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Innovation Dutch Disease: Impact of Currency Appreciation on R&D and Technological Upgrading

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Abstract

A key idea in the literature on trade and innovation is that competition may affect firms' innovative activities. It has been difficult to investigate this relationship empirically because research and development (R&D) investment data is rarely available at the firm level. This paper takes advantage of a new micro dataset to investigate the effect of the currency appreciation on firms' innovation investment decisions in a developing country. We focus on a natural experiment, examining the impact of a sharp real appreciation of the Colombian Peso in the late 2000s on Colombian manufacturing firms. We introduce a new measure of exposure to exchange rate fluctuations, emphasizing firms' exposure to import penetration in domestic and international markets. The key finding is that real exchange rate appreciation is associated with firms' decision to reduce their innovation, measured by R&D and broader innovation investment that includes machinery, equipment, and ICTs.

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1 Introduction

Deindustrialization due to a sudden resource windfall or *Dutch Disease* may occur on account of the usual appreciation of the real exchange rate (RER) (Corden & Neary, 1982). Exports and import-competing manufacturing sectors are hit by additional competitive pressure when the prices of foreign goods become relatively lower due to currency appreciation. While many papers have examined the impact of resource windfalls on local outcomes (Van der Ploeg, 2011; Cust & Poelhekke, 2015), little attention has been given to the impact of the currency appreciation effect on intangible investment, that might undermine not only the short but the long term performance too. Endogeneus growth theory enphasise the importance of innovation for development (Aghion & Howitt, 1992). Thus, the lack of attention to the *Dutch Disease* effect on intangible investment is surprising since the crowding out of manufacturing has been mentioned as a major reason for the resource curse, and the importance of innovation for development.

This phenomenon demands particular attention by the growing body of international economics literature concerned with questions that are primary raised in the economics of innovation. Since Schumpeter (1943), many theoretical and empirical studies have explored the relationship between competition and innovation. In theory, predictions regarding whether competition hurt or increase innovation incentives are ambiguous. Schumpeter (1943) argues that competition reduces innovation rents and shrinks the profit differential between innovative and non-innovative firms. Thus, the increase in competitive pressure would lead to less innovative effort. On the other hand, Arrow (1962) argues that market power allows even non-innovative firms to sell their products and earn large profits, therefore bringing to market new products will only crowd out their existing products and have little impact on their profits. Conversely when, product market competition is fierce, only innovative firms are able to escape the competitive pressure and generate profits.

Identifying such effects empirically has been challenging because of a scarcity of direct information on the innovative activities of firms in developing countries.

Verhoogen (2008) examines the effect of real exchange rates and finds a positive effect of Mexican Peso depreciation on quality and skilled labor, but not on R&D. Empirical papers testing the effect of RER changes in innovation investment also provide support for both, positive and negative effects, thus the debate is still non-conclusive (Zietz & Fayissa, 1994; Funk, 2003; Alvarez & López, 2015; Branstetter & Kwon, 2016). Most of the within-country evidence is based on data from high-income economies. Thus, there is very little evidence of the effect of currency appreciation on research and development (R&D) or technological upgrading decisions for developing countries.

This paper takes the advantage of a newly constructed combination of Colombian firm-level datasets to assess the impact of the RER revaluation on firms' innovation investment. Colombia provides an ideal setting for studying the potential effect of the resource windfall on manufacturing innovation via the currency appreciation channel. We exploit an exogenous exchange rate appreciation shock that affected firm's decisions to invest in innovation and technological upgrading. In 2003, the Colombian currency began one of the most marked periods of real appreciation in the country's recent history. Apart from the decrease of recorded during one year owing to the global financial crisis, the real exchange rate appreciated more than 40% in the period 2003-2010. One factor that contributed to the appreciation was the dramatic increase in mineral prices during the period. Since oil makes up about half of the country's total exports, the 275% rise in real oil prices resulted in windfall profits and pushed up the nominal exchange rate.

The empirical analysis targets two main objectives. First, it presents and computes a new measure of external exposure for Colombian manufacturing sectors. The extent to which a RER shock changes the competitive pressure faced by a firm is determined by its exposure to foreign markets, through export shares of production, and import penetration in both domestic and foreign markets. In recent years, increasing evidence emerged that firm's exposure to trade varies significantly even within exporting industries (Schott, 2004). This implies that firms within the same industry may be hit very differently by a RER shock. We calculated a firm-level measure of RER using product-level data that accounts for foreign competition in local and international markets. Most estimations of real effective exchange rate (REER) use bilateral RERs with destinations markets disregarding the potential competition from third countries. Instead, we construct a measure of effective international competition in destination markets accounting for firms from third countries that also export to those foreign markets.

Our second objective is to examine the trade exposure channels for the transmission of RER changes into R&D investment and technological upgrading. In order to investigate the influence of the RER shock on firm-level innovation investment decisions, we primary rely on the heterogeneity of exposure to the shock across firms. Since previous analyses have used variation on sector-specific RERs weighted by sector-level trade shares, this firm-level REER measure is the key feature that distinguishes our analysis from other studies attempting to quantify the effect of real exchange rate movements on R&D (Zietz & Fayissa, 1994; Funk, 2003; Branstetter & Kwon, 2016) and technology licensing (Alvarez & López, 2015). We estimate regressions to study the responsiveness of firm's innovation investment to real exchange rate movements using fixed effects and dynamic panel equations.

Our results show that the firm-level implications of exchange rate movements for innovation investment strongly depends on the form of external exposure of the producers: the higher the exposure to international competition, either by the export or import competing mechanism, the more real effective exchange rate appreciation (REER) dampen investment in R&D. A REER appreciation equivalent to 5.4% (one standard deviation) is associated with an average decrease on R&D investment of 12.3%. We find a similar pattern regarding a broader measure of innovation investment that includes other categories such as equipment and machinery, and information and communication technologies (ICTs). Our findings are robust to the use of measures of REER volatility and other cofounding shocks. We also find that innovation investment exhibits a high degree of state dependency, thus the innovative effort reduction due to currency appreciation may be even larger in the long run.

The rest of the paper is organized as follows. Section 2 describes the background of the Dutch disease phenomenon, the Colombia's economical context and a review of the related literature. Section 3 describes the data set, the empirical strategy and explains the new measure of real effective exchange rate accounting for foreign competition in domestic and international markets. Section 4 presents the empirical results of the effect of real exchange rate appreciation and investment in innovation. Section 5 concludes.

2 Background

As stated in the introduction, the central goal of this paper is to test the hypothesis of whether exchange rate appreciation lead to lower levels of innovation investment in the Colombian manufacturing sector. To place the motivations and results of this study in context, this section provides three subsections. First a brief description of the mechanism that generates deindustrialization through currency appreciation known as the *spending effect* of *Dutch Disease*. Second, a brief analysis of Colombian economic context in terms of trade, performance and innovation investment in the past decades. Third, a critical review of the related literature.

2.1 Dutch disease: The Spending Effect

The rise of the raw material sector can generate an increase in the national income and improvements in the balance of payments, but it may also affect in a negative way the production of the manufacturing sector. *Dutch Disease* is frequently understood as the de-industrialization process of an economy, which is associated with the real exchange appreciation, produced as a consequence of an export windfall due to resource price boom or discovery (Corden & Neary, 1982). Other tradable activities may be displaced, partly because factors of production are drawn into resource extraction, and partly because they are employed to meet increased demand of non-tradeable arising from domestic spending of resource revenues (Corden & Neary, 1982). However, the resource crowding-out channel of Dutch disease is not explored in this paper.

The competitiveness of the manufacturing sector is reduced due to the real appreciation of the national currency, through the increase in either the nominal exchange rate or the national prices. Venables (2016) describes two mechanisms to explain this effect. First, supposing that the country has a flexible exchange rate regime, the windfall will generate appreciation of the local currency. Second, the resource boom generates higher income revenues to the government, through taxes and royalties, as well as directly to the owners of the factors. The subsequent increase in the demand drives up the prices of non-tradeable goods. Both the nominal appreciation of the local currency and the increase in local prices generate a real appreciation of currency and a contraction in the traditional manufacturing sector that is exposed to foreign competition. This mechanism, known as the *Spending Effect* of *Dutch Disease,* set the stage for the currency appreciation shock that is used as a natural experiment in this paper.

2.2 Currency appreciation and innovation investment: the Colombian context

Colombia is a developing country considered as an upper-middle income country[1], highly dependent on natural resource exports and fairly open to world trade. Colombia's economic development has been based first exports of agricultural and, more recently mining commodities. Since the early year of the 20th century, it has undergone several phases of economic growth with different drivers and modes of interactions with the international economy. During the late 1980's and early 1900s, as the forces of globalization gained momentum, many Latin American dismantled their trade barriers (Haltiwanger, Kugler, Kugler, Micco, & Pages, 2004) and implemented labor market reforms (Heckman & Pages, 2004).

Colombia's productivity performance has lagged relative to other world regions and has been correlated with shocks in the mining sector during the last three decades (See Figure 1). After slowing during the debt crisis of the 1980s, growth accelerated mildly through most of the 1990s when rising oil exports and public expenditure became significant drivers of growth. Colombia's labor productivity stagnated from the mid-1990's to 2005, during which time levels were not much higher than they were in 1990. The sharp recession was followed by rates of expansion between 2003 and 2011 that coincided with the boom of commodity prices. That expansion was much higher much higher than anything experienced over the previous two decades. Labor productivity grew substantially during the mid-2000s, largely reflecting factors such as improved security that provides incentives to invest in the extractive and non-tradable sectors. The sectors with the strongest labor productivity over the last decade were non-tradables, such as personal services, construction and retail and restaurants (OECD, 2013).

Exports have been dominated by primary commodities, mostly oil and mining products (See Figure 2). During the 2000's, the mining exports represented 66% of total exports on average. From 2003 to 2014, with the increase in international prices, their

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[1] According to the World Bank

participation reached the 75% levels. Among mineral commodities, Colombian exports are mainly concentrated in oil, coal, ferronickel and gold. Figure 3 presents the evolution of mineral commodity exports using a customized Colombian commodities' price index using the export mix weights to account for the relevance of each commodity. The international prices of commodities exported by Colombia almost quadrupled between 2002 and 2009.

The United States, Europe and more recently China are the principal destinations for oil and mineral commodities, whereas the markets for Colombian manufacturing exports are mostly regional. During the last decade the importance of China rose up to be Colombia's second trade partner after the United States. In 2014, 11% of Colombia's exports were destined to China. The majority of exports to China were concentrated in crude petroleum oils (84%) and other minerals. Other markets in the Latin America are the main destinations for Colombian manufacturing exports (See Figure 4). The importance of neighboring Venezuela, traditionally one of the principal destinations of non-traditional exports, diminished after 2010.

Colombian manufacturing has been characterized by an increasing exposure to international trade. About twenty Free Trade Agreements have been concluded, mainly with other American countries. The average tariff fell from 12% in 2006 to 8% in 2010 (OECD, 2013). In relation to productivity, the effects of the 1990s liberalization on productivity has been widely studied. Eslava et al. (2004) using instrumental variable techniques to estimate Total Factor Productivity (TFP), find that aggregate TFP and its dispersion increased after the reforms. The intensified competition imposed market discipline, forcing plants to either increase productivity and charge lower prices, or exit the market. Moreover, the increase in overall productivity was largely driven by the reallocation away from low and towards high productivity plants improving the market share of the latter ones (Eslava M. , Haltiwanger, Kugler, & Kugler, 2013).

