The Real Exchange Rate, Innovation and Productivity: Regional Heterogeneity, Asymmetries and Hysteresis*

Laura Alfaro†
Harvard Business School and NBER

Alejandro Cuñat‡
University of Vienna and CES-ifo

Harald Fadinger§
University of Mannheim and CEPR

Yanping Liu¶
University of Mannheim

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Abstract

We evaluate manufacturing firms' responses to changes in the real exchange rate (RER) using detailed firm-level data for a large set of countries for the period 2001-2010. We uncover the following stylized facts: In export-oriented emerging Asia, real depreciations are associated with faster growth of firm-level TFP, higher sales and cash-flow, and higher probabilities to engage in R&D and to export. We find negative effects for firms in other emerging economies, which are relatively more import dependent, and no significant effects for firms in industrialized economies. Motivated by these facts, we build a dynamic model in which real depreciations raise the cost of importing intermediates, affect demand, borrowing-constraints and the profitability of engaging in innovation (R&D). We decompose the effects of RER changes on productivity growth across regions into these channels. We estimate the model and quantitatively evaluate the different mechanisms by providing counterfactual simulations of temporary RER movements and conduct several robustness analyses. Effects on physical TFP growth, while different across regions, are non-linear and asymmetric.

JEL Codes: F, O.

Key Words: real exchange rate, innovation, productivity, exporting, importing, financial constraints, firm-level data

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†Email: lalfaro@hbs.edu.
‡Email: alejandro.cunat@univie.ac.at.
§Email: harald.fadinger@uni-mannheim.de.
¶Email: yanping.liu@uni-mannheim.de.

1 Introduction

The aftermath of the global financial crisis, the expansionary policies implemented therein, and the end of the commodity cycle in emerging markets have renewed the debate on the effects of real exchange rate (RER) movements on the economy. Policy-makers in Asia and Latin America have expressed concerns that large capital inflows can bring about the appreciation of their RERs and subsequent losses of competitiveness. Similarly, in rich countries, concerns about appreciated RERs and their impact on economic activity, mainly in the manufacturing industry, have made recent headlines.

At the aggregate level, for example, there has been much talk about reserve accumulation and capital controls to limit exchange rate appreciations.[1] At the microeconomic level, the idea of governments defining interventionist industrial policies has ceased to be taboo even in the political debate of market-friendly countries. WTO membership forbids many of the classical trade-policy instruments (production and export subsidies, import tariffs and other protectionist measures) used in industrial policies in the past.[2] RER depreciations, while producing effects comparable to those of the combination of import tariffs and export subsidies, are not constrained by the WTO.

On the academic side, however, the empirical evidence on the effects of RER changes is far from conclusive. On the one hand, an extensive empirical literature has attempted to characterize the aggregate effects of RER depreciation (Rodrik, 2008, and references therein) and the associated economic growth effects through the positive impact on the share of tradables relative to nontradables. Still, evidence on the channels through which this positive effect operates (larger aggregate saving, positive externalities from specializing in tradables, etc.) is elusive and hard to obtain. Moreover, a number of empirical issues (omitted variables, reverse causality, etc.) cast doubt on the accuracy of this macro evidence (see Henry, 2008, and Woodford, 2008). On the other hand, evidence based on firm-level studies is relatively scarce. Here, data availability for a wide range of countries including emerging economies has been an obvious constraint, limiting the analysis of firm-level mechanisms and their aggregate implications.

This paper revisits this question by studying the effects of medium-term fluctuations in the RER on firm-level productivity and R&D activity, thus shedding light on the microeconomic channels through which RER changes affect the economy. A first look at the data in the form of reduced-form evidence shows that the effects of RER depreciations on firm-level innovation activity and productivity growth are on average positive in emerging Asia and negative in Latin America and Eastern Europe. When conditioning on trade participation, effects are positive for exporters and negative for importers in all regions. In the second part of the paper, we develop and estimate a dynamic model of exporting, importing and R&D investment subject to sunk costs and credit constraints in order to look into the microeconomics of RER effects on firm-level activity. Our counterfactuals show that RER effects vary by region in terms of direction, non-linearities and asymmetries. Some of our results evoke the hysteresis literature (Baldwin, 1988 and Baldwin and Krugman, 1989), but we provide a much richer

[1]See Alfaro et al. (2017), Benigno et al. (2016), Magud et al. (2011) and references therein for a discussion.
[2]Barattieri et al. (2017), for example, analyze macro-level effects of recent trade policy, in particular anti-dumping.

picture and a wealth of effects hitherto unnoticed, which we discuss below.

Regarding our reduced-form evidence, we combine several data sets on cross-country firm-level data to overcome several econometric concerns. The use of firm-level data for the manufacturing sector allows us to exploit the autonomous component driving changes in the exchange rate (see Gourinchas, 1999). Our analysis uses either movements in the aggregate RER, or disaggregated trade-weighted exchange rates, which enables us to control for country-time fixed effects, thereby eliminating spurious correlation due to aggregate shocks to the manufacturing sector.[3] In this way, we can consider RER movements as shifts in the relative price of tradables that operate as demand shocks exogenous to individual firms. This allows us to abstract from the underlying sources of aggregate shocks that bring about the RER movements.[4]

We use firm-level data from Orbis (Bureau van Dijk) for around 70 emerging economies and 20 industrialized countries for the period 2001-2010 to evaluate manufacturing firms' responses to changes in the RER. We complement the Orbis data with Worldbase (Dun and Bradstreet), which provides plant-level information on export and import activity and multinational status; and the World Bank's Exporter Dynamics Database, which reports entry and exit rates into exporting computed from customs microdata covering the universe of export transactions for a large set of economies (Fernandes et al., 2016). We complete the analysis with evidence from countries for which we have detailed administrative micro data: China, Colombia, Hungary, and France.[5]

We find that, for manufacturing firms in Asian emerging economies, RER depreciations are associated with (i) faster firm-level growth in revenue-based total factor productivity (TFPR), sales and cash flow; (ii) a higher probability to engage in R&D; (iii) and a higher probability to export. In Latin American and Eastern European countries (other emerging economies), the effects of RER depreciations on these outcomes are instead negative. Finally, for manufacturing firms from industrialized countries, there are no significant effects of real depreciations. When separating the impact of RER depreciations by firms' trade status, we uncover that the positive effects are concentrated on exporting firms, while firms importing intermediates tend to be affected negatively. Finally, we also provide evidence that firms' R&D choices depend positively on the level of their internal cash flow. This dependence is stronger in less developed local financial markets.

In light of this reduced-form evidence, we construct a dynamic firm-level model of exporting, importing and R&D investment. We analyze productivity effects related to innovation and abstract from spillovers or externalities usually mentioned in this literature. The model allows for market-size effects: real depreciations increase firm-level demand, thus raising the profitability to engage in exporting and R&D. In this context, our structural model helps us disentangle the demand effects caused by a real depreciation from true physical productivity growth. We also consider the role of productivity effects from importing inputs, as real depreciations increase the cost of importing

[3]We perform several alternative analyses. See section 2 for details.

[4]For example, Bussière et al. (2015) find that RER movements due to financial inflows have different aggregate growth effects than those due to supply shocks in the manufacturing sector.

[5]We take these countries as examples of the different regions of study. Complementary evidence comes from the Worldbank's World Enterprise Survey, a survey covering a broad sample countries.

such goods, thereby reducing profitability and productivity. Finally, we model financial constraints: depending on the firm's export and import intensity, depreciations may either relax or tighten these by affecting firms' cash flow. This affects the firms' ability to overcome sunk- and fixed-cost hurdles for financing R&D costs.[6]

We structurally estimate the model for each region using an indirect-inference procedure. We match the reduced-form regression coefficients of the impact of RER changes on firm-level outcomes as well as a number of additional firm-level statistics. We find that real depreciations have the largest positive effects on revenue-based and physical productivity growth in economies with high absolute and relative export orientation[7] where firms are likely to be financially constrained (emerging Asia). In this region, the additional demand for exports dominates the negative effect on TFPR operating via the higher costs of imported intermediates. Thus, firm-level profitability increases on average. This induces additional firms to engage in R&D and leads to faster physical TFP growth. By contrast, negative effects are found for other emerging markets (Latin America and Eastern Europe), which are not particularly export oriented and rely heavily on imported intermediates. Finally, negative and positive effects of real depreciations tend to offset each other in industrialized economies.

We quantitatively evaluate the different mechanisms by providing counterfactual simulations of temporary RER movements. Several key results emerge. First, even short-lived (temporary) real depreciations can trigger sizable (positive or negative) long-run impacts on innovation and productivity growth because the evolution of TFP is very persistent. In emerging Asia, a 25-percent real depreciation over a five-year period (corresponding to one standard deviation of RER changes) raises TFPR growth by up to 7 and physical TFP growth by up to 0.5 percentage points. In the other emerging economies, the same depreciation reduces TFPR growth by around 3 and physical TFP growth by up to 0.3 percentage points.

