tfrac{1-c}{\beta} \right]$$
$$\phi_1 = \tfrac{1}{\beta} \left[\tfrac{I}{K} + \tfrac{1-c}{b} \right]$$
$$\phi_2 = \beta \left[\tfrac{I}{K} + (1-\delta) \right]$$
$$\phi_3 = \tfrac{\beta}{\psi b}$$
$$\phi_4 = \tfrac{\beta}{b}$$
$$\phi_5 = \tfrac{\beta}{\psi b} \left[\exp\left(\mu + \tfrac{\sigma^2}{2} \right) - 1 \right]$$
$$\phi_6 = \tfrac{\beta}{b} \left[\exp\left(\mu + \tfrac{\sigma^2}{2} \right) - 1 \right]$$
$$\phi_7 = \tfrac{\beta}{b} \left(\tfrac{S^*}{\psi K} - \tfrac{Z^*}{K} \right) \exp\left(\mu + \tfrac{\sigma^2}{2} \right)$$
$$\phi_8 = \tfrac{\beta}{2b} \left(\tfrac{S^*}{\psi K} - \tfrac{Z^*}{K} \right) \exp\left(\mu + \tfrac{\sigma^2}{2} \right).$$

Table 1: Overall Imports, Exports, and Total Trade, by Partner, 1981-1987 (millions of constant 1982 U.S. dollars)

Rank	Partner	Imports	Rank	Partner	Exports	Rank	Partner	Total Trade
1	U.S.A	$8,109	1	U.S.A	$2,357	1	U.S.A.	$10,466
2	Japan	3,165	2	Venezuela	1,027	2	Japan	3,499
3	Germany (West)	1,694	3	Italy	446	3	Germany (West)	1,818
4	Brazil	1,092	4	Netherlands	352	4	Venezuela	1,778
5	France	998	5	Japan	333	5	France	1,117
6	Canada	864	6	Ecuador	287	6	Brazil	1,113
7	Spain	819	7	Panama	268	7	Italy	1,084
8	Venezuela	751	8	Peru	248	8	Canada	936
9	Italy	639	9	U.K.	178	9	Peru	882
10	Peru	633	10	Germany (West)	123	10	Spain	850
11	U.K.	622	11	France	120	11	U.K.	800
12	Mexico	615	12	Chile	91	12	Panama	740
13	Switzerland	479	13	Canada	71	13	Mexico	663
14	Panama	472	14	Belgium	58	14	Ecuador	647
15	Sweden	388	15	Argentina	53	15	Netherlands	613

Table 2: Summary Statistics

Variable	Mean	St. Dev.	Min	Max
Investment Rate, $(\frac{I_{ijt}}{K_{ijt-1}})$	0.21	0.22	0.00	1
Total Sales, $(\frac{S_{ijt}}{K_{ijt-1}})$	99.62	8,255.03	0.00	953,602.00
Cash Flow, $(\frac{C_{ijt}}{K_{ijt-1}})$	0.1421	88.59	-2652	8808.86
Average Mark-up (ψ_i)	1.39	0.51	0.20	30.03
ΔExchange Rate (Δe_{jt})	0.10	0.08	-1.27	1.50
Fraction Importers	0.34	0.47	0.00	1.00
Fraction Exporters	0.15	0.35	0.00	1.00
Average Import Exposure, (χ_i^{imp})	0.06	0.14	0.00	0.87
Average Export Exposure, (χ_i^{exp})	0.02	0.11	0.00	1.00
Real Exchange Rate Volatility, (ev_{jt}^{GARCH})	0.13	0.04	0.07	0.33
Real Exchange Rate Volatility, (ev_{jt}^{StDev})	0.10	0.02	0.06	0.25

Note: The total number of observations is N=11,514.
Fraction Importer and Fraction Exporter are the fraction of the firms in the sample that import and export, respectively.