Colombian manufacturing firms also faced increasing import penetration from China and this consistent with the regional and global trend. Since 2001, China's accession to the World Trade Organization (WTO) gave it most-favored nation status among the 153 WTO members (Branstetter & Lardy, 2008). Overall, Colombia imported 19% of its goods and services from China in 2014, with more than three-quarters of their value added concentrated in medium-high (30%) and high-tech industries (52%). However, Chinese imports had also a dramatic increase in low-technology sectors such as textiles and apparel. Chinese import penetration increased form 3% in 2000 to 19% in 2012 (OECD/ELAC/CAF, 2015). Using a firm-level measure of import penetration at firm, we find that Chinese import penetration rose from less than 1% in 2000 to more than 6% in 2013 (See Figure 5). Moreover, Colombian manufactures exporters are also affected by the rising Chinese import penetration in their destination markets since most of their exports go to the region. In Latin America, Chinese import penetration rose from 1% in 2000 to 6.5% in 2012 accounting for most of import penetration growth from a particular country after 2000 (OECD/CAF/ECLAC, 2015).

2.2.1 Colombia's Peso appreciation in the late 2000s

The sudden increase in wealth created an unprecedented inflow of capital that induced the appreciation of the Colombian currency. The rapid growth in mineral exports, especially oil, and rising commodity prices have been accompanied by large capital inflows, primary to the minerals industries. The rise of the oil sector has been accentuated since 2003 when the conditions to explore the country became friendlier to investment through legislation reform[2]. Direct foreign investment in the mineral sector started to rise significantly. By the end of 2005, foreign direct investment (FDI) in oil and mining reached the 80% of the total FDI that grew nearly 15% a year during the 2000's (See Figure 6). Therefore, Colombia received at the same time more foreign currency from oil revenues and more from FDI pushing the value of the currency.

Sustained growth in non-tradeable sector provides additional evidence of the *Spending Effect* (Corden & Neary, 1982). The non-tradeable sectors grew relatively more during the 2000s (See Figure 7). Thus, the rising terms of trade and related capital inflows have contributed to a sharp appreciation of the exchange rate. Figure 8 shows the evolution of the bilateral real exchange rate since 2000 with the US Dollar. In the period 2003 to 2010, the real exchange rate between Colombia and the US (Colombian pesos for one US Dollar) fell more than 40%. Estimates of the effect of the price of commodities

[2] Act 1760 of 2003 was aimed to restructure the Oil & Gas industry favoring the investment climate for foreign investment

have had an appreciation effect on the real exchange rate of 15% in the time horizon of eight years (Poncela, Senra, & Sierra, 2016). This is the shock we use in this paper.

The recent commodities boom posed economic challenges for the non-mining tradeable sectors in Colombia. As the Colombian peso appreciates in real terms, it makes Colombian products less competitive than their foreign competitors, and may have a negative impact on performance in sectors that produce tradable goods. Therefore, the concern of the non-traditional exporting sectors was legitimate since its upward trend of mineral exports and the share of manufacturing exports' decrease (See Figure 2). Sierra & Manrique (2015) found that a 1% effect appreciation of currency produced a decrease in sectorial value added between 0.26% and 0.29%. The most affected sectors where those with a larger share in total industrial value added. Conversely, using firm-level data, Griffin (2015) found no strong evidence that the real exchange rage appreciation negatively affected profits between 2000 and 2012. Therefore, there is still an open debate about the effect of the strong appreciation of Peso during the 2000's.

2.2.2 R&D and innovation investment in Colombia

Colombia spends a small fraction of its GDP on innovation activities and much recent growth has been driven by the oil and gas sector. Using the investment data from the Innovation and Technological Development Survey (EDIT[3]) from 2007 to 2014, we observe the remarkable increase of investment in levels to the point almost all R&D growth at the aggregate level was due to the Oil and Gas industry (See Figure 9). In terms of research intensity, this trend is even more dramatic (See Figure 10). The Oil and Gas sector more than tripled their R&D intensity, while the rest of the sectors reduced slightly their R&D intensity averages. Thus, we have context such that firms avoid increasing their innovation investment at aggregate levels, while they face a very strong currency appreciation shock.

Innovation and R&D investment has contributed to productivity and employment in Colombia. Based on a similar data set used by this paper between 2003-2004, (Arbeláez & Parra-Torrado, 2011) find that greater innovation efforts significantly increase the probability of any innovation output. They also show that innovation output, measured as the introduction of new goods and services to the international market,

[3] Encuesta de Desarrollo e Innovación Tecnológica

boosts sales and TFP. For the case of labor productivity, there is evidence found positive effects of innovation on labor productivity (Crespi & Zuñiga, 2012). (Caballero, Parra-Torrado, Ortiz, Peza, & Haven, 2012) find that product and process innovation had a positive and significant effect on employment quantities.

2.3 Related Literature

This paper is related to a number of different strands in the trade, development and innovation literature, and especially to studies that examine the effect of currency appreciation on economic performance, and the differential transmission of trade shocks across different levels of exposure to international trade. The most recent empirical literature in trade examines the changes in trade environment and its impact on firm-level performance using microdata at the level of the firm or plant (Bernard, Eaton, Jensen, & Kortum, 2003; Bernard & Jensen, 2004; Lileeva & Trefler, 2010; Bustos, 2011). They provide evidence that firms within the same industry may be hit very differently by a trade shock.

While examinations of the Dutch disease using firm-level data are still scarce, some papers have shed light on this particular aspect of the resource curse without finding significant effect. (Smith B. , 2014) examined the impact of the oil price boom in the 1970s and the subsequent bust on manufacturing in oil-dependent countries. He showed that manufacturing exports, value added, wages, and employment actually increased during the boom, and that these effects decreased during the bust, albeit gradually. (Allcott & Keniston, 2014) showed that manufacturing actually performs better, not worse, in resource rich US counties. There is also recent evidence on similar effects in developing countries. Caselli & Michaels (2013), focusing on Brazil, found that the resource bonanza may induce appreciation of the real exchange rate and decline of non-resource export sectors. Using data from Indonesia, Cust et al. (2015) find that oil and gas production causes wage growth and small firms had no choice but to exit and surviving firms adapt by raising their labor productivity through investment and product range expansion. However, the effect of natural resource boom on technology and innovation investment has not been addressed yet. Since most results are looking at short term variables, innovation investment provides a way to test longer term consequences of the phenomenon.

The trade literature examines the effect of RER fluctuations on firm-level outcomes such as investment (Campa & Goldberg, 1995; Kandilov & Leblebicioğlu, 2011), skill upgrading (Verhoogen, 2008; Elkholm, Moxnes, & Ullveit-Moe, 2012) and productivity (Tomlin & Fung, 2015). For the case of developing countries, several empirical papers have shown that indicators of quality and technology choices respond positively to shocks to export market access (Verhoogen, 2008; Teshima, 2008; Bustos, 2011). Verhoogen (2008) examines the effect of real exchange rates and finds a positive effect of Mexican Peso depreciation on quality and skilled labor. However, none of them examines how changes in RER's may affect the decision of undertaking R&D in a developing country. Our paper departure from previous literature, namely the focus advantage on investment in technology and innovation as the outcome of interest, has the of isolating a particular mechanism through which firm productivity can improve.

The relationship between competition and innovation has been tested multiple times with varied outcomes. There is substantial empirical work (Nickell S. J., 1996; Blundell, Griffith, & Van Rennen, 1999; Carlin, Schaffer, & Seabright, 2004; Okada, 2005; Schmitz, 2005; Gorodnichenko, Svejnar, & Terrell, 2010; Bloom, Draca, & Van Rennen, 2016) that finds a positive relationship between competition and innovation (or productivity). Conversely, Scherer & Huh (1992) find a small negative effect of high-technology imports on R&D expenditure of US companies. Aghion et al. (2005) test an inverted-U relationship using data from publicly listed British firms[4]. They show that for lower levels of competition the relationship is positive, while for relatively higher values of competition the relationship with innovation is negative. Using U.S data, Hashmi (2013) finds that the average innovative activity in the U.S. manufacturing industries is small and negatively related with market competition. Thus, the effect of competition on innovation is still inherently ambiguous and focused on high-income economies.

For the case of competitive effect induced by RER changes on innovation investment, the empirical evidence is again non-conclusive and relies on RER estimation at the industry level. Zietz & Fayissa (1994) suggest that changes in R&D expenditures in response to exchange rate appreciation are conditional upon the intensity of firms'

[4] In the innovation literature, this idea was suggested by (Scherer, 1967) who found an inverted-U relationship between market concentration and employment of scientists and engineers.

innovation efforts. Using the observations from a panel of manufacturing firms in the US, they provide some evidence suggesting that only R&D-intensive firms increase their R&D expenditures following the increase in competition caused by the exchange rate appreciations. On the other hand, Funk (2003) suggest that changes in R&D expenditures to exchange rate swings may depend on the firms' export status. His findings suggest that exchange rate appreciation negatively affects the R&D investment of the domestic firms, and has no significant effect on the R&D investment of the exporting firms. At the industry level during the 1990s in the UK, Becker & Pain (2008), found that exchange appreciation may have an adverse effect on R&D activities. For the case of South Korea, there is causal evidence of the positive effect of devaluation on R&D investment (Branstetter & Kwon, 2016). For the case of developing countries, Alvarez & López (2015) using Chilean data, found evidence of a negative relationship between technology licensing and currency appreciation. However, none of the existing studies examines the effect of appreciation on R&D investment in a developing country.

We believe that our approach has a clear advantage. There is growing empirical evidence on the heterogeneity of firms with respect to trade activity, therefore a firm-level measure of REER exposure adds precision to our estimates. Previous studies investigating the impact of changes in foreign competition have not taking this into account as they use industry-level measures of trade exposure. We put together a data set that merge data on innovation, manufacturing and trade data at the firm level. Access to firm-level data allows us to develop firm-specific trade exposure measures. Using destination shares for exports and origin shares for imports for each product and firm, we are able to estimate the trade-weighted RER exposure for each firm.

Additionally, we incorporate the import competition faced in the domestic and export markets. This is a critical feature in because it accounts for recent trends such the increase of Chinese import penetration in Latin American countries, which are the main destinations for Colombian manufacturing exporters. In the existing literature, there are three distinct channels of exchange rate exposure: (i) the firm export sales, (ii) the firm's purchases of imported inputs, and (iii) import competition faced in the domestic market (Campa & Goldberg, 1995). Our approach differs in two aspects. First, we do not consider the firms' purchases of imported inputs a first order effect since other import/export competitor would face the same international prices. Second, we incorporate the existing competitive pressure induced by differences in RER when third countries also export the similar products to a common destination market.