Second, the quantitative effects of real depreciations and appreciations are non-linear and asymmetric, as first discussed by the hysteresis literature (Baldwin, 1988, Baldwin and Krugman, 1989, and Dixit, 1989). In the case of emerging Asia, for example, the negative impact of a real appreciation on TFPR and physical TFP growth is roughly a third of the size of the positive effect of a real depreciation of the same magnitude. In other emerging markets, the positive impact of an appreciation on productivity is more than twice as large as the negative impact of a depreciation of identical magnitude. These regional asymmetries are due to the heterogeneous impact of depreciations on average firm-level profitability and the corresponding changes in the option value of engaging in R&D: firms' innovation responses to a positive profitability shock are larger than to a negative one because of sunk costs. These differences across regions also find support in our reduced-form evidence.

Third, the quantitative effects of depreciations are non-linear: for emerging Asia, doubling the

[6] Our analysis is silent on a number of questions. First, we take RER movements as given and do not attempt to explain how they come about. Second, we do not provide a welfare analysis weighing benefits and costs of RER depreciations. Among the latter, for example, one should consider the costs of reserve accumulation, inflation, financial repression, tensions among countries, etc. (See Woodford (2008) and Henry (2008)).

[7] "High relative export orientation" means that firms display an export intensity (export probability and exports over sales) that is large relative to their import intensity (import probability and imports over sales).

magnitude of a depreciation leads to (positive) effects on firm-level outcomes that are more than double in magnitude. In other emerging markets instead, the (negative) impact of a larger depreciation is comparatively smaller in proportional terms than the impact of a depreciation of half the size. These non-linearities are explained by the substitution effects between domestic and imported inputs. These cushion the impact of larger depreciations on import costs in emerging Asia and boost the impact of larger appreciations in other emerging economies.

Finally, we also look into the valuation effects associated with changes in the RER (balance-sheet channel). This channel may be relevant since devaluations raise the domestic value of debt for firms that issue unhedged foreign-denominated liabilities, weakening their balance sheets.[8] In terms of foreign currency debt, data on currency composition and hedging for a wide range of countries is not easily available. We complement our analysis with information on currency denomination of foreign debt from the World Bank Enterprise survey and national sources.[9] We uncover that Eastern European and Latin American firms are more exposed to foreign currency debt than firms from emerging Asia. Moreover, exporters borrow more in foreign currency compared to other firms. We then extend our structural model to account for a simple form of valuation effects. We show that for the empirically observed foreign-debt shares, the qualitative and quantitative implications of our simulated cases are similar: exporting and importing continue to be the dominating factors through which RER movements affect firm-level innovation decisions and TFP growth.

In addition to the literature mentioned above on the real effects of RER, our findings relate to research based on firm-level data studying the link between trade, innovation, and productivity growth. Regarding the connection between exporting and innovation activity, Lileeva and Trefler (2010) and Bustos (2011) find that foreign tariffs reductions enhance firms' incentives to innovate and export. Aw et al. (2014) structurally estimate a dynamic framework to study the joint incentive to innovate and export for Taiwanese electronics manufacturers. Aghion et al. (2017) analyze the competition and market-size effects associated with trade shocks on innovation. In terms of the relationship between imports and innovation, Bloom et al. (2015) uncover that European firms most affected by Chinese competition in their output markets increased their innovation activity. Autor et al. (2016) find instead that rising import competition from China has severely reduced the innovation activity of US firms. None of these papers uses cross-country firm-level data or changes in the RER to identify changes in the incentives for innovation; furthermore, none takes into account the impact of imported intermediate inputs and financial constraints.

As far as the link between imports and productivity is concerned, Amiti and Konings (2007) find substantial productivity gains from importing intermediates for Indonesian firms, while Halpern et al. (2015) structurally estimate these gains for Hungarian manufacturing firms. This result evokes the findings of Gopinath and Neimann (2014), who uncover large productivity losses due to reductions

[8] A vast literature has analyzed the effects of the balance-sheet channel. For theoretical work, see Céspedes et al. (2004) and references therein; Salomão and Varela (2017) develop a firm-dynamics model with endogenous currency-debt composition using data for Hungary. Kohn et al. (2017) study the impact of financial frictions and balance-sheet effects on aggregate exports.

[9] We cross-check the data with additional sources, as explained in the next section.

in imports at the product and firm level during the Argentine crisis that followed the collapse of the currency board.[10] [11]

Firm-level evidence from rich countries suggests a much more muted impact of real exchange rate movements on exports (Berman et al., 2012 for France; Amiti et al., 2014, for Belgium; Fitzgerald and Haller, 2014 for Ireland, among others). Ekholm et al. (2012) even find faster firm-level productivity growth in response to RER appreciation in Norway. This suggests that emerging markets display features that are very different from those of industrialized countries. In this regard, the stronger financial frictions that emerging markets are subject to and the stronger prevalence of importing intermediate inputs in industrialized countries, Latin America and Eastern Europe are a natural point of departure for our research into the determinants of the effects of RER changes on firm-level behavior.

The relation between financial constraints and trade is explored by Manova (2013). She develops a static model of financial constraints and exporting in which fixed and variable costs of exporting have to be financed with internal cash flows. These financial constraints reduce exports at the extensive and the intensive margins. Gorodnichenko and Schnitzer (2013) also consider innovation activity in this context: they produce a static model in which exports and innovation are complementary activities for financially unconstrained firms, but might become substitutes when financial constraints are binding. Aghion et al. (2012) uncover that R&D activity becomes pro-cyclical for credit-constrained French firms in sectors dependent on external finance, whereas R&D is counter-cyclical for non-constrained firms in the same sectors. Finally, Midrigan and Xu (2014) use Korean producer-level data to evaluate the role of financial frictions in determining total factor productivity (TFP): they find that financial frictions distort entry and technology adoption decisions and generate dispersion in the returns to capital across existing producers, and thus productivity losses from mis-allocation. In line with this literature, our paper shows that RER depreciations enable firms to access foreign markets more easily, thus potentially relaxing the financial constraints that prevent them from investing in R&D activity.

The rest of the paper is structured as follows. The next section presents our data and reduced-form evidence on the relationship between RER changes and a number of firm-level outcomes. This motivates the theoretical model we present in Section 3. Section 4 discusses our estimation strategy, whereas Section 5 presents our main estimation results. In Section 6 we use our estimated model to run a number of counter-factual experiments and in Section 7 we report a number of extensions and robustness checks. Section 8 presents some concluding remarks.

[10]The role of imperfect substitution between foreign and domestic inputs has also been shown to be quantitatively important in explaining productivity losses in sovereign default episodes and, more generally, in explaining effects of large financial shocks. See Mendoza and Yue (2012) and references therein.

[11]Large devaluations in emerging markets have also been used to study exporting behavior: Verhoogen (2008) analyzes the behavior of exporting manufacturing firms in Mexico following the 1994 devaluation and finds quality upgrading in response to devaluation. See also Alessandria et al. (2010) and Burstein and Gopinath (2014) for an overview of the effects of large devaluations.

2 Reduced-form Empirical Evidence

2.1 Data and Sources

We combine several data sources.[12] Orbis (Bureau Van Dijk) provides information for listed and unlisted firms on sales, materials, capital stock (measured as total fixed assets), cash flow (all measured in domestic currency),[13] employees, and R&D participation. Our sample spans the period 2001-2010: we have an unbalanced annual panel of firms in 76 emerging economies and 23 industrialized countries. Data coverage varies a lot across countries and the sample is not necessarily representative in all countries (see Table A-1, Panel A). We focus on manufacturing firms (US-SIC codes 200-399). The sample is selected according to the availability of the data necessary to construct TFP (gross output, materials, capital stock and employees) and includes around 1,333,000 observations corresponding to around 495,000 firms (see Table A-1, Panel B for descriptive statistics). Worldbase (Dun and Bradstreet) provides plant-level information of production activities, export and import status and plant ownership for the same set of countries as Orbis.[14] We use an algorithm to match firms in the two data sets based on company names. We use the export and import status in the first year the firm reports this information and are able to match around 177,000 firms. We also construct a dummy for the multinational status of a company for the same set of firms.

The World Bank's Exporter Dynamic Database reports entry rates into exporting by country for a large set of countries computed from underlying census customs micro data covering all export transactions (see Fernandes et al., 2016 for more details). We also use representative firm-level data from the Worldbank's 2016 version of the World Enterprise Survey to compute statistics on export and import probabilities and intensities for emerging economies. In addition, we employ information on the fraction of manufacturing firms performing R&D by country from the OECD's Science, Technology and Innovation Scoreboard, which is based on representative survey data.

As mentioned in the introduction, we use detailed micro data from China, Colombia, Hungary and France, as examples of the different regions, to complete the analysis. As explained in the next section, we use information on sales, exports, and imports from the detailed administrative plant-level data.

We obtain data on the exposure of firms to foreign-currency borrowing from various sources which we exploit in the robustness section. We use the 2002-2006 version of the World Entreprise Survey. This dataset has the advantage that it provides information for a wide range of countries included in our sample. For a subset of countries, we have more detailed data collected from Central Banks and the IADB research department.[15]

[12] A detailed explanation of the datasets we use can be found in the Appendix.