Table 3: Industry Real Exchange Rate Volatility Measures–Sample Average and Change, 1987-1981, Ordered by Average ev_{jt}^{GARCH}

	ev_{jt}^{GARCH}		ev_{jt}^{StDev}	
3-digit ISIC Manuf. Industry	**Average**	**Change 1987-1981**	**Average**	**Change 1987-1981**
Non-ferrous Metal	0.202	0.127	0.158	0.123
Products of Petroleum and Coal	0.167	0.153	0.113	0.095
Glass and Glass Products	0.155	0.112	0.124	0.078
Pottery and China	0.146	0.132	0.102	0.066
Wearing Apparel	0.141	0.148	0.090	0.053
Other Non-metallic Mineral Products	0.135	0.093	0.112	0.081
Wood Products	0.133	0.134	0.091	0.067
Other Plastic Products	0.131	0.127	0.102	0.049
Food	0.130	0.104	0.122	0.054
Printing and Publishing	0.129	0.113	0.111	0.058
Iron and Steel	0.122	0.088	0.130	0.055
Fabricated Metal Products	0.121	0.099	0.104	0.053
Petroleum Refineries	0.117	0.098	0.106	0.052
Furniture	0.115	0.112	0.087	0.048
Industrial Chemicals	0.112	0.089	0.109	0.048
Other Chemicals	0.109	0.097	0.102	0.038
Footwear	0.106	0.105	0.086	0.034
Paper and Paper Products	0.105	0.074	0.099	-0.010
Rubber Products	0.103	0.083	0.105	0.039
Leather Products	0.099	0.098	0.086	0.028
Tobacco	0.097	0.097	0.088	0.020
Transport Equipment	0.096	0.068	0.107	0.034
Textiles	0.094	0.085	0.089	0.026
Non-electrical Machinery	0.093	0.073	0.104	0.035
Scientific Equipment	0.088	0.070	0.097	0.024
Other Manufacturing Products	0.087	0.088	0.102	0.017
Beverages	0.085	0.080	0.084	0.007
Electrical Machinery	0.083	0.085	0.092	0.014

Table 4: Investment and Real Exchange Rate Volatility

Dependent variable : $(\frac{I_{ijt}}{K_{ijt-1}})$	(1)	(2)	(3)	(4)
Lagged investment rate $(\frac{I_{ijt-1}}{K_{ijt-2}})$	0.080**	0.079**	0.081**	0.079**
	(0.016)	(0.0156)	(0.016)	(0.016)
Sales/100 $(\frac{S_{ijt}}{100*K_{ijt-1}})$	-0.014**	-0.015**	-0.014**	-0.015**
	(0.006)	(0.006)	(0.006)	(0.006)
Lagged sales/100 $(\frac{S_{ijt-1}}{100*K_{ijt-2}})$	0.016**	0.016**	0.017**	0.017**
	(0.008)	(0.008)	(0.008)	(0.008)
Cash flow/100 $(\frac{C_{ijt}}{100*K_{ijt-1}})$	-0.003	-0.002	-0.002	-0.002
	(0.006)	(0.006)	(0.006)	(0.006)
Lagged cash flow/100 $(\frac{C_{ijt-1}}{100*K_{ijt-2}})$	0.001	0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Δ*Exchange rate* (Δe_{jt})	0.053	0.045	0.053	0.055
	(0.076)	(0.076)	(0.076)	(0.077)
Exchange rate volatility (ev_{jt}), *GARCH*	-0.629**	-0.759**		
	(0.166)	(0.236)		
Exchange rate volatility (ev_{jt}), *STDEV*			-0.372**	-1.100**
			(0.171)	(0.374)
Number of observations	11,514	11,514	11,514	11,514
Joint signf. of Int. rate interactions $(p-value)$		0.000		0.000
$F-Statistic$ $(p-value)$	0.000	0.000	0.000	0.000
Hansen test $(p-value)$	0.267	0.226	0.285	0.247
1st order serial correlation $(p-value)$	0.000	0.000	0.000	0.000
2nd order serial correlation $(p-value)$	0.628	0.663	0.587	0.621

Note: Two-step coefficients and robust standard errors with the Windmeijer (1995) small sample correction are reported.

** and * denote significance at 5% and 10%, respectively.

A set of year dummies are included in all specifications.