3 Empirical Strategy and Data

3.1 Theory background

The innovation and trade literature have been interested in the relationship between innovation and (international) competition. On one hand, the leading theoretical models in industrial organization (Cohen & Levin, 1989; Gilbert, 2006) or in growth theory predicted that more intense product market competition discourages innovation and growth as it reduces the rents from innovating. As Dasgupta & Stiglitz (1980) suggested, we refer this as the Schumpeterian effect of product market competition. Aghion & Howitt (1992) pioneered the Schumpeterian endogenous growth model that predicts negative monotone relationship between competition and innovation. A second class of innovation models stresses the importance of trade in increasing market size and fostering innovation through this market expansion effect (Schmookler, 1966; Krugman, 1980). Using a similar approach, Rodrik (1991) shows that if trade liberalization reduces the domestic market shares of unshielded domestic producers without expanding their international sales, their incentives to invest in innovation will decrease as protection ceases. Similarly, the other side of the coin, lower trade costs generate a larger market size over which to spread the fixed cost of investing in new technologies (Lileeva & Trefler, 2010; Bustos, 2011; Tabrizy, 2016).

On the other hand, the common view, dating back to Adam Smith (1776) was that competition enhances growth because it exerts pressure on firms to cut costs, reduce slack and innovate to maintain market position, by introducing new products and improving processes. Arrow (1962) argues that in poorly competitive markets even non-innovative firms are able to sell their profits and earn comfortable profits. Hart (1983) formalized the idea that competition increases productivity by acting as an incentive scheme to ensure managers do not buy themselves a “quiet life”. In an influential paper, Aghion et al. (2005) develop a model in the Schumpeterian tradition and derive an inverted-U relationship between competition and innovation. For lower levels of competition, the relation is positive but for higher levels of competition the relation is negative. The rising Chinese import competition from in world markets Autor et al. (2013), has also motivated models that explain how trade with low-wage countries could in theory reduce the opportunity cost of innovation by releasing factors of production "trapped" in producing old goods (Bloom, Romer, Terry, & Van Reenen, 2013). As the theory, the relationship between competition and innovation is ambiguous.

3.2 A technology catch-up model à la Rodrik (1991)

Trade theory offers conflicting predictions about the evolution of firm technology investments following an increased in import competition, especially in cases where imperfect competition is present. On one hand increased exposure to foreign competition reduces their market power, and might expand output and move down the average cost curve, this might result in the exploitation of the economies of scale. Gains from scale economies are not very likely in developing countries, where the increasing returns to scale are usually associated with the import-competing industries, whose output is likely to contract as a result of intensified foreign competition (Rodrik, 1988). We modified the proposed model by Rodrik (1991), where firms invest in superior technology to reduce their cost, their incentive to cut costs might increase with their output. We incorporate the effect of appreciation of RER instead of a trade liberalization episode that increases import competition.

Let the firm is monopolist at home responding to a residual demand $p(e)$ depending on e, the firm-specific trade-weighted real exchange rate. Its maximized flow profits can be written as

(1) $\pi(c,e) = \max_{q}\{q \cdot p(e) - cq\}$

where c denotes the firm's (constant) marginal cost, q its output, $p(e)$ the inverse aggregate demand function it faces at home and abroad and let the international benchmark level of costs be c^{*}, with $c > c^{*}$ initially.

The firm can reduced its costs (all the way down to c^{*}) by investing resources in R&D, technology and overall tinkering. I model this by letting the firm choose the rate at which domestic costs decline, and denote this rate β. Then at any point in time, the cost level is given by

$$(2)\ c(t) = \begin{cases} c_0\text{-}\beta t, & t < T \\ c^*, & t \geq T \end{cases}$$

Here T denotes the time that elapses before the domestic firm fully catches up with foreign technology, and c_0 represents the initial level of domestic costs. This implies

$$(3)\ \beta = \frac{1}{T}(c_0\text{-}c^*)$$

$$(4)\ c(t) = c_0\text{-}\left(\frac{t}{T}\right)\left(c_0\text{-}c^*\right), for\ t \leq T$$

The present discounted value of expenditures made on innovation, ϕ increases with β, and can be written as $\phi(\beta)$, with $\phi'(\beta) > 0$ and $\phi''(\beta) > 0$.

Since both $c(t)$ and T can be written as a function of T, the firm's objective function can also be stated as a function of β alone:

$$(5)\ V(T) = \int_0^T \exp(\text{-}\rho t)\, \pi(c(t), e)dt + \int_T^\infty \exp(\text{-}\rho t)\, \pi\left(c^*, e\right)dt\text{-}\phi(\beta)$$

where ρ is the discount factor. After simplifying, the first order condition becomes:

$$(6) \int_0^T \exp(\text{-}\rho t)\, t\pi_c(c(t), e)dt + \phi'(\beta) = 0$$

This sets the marginal cost of technological effort equal to the discounted sum of its benefits over the catch-up period.

Notice that equation (1), implies $\pi_c(c(t), e) = \text{-}q$, so that the benefits of innovation effort are directly proportional to the scale of output. As long as $\phi'(\beta)$ is finite and strictly positive, and assuming second-order condition is satisfied, the catch-up is completed within the open interval $(0, \infty)$.

To gauge the effects of changes in the exchange rate, we perform comparative statics with respect to e. Differentiating (6) yields:

$$(7)\ \frac{dT}{de} = \text{-}\frac{1}{V''(T)}\left[\int_0^T \exp(\text{-}\rho t)\, t\pi_{ce}(c(t), e)dt\right]$$

Since the second-order condition requires $V''(T)$ to be negative, the sign of this expression depends solely on $\pi_{cm}(c(t), e)$. But from (1), $\pi_{ce}(c(t), e) = \text{-}\frac{\partial q}{\partial e}$ so that π_{ce}

is *positive* as long as currency appreciates, import competition rises and reduces the output of the domestic firm. Since this is the regular case, we can conclude that $\frac{dT}{de} > 0$; an appreciation would slow down the rate of increase of domestic productivity and delay technological catch-up. The economic mechanism at work is simple. The larger the scale of output, the greater the benefits to the firm from a given reduction in costs. Since real exchange rate appreciates, imports increase because their prices are relatively lower, it reduces the incentive to invest in R&D and technology upgrading.

3.3 Data sources

We are able to obtain data from three main datasets. The first data set is a transaction-level dataset of exports and imports (EXPO/IMPO), the second dataset is an establishment-level annual manufacturing census (EAM). The third one is the Innovation and Technological dataset that uses the same directory from EAM but information is reported at the firm level (EDIT). Therefore, the merge of the three datasets is possible at the level of the firm.

The Annual Manufacturing Survey (EAM) gathers background and detailed information of the manufacturing sector, which allows a deep knowledge of its structure, characteristics and more importantly, its evolution. The EAM is a nationwide survey of Colombian establishments with more than 10 employees and/or an output value that exceeds $120 million in constant 2007 pesos (approximately US$ 40.000 as of today). The data is available annually, and in recent years more than 9,000 plants have been surveyed. This gives the EAM census-like properties. This sample corresponds to industrial directories reported by the guilds and updated every year by micro-surveys to detect the appearance of new units of analysis. The EAM includes information for each plant on: value of output and prices charged for each product manufactured; and overall cost and prices paid for each material used in the production process. Data including product-level information is available for the 2000-2014 for production and material consumption. Intermediate consumption includes consumptions of input materials and packaging materials and direct and indirect costs of production. The data set also provides information on plant age as well as industry classification. The information corresponds to the 3 and 4-digit disaggregation according to the International Standard Industrial Classification (ISIC rev.3) adapted for Colombia.

The Development and Technological Innovation Survey (EDIT) constitutes a fundamental tool for characterizing the innovative behavior and activities of manufacturing firms in Colombia. This survey carried out every two years within the manufacturing sector since 2003 to all industrial firms according to the directory of establishments in the EAM. The EDIT methodology has been refined over time and the survey forms vary significantly between different periods in which the survey has been conducted. In the survey, the Science, Technology and Innovation (STI) investment is classified as follows: i) R&D (Internal and external) ii) investment in equipment and machinery; ii) Information and Communication Technologies (ICTs); iii) Technology transfer; iv) Technical assistance; v) Engineering and Industrial Design; vi) Training. Since 2007, only firms that reported at least an innovation attempt (*potentially innovative*) are enquired about innovation investment. However, comparable innovation-related investment figures are only available from between 2007-2014 and the following versions. Since EDIT is a rider of the AMS, we can merge both surveys at the firm level, which is extremely useful for our research purposes.

The third source of data is official custom trade records. The dataset, composed of every official export/import transaction made by Colombian firms, originates in the Colombian tax and customs authority (DIAN). Each export transaction record includes the tax ID of the exporter, the product shipped (classified according to the Colombian harmonized tariff schedule) and the value "Free-on-board" (FOB) of the shipment. It also includes the country of destination, point (custom) of exit, the state of origin, the quantity in kilograms and the month. This data source is complemented with the export information about firm operating in *Zonas Francas* (Free Trade Zones) from 2005. Firms located in those areas, by law are considered beyond the customs territory and therefore, their trade flows are not reported to DIAN and included in the official customs records. Fortunately, this dataset is reported to DANE instead. Import transaction records include data of the product, the country of origin and the value "Cost, Insurance and Freight" (CIF) of the shipment.

We matched firms from EAM and EDIT with customs data, obtaining a panel with exports and destinations by firm and product. The EAM is collected at the plant level, while the customs records are at the firm level. Plants share the same tax identification number since the same firm owns them. We aggregated the information across plants belonging to the same firm in the EAM, yielding a firm-level panel. We also dropped out transactions that cannot be considered as exports by a firm seeking profit. For example, individuals that move from Colombia to a foreign country and choose to ship their belongings are required to submit to DIAN an official export record. Thus, this transaction shows up in the database as an export by an individual with its own tax ID. Finally, using export values, the matching ratio is close to 80 percent on average and it is increasing over time reaching values close to 90%.

Although the Colombia data are of high quality, the data still contain a fair amount of noise. We undertake a careful procedure to clean the data and reduce the influence of outliers. See Appendix A.1 for full details on the cleaning and processing of the datasets.

3.4 A New Measure for Trade-Weighted Real Effective Exchange Rate

We start by defining a measure of Trade-Weighted Real Exchange rate (REER) by combining the export and the import-penetration weighted measures of RER. For a firm *i*, total revenue during time t can be expressed as:

$$revenue_{it} = p_{it}^{d}(e_t)q_t^{d} + p_{it}^{f}(e_t)q_t^{f}$$

where q_t^d and q_t^f are the quantities supplied by the firm to the domestic and foreign markets, p_t^d and p_t^f are the demands faced by the firm. This expression can be written also as

$$revenue_{it} = [\gamma_t q_{it} p_{it}^{d}(e_t) + (1-\gamma_{it})\, q_{it} p_{it}^{f}(e_t)] = [\gamma_t p_{it}^{d}(e_t) + (1-\gamma_{it})\, p_{it}^{f}(e_t)]\, q_{it}$$

where $q_{it} = q_t^d + q_t^f$ and γ_t is the share of exports in output so

$$q_t^f = \gamma_t q_{it} \text{ and } q_t^f = (1-\gamma_{it}) q_{it}$$

The domestic and foreign demand depends on the firm-level free trade prices index p_{it}^{FT} and the firm-level import-penetration MPREER$_{it}$ and export-weighted real exchange rate $EREER_{it}$, such that

$$p_t^d(e_t) = p_{it}^{FT}\,\mathrm{MPREER}_{it} \text{ and } p_t^f(e_t) = p_{it}^{FT}\,\mathrm{EREER}_{it}.$$

Therefore

$$revenue_{it} = [\gamma_t \mathrm{EREER}_{it} + (1-\gamma_{it})\,\mathrm{MPREER}_{it}]\,p_{it}^{FT} q_{it}$$

Export-Weighted Real Effective Exchange Rate

We exploit the differences between Real Effective Exchange Rates that face each firm weighted by exports shares in each destination. An exporter faces competitive pressure due to changes in RER fluctuations when the domestic industry in the destination market produces the exported product, but also when the product is exported from a third country. We propose a measure of the destination's import mix weighted RER from a country *c* to a particular destination *d* for a product *p* in time *t*:

$$MDRER_{pcdt} = MS_{pcdt} \cdot\ RER_{cdt} + \textstyle\sum_{m\ exports\ p\ to\ d} MS_{pdmt} \cdot\ RER_{cmt}$$

where $MS_{pmdt} = \frac{Imports\ of\ product\ p\ from\ country\ m\ to\ destination\ d\ in\ time\ t}{Total\ imports\ of\ product\ p\ into\ destination\ d\ in\ time\ t}$ and RER_{cdt} is the bilateral real exchange rate of country *c* to country *d* in time *t*.