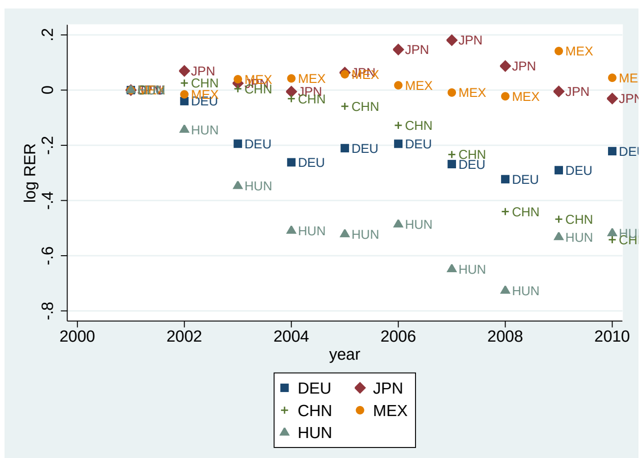
[13] Cash flow is the difference in the amount of cash available at the beginning and end of a period.

[14] This data set is more comprehensive in terms of coverage than Orbis, providing the 4-digit SIC code of the primary industry in which each establishment operates, and SIC codes of as many as five secondary industries, basic operational information, such as sales, employment, export and import status, and ownership information to link plants within the same firm. However, it does not include the balance-sheet variables necessary to construct TFP nor information on plants' R&D status.

[15] We use data provided by the IADB databases compiled as part of the Research Network project Structure and Composition of Firms' Balance Sheets. For Colombia the data comes from Barajas et al. (2016), for Brazil, Valle et al. (2017) and Chile, Alvarez and Hansen (2017). We thank Liliana Varela for help with Hungary.

As far as macro data is concerned, we use the real GDP growth rate from the Penn World Tables 8.0 (PWT 8.0); compute inflation rates from GDP deflators as reported by the IMF; and take information on private credit/GDP by country from the World Bank's Global Financial Development Database. We define the real exchange rate (RER) as $\log(e_{c,t}) = \log(1/P_{c,t})$, where $P_{c,t}$ is the price level of GDP in PPP (expenditure-based) from PWT 8.0 in country c in year t.[16] This RER is defined relative to the U.S. An increase indicates a real depreciation of the currency (making exports cheaper and imports more expensive). We also construct export-weighted and import-weighted country-sector-specific RERs by combining country-level PPP deflators with bilateral sectoral export and import shares at the 3-digit US-SIC level (164 manufacturing sectors) from UN COMTRADE database. We define $\log(e^{EXP}_{sc,t}) \equiv \sum_{c'} w^{EXP}_{cc's0} \log(P_{c',t}/P_{c,t})$, where $w^{EXP}_{cc's0}$ is the export share of country c to country c' in sector s in the first period of the sample and $\log(e^{IMP}_{sc,t}) \equiv \sum_{c'} w^{IMP}_{cc's0} \log(P_{c',t}/P_{c,t})$, where $w^{IMP}_{cc's0}$ is the import share of country c from country c' in sector s in the first period of the sample. Figure 1 presents the (yearly) time path of the aggregate RER for selected countries over our sample period. RER fluctuations can be quite persistent (e.g. China) and display substantial variation across countries (for export and import-weighted RERs also, across sectors). We exploit this variation to identify the effects of changes in RER on firm-level outcomes.

Figure 1: log RER relative to PPP Dollar (Normalized to 0 in 2001)



2.2 Firm-level Effects of RER Changes

Since the aggregate RER is the relative price of the foreign vs. domestic aggregate goods basket, endogeneity to aggregate shocks is a concern. However, a large body of empirical work has shown that the RER contains an important autonomous component driven by changes in the nominal exchange rate

[16] We obtain similar results using PPP from PWT 7.1. We prefer using version 8.0 since the accuracy of version 7.1 has recently been questioned (see Feenstra et al., 2015). However, since we use growth rates of RER rather than levels and the measurement problems are related to levels, our results are not affected by them. See Cavallo (2017) for an in-depth discussion.

and that fluctuations in the RER are very hard to predict with fundamentals in the short and medium run (Gourinchas, 1999 and references therein; Corsetti et al., 2014). Our analysis thus considers the exogenous component of RER fluctuations as exogenous demand shocks that impact on firms' export, import and innovation decisions. The fact that we investigate how *firm-level* outcomes of manufacturing firms are affected by RER movements makes reverse causality unlikely.

Omitted-variable bias is perhaps more of a concern. In particular, positive aggregate supply shocks should be positively correlated with the RER, while positive demand shocks should negatively correlate with the RER. Therefore we always control for the aggregate growth rate of the economy. As an alternative, we identify the causal impact of RER fluctuations by using trade-weighted exchange rates. In this case, we can control for country-time fixed effects, which eliminate any spurious correlation due to aggregate shocks to the manufacturing sector.[17] Here we can also dismiss endogeneity concerns due to country-sector-specific shocks: the trade-weighted RERs are constructed using pre-sample trade-weights and each of the 163 manufacturing sectors has negligible weight in a given country's aggregate price level, which is used to construct the RERs. Finally, we also consider an instrumental-variable strategy that exploits exogenous fluctuations in world commodity prices and world capital flows. Both higher commodity prices and larger world-level capital flows are plausibly exogenous to domestic shocks and policies and tend to appreciate the RER through their impact on domestic inflation. Moreover, the domestic effects of these external shocks are larger for countries that rely more on commodity trade or have more open financial accounts.

In presenting the results from regressing a number of firm-level variables on the growth rate of the aggregate or trade-weighted RER, we allow the effect of the RER to vary by region: emerging Asia; other emerging economies; industrialized economies.[18] This choice is motivated by our finding that the estimates vary systematically across these regions. First, we run the following regressions at the firm level:

$$\Delta \log(Y_{ic,t}) = \beta_0 + \sum_{r \in R} \beta_r \Delta \log(e_{c,t}) I_r + \beta_2 X_{c,t} + \delta_{sc} + \delta_t + u_{ic,t}, \tag{1}$$

where I_r is a dummy for country c belonging to region r, δ_{sc} is a 3-digit-sector-country fixed effect (controlling for the average growth rate in a given sector-country pair) and δ_t is a time fixed effect. The vector $X_{c,t}$ consists of business-cycle controls and includes the real GDP growth rate and the inflation rate. Controlling for inflation corrects for the fact that our dependent variables are measured in nominal value of domestic currency,[19] while we control for real GDP growth because open-economy macro models predict that changes in the real exchange rate are correlated with economic growth. We cluster standard errors at the country level since all firms in a given country are exposed to the same RER shock and RERs are auto-correlated. This choice of clustering implies that standard errors are robust to arbitrary correlation of the error terms across firms within a given country-year and over

[17]In other specifications we also control for country-sector-time fixed effects and identify differential impacts on exporters and importers (see below).

[18]The set of countries in each region and the corresponding numbers of observations, the descriptive statistics for firm-level variables and for the growth rate of the RER are listed in Table A-1 Panels A-D.

[19]We use domestic currency values. Section 7.1 analyzes valuation effects.

time within a given country.

We consider five different firm-level dependent variables $\Delta \log(Y_{ic,t})$: 1) the revenue-based TFP (TFPR) growth rate, constructed from value added; 2) the revenue-based TFP growth rate, constructed from gross output;[20] 3) the growth rate of sales; 4) the growth rate of cash flow; 5) the change of an indicator variable for R&D.[21] We also consider the (log) entry rate into exporting at the country-time level, defined as the number of new exporters relative to the number of total exporters, from the World Bank's Exporter Dynamics Database.

Table 1 reports results based on yearly data and aggregate RERs. In emerging Asia, real depreciations have a significantly positive impact on firm-level outcomes: a one-percent depreciation of the RER increases value-added TFPR growth by 0.24 percent, gross-output TFPR growth by 0.12 percent, sales by 0.2 percent, and cash flow by 0.78. The probability of R&D increases by 0.19 percentage points and the export entry rate increases by 0.55 percentage points. By contrast, in the other emerging economies, real depreciations are associated with significantly slower TFPR and sales growth, while there is no significant effect on cash flow, R&D probabilities and export entry. Finally, in industrialized countries, a real depreciation has no significant effect on firm-level TFPR, sales, R&D probabilities and export entry rates, while the impact on cash flow is negative. These results are robust to excluding the years of the global financial crisis from our sample and to using alternative productivity measures (see Tables A-2 and A-3 in the Appendix).

In Table A-4 in the Appendix we show that these results are robust when instrumenting for RER changes with (i) trade-weighted world commodity prices (using pre-sample trade weights) and (ii) interactions of world gross financial flows with pre-sample values of the Chinn-Ito index for financial account openness.[22] World commodity prices interacted with commodity-country-specific trade weights are strongly negatively correlated with RER changes, in particular for emerging economies. The rationale for the second instrument is that world gross financial flows should also be independent of local economic conditions and act as a push factor for the RER, in particular for countries with an open financial account, as measured by the Chinn-Ito index.[23]

Replacing the aggregate RER with export- and import-weighted sector-specific RERs as separate explanatory variables allows us to include country-time fixed effects in the regression. This way we directly control for aggregate shocks to the manufacturing sector that might be correlated with firm-

[20] We construct our TFP measures by adapting the methodology of De Loecker (2011) and Halpern et al. (2015). We explain our approach in detail in Section 4 and in Appendix A-1.2.