The instruments for the first-differenced equations are: $(\frac{I_{ijt-2}}{K_{ijt-3}})$, $(\frac{I_{ijt-3}}{K_{ijt-4}})$, $(\frac{S_{ijt-2}}{K_{ijt-3}})$, $(\frac{S_{ijt-3}}{K_{ijt-4}})$, $(\frac{C_{ijt-2}}{K_{ijt-3}})$, $(\frac{C_{ijt-3}}{K_{ijt-4}})$, $(\frac{Costs_{ijt-2}}{K_{ijt-3}})$, $(\frac{Costs_{ijt-3}}{K_{ijt-4}})$, $\Delta(\Delta e_{jt-1})$, $\Delta(ev_{jt-1})$. The instruments for the equations in levels are: $\Delta(\frac{I_{ijt-1}}{K_{ijt-2}})$, $\Delta(\frac{S_{ijt-1}}{K_{ijt-2}})$, $\Delta(\frac{C_{ijt-1}}{K_{ijt-2}})$, $\Delta(\frac{Costs_{ijt-1}}{K_{ijt-2}})$, Δe_{jt-1}, ev_{jt-1}.

The F-Statistics reports the p-values for the test of joint significance of all explanatory variables.

The p-values for the Hansen test of overidentifying restrictions (where the null hypothesis is that the instruments are valid, i.e., uncorrelated with the error term) are reported.

The Arellano-Bond (1991) serial correlation tests are applied to the first-differenced residuals.

Table 5: Impact of Mark-up

	(1)	(2)	(3)
Dependent variable : $(\frac{I_{ijt}}{K_{ijt-1}})$			
Lagged investment rate $(\frac{I_{ijt-1}}{K_{ijt-2}})$	0.224**	0.226**	0.164*
	(0.113)	(0.115)	(0.090)
Sales/100 $(\frac{S_{ijt}}{100*K_{ijt-1}})$	-0.011	-0.011	0.172**
	(0.009)	(0.009)	(0.053)
Sales/100 $(\frac{S_{ijt}}{100*K_{ijt-1}}) * Mark-up\ (\psi_i)$			-0.160**
			(0.044)
Lagged sales/100 $(\frac{S_{ijt-1}}{100*K_{ijt-2}})$	0.012	0.012	-0.208**
	(0.009)	(0.011)	(0.075)
Sales/100 $(\frac{S_{ijt-1}}{100*K_{ijt-2}}) * Mark-up\ (\psi_i)$			0.195**
			(0.064)
Cash flow/100 $(\frac{C_{ijt}}{100*K_{ijt-1}})$	0.005	0.005	0.121
	(0.006)	(0.006)	(0.126)
Cash flow/100 $(\frac{C_{ijt}}{100*K_{ijt-1}}) * Mark-up\ (\psi_i)$			-0.096
			(0.109)
Lagged cash flow/100 $(\frac{C_{ijt-1}}{100*K_{ijt-2}})$	-0.006**	-0.006**	-0.017**
	(0.002)	(0.002)	(0.006)
Lagged cash flow/100 $(\frac{C_{ijt-1}}{100*K_{ijt-2}}) * Mark-up\ (\psi_i)$			0.008**
			(0.003)
Δ*Exchange rate* (Δe_{jt})	0.018	0.019	0.0066
	(0.081)	(0.082)	(0.079)
Exch. rate vol. (ev_{jt})	-0.622**	-0.836**	-0.857**
	(0.190)	(0.204)	(0.192)
Exch. rate vol. $(ev_{jt}) * Mark-up\ (\psi_i)$	0.052	0.261**	0.239**
	(0.032)	(0.074)	(0.080)
Exch. rate vol. $(ev_{jt}) * Mark-up\ squared\ (\psi_i^2)$		-0.036**	-0.031**
		(0.010)	(0.014)
Number of observations	11,514	11,514	11,514
$F-Statistic\ (p-value)$	0.000	0.000	0.000
$Hansen\ test\ (p-value)$	0.520	0.537	0.611
$1st\ order\ serial\ correlation\ (p-value)$	0.000	0.000	0.000
$2nd\ order\ serial\ correlation\ (p-value)$	0.189	0.188	0.374

Note: The instruments for the first-differenced equations of the specification in the first column are: $(\frac{I_{ijt-3}}{K_{ijt-4}})$, $(\frac{S_{ijt-3}}{K_{ijt-4}})$, $(\frac{C_{ijt-3}}{K_{ijt-4}})$, $(\frac{Costs_{ijt-3}}{K_{ijt-4}})$, $\Delta(\Delta e_{jt-1})$, $\Delta(ev_{jt-1})$ and $\Delta(ev_{jt-1}) * \psi_i$. The instruments for the equations in levels are: $\Delta(\frac{I_{ijt-2}}{K_{ijt-3}})$, $\Delta(\frac{S_{ijt-2}}{K_{ijt-3}})$, $\Delta(\frac{C_{ijt-2}}{K_{ijt-3}})$, $\Delta(\frac{Costs_{ijt-2}}{K_{ijt-3}})$, Δe_{jt-1}, ev_{jt-1}, and $\Delta ev_{jt-1} * \psi_i$. In column (2) $\Delta(ev_{jt-1}) * \psi_i^2$ and $ev_{jt-1} * \psi_i$ are added to the instrument set for the first-differenced and the levels equations. In addition to the list of instruments for the specification in column (2), we use lags 3 of the sales and cash flow interactions as GMM-type instruments for the specification in column (3).
See Table 4 for additional notes.