The first term accounts for the weighted effect if the bilateral RER between the country of origin and the destination market. The second term depends on the share of the product that comes from a third country *m* and the bilateral RER between the country of origin *c* and the third country *m*. When country *c* is the only exporter of p to destination *d*, the $MDRER_{pcdt}$ is equal to the bilateral RER_{cdt}. This case is equivalent to the measure considered in previous literature, which requires at least the assumption that competitors from third countries, either do not exist or face the same changes in bilateral RER with country *c*.

Since a firm *i* may export several products *p* to different destinations *d*, we use the respective product and country shares to obtain the Export-weighted Real Effective Exchange Rates (EREER). The EREER for a firm *i* in time *t* from country *c* follows:

$EREER_{it} = \sum_{d\in dest(i)} \left(\frac{Export\ to\ country\ d_{it}}{Total\ Exports_{it}}\right) \left[\sum_{p\ exported\ to\ d} \chi_{pdt} \cdot MDRER_{pcdt}\right]$ where $\chi_{pdt} = \frac{Export\ of\ product\ p\ to\ d\ in\ t}{Total\ exports\ to\ d\ in\ t}$.

Import-Penetration Weighted Real Effective Exchange Rate

In order to explore the relationship between changes in import penetration and local production, a decomposition was used to separate out the direct contributions of domestic demand, exports and changes to import penetration to changes in sales. The decomposition starts from the basic accounting identity:

$$Q_{pt} = D_{pt} + X_{pt} \text{-} M_{pt}$$

where D_{pt} is domestic absorption of product p at time t, Q_{pt} is domestic production of product p at time t, X_{pt} is exports of product p at time t, and $M_{pt}$is imports of product p at time t.

Defining import penetration for product p from country k at time t:

$$m_{pkt} = \frac{M_{pkt}}{D_{pt}}$$

Using the product mix of each firm, we define the exposure of firm *i* to import penetration of country *k* in time *t* as:

$$\rho_{ikt} = \frac{\sum_{p=1}^{n_i} s_{ip} \cdot m_{pkt}}{\sum_{p=1}^{n_i} s_{ip}}$$

where n_i is the number of products produced by firm *i*, and s_{ip} is sales of product *p* by firm *i*.

Since a firm *i* may produce several products *p* that compete with imports from different countries k, we use the respective product and country shares to obtain the Import-Penetration weighted Real Effective Exchange Rates (MPREER). The MPREER for a firm *i* in time *t* from country *c* follows:

$$MPREER_{it} = \frac{\sum_{k \in origin(p)} (\rho_{ikt} \cdot RER_{kt})}{\sum_{k \in origin(p)} \rho_{ikt}}$$

Trade-Weighted Real Effective Exchange Rate

Finally, we get a combined measure of REER using γ_{it}, export to sales ratio in time t:

$$REER_{it} = (1 - \gamma_{it})(MPREER_{it}) + \gamma_{it}(EREER_{it})$$

3.5 Econometric Specification

3.5.1 *Baseline specification for Base Hypothesis: Peso Appreciation*

The theoretical discussion suggests a reduced-form model for R&D of the form $r_{it} = r(REER_{it\text{-}1}, \boldsymbol{x_{it\text{-}1}})$ where $REER_{it}$ is the trade-weighted Real Effective Exchange

Rate. We employ the following log-linear equation to estimate the impact of the Peso Appreciation on firms R&D investment:

(8) $rd_{it} = \beta_0 + \beta_1 REER_{it\text{-}1} + \beta_2 y_{it} + \boldsymbol{\gamma x_{it\text{-}1}} + \alpha_{tj} + \mu_i + \varepsilon_{it}$

rd_{it} : Natural log of R&D investment by firm *i* in year *t*

$y_{it\text{-}1}$: Natural log of lagged sales of firm *i* in year *t*

$REER_{it\text{-}1}$: Trade-Weighted Real Effective Exchange Rate for firm *i* in year t-1

$\boldsymbol{x_{it\text{-}1}}$**:** Vector of lagged control variables

α_{tj}: Year-Industry dummy variables

μ_i: Firm fixed effects

ε_{it}: Captures measurement error and idiosyncratic shocks to R&D

The variable of interest is β_1. $\beta_1 > 0$ implies that a greater depreciation leads to a higher level if R&D investment and for our particular case a greater appreciation leads to smaller R&D. Lagged sales are included to control for size and firm-level demand. Other controls include measures of age, market share and diversification. Age is measures in years since the first year of operation. Market share is the weighted average market share for each product produced by the firm. Industry diversification is the inverse of the Herfindahl-Hirschman Index of product segment concentration. Each of these variables was lagged one period to allow for a delayed impact on R&D expenditure.

Firms' decisions to invest in research and development are subject to both common and idiosyncratic shocks. To account for the first one, we include firm and time-industry fixed effects. Firm fixed effects absorb all time-invariant determinants of the innovation investment at the firm level. They are particularly important since the very different technological opportunity and appropriability conditions facing firms (Levin, Klevorick, Nelson, & Winter, 1987) that are hard to proxy by explicit variables. Industry-by-year fixed effects ensure that β_1 is identified with different shocks of R&D capital within the same industry-year.

3.5.2 Dynamic Panel Estimation

There are a series of characteristics of R&D that suggest this type of investment should not be analyzed in a static framework as in (8) but in dynamic framework. One of such characteristics is that R&D typically behaves as though it has high adjustment costs. Theory suggests these are important because of the high cost of contemporary hiring and firing of highly skilled employees with firm-specific knowledge. Firms therefore tend to smooth their R&D investment over time (Hall, Griliches, & Hausman, 1986; Lach & Schankerman, 1989).

Another characteristic of R&D that calls for a dynamic approach is that there is typically a high degree of uncertainty associated with the output of R&D investment, and sustained commitment to R&D is often required for projects to be successful. The role of uncertainty implicit in the early adjustment costs literature in the context of capital investment, which captures the role of backward-looking expectations formation through lagged variables. Firms therefore tend to smooth their R&D investment overtime (Hall, Griliches, & Hausman, 1986; Lach & Schankerman, 1989). Most studies use a dynamic model by introducing a lagged dependent variable into (1).

(9) $rd_{it} = \beta_0 + \beta_1 rd_{it\text{-}1} + \beta_2 REER_{it} + \boldsymbol{\gamma x_{it\text{-}1}} + \alpha_t + \mu_i + \varepsilon_{it}$

Inclusion of lagged R&D in (9) requires an instrumental variables estimator in order to avoid the downward bias that can result when using a fixed effects estimator in panels where the number of time periods is small (Nickell S. , 1981). One instrumental variable that has been applied widely in the R&D panel data literature is the first-differences generalized methods of moments (GMM) estimator, whereby the model is estimated in first differences and lagged levels are used as instruments (Anderson & Hsiao, 1982; Arellano & Bond, 1991).

The estimation method applied here is the GMM panel data developed by Arellano and Bond (1991) in order to account for endogeneity of regressors. This method is efficient within the class of instrumental variable procedures. GMM estimation is based upon the assumption that the disturbances in the equations are uncorrelated with a set of instrumental variables. The obvious candidate to instrument is $rd_{it\text{-}2}$ as this will be uncorrelated with $\Delta\varepsilon_{it}$ in the absence of serial correlation in the ε_{it} process. It is therefore necessary to test for second-order serial correlation in the first-differenced specification and the diagnosis are given for this.

3.5.3 Sample size across regressions

Our estimation sample is compiled in the following way. We first include includes firms that invested at least one period in R&D. We also removed firm-years with incomplete sales data. In terms of outlyiers, we remove firms-year observations without skilled personnel or innovation related personnel but were reporting positive invesment in R&D. Obvervations with contemporaneus invesment in STI greater than industrial production. We finally drop observations from the oil and gas sector since our main objective is to measure the impact on the non-mining sector. Our resulting sample consist of a panel of about 24,389 firm-year observations pertaining to 3,829 companies over the period from 2007 to 2014.

3.6 Descriptive statistics

Descriptive statistics for the firm-year observations entering the analysis are presented in Table 1. The empirical analysis exploits the large peso appreciation over the 2000s. Our trade-weighted measure for REER[5] exchibits a large appreciation (fall) beween 2006 and 2010. The 3-year and the 5-year average decrese are arround 8.8 and 6.4 respectetively with respect to the 100 base level in 2010. It has an overall standard deviation equivalent to 5.4% of the mean value during the first year of the sample (2006). In terms of heterogeneity, the REER shock also variates across firms since the 10th exhibits a small decay compared with median and the 90th percentile. (See Figure 11). This is particularly important since we primary rely on the heterogeneity of exposure to the shock across firm to estimate the influence of the RER shock on firm-level innovation investment decisions.

4 Results

This section reports the results from the regressions. There are two type of results. The first subsection reports the results for the baseline equation. The subsection 4.2 reports the results for the dynamic equation that includes a lagged dependent variable as a covariate. The subsection 4.3 includes the key robustness checks for the baseline specification. In all subsections we include results for R&D investment and the alternative measure STI investment. The last subsection provides some additional discussion of the results.

4.1 Baseline results

We now present the results for R&D and STI investment. In each case we organize

[5] REER estimation has been done using Real Exchange Rates calculated for the top 22 trade partners provided by the Colombian Central Bank.

our discussion around the core empirical specification introduced above. As noted earlier, the core regressors are the same for except for the fact that lagged innovation investment is included in the dynamic equation.

Table 2 presents the results of estimating equation (8) by OLS. The main coefficient of interest is the REER coefficient. In columns 1-4, we present the regression results using R&D as the dependent variable. We expect this coefficient to be positively correlated with innovation investment. When we include year-industry fixed effects, it is positive and significant at 5% levels when controlling by year-industry fixed effects. In columns (3) and (4), we include additional controls. The implied elasticity of the coefficient in column (4) is 2.29. Therefore, for a change equivalent to the 1% depreciation of REER, we would expect the investment in R&D to be increased 2.29%. A currency appreciation equivalent to one standard deviation (5.4%) would lead to an average decrease on R&D investment of 12.3%. Sales' coefficients are positive and suggest that firm size and innovation investment exhibits a positive relationship, which is consistent with the existing literature on size and innovation (Cohen & Levin, 1989).