[21] That is, in the case of R&D status we estimate a linear probability model.

[22] We construct two instruments for the RER. The first one is based on a trade-weighted average of world commodity prices (a fixed set of agricultural commodities, metals, oil). For each country and commodity we compute exports and imports (using trade data from WITS) in the pre-sample year 2000 to construct trade weights. We then compute the instrument as a country-specific trade-weighed average of world commodity prices (using price information from the Worldbank). Our second instrument is based on world capital flows. We compute world capital flows as the sum of equity and debt inflows across countries (from IMF). We then interact this variable (which has only time variation), with the value of the Chinn-Ito index (Chinn and Ito, 2006) for financial openness in the pre-sample year 2000.

[23] Changes in the instruments are strongly negatively correlated with changes in the real exchange rate in the first-stage regressions (not reported). The first-stage multivariate Kleibergen-Paap F-statistic is always around 9 except for cash flow growth. For this outcome the instrumental variable estimates might be somewhat biased due to weak first stages. The over-identification tests, which posit that instruments are exogenous under the null hypothesis, cannot be rejected according to the Hansen statistic.

Table 1: The aggregate RER and firm-level outcomes

	(1) Δ log TFPR$_{VA,it}$	(2) Δ log TFPR$_{GO,it}$	(3) Δ log sales$_{it}$	(4) Δ log c. f.$_{it}$	(5) Δ R&D prob.$_{it}$	(6) Δ log exp. entry rate$_{ct}$
$\Delta \log e_{ct} \times$	0.239***	0.120***	0.195	0.783***	0.191*	0.552***
emerging Asia$_c$	(0.0895)	(0.0198)	(0.216)	(0.114)	(0.095)	(0.207)
$\Delta \log e_{ct} \times$	-0.546***	-0.105**	-0.762***	-0.557	0.16	0.063
other emerging$_c$	(0.185)	(0.0426)	(0.274)	(0.414)	(0.125)	(0.059)
$\Delta \log e_{ct} \times$	0.0196	-0.031	-0.282	-0.319**	-0.168	-0.275
industrialized$_c$	(0.103)	(0.0309)	(0.217)	(0.126)	(0.149)	(0.274)
Observations	1,333,986	1,333,986	1,275,606	772,970	148,367	392
R-squared	0.057	0.038	0.103	0.024	0.016	0.107
Country-sector FE	YES	YES	YES	YES	YES	NO
Time FE	YES	YES	YES	YES	YES	YES
Business cycle controls	YES	YES	YES	YES	YES	YES
Cluster	Country	Country	Country	Country	Country	Country

Notes: The dependent variable in columns (1)-(5) is the annual log difference in the following firm-level outcomes computed from Orbis for manufacturing firms for the years 2001-2010: revenue-based TFP computed from value-added (column 1), revenue-based TFP computed from gross output (column 2), nominal sales (column 3), cash flow (column 4), an indicator for R&D status (column 5). The construction of TFP is explained in section 4 of the paper. In column (6) the dependent variable is the log annual change in the export entry rate compute from the Worldbank's export dynamics database. The main explanatory variable of interest is the annual log difference in the real exchange rate from the PWT 8.0 interacted with dummies for: emerging Asia; other emerging economy; industrialized economy. The regressions also control for the real growth rate of GDP in PPP (from PWT8.0) and the inflation rate (from IMF). Standard errors are clustered at the country level.

level outcomes. The regression specification is thus:

$$\Delta \log(Y_{ic,t}) = \beta_0 + \sum_{r \in R} \beta_r^{EXP} \Delta \log(e_{c,t}^{EXP}) I_r + \sum_{r \in R} \beta_r^{IMP} \Delta \log(e_{c,t}^{IMPp}) I_r + \delta_{sc} + \delta_{c,t} + u_{ic,t}, \qquad (2)$$

where $\delta_{c,t}$ is a country-time-specific fixed effect that controls for any unobserved shock to the manufacturing sector of a given country. We now cluster standard errors at the country-industry level.

Table A-5 in the Appendix presents the corresponding results, which are similar to those in Table 1. In emerging Asia, real depreciations of the export-weighted RER are highly significant and are associated with faster TFPR, sales and cash flow growth and higher R&D probabilities. In the set of other emerging economies, real depreciations of the export-weighted RER have instead an (insignificantly) negative impact on firm-level outcomes. In industrialized countries, they have no significant effects on firm-level outcomes. By contrast, depreciations of the import-weighted RER (which measure mostly changes in import competition) have no statistically significant impact on outcomes.[24]

2.3 Trade Status

The heterogeneity of effects of the RER across regions begs for some explanation. In comparison with firms from emerging Asia, which are intensive in exports relative to imports, firms in other emerging

[24]Finally, we have also found very similar results using specifications in 3-year annualized differences. These results are available on request.

economies (mostly Latin America and Eastern Europe) are relatvely import intensive. Under these circumstances, the positive effects from a more depreciated RER that derive from larger exports are likely to be dominated by an increase in production costs brought about by more expensive imported materials. Finally, firms in industrialized countries have intermediate degrees of export and import participation.

Table 2 provides evidence for differences in export and import orientation by reporting import and export probabilities and intensities (imports/sales for importers; exports/sales for exporters) based on representative micro data sets for four countries for which we have detailed administrative plant-level data available: China, Colombia, Hungary, and France.[25] We find that China, representative for emerging Asia, has a high relative export orientation compared to the other countries (China's export probability divided by its import probability is 1.53, whereas its average export intensity divided by the corresponding import intensity is 4.62) while Colombia (0.82 and 0.71) and Hungary (0.90 and 0.42), representative for the other emerging economies, have a low relative export orientation. Firms in France (1.15 and 1.64), representative for industrialized countries, have intermediate relative export propensities and intensities.[26] In Appendix Table A-6 we compute the same statistics for emerging Asia and other emerging economies using data from the Worldbank's 2016 Enterprise Survey, which include a much larger sample of countries in these regions and find extremely similar numbers, thus confirming the representativeness of the four countries for their respective regions.[27]

In order to provide direct evidence that the effect of RER changes on firm-level outcomes depends on the firms' trade status, we run firm-level outcomes on changes in the RER, allowing for differential effects for exporters (for which we expect the effects of RER depreciations to be positive) and importers (for which we expect the effects to be negative). Since the interaction of trade status with the RER varies at the firm-country-time level, this specification allows us to include country-sector-time fixed effects. In this way we can control for any unobserved shocks to a given country-sector-pair. These fixed effects absorb the impact on the baseline category (domestic firms which neither export nor import). We also control for an interaction of RER with a dummy for the multinational status of the firm, which is highly correlated with trade participation.[28] Again, we cluster standard errors at the country level.

$$\Delta \log(Y_{ic,t}) = \beta_0 + \sum_{r \in R,} \sum_{T \in exp,imp} \beta_{Tr} \Delta \log(e_{c,t}) I_T I_r + \sum_{r \in R,} \sum_{T \in exp,imp} I_T I_r + \delta_{sct} + u_{ic,t} \qquad (3)$$

[25]The numbers for China have been computed by the authors from representative plant-level administrative data; information for Colombia is also from administrative data (we thank Norbert Czinkan for sharing this information with us); data for Hungary are from Halpern et al, 2015; data for France are from Blaum et al, 2015. The analysis considers that many firms are exporters and importers.

[26]Defever and Riaño (2017) document similar evidence for a broader sample of countries.

[27]The Worldbank's Enterprise Survey does not cover most industrialized countries. We also performed complementary analysis on regional differences in import and export propensity for the full set of countries in each region using information from Worldbase, which reports export and import status by plant. We analyzed import and export probabilities by plant-size bin (small ($\leq$ 50 employees), medium (50-200 employees), large ($\geq$ 200 employees) and region (Emerging Asia, other emerging, industrialized) for the years 2000, 2005 and 2009. Results from Worldbase confirm that plants in emerging Asia are much less likely to import than plants in the other regions. Similarly, the export propensity is also somewhat lower in emerging Asia than in the other regions.

[28]To avoid endogeneity of firms' status, we keep the firms' trade and multinational status fixed over the sample period and equal to the status in the first period we observe it.

Table 2: Evidence on import and export propensity/intensity of manufacturing plants

(Computed from representative micro data)

	China	Colombia	Hungary	France
Export prob.	0.26	0.37	0.35	0.23
Import prob.	0.17	0.45	0.39	0.20
Relative export prob.	1.53	0.82	0.90	1.15
Avg. export intensity (exporters)	0.6	0.10	0.10	0.23
Avg. import intensity (importers)	0.13	0.14	0.24	0.14
Relative export intensity	4.62	0.71	0.42	1.64

Data Sources: China: computed from administrative data; Colombia: computed from administrative data; Hungary: Halpern et al, 2015; France: Blaum et al, 2015.

Table 3 reports the corresponding results. As expected, in emerging Asia the interaction term of RER changes with export status is positive, highly significant and large, while the interaction with import status is negative and strongly significant. Similarly, for firms in other emerging countries the interaction effect with export status is positive and significant and the interaction effect with import status is negative. Finally, for firms in industrialized countries the interaction effects with export status and import status are small and mostly statistically insignificant.[29]

2.4 Financial Constraints

In order to understand the effect of financial constraints on R&D decisions, we first check if the probability to engage in R&D is affected by the availability of internal cash flow. We allow the impact of internal cash flow to depend both on firm size and the country's financial development.