Table 6: Impact of External Exposure

	(1)	(2)
$Dependent\ variable: (\frac{I_{ijt}}{K_{ijt-1}})$		
$Lagged\ investment\ rate\ (\frac{I_{ijt-1}}{K_{ijt-2}})$	0.244*	0.242*
	(0.113)	(0.125)
$Sales/100\ (\frac{S_{ijt}}{100*K_{ijt-1}})$	-0.010	-0.010
	(0.014)	(0.015)
$Lagged\ sales/100\ (\frac{S_{ijt-1}}{100*K_{ijt-2}})$	0.011	0.011
	(0.018)	(0.018)
$Cash\ flow/100\ (\frac{C_{ijt}}{100*K_{ijt-1}})$	0.003	0.003
	(0.006)	(0.006)
$Lagged\ cash\ flow/100\ (\frac{C_{ijt-1}}{100*K_{ijt-2}})$	-0.006	-0.006
	(0.004)	(0.004)
$\Delta Exchange\ rate\ (\Delta e_{jt})$	0.016	0.016
	(0.084)	(0.084)
$Exch.\ rate\ vol.\ (ev_{jt})$	-0.559**	-0.520**
	(0.187)	(0.199)
$Exch.\ rate\ vol.\ (ev_{jt}) * Mark-up\ (\psi_i)$		-0.005
		(0.028)
$Exch.\ rate\ vol.\ (ev_{jt}) * Export\ exp.\ (\chi_i^{exp})$	0.347**	0.516
	(0.157)	(0.412)
$Exch.\ rate\ vol.\ (ev_{jt}) * Export\ exp.\ (\chi_i^{exp}) * Mark-up\ (\psi_i)$		-0.138
		(0.243)
$Exch.\ rate\ vol.\ (ev_{jt}) * Import\ exp.\ (\chi_i^{imp})$	0.543**	-1.619**
	(0.149)	(0.438)
$Exch.\ rate\ vol.\ (ev_{jt}) * Import\ exp.\ (\chi_i^{imp}) * Mark-up\ (\psi_i)$		1.613**
		(0.312)
$Number\ of\ observations$	11,514	11,514
$F-Statistic\ (p-value)$	0.000	0.000
$Hansen\ test\ (p-value)$	0.820	0.841
$1st\ order\ serial\ correlation\ (p-value)$	0.000	0.000
$2nd\ order\ serial\ correlation\ (p-value)$	0.179	0.180

Notes: In addition to the list of instruments listed in Table 5, we use lags 3 of import exposure and export exposure interactions as GMM-type instruments. See Table 4 for additional notes.

Table 7: Industry Results

Industry	Impact of exch. rate vol.	Mark-up	Export exposure	Import exposure
Fabricated metal products, machinery and equipment	-1.151** (0.586)	1.492	0.030	0.279
Basic metal industries	-0.757* (0.403)	1.500	0.119	0.253
Food, beverages and tobacco	-0.716 (0.468)	1.392	0.080	0.098
Textile, wearing apparel and leather	-0.270 (0.267)	1.304	0.087	0.065
Chemicals, petroleum, coal, rubber and plastic	-0.048 (0.790)	1.495	0.140	0.264
Wood products, paper and printing	-0.027 (0.934)	1.394	0.052	0.147
Non-metallic mineral products	0.972 (2.144)	1.642	0.059	0.060
Partial Corr. with the Impact of exch. rate vol.		0.738 [0.154]†	0.407 [0.497]	-0.794 [0.109]

Note: Estimates from industry-specific regressions with robust standard errors, average mark-up, average export and import exposures for each 2 digit ISIC industry are reported.

† The p-values for the partial correlation coefficients are reported.