In columns 5-8, we present the regression results using STI as the dependent variable. It includes the investment in equipment and machinery as well as other investment related broadly with innovation. It is positive and statistically significant at 5% levels in all cases. In columns (7) and (8), we include additional controls. In terms of economic significance, the implied elasticity of the coefficient in column (8) is 3.51. A currency appreciation equivalent to one standard deviation would lead to an average reduction on STI investment of 18.8%. Sales' coefficients are positive and significant. The coefficient of the industrial diversification index is negative and significant in contrast to the R&D case that is negative and insignificant. More diversified firms can be associated with lower levels on (less widely applicable) STI investment, since a costly upgrade for machinery and equipment machinery might be tightly related with the improvement of a few product lines but not necessary to all products.

4.2 Dynamic equation results

Table 3 presents the main results of estimating the dynamic panel equation (9). We report the results for the one-step GMM estimator for the first-differenced equation with robust standard errors. In order to be able to estimate the effect since 2007, we include lagged values for the innovation variables since 2005 in order to avoid losing the first two years of the sample. In particular, the first two years are important in terms of the appreciation shock. All lagged dependent variables are positive and significant at 1%, which indicates evidence of state dependence or persistence. The strong persistence statement implies that the long-run impact on investment is considerably higher. In columns 1-4, we present the regression results using R&D as the dependent variable of interest. The R&D coefficient is positive as we expected and significant at 1% levels when controlling by year fixed effects. Arellano and Bond (1991) suggest two test to assess the validity of dynamic specifications. Crucially, second-order serial correlation should be absent and the results did not meet that test for the case of R&D[6].

In columns 5-8, we present the regression results using STI as the dependent variable. The REER coefficient is positive and significant at 1% levels when controlling by year fixed effects. For the case of STI, we cannot reject the null hypothesis of no autocorrelation of first-differenced errors for the case AR(2), so there are not potential issues. The implied elasticity of the coefficient in column (8) is 7.01. Therefore, a currency appreciation equivalent to one standard deviation would lead to an average reduction on STI investment of 37.6%. The lagged STI investment coefficient is also positive and significant but smaller that the R&D lagged coefficient. Since most of the STI investment is done in tangible assets such as machinery and equipment, the results are consistent with the idea of a measure of technology investment that is less recurrent.

Table 4 presents the results using additional lags on the innovation dependent variable in order to address the issue of autocorrelation of first-differenced. In order to avoid losing the first years of the sample, we include lagged variables since 2003 to allow for autocorrelation of first-differenced errors up to AR(3). The R&D coefficients are positive as we expected and also are significant at 1% levels even after controlling by year fixed effects. The estimates are also economically significant. For change equivalent to the 1% depreciation of REER, we would expect the R&D investment to be increased by 8%. Therefore, a currency appreciation equivalent to one standard deviation would

[6] The also suggested the a Sargan test for over-identifying restrictions but the distribution is unknown when robust standard errors are obtained. Moreover, it is well-known that in finite samples the Sargan test statistics obtained from one-step estimator often over-reject the null in the presence of heteroscedasticity (Arellano & Bond, 1991).

lead to an average reduction close to 43% on R&D investment.

Taking results from Tables 3 and 4 together, there is no evidence that we are over estimating the effects of the peso appreciation on R&D and technology upgrading in the FE estimates in Tables 2. Thus, our results suggest that the real exchange rate appreciation had a strong statistical and economic impact on R&D and STI investment for the potentially innovative firms of the sample.

4.3 Robustness checks

We preform two kinds of analysis to provide evidence that alternative hypothesis cannot fully explain the results from previous subsections. Annex B.1 deals with an alternative hypothesis: The Venezuela trade sanctions in 2009. Annex B.2 show additional results from the regressions that control for REER volatility.

4.4 Discussion

Under several specifications we consistently find significant evidence of the negative effect of peso appreciation on the investment decisions at the level of the firm for the period 2007-2014. Our results are consistent with the results from Zietz & Fayissa (1994) and Becker & Pain (2008). These empirical results lend support to the notion that firms increase R&D in response to expanding market opportunities or decrease in response to increased import competition (Scherer & Huh, 1992). For the case of developing countries, our findings are consistent with theoretical predictions derivate from imperfect competition models (Rodrik, 1991), endogenous growth (Aghion & Howitt, 1992), and provides support the Schumpeterian effect of product market competition (Dasgupta & Stiglitz, 1980).

The negative effects of peso appreciation on productivity may be even higher in long-run for at least two reasons. First, we found evidence of strong persistence of innovation investment that implies that the negative effect can be amplified in the following years. Secondly, since R&D had investment had an effect on future productivity (Arbeláez & Parra-Torrado, 2011), a premature reduction on technology investment might hamper future productivity levels and delay the technological catch-up for the case of a developing country (Rodrik, 1991). Thus, the estimates of this paper can be considered conservative given the technological under-investment induced via currency appreciation shock, that may deter firm of obtaining future productivity improvements and performing R&D efforts.

5 Conclusions

This paper has produced micro-level econometric evidence of the negative effect of a currency appreciation on firm's investment decisions on R&D and technology spending in the context of a developing country. Researchers have been investigating the effect of RER shocks on firm's R&D investment decisions using industry-level measures of RER. However, to the best of our knowledge, the literature has not provided a measure of RER exposure and its implementation that accounted for international competition in foreign markets from third countries. In estimating the effect of Colombian Peso appreciation on R&D and technological upgrading investment, we account for this particular source of exposure that can induce a measurement error bias.

The findings were robust across a number of dynamic panel estimation techniques. So far we have been able to find robust evidence of the existence of a negative correlation between the currency appreciation and the investment in innovation for the period 2007-2014. That is, as firms are more exposed to a real effective currency appreciation, they decide to invest less in innovation. Moreover, the consequences of a strong appreciation may continue to affect negatively firms in the long run, since R&D is one of the documented mechanisms for productivity improvement. If that is the case, the negative effects of RER shocks into firm performance would be underestimated by the existing studies. Moreover, our results contribute to the growing literature of micro-evidence of the effects of Dutch Disease measuring innovation investment, which is key determinant of future firm performance and overall competitiveness.

For future research it would be useful to expand this analysis with a longer panel. Having more periods before the RER shock would be beneficial in order to account for pre-trends and generate a more robust causal estimation. Having more periods in the future would serve to estimate in the effects on firm innovation and performance in the medium and long run.

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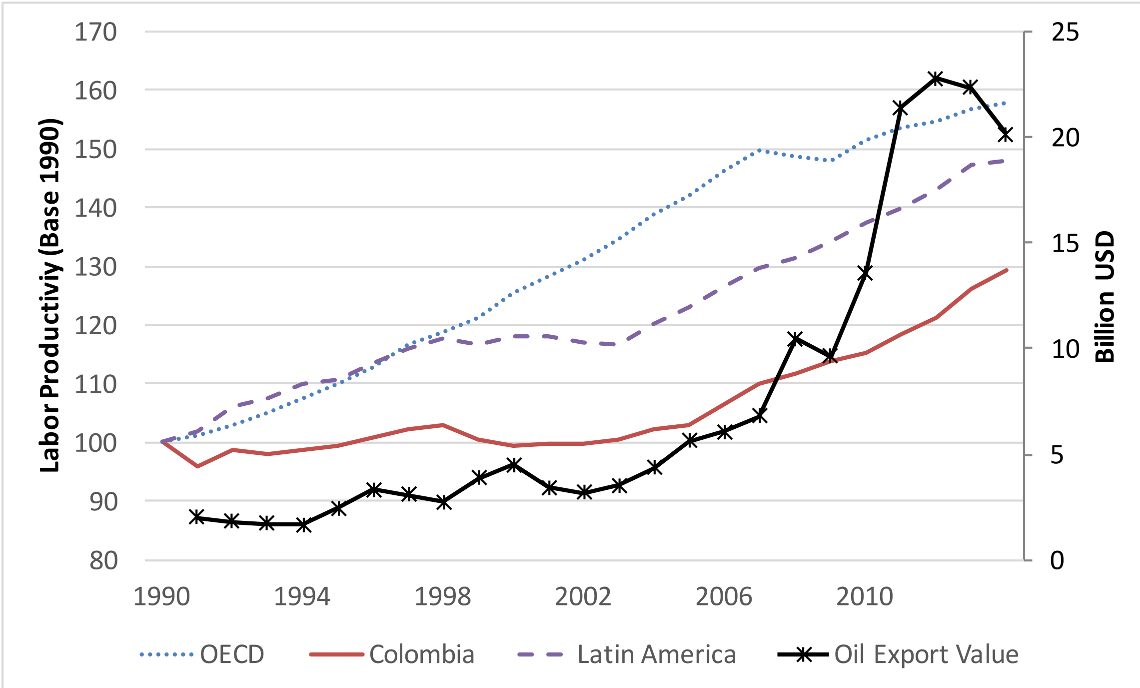
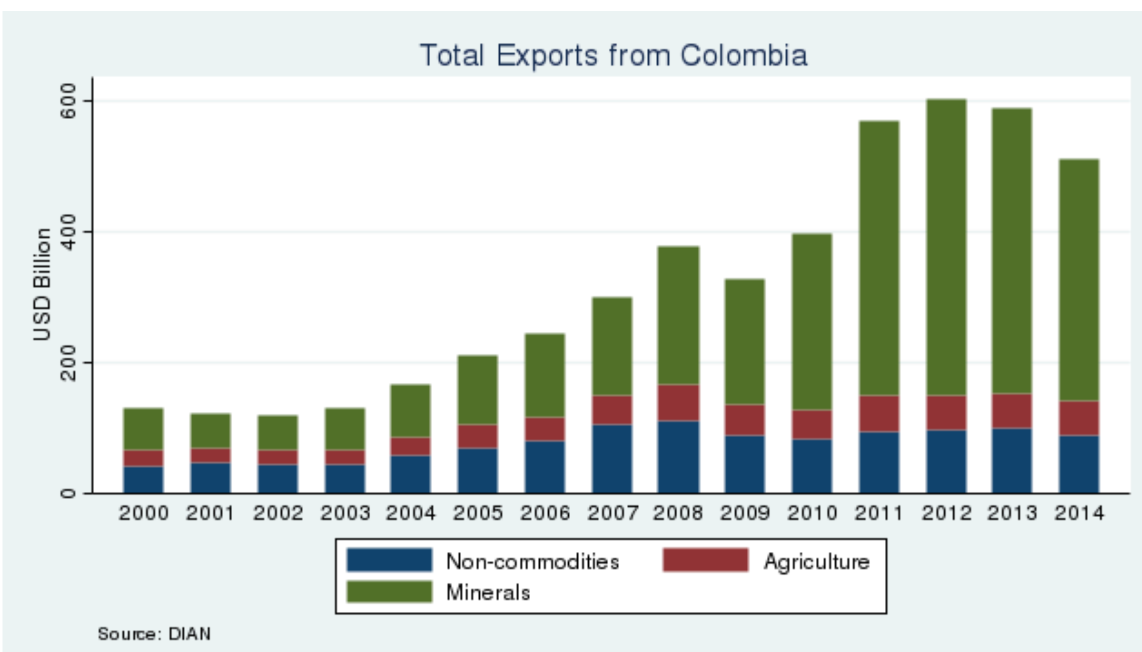
Figures