We run the following regression for the firms in the Orbis dataset:

$$I_{iRD,t} = \beta_0 \sum_{i=1}^{4} \beta_{1i} \log(cashflow)_{i,t} \times size_i + \sum_{i=1}^{4} \beta_{2i} \log(cashflow)_{i,t} \times size_i \times fin.dev._c + \beta_4 X_{ic,t} + \nu_{i,t}, \tag{4}$$

where $I_{iRD,t}$ is an indicator that equals one if firm i performs R&D in year t. *log(cash flow)*$_{i,t}$ is the firm's cash flow (in logs), $size_i$ is a dummy indicator for the firm-size quartile (measured in terms of log(employment)) and *financial dev* is a measure of the country's financial development (private credit/GDP). Credit-constrained firms are more likely to rely on internal cash flow to finance investment projects. A positive relationship between cash flow and investment therefore suggests the presence of financial constraints. The problem of financial constraints becomes even more important in

[29]The interactions with dummies for multinational status are mostly insignificant in all regions.

Table 3: The aggregate RER and firm-level outcomes by firm's trade participation status and region

	(1)	(2)	(3)	(4)	(5)
	Δ log $\text{TFPR}_{VA,it}$	Δ log $\text{TFPR}_{GO,it}$	Δ log sales_{it}	Δ log c. f._{it}	Δ R&D prob._{it}
$\Delta \log e_{ct} \times$	0.197**	0.030	0.135***	0.243***	0.065***
emerging $\text{Asia}_c \times \text{exporter}_f$	(0.075)	(0.019)	(0.036)	(0.035)	(0.011)
$\Delta \log e_{ct} \times$	-0.157***	-0.016**	-0.099***	-0.123**	-0.101***
emerging $\text{Asia}_c \times \text{importer}_f$	(0.041)	(0.008)	(0.024)	(0.049)	(0.012)
$\Delta \log e_{ct} \times$	-0.005	0.019	-0.088***	-0.096	-0.049*
emerging $\text{Asia}_c \times \text{multinational}_f$	(0.045)	(0.019)	(0.015)	(0.059)	(0.024)
$\Delta \log e_{ct} \times$	0.394**	0.087**	0.333***	1.162***	0.167***
other $\text{emerging}_c \times \text{exporter}_f$	(0.159)	(0.036)	(0.079)	(0.281)	(0.029)
$\Delta \log e_{ct} \times$	-0.251	-0.074	0.005	-0.803***	-0.119
other $\text{emerging}_c \times \text{importer}_f$	(0.177)	(0.046)	(0.102)	(0.203)	(0.072)
$\Delta \log e_{ct} \times$	-0.027	-0.083**	0.382	0.502*	0.036
other $\text{emerging}_c \times \text{multinational}_f$	(0.127)	(0.040)	(0.248)	(0.292)	(0.024)
$\Delta \log e_{ct} \times$	0.006	-0.004	0.025	0.272***	-0.004
$\text{industrialized}_c \times \text{exporter}_f$	(0.021)	(0.009)	(0.033)	(0.085)	(0.018)
$\Delta \log e_{ct} \times$	0.046	0.012***	0.068***	-0.052	-0.042**
$\text{industrialized}_c \times \text{importer}_f$	(0.028)	(0.004)	(0.014)	(0.078)	(0.016)
$\Delta \log e_{ct} \times$	0.033	0.020*	0.045	0.144	-0.040
$\text{industrialized}_c \times \text{multinational}_f$	(0.034)	(0.011)	(0.043)	(0.088)	(0.028)
Observations	511,061	511,061	481,733	313,856	35,151
R-squared	0.094	0.076	0.16	0.063	0.116
Country-sector-time FE	YES	YES	YES	YES	YES
Firm status controls	YES	YES	YES	YES	YES
Cluster	Country	Country	Country	Country	Country

Notes: The dependent variable in columns (1)-(5) is the annual log difference in the following firm-level outcomes computed from Orbis for manufacturing firms for the years 2001-2010: revenue-based TFP computed from value-added (column 1), revenue-based TFP computed from gross output (column 2), nominal sales (column 3), cash flow (column 4), an indicator for R&D status (column 5). The construction of TFP is explained in section 4 of the paper. The main explanatory variable of interest is the triple interaction between the annual log difference in the real exchange rate from the PWT 8.0; firm-level indicators for exporting, importing and multinational status; and dummies for: emerging Asia; other emerging economy; industrialized economy. The regressions also control for the firms' exporter, importer and multinational status. Standard errors are clustered at the country level.

the context of intangible investments such as R&D, as these are difficult to pledge as collateral. Moreover, internal cash flow may have a different impact on the probability to engage in R&D depending on firm size and we allow for this by interacting cash flow with dummies for firm size quartiles. We always include the following set of additional controls: firm-size-bin dummies, capital stock (in logs), the inflation rate and the real growth rate of GDP. Depending on the specification, we include different fixed effects (country and sector, or country-sector). Since we are regressing firm-level variables on each other, endogeneity is of course a concern here and we thus emphasize that these are just conditional correlations that we will replicate with our structural model.[30]

We report results for these specifications in Table 4. The coefficient on (log) cash flow interacted with the dummy for the smallest firm-size quartile is insignificant, suggesting that for these firms R&D status is insensitive to cash flow. This is due to the fact that small firms hardly carry out any R&D investments. Medium-size to large firms do invest in R&D, but tend to be financially constrained: for them, cash flow is robustly positively related to R&D, as indicated by the significantly positive coefficients on the interaction between (log) cash flow and the dummies for the 3rd and 4th firm-size quartiles. Finally, the triple interaction term between (log) cash flow, the firm-size-bin dummies and the country's financial development is negative and statistically significant for the 3rd and 4th firm-size bin: for these firms the role of internal cash flow for R&D is smaller when the country has a more developed capital market. Table 5 reports the predicted marginal effects of (log) cash flow for each region by firm-size quartile. Cash flow has no significant impact on R&D for the smallest quartile of firm size. By contrast, its association with R&D for large firms is most prominent for the set of other emerging economies (around 0.046), intermediate for emerging Asia (0.039), and smallest for industrialized countries (0.027). Thus, the presence of developed capital markets reduces the relevance of internal cash flow for firms engaging in R&D activity.

2.5 Summary of Stylized Facts

- For firms in emerging Asia, real depreciations are associated with faster revenue-based productivity growth, faster sales growth, faster growth of cash flow, a higher probability to engage in R&D, and higher export entry rates.
- In other emerging markets (Latin America and Eastern Europe), real depreciations have a significantly negative effect on firm-level outcomes.
- In industrialized countries real depreciations have no significant effects on firm-level outcomes.
- Real depreciations affect exporters positively and firms importing intermediates negatively.
- In comparison with firms in industrialized countries, emerging-Asia firms are relatively more likely to export and have a high relative export intensity. Firms from other emerging economies

[30] Using lagged cash flow instead of current cash flow mitigates endogeneity concerns and gives very similar results. More generally, as documented by Lerner and Hall (2010), there is substantial evidence on the role of internal funds and cash flowing financing R&D.

Table 4: R&D sensitivity to cash flow by firm-size quartiles and level of financial development

	(1)	(2)
	R&D prob.$_{it}$	R&D prob.$_{it}$
log(cash flow)$_{ft}\times$	0.015	0.008
size quartile 1_f	(0.019)	(0.019)
log(cash flow)$_{ft}\times$	0.035**	0.018
size quartile 2_f	(0.0153)	(0.014)
log(cash flow)$_{ft}\times$	0.052***	0.048***
size quartile 3_f	(0.005)	(0.006)
log(cash flow)$_{ft}\times$	0.056***	0.059***
size quartile 4_f	(0.003)	(0.003)
log(cash flow)$_{ft}\times$	-0.0001	-0.0001
size quartile $1_f\times$ credit$_c$	(0.0001)	(0.0001)
log(cash flow)$_{ft}\times$	-0.0002*	-0.0001
size quartile $2_f\times$ credit$_c$	(0.0001)	(0.0001)
log(cash flow)$_{ft}\times$	-0.0002***	-0.0002***
size quartile $3_f\times$ credit$_c$	(0.00004)	(0.00004)
log(cash flow)$_{ft}\times$	-0.0002***	-0.0002***
size quartile $4_f\times$ credit$_c$	(0.00002)	(0.00002)
R-squared	0.347	0.383
Observations	117,394	117,142
Time FE	YES	YES
Sector FE	YES	NO
Country FE	YES	NO
Sector-country FE	NO	YES
Firm controls	YES	YES
Business cycle controls	YES	YES
Cluster	Firm	Firm

Notes: The dependent variable is an indicator for the firm's R&D status. Explanatory variables are firm-level cash flow (in logs) interacted with 4 dummies for the quartiles of (log) firm employment and triple interactions of these variables with financial development (measured as private credit/GDP). Further controls include (coefficients not reported): dummies for quartiles of (log) firm employment, capital (in logs), the real GDP growth rate (from PWT 8.0) and the inflation rate (from IMF).

Table 5: Marginal effects of cash flow on R&D (estimates by region)

	emerging East Asia	other emerging	industrialized
credit/GDP	0.84	0.50	1.47
marginal effect of cash flow – firm-size quartile 1	0	0	0
marginal effect of cash flow – firm-size quartile 2	0.017	0.024	0.003
marginal effect of cash flow – firm-size quartile 3	0.034	0.041	0.020
marginal effect of cash flow – firm-size quartile 4	0.039	0.046	0.026

Notes: Predicted marginal effects of (log) cash flow by firm size quartile for each region.

are relatively more likely to import and have a high relative import intensity.

- R&D choices of medium-sized and large firms depends on the level of internal cash flow and the more so the less developed local financial markets are. Cash flow matters most for R&D decisions of firms in the set of other emerging economies; it has an intermediate impact on R&D in emerging Asia; and does not play much of a role for R&D decisions in industrialized economies.

3 Theoretical Framework

Motivated by this empirical evidence, we build a model with heterogeneous firms that choose whether or not to invest in R&D, which in turn affects their future productivity. The model focuses on the manufacturing sector, which is our object of empirical analysis. We adopt a small-open-economy approach in which aggregate variables are given. Since R&D is an intangible investment that cannot be used as collateral easily, borrowing constraints are key: only firms with sufficiently large operating profits can finance the fixed sunk costs involved in R&D activity. RER fluctuations change cash flows and affect thereby the behavior of firms. Domestic firms self-select into exporting their output and/or importing materials. This creates channels through which the RER affects the revenues and profits of domestic firms, potentially influencing their decision-making regarding R&D.

3.1 The Real Exchange Rate

We think of the RER as the price of a country's consumption basket relative to that of the rest of the world. In the Appendix, we model its fluctuations in a Balassa-Samuelson way: productivity increases in a freely traded numéraire sector lead to higher prices in the rest of the economy (manufacturing and non-tradables), thereby bringing about an RER appreciation, making exportables more expensive and importables cheaper.

The logarithm of the cost-shifter (inverse of productivity) in the numéraire sector follows an AR(1) process:

$$\log(e_t) = \gamma_0 + \gamma_1 \log(e_{t-1}) + \nu_t, \quad \nu_t \sim N(0, \sigma_\nu^2). \tag{5}$$

Because of our assumptions the (log) real exchange rate $\log(P_t^*/P_t) \approx \log(e_t)$: a higher e_t leads to lower factor prices and thereby a real depreciation.

3.2 Preferences and Technologies

There is a continuum of differentiated varieties of manufacturing goods. Consumers have the following preferences over manufacturing varieties i,

$$D_{T,t} = \left(\int_{i \in \Omega_T} d_{i,t}^{\frac{\sigma-1}{\sigma}} di + \int_{i \in \Omega_T^*} d_{i,t}^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}, \tag{6}$$

where Ω_T and Ω_T^* denote the sets of domestically produced and imported varieties, respectively, which are given. We take aggregate variables as exogenous. Since each variety is associated with a different producer, the number of firms equals the number of varieties. Firms are infinitely lived and heterogeneous in terms of log-productivity $\omega_{it} + \epsilon_{it}$. Here $\omega_{i,t}$ follows a Markov process defined below and $\epsilon_{i,t}$ is independently drawn from $N(0, \sigma_\epsilon^2)$. We assume that $\omega_{i,t}$ is realized before firms make decisions in each period, while $\epsilon_{i,t}$ is realized after decisions have been made.

Each firm produces a single variety of the manufacturing good using technology:

$$Y_{i,t} = \exp\left(\omega_{i,t} + \epsilon_{it}\right) K_{i,t}^{\beta_k} L_{i,t}^{\beta_l} M_{i,t}^{\beta_m}. \tag{7}$$

$K_{i,t}$, $L_{i,t}$, and $M_{i,t}$ denote the amount of capital, labor and materials, respectively, employed by firm i.

3.3 Imports

We follow Halpern et al. (2015) and assume that manufacturing firms can use domestic and imported intermediates, which are imperfect substitutes with elasticity of substitution ε:

$$M_{i,t} = \left[\left(B^* X_{i,t}^*\right)^{\frac{\varepsilon}{\varepsilon-1}} + X_{i,t}^{\frac{\varepsilon}{\varepsilon-1}}\right]^{\frac{\varepsilon-1}{\varepsilon}}. \tag{8}$$

$X_{i,t}$ is the quantity of domestically produced intermediates used by firm i; $X_{i,t}^*$ is the quantity of imported intermediate inputs. B^* is a quality shifter that allows imported intermediates to be of a different quality compared to that of domestic intermediates. In case a firm decides to import foreign inputs, the price index of intermediates is

$$P_{M,t} = P_{X,t} exp\left[-\tilde{a}_t\left(e_t\right)\right], \tag{9}$$

where $P_{X,t}$ is the price of domestically produced intermediates and $\tilde{a}_t\left(e_t\right) = (\varepsilon - 1)^{-1} \ln\left[1 + \left(A_t e_t^{-1}\right)^{\varepsilon-1}\right]$ is the cost reduction from importing that results from a combination of relative price, quality and imperfect substitution. ($A_t \equiv B^*/P_{X,t}^*$ is the quality-adjusted relative cost of imported intermediates.) Cost reductions from importing are increasing in the quality of foreign inputs and decreasing in e_t in a non-linear fashion: the possibility of substituting domestic intermediates for foreign intermediates in the event of a depreciation implies that the latter's effect on $\tilde{a}_t\left(e_t\right)$ is less than proportional. As we show in the Appendix, a higher e_t leads to lower domestic factor prices, a lower price of domestic intermediates[31] and thus a higher relative price of imported intermediates. An increase in e_t raises $P_{X,t}^*/P_{X,t}$ and thus the price of materials for importing relative to non-importing firms, for which $P_{M,t} = P_{X,t}$.

Material expenditure $\tilde{M}_t \equiv P_{M,t} M_t$ can be written as $\tilde{M}_t = P_{X,t} exp\left[-\tilde{a}_t\left(e_t\right)\right] M_t$. Substituting

[31] In fact, $P_{X,t} = e_t^{-1}$

this into the production function and taking logs, and using $z \equiv \log Z,\ Z = K, L, \tilde{M}$,

$$y_{i,t} = \beta_0 + \beta_k k_{i,t} + \beta_l l_{i,t} + \beta_m \tilde{m}_{i,t} - \beta_m \log(P_{X,t}) + \beta_m \tilde{a}_{i,t}(e_t) + \omega_{i,t} + \epsilon_{i,t}. \tag{10}$$

The term $\beta_m \tilde{a}_{i,t}(e_t)$ captures the productivity gains from importing intermediates. In case the firm does not import, the term $\beta_m \tilde{a}_{i,t}(e_t)$ disappears from the corresponding expression for the production function. We discuss the choice to import intermediates below.

3.4 Demand

Given preferences (6), demand faced by firm i is

$$d_{i,t} = (p_{i,t}/P_{T,t})^{-\sigma} D_{T,t} \text{ and } d^*_{i,t} = \left(p_{i,t}/P^*_{T,t}\right)^{-\sigma} D^*_{T,t}. \tag{11}$$

Here, $d_{i,t}$ is the domestic demand and $d^*_{i,t}$ is foreign demand faced by firm i; $p_{i,t}$ is the price charged by firm i. $P_{T,t}$ is the price index of the manufacturing sector and $D_{T,t}$ is demand for the CES aggregate by domestic consumers, both taken as given by firms. The number of foreign firms Ω^*_T, foreign demand $D^*_{T,t}$ and the foreign price level $P^*_{T,t}$ are also given. Firms behave as monopolists and charge a constant mark-up over their marginal production costs.[32] Firm i's domestic revenue is

$$R^d_{i,t} = p^{1-\sigma}_{i,t} P^{\sigma-1}_{T,t} \left(P_{T,t} D_{T,t}\right). \tag{12}$$

As shown in the Appendix, non-importing (NI) firms face factor costs proportional to e^{-1}. By substituting the optimal price (before ϵ_{it} is realized) into (12) we get:

$$R^d_{i,t}(\omega_{i,t}) = \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \exp\left[(\sigma-1)\omega_{i,t}\right] e_t^{\sigma-1} P^{\sigma-1}_{T,t}\left(P_{T,t} D_{T,t}\right). \tag{13}$$

Variable domestic profits are given by $\Pi^d_{i,t} = R^d_{i,t}/\sigma$. Notice that e_t affects $R^d_{i,t}$ by (i) impacting on the marginal cost faced by the firm and thereby the price $p_{i,t}$ it charges, and (ii) by shifting the domestic aggregate price level in manufacturing $P_{T,t}$. Both effects are proportional to e_t^{-1} and cancel out. (See the Appendix). Thus, conditional on aggregate expenditure on manufacturing ($P_{T,t} D_{T,t}$), e_t has no effect on $R^d_{i,t}$ and $\Pi^d_{i,t}$. By contrast, in the case of importing (I) firms, e_t has an additional negative effect on revenue (and profits) through the effect of the price of imported intermediates on the price these firms charge:

$$R^d_{i,t}(\omega_{i,t}) = \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \exp\left[(\sigma-1)\omega_{i,t}\right] e_t^{\sigma-1} exp\left[-\tilde{a}_t(e_t)\right]^{(1-\sigma)\beta_m} P^{\sigma-1}_{T,t}\left(P_{T,t} D_{T,t}\right). \tag{14}$$

Hence, a real depreciation reduces the domestic revenue and profits of importers.