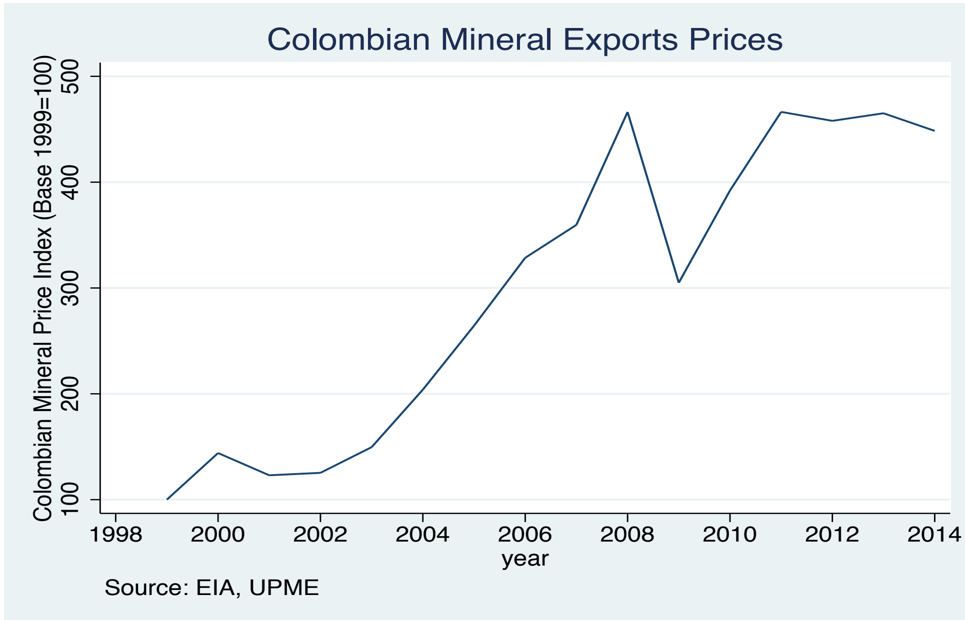
Notes: Labor productivity measured as GDP per hour worked relative to 1990 (=100). Oil export values in million dollars at constant prices (base year=1990).
Source: Penn Tables 9.0, Comtrade

Figure 1: Evolution of labor productivity and oil revenue, 1990-2011



Notes: Agricultural commodities includes tariff codes up to chapter 15. Mineral commodities are considered mineral products (chapters 27 and 28) and base metals (From chapter 72 to 83)). Export values at constant prices relative to 2000.

Figure 2: Exports from Colombia 2000-2014



Notes: The commodities included are oil, coal, gold, gas and nickel. The mean mineral export basket shares between 1999 and 2014 are respectively 73%, 5%, 6.5%, 5,6%, and 9.5%.

Figure 3: Colombian mineral commodities' price index

Figure 4: Export destinations for Colombian Manufacturing Exports

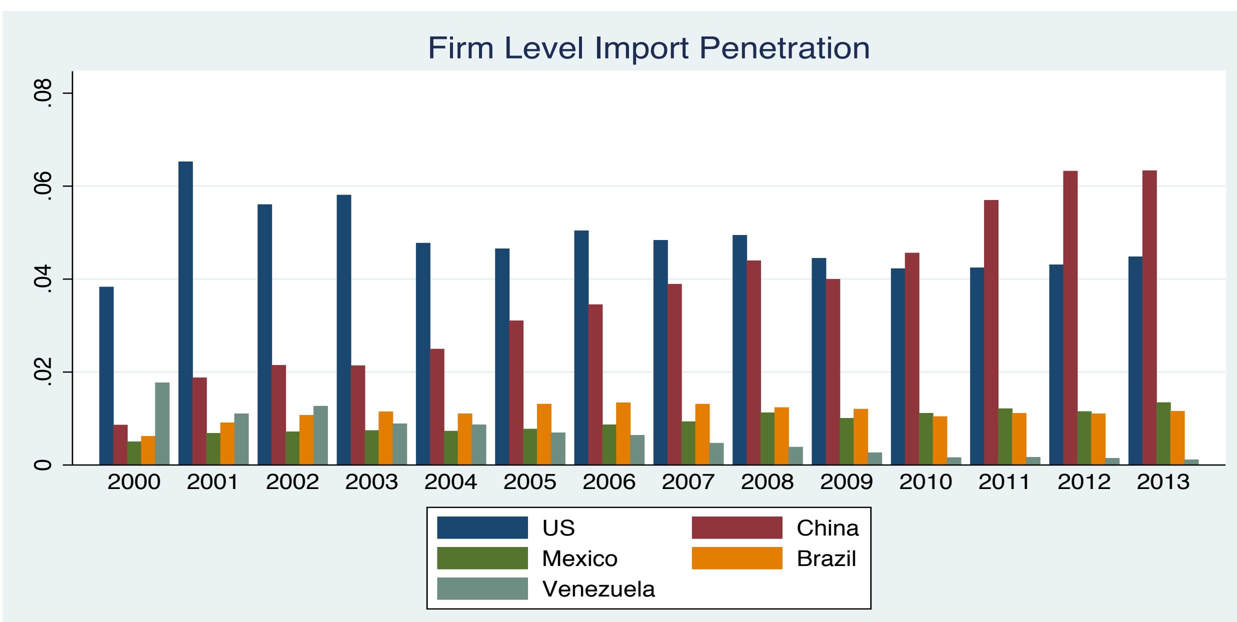


Figure 5: The rise of Chinese import penetration after 2000 (Source: DIAN-DANE)

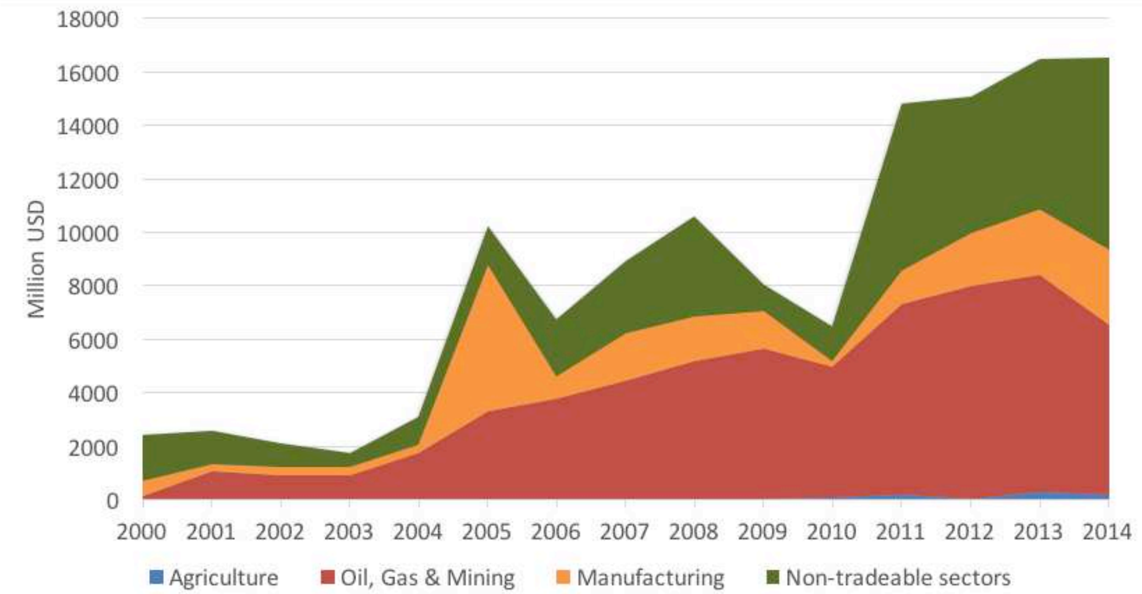


Figure 6: Foreign Direct Investment in Colombia 2000-2014 (Source: Banco de la República)

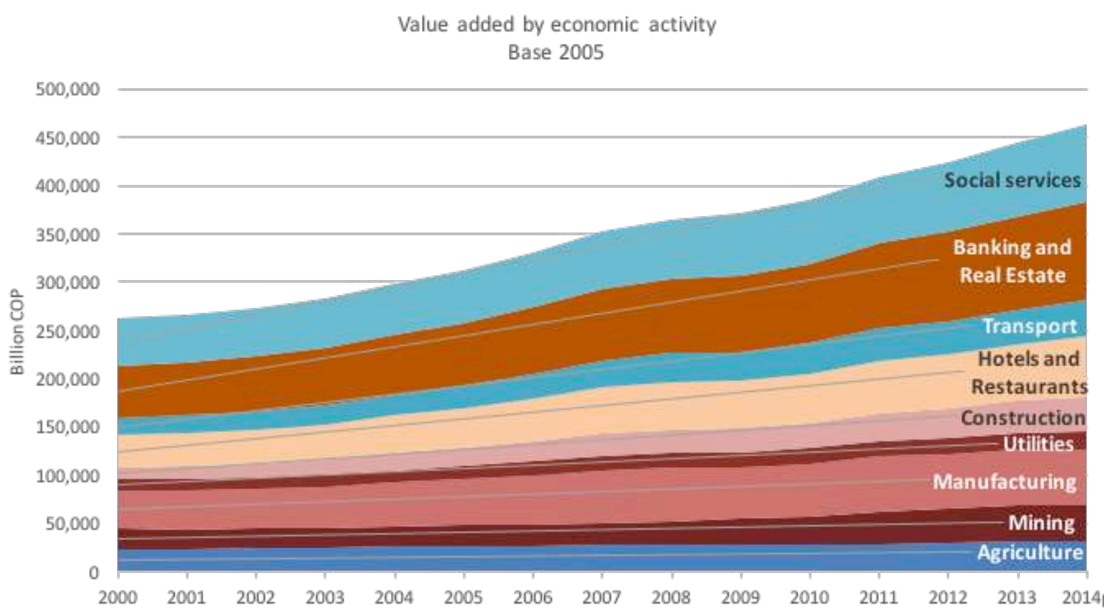


Figure 7: Sectorial growth was concentrated on non-tradeable sectors (Source: DANE)

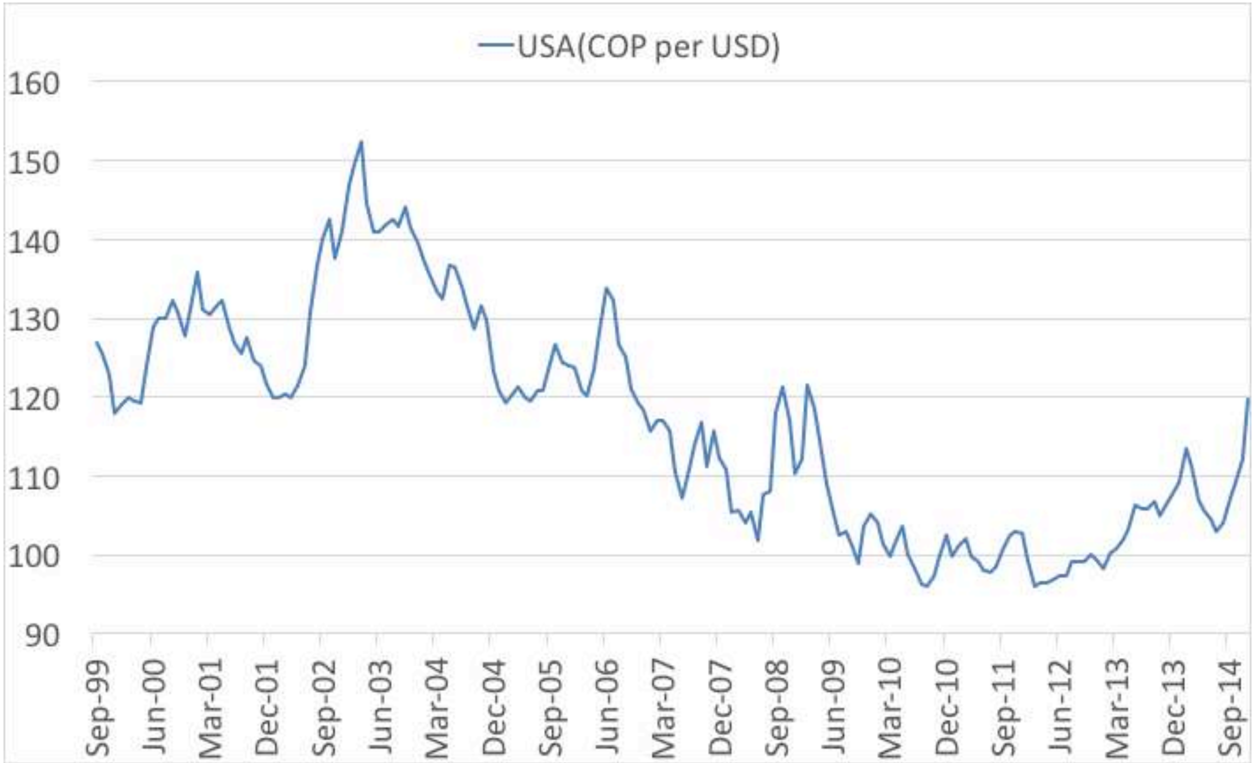
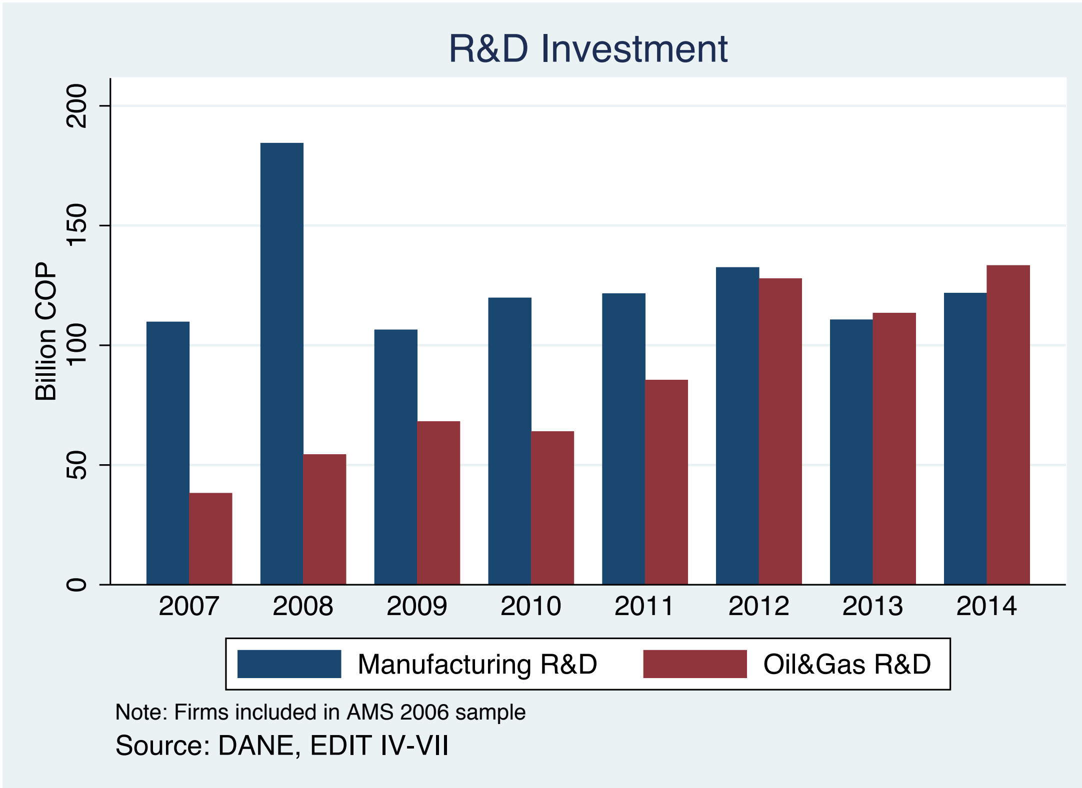


Figure 8: Bilateral Real Exchange Rate Colombia-USA. Colombian Pesos per US Dollar (Source: Banco de la República)



Notes: Investment values are deflated to 2000 values.