[32] The price charged by non-importing firms is $p_{i,t}(\omega_{i,t}, e_t) = e_t^{-1} \frac{\sigma}{\sigma-1} \exp(-\omega_{i,t})$. Importing firms charge $p_{i,t}(\omega_{i,t}, e_t) = e_t^{-1} exp\left[-\tilde{a}_t(e_t)\right]^{\beta_m} \frac{\sigma}{\sigma-1} \exp(-\omega_{i,t})$.

3.5 Exports

If a firm with log-productivity level ω_{it} chooses to export, its export revenue is

$$R_{i,t}^{x} = p_{i,t}^{1-\sigma} \left(P_{T,t}^{*}\right)^{\sigma-1} \left(P_{T,t}^{*} D_{T,t}^{*}\right). \tag{15}$$

For non-importing (NI) firms,

$$R_{i,t}^{x}\left(\omega_{i,t}\right) = \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \exp\left[\left(\sigma-1\right)\omega_{i,t}\right] e_t^{\sigma-1} \left(P_{T,t}^{*}\right)^{\sigma-1} \left(P_{T,t}^{*} D_{T,t}^{*}\right). \tag{16}$$

Variable export profits are $\Pi_{i,t}^{x} = R_{i,t}^{x}/\sigma$. Changes in e_t affect export revenues and profits by impacting a firm's marginal cost. A real depreciation reduces domestic factor costs, thereby reducing export prices and increasing sales and profits in the export market. (The foreign price level $P_{T,t}^{*}$ is unaffected by the shift in e_t.) This effect is smaller for exporters that also import (I), since a real depreciation makes imports of intermediate inputs more expensive.[33]

3.6 Exporter and Importer Status

Importing and exporting decisions involve per-period fixed costs f_m and f_x, respectively.[34] Each firm's fixed costs are i.i.d. random draws. More productive firms self-select into one or both of these activities. The resulting decisions are static choices. Moreover, they are complements: each activity raises the gain from the other. We assume that export and import decisions are made after $\omega_{i,t}$ is realized, but before $\epsilon_{i,t}$ is observed.

Firm i therefore chooses one among four different "regimes", which characterize the following per-period profit function:

$$\Pi_{i,t}\left(\omega_{i,t}\right) = \max\left[\Pi_{i,t}^{(x,m)}\left(\omega_{i,t}\right) - f_x - f_m, \Pi_{i,t}^{(x,0)}\left(\omega_{i,t}\right) - f_x, \Pi_{i,t}^{(0,m)}\left(\omega_{i,t}\right) - f_m, \Pi_{i,t}^{(0,0)}\left(\omega_{i,t}\right)\right], \tag{17}$$

where $\Pi_{i,t}^{x,m}\left(\omega_{i,t}\right) = \Pi_{i,t}^{d}\left[\omega_{i,t}, exp\left[-\tilde{a}_t\left(e_t\right)\right]\right] + \Pi_{i,t}^{x}\left[\omega_{i,t}, e_t, exp\left[-\tilde{a}_t\left(e_t\right)\right]\right]$ are the profits of a firm that both exports and imports; $\Pi_{i,t}^{(x,0)}\left(\omega_{i,t}\right) = \Pi_{i,t}^{d}\left(\omega_{i,t}\right) + \Pi_{i,t}^{x}\left(\omega_{i,t}, e_t\right)$ are the profits of an exporting firm that does not import materials; $\Pi_{i,t}^{(0,m)}\left(\omega_{i,t}\right) = \Pi_{i,t}^{d}\left[\omega_{i,t}, exp\left[-\tilde{a}_t\left(e_t\right)\right]\right]$ are the profits of an importing non-exporter; and $\Pi_{i,t}^{(0,0)}\left(\omega_{i,t}\right) = \Pi_{i,t}^{d}\left(\omega_{i,t}\right) > 0$ are the profits of a firm that neither exports nor imports. Notice that firms that choose to export and/or import can always finance the corresponding fixed costs with their profits.

3.7 Dynamic Choice of R&D

Unlike the static export and import choices, the R&D choice is dynamic due to both the existence of fixed and sunk costs and its impact on productivity, which is persistent. Innovation increases

[33] As in the case of domestic sales, export revenues and profits of importers and non-importers differ by term $exp\left[-\tilde{a}_t\left(e_t\right)\right]^{(1-\sigma)\beta_m}$.

[34] Unlike with the R&D decision, we assume no one-time sunk cost is required for either of these two activities.

productivity, but is subject to sunk costs $f_{RD,0}$ in the period the firm starts innovating and fixed costs f_{RD} in other periods in which it innovates. We follow Aw et al. (2011) and assume that log-productivity $\omega_{i,t}$ follows the following Markov process

$$\omega_{i,t} = \alpha_0 + \alpha_1 \omega_{i,t-1} + \alpha_2 I_{iRD,t-1} + u_{i,t}, \quad u_{i,t} \sim N(0, \sigma_u^2), \tag{18}$$

where $I_{iRD,t-1}$ is an indicator variable for innovation in $t-1$ and α_2 is the log-productivity return to innovation. Under $|\alpha_1| < 1$, the stochastic process is stationary and the model does not produce any long-run productivity trends. A firm that always engages in R&D has expected log-productivity $E(\omega_{i,t}|I_{iRD,t} = 1 \quad \forall t) = \frac{\alpha_0+\alpha_2}{1-\alpha_1}$, whereas a firm that never does R&D has expected log-productivity $E(\omega_{i,t}|I_{iRD,t} = 0 \quad \forall t) = \frac{\alpha_0}{1-\alpha_1}$.

We model credit constraints by assuming that in each period the sum of all sunk and fixed costs cannot go beyond a proportion θ of current period's profits:

$$I_{iRD,t}\left[f_{RD,0}\left(1 - I_{iRD,t-1}\right) + f_{RD} I_{iRD,t-1}\right] \leq \theta \Pi_{i,t}\left(\omega_{i,t}, e_t\right). \tag{19}$$

Parameter $\theta \in [1, \bar{\theta}]$ reflects the quality of the financial system: the lower θ, the more financially constrained the firms.

As in Manova (2013), since firms do not have any savings from past cash flows or profits and they rent whatever physical they use, they cannot pledge any assets as collateral.[35] In order to avoid moral-hazard problems, lenders expect borrowing firms to have some "skin in the game" by financing a fraction of the investment themselves (that is, a down-payment).[36] The more important the moral-hazard problems, the lower θ, which implies a larger fraction of the project must be financed by the firm's profits.

To sum up, firms maximize

$$\mathbb{E}_0 \sum_{t=0}^{\infty} (1+r)^{-t} \left\{\Pi_{i,t} - I_{iRD,t}\left[f_{RD,0}\left(1 - I_{iRD,t-1}\right) + f_{RD} I_{iRD,t-1}\right]\right\} \tag{20}$$

s.t. (5), (17), (18), (19).[37] This objective function can be derived by maximizing the value of the firm given an initial debt level $B_{i,0}$, the budget constraint

$$\begin{aligned} B_{i,t+1} + \Pi_{i,t} &= I_{iRD,t}\left[f_{RD,0}\left(1 - I_{iRD,t-1}\right) + f_{RD} I_{iRD,t-1}\right] + (1+r) B_{i,t}, \text{for } B_{i,t} > 0, \\ \Pi_{i,t} - I_{iRD,t}\left[f_{RD,0}\left(1 - I_{iRD,t-1}\right) + f_{RD} I_{iRD,t-1}\right] &= dividends_{i,t}, \text{for } B_{i,t} = 0, \end{aligned} \tag{21}$$

and the condition $\lim_{t\to\infty} B_{i,t}/\left(1+r\right)^t \leq 0$. The current state for firm i in year t is given by the vector

[35] In Manova (2013), firms cannot use profits from past periods to finance future operations: in the absence of debt they have to distribute all profits to shareholders due to (unmodeled) principal-agent problems; in the presence of outstanding debts they use all profits for repayment.

[36] Alternatively, one could assume that a constant fraction of profits goes to dividends and the rest to debt repayment.

[37] Discounting with the riskless interest rate r implicitly assumes that firm owners are risk neutral or able to diversify away the firm's idiosyncratic risk.

$s_{i,t} = (\omega_{i,t}, e_t, I_{iRD,t-1})$. The firm's value function is then

$$\begin{aligned} & V_{i,t}(s_{i,t}) = \\ = \quad & \max_{I_{iRD,t}} \Big\{ \Pi_{i,t}(\omega_{i,t}, e_t) - [f_{RD,0}(1 - I_{iRD,t-1}) + f_{RD} I_{iRD,t-1}] + \beta \mathbb{E}_t V_{i,t+1}\left(s_{i,t+1} | I_{iRD,t} = 1, s_{i,t}\right), \\ & \Pi_{i,t}(\omega_{i,t}, e_t) + \beta \mathbb{E}_t V_{i,t+1}(s_{i,t+1} | I_{iRD,t} = 0, s_{i,t}) \Big\}, \end{aligned} \tag{22}$$

where $\beta = (1 + r)^{-1}$. The firm then chooses an infinite sequence of R&D decisions $I_{iRD,t}$ that maximizes the value function subject to the financial constraint for R&D.