Figure 9: Industrial R&D Investment

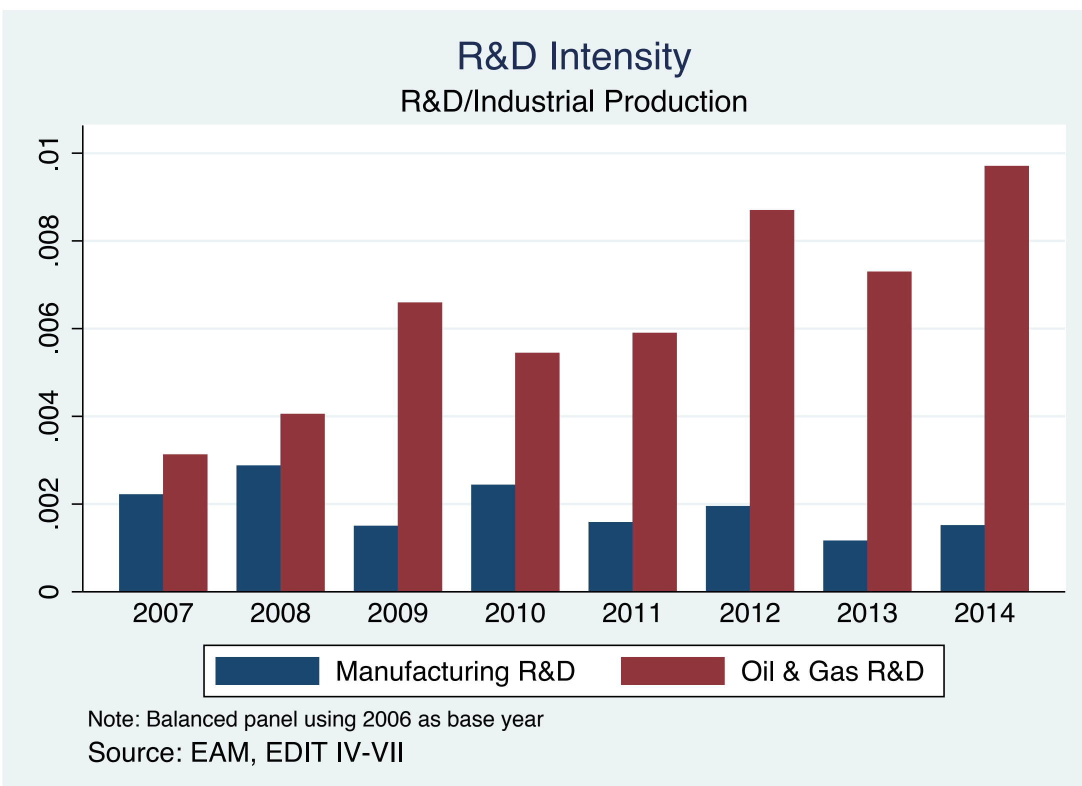


Figure 10: Industrial R&D Intensity

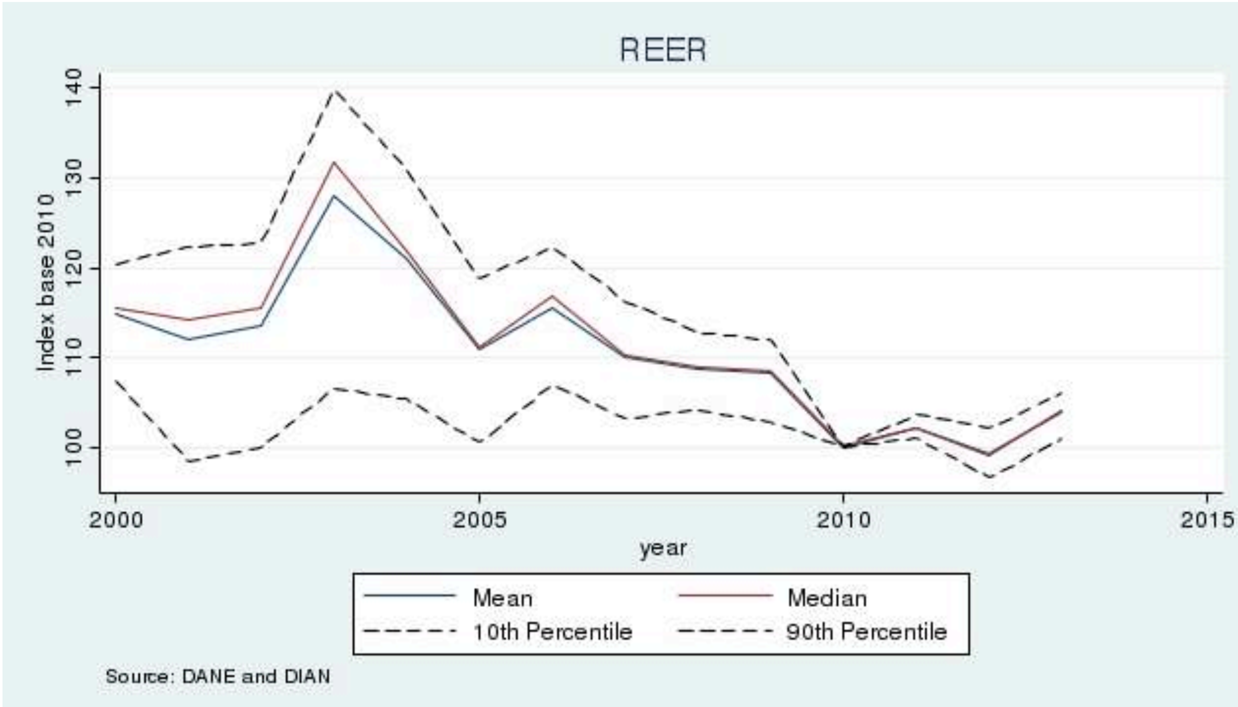


Figure 11: REER appreciation shock

TABLE 1

VARIABLES	Observations	Panel Mean	Panel SD	Panel Min	Panel Max	First year Mean	First year SD	Last Year Mean	Last Year SD
			2007-2014			2007		2014	
R&D (Internal +External)	24,389	40,395	496,981	0	3.554e+07	40,105	344,187	36,359	477,897
STIA	24,389	387,417	3.053e+06	0	1.650e+08	635,319	4.361e+06	262,499	2.432e+06
STI2: STI without Equi...& Mach.	24,389	117,947	1.333e+06	0	8.912e+07	125,953	770,888	123,983	2.121e+06
STI3: STI2 without ICTs	24,389	93,447	1.210e+06	0	8.668e+07	96,083	694,671	104,739	2.045e+06
Sales	24,389	2.311e+07	9.708e+07	0.610	3.327e+09	2.434e+07	1.069e+08	2.484e+07	1.051e+08
			2006-2013			2006		2013	
Age	24,389	23.86	14.65	0	122	21.49	14.52	26.64	14.82
Age^2	24,389	784.0	999.9	0	14,884	672.4	941.7	929.1	1,083
REER	24,389	105.7	6.237	90.86	146.8	116.3	6.123	104.0	2.007
5-year change REER	24,063	-8.763	10.74	-55.54	49.33	5.408	9.779	-4.801	3.819
3-year change REER	24,161	-6.398	7.838	-48.79	40.58	-9.528	12.40	3.833	2.209
Exports to Sales Ratio	24,389	0.0711	0.163	0	1	0.0799	0.173	0.0643	0.159
Exports to Ven. To Sales Ratio	24,389	0.0159	0.0636	0	1	0.0189	0.0634	0.00825	0.0461
Venezuela Dependency Dummy	24,389	0.166	0.372	0	1	0.171	0.377	0.161	0.368
Augmented Ven. Dep. Dummy	24,389	0.233	0.423	0	1	0.236	0.425	0.228	0.420
Import Penetration	24,389	0.226	0.230	0	1.000	0.216	0.230	0.25	0.234
Chinese Import Penetration	24,389	0.0457	0.0793	0	0.866	0.0334	0.0719	0.0620	0.0967
Industrial diversification	24,389	1.621	0.901	1	10.40	1.607	0.870	1.631	0.914
Market Concentration	24,389	0.0756	0.142	0.00277	1	0.0879	0.156	0.0708	0.137
Market Share	24,389	0.0729	0.149	1.09e-06	1	0.0802	0.159	0.0666	0.138

Notes: REER is Trade-Weighted value for Real Effective Exchange Rate. R&D stands for the annual investment in Research and Development. STIA stands for the investment in Science, Technology and Innovation (Includes machinery and equipment). Values are reported in thousand pesos. Exports include only non-commodities.

TABLE 2

VARIABLES	(1) Log(R&D)	(2) Log(R&D)	(3) Log(R&D)	(4) Log(R&D)	(5) Log(STIA)	(6) Log(STIA)	(7) Log(STIA)	(8) Log(STIA)
$REER_{t-1}$	0.0558***	0.0217**	0.0517***	0.0217**	0.283***	0.0332**	0.247***	0.0338**
	(0.00461)	(0.0101)	(0.00531)	(0.0101)	(0.00924)	(0.0145)	(0.00926)	(0.0145)
$Log(Sales_{t-1})$	0.0632	0.0441	0.0434	0.0391	0.345***	0.337***	0.287***	0.329***
	(0.0623)	(0.0591)	(0.0652)	(0.0607)	(0.0970)	(0.0947)	(0.103)	(0.0981)
Mkt. $Share_{t-1}$			0.591	0.335			0.787	0.0861
			(0.473)	(0.474)			(0.729)	(0.732)
Industrial $Div._{t-1}$			0.0249	0.0273			-0.266***	-0.180**
			(0.0502)	(0.0503)			(0.0848)	(0.0813)
Age_{t-1}			-0.0109	0.00893			-0.0707**	0.0296
			(0.0182)	(0.0186)			(0.0338)	(0.0264)
Age_{t-1}^2			-0.000122	0.000179			-0.00167**	-0.000562
			(0.000358)	(0.000306)			(0.000699)	(0.000418)
(Year x Ind.) FE 2-digit ISIC		Yes		Yes		Yes		Yes
Observations	24,389	24,389	24,389	24,389	24,389	24,389	24,389	24,389
R-squared	0.016	0.044	0.017	0.044	0.139	0.239	0.151	0.239
Number of firm-id	3,829	3,829	3,829	3,829	3,829	3,829	3,829	3,829

Notes: Panel data from 2007-2014. REER is Trade-Weighted value for Real Effective Exchange Rate. R&D stands for the annual investment in Research and Development. STIA stands for the investment in Science, Technology and Innovation (Includes machinery and equipment). Figures in parenthesis are robust clustered standard errors using 3-digit ISIC codes. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

TABLE 3

VARIABLES	(1) Log(R&D)	(2) Log(R&D)	(3) Log(R&D)	(4) Log(R&D)	(5) Log(STIA)	(6) Log(STIA)	(7) Log(STIA)	(8) Log(STIA)
$REER_{t-1}$	0.0977***	0.0835***	0.0975***	0.0820***	0.272***	0.0673***	0.254***	0.0663***
	(0.00615)	(0.00904)	(0.00611)	(0.00903)	(0.00816)	(0.0140)	(0.00898)	(0.0140)
$Log(R\&D_{t-1})$	0.407***	0.422***	0.410***	0.421***				
	(0.0137)	(0.0134)	(0.0137)	(0.0135)				
$Log(STIA_{t-1})$					0.305***	0.233***	0.279***	0.233***
					(0.0105)	(0.0110)	(0.0123)	(0.0110)
$Log(Sales_{t-1})$	0.0383	0.0445	0.0445	0.0528	-0.161	-0.0474	-0.117	-0.00342
	(0.0730)	(0.0747)	(0.0753)	(0.0769)	(0.126)	(0.118)	(0.127)	(0.119)
Mkt. $Share_{t-1}$			-0.233	-0.336			-0.793	-1.579*
			(0.656)	(0.648)			(0.988)	(0.878)
Industrial $Div._{t-1}$			0.0175	0.0156			-0.155	-0.107
			(0.0652)	(0.0662)			(0.105)	(0.0978)
Age_{t-1}			0.0116	0.0292			-0.0396	0.00455
			(0.0200)	(0.0207)			(0.0541)	(0.0316)
Age_{t-1}^2			-8.88e-05	0.000179			-0.00175	0.000433
			(0.000371)	(0.000382)			(0.00127)	(0.000579)
Year FE		Yes		Yes		Yes		Yes
AR(1) test (p-value)	-23.08(0.0)	-23.45(0.0)	-23.03(0.0)	-23.41(0.0)	-34.99(0.0)	-35.25(0.0)	-32.89(0.0)	-35.24(0.0)
AR(2) test (p-value)	-9.10(0.0)	-9.00(0.0)	-9.07(0.0)	-9.00(0.0)	4.35(0.0)	-0.15(0.88)	3.84(0.0)	-0.15(0.88)
AR(3) test (p-value)	6.81(0.0)	6.78(0.0)	6.82(0.0)	6.76(0.0)	0.04(0.96)	1.64(0.10)	-0.12(0.90)	-1.66(0.10)
AR(4) test (p-value)	-1.44(0.15)	-1.51(0.13)	-1.44(0.15)	-1.53(0.13)	0.42(0.67)	-1.29(0.19)	-0.44(0.65)	-1.32(0.18)
Observations	20,526	20,526	20,526	20,526	20,526	20,526	20,526	20,526
Number of firm-id	3,580	3,580	3,580	3,580	3,580	3,580	3,580	3,580

Notes: Panel data from 2007-2014. REER is Trade-Weighted value for Real Effective Exchange Rate. R&D stands for the annual investment in Research and Development. STIA stands for the investment in Science, Technology and Innovation (Includes machinery and equipment). Figures in parenthesis are robust standard errors. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

TABLE 4

VARIABLES	(1) Log(R&D)	(2) Log(R&D)	(3) Log(R&D)	(4) Log(R&D)	(5) Log(STIA)	(6) Log(STIA)	(7) Log(STIA)	(8) Log(STIA)
$REER_{t-1}$	0.0922***	0.0769***	0.0945***	0.0757***	0.269***	0.0483***	0.260***	0.0480***
	(0.00676)	(0.00956)	(0.00689)	(0.00956)	(0.00874)	(0.0172)	(0.00927)	(0.0172)
Log(R&D $_{t-1}$)	0.617***	0.601***	0.629***	0.602***				
	(0.0498)	(0.0700)	(0.0520)	(0.0700)				
Log(STIA $_{t-1}$)					0.572***	0.633***	0.537***	0.630***
					(0.0190)	(0.0954)	(0.0223)	(0.0965)
Log($Sales_{t-1}$)	-0.0144	0.0217	-0.00337	0.0353	-0.368**	-0.286*	-0.288*	-0.231
	(0.0824)	(0.0824)	(0.0852)	(0.0846)	(0.150)	(0.157)	(0.149)	(0.158)
Mkt. $Share_{t-1}$			-0.454	-0.406			-1.415	-1.744
			(0.748)	(0.724)			(1.126)	(1.090)
Industrial $Div._{t-1}$			0.0161	0.0149			-0.0794	-0.0159
			(0.0726)	(0.0720)			(0.125)	(0.129)
Age_{t-1}			0.00426	0.00656			-0.0328	-0.0237
			(0.0230)	(0.0229)			(0.0408)	(0.0378)
Age_{t-1}^2			0.000426	0.000563			-0.000661	0.000678
			(0.000413)	(0.000422)			(0.000792)	(0.000684)
Year FE		Yes		Yes		Yes		Yes
AR(1) test (p-value)	-11.72(0.0)	-8.66(0.0)	-11.41(0.0)	-8.67(0.0)	-28.14(0.0)	-8.87(0.0)	-25.67(0.0)	-8.75(0.0)
AR(2) test (p-value)	-7.77(0.0)	-7.87(0.0)	-7.71(0.0)	-7.85(0.0)	7.52(0.0)	3.26(0.0)	7.13(0.0)	3.21(0.00)
AR(3) test (p-value)	6.25(0.0)	5.32(0.0)	6.22(0.0)	5.33(0.0)	-0.23(0.79)	2.61(0.01)	-0.25(0.80)	2.61(0.01)
AR(4) test (p-value)	-1.35(0.17)	-1.44(0.15)	-1.37(0.17)	-1.46(0.14)	1.00(0.32)	-1.17(0.24)	1.02(0.31)	-1.18(0.24)
Observations	22,549	22,549	22,549	22,549	22,549	22,549	22,549	22,549
Number of firm-id	3,817	3,817	3,817	3,817	3,817	3,817	3,817	3,817

Notes: Dynamic panel data using Arellano & Bond (1991) from 2007-2014. Additional innovation data from 2003-2006 is used as instruments in order to avoid losing the first four years of data. Estimation of GMM is carried out with the xtdpd command. REER is Trade-Weighted value for Real Effective Exchange Rate. R&D stands for the annual investment in Research and Development. STIA stands for the investment in Science, Technology and Innovation (Includes machinery and equipment). Figures in parenthesis are robust standard errors. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.