This way of modeling R&D choice helps us understand the economics of the results reported in Table 4. Small (that is, low-productivity) firms that barely make any profits are unlikely to carry out any R&D activity: for high enough sunk costs, these firms have no incentive whatsoever in investing in R&D, even in the absence of credit constraints, as the net present value of such a decision is negative. For higher-productivity firms, the net present value of investing in R&D is positive, but the credit constraint limits such activity to the amount of current profits corrected by the tightness of the constraint. Moreover, the looser the constraint, the less current profits matter for R&D decisions. Finally, for very highly productive firms, current profits are large enough for them to finance R&D regardless of the credit constraint. Their investment activity is guided exclusively by the net present value of R&D activity.

To summarize, the timing of decision making we assume is the following:

1. Observe $s_{i,t} = (\omega_{i,t}, e_t, I_{iRD,t-1})$.
2. Observe the realizations of $f_{ix,t}$ and $f_{im,t}$.
3. Choose variables inputs ($M_{i,t}$, $L_{i,t}$, $K_{i,t}$), export status $I_{ix,t}$ and import status $I_{im,t}$.
4. Make R&D decision $I_{iRD,t}$.
5. Observe realization of additional productivity shock $\epsilon_{i,t}$.
6. Produce output $Y_{i,t}$ and sell according to demand.

Having set up the model, we now turn to its structural estimation.

4 Estimation

In this section, we present our calibration/estimation strategy. For a given elasticity of demand σ from the estimation of the production function (7), we obtain parameters α_0, α_1, α_2, which determine the stochastic process for log-productivity, and the output elasticities, β_l, β_k, β_m. Then, by estimating the AR(1) process specified for $\log(e_t)$ in equation (5), we obtain the parameters ruling the stochastic process of the RER (γ_0, γ_1, σ_v^2). Finally, given values for the substitution elasticity between intermediates ε and the interest rate r, the rest of the model's parameters (f_x, f_m, $f_{RD,0}$, f_{RD}, θ, D_T, D_T^*, σ_u^2) are estimated by using an indirect-inference approach that matches model and data statistics.[38]

4.1 Production-function Estimation

We follow de Loecker (2011) and Halpern et al. (2015) to recover our firm-level productivity measure. Substituting the demand function (11) into the definition of total revenue, the latter can be expressed as:[39]

$$R_{i,t} = p_{i,t}d_{i,t} + I_{iX,t}p_{i,t}^* d_{i,t}^* = (Y_{i,t})^{\frac{\sigma-1}{\sigma}} G_{i,t}\left(D_{T,t}, D_{T,t}^*, e_t\right), \tag{23}$$

where $Y_{i,t}$ is physical output and $G_{i,t}$ captures the state of aggregate demand, which depends on the RER e_t. $G_{i,t}$ varies by firm only through $I_{iX,t}$, an indicator variable that equals one if the firm exports and thus allows the firm to also attract foreign demand. Taking logs and plugging in production function (10), we obtain a log-linear expression of firm revenue in terms of physical output and aggregate demand:

$$r_{i,t} = \left[\tilde{\beta}_0 + \tilde{\beta}_k k_{i,t} + \tilde{\beta}_l l_{i,t} + \tilde{\beta}_m \tilde{m}_{i,t} - \tilde{\beta}_m \log(P_{X,t}) + \tilde{\beta}_m \tilde{a}_{it}(e_t) + \tilde{\omega}_{it} + \tilde{\epsilon}_{i,t}\right] + g_{i,t}\left(D_{T,t}, D_{T,t}^*, e_t\right), \tag{24}$$

where x indicates the natural log of the variable and $\tilde{x}$ indicates multiplication by $\frac{\sigma-1}{\sigma}$. In Appendix A-1.2 we show how to combine (24) with the Markov process for log productivity (18) in order to consistently estimate output elasticities $\tilde{\beta}_i$ and the return to R&D $\tilde{\alpha}_2$.

Having recovered the output elasticities, we can construct revenue-based productivity (TFPR) as

$$tfpr_{i,t} \equiv r_{i,t} - \tilde{\beta}_l l_{i,t} - \tilde{\beta}_k k_{i,t} - \tilde{\beta}_m m_{i,t} = \left[\tilde{\beta}_0 + \tilde{\omega}_{i,t} + \tilde{\epsilon}_{i,t} + \tilde{\beta}_m \tilde{a}_{i,t} - \tilde{\beta_m} \log P_{X,t}\right] + g_{i,t}\left(D_{T,t}, D_{T,t}^*, e_t\right). \tag{25}$$

Notice that measured revenue-based productivity is a combination of physical productivity $\tilde{\beta}_0 + \tilde{\omega}_{i,t} + \tilde{\epsilon}_{it}$, import effects on productivity $\tilde{\beta}_m \tilde{a}_{i,t}(e_t)$ and demand $g_{i,t}\left(D_{T,t}, D_{T,t}^*, e_t\right)$. We thus need to use our structural model to decompose it into these three effects.[40]

4.2 Decomposing the Revenue-based Productivity Effects of RER Changes

We now use our structural model to derive a decomposition that splits the revenue-based productivity elasticity into its different components. In the reduced-form regressions we used the following

[38] We assume that firms pick draws for the different fixed costs from a number of exponential distributions with means $\bar{f}_x$, $\bar{f}_m$ $\bar{f}_{RD,0}$, $\bar{f}_{RD}$, and variances f_x^2, f_m^2, $f_{RD,0}^2$,f_{RD}^2.

[39] Details of the derivation can be found in Appendix A-1.2.

[40] In the construction of TFPR for the reduced-form estimates, we do not adjust for the markup term (i.e., we do not multiply the output elasticities by $\sigma/(\sigma-1)$) since this requires an assumption on the value of σ. As we showed in Appendix Table A-3 adjusting output elasticities for this term makes no substantial difference for the empirical results. Consistently, when computing the decomposition of tfpr from the structural model, we also multiply coefficients by $(\sigma-1)/\sigma$ (see below).

econometric specification:

$$\mathbb{E}(tfpr_{ic,t}|X_{ic,t}) = \beta_0 + \beta_1 \log e_{c,t} + \beta_2 X_{ic,t} + \delta_i + \delta_t \tag{26}$$

Taking differences to eliminate δ_i, we obtain the regression specification in (1):

$$\Delta tfpr_{ic,t} = \beta_1 \Delta \log e_{ct} + \beta_2 \Delta X_{ic,t} + \Delta\delta_t + \Delta u_{ic,t}. \tag{27}$$

Taking expectations of (25) and derivatives with respect to RER, we can compute the model counterpart to the reduced-form regression coefficient β_1, the expected elasticity of TFPR with respect to RER:

$$\beta_1 \equiv \frac{\partial \mathbb{E}(tfptr_{i,t})}{\partial \log e_t} = \underbrace{\tilde{\alpha}_2 \frac{\partial Prob(I_{iRD,t-1}=1)}{\partial \log e_t}}_{\text{innovation}} + \underbrace{\tilde{\beta}_m \frac{\partial \mathbb{E}(\tilde{a}_{i,t})}{\partial \log e_t}}_{\text{imports}} + \underbrace{\frac{\partial \mathbb{E}(g_{i,t}(D_{T,t}, D^*_{T,t}, e_t))}{\partial \log e_t}}_{\text{demand}} \tag{28}$$

Note that $\frac{\partial Prob(I_{RD,t-1}=1)}{\partial \log e_t} = \frac{1}{\gamma_1}\frac{\partial Prob(I_{RD,t}=1)}{\partial \log e_t}$. This is the **innovation channel** of the elasticity of TFPR with respect to RER. Specifically, this channel combines the *market-size effect* that induces changes in innovation through variation in the net present value of future profits and the *financial-constraints channel*, which operates through a change of current profits and a variation of the borrowing constraint. We will further decompose it into these two effects below.

The second term is the **importing channel** of the elasticity of TFPR with respect to the RER. It operates through changes in marginal costs due to changes in imported intermediates. It can be further divided into an *extensive margin* (change in the probability to import weighted with the average import intensity) and an *intensive margin* (change in import intensity weighted with the average probability to import).[41] This channel, which affects the elasticity of TFPR negatively, is more important the larger the fraction of importers and the higher their import intensity.

Finally, the third term is the **demand channel** of the elasticity of TFPR. An increase in the RER increases demand for *exporters.* Again, this term can be further decomposed into extensive and intensive margins. It combines the change in the probability of exporting weighted by average export sales and the average change in exports weighted by the probability of exporting.[42] The demand channel is more important the larger the fraction of exporters and their export intensity. We will use our structural model to decompose the observed average elasticities of TFPR with respect to the RER into these three components.

[41] $\tilde{\beta}_m \frac{\partial \mathbb{E}(\tilde{a}_{i,t})}{\partial \log e_t} = \tilde{\beta}_m \left[\frac{\partial Prob(I_{im,t}>0)}{\partial \log e_t}\mathbb{E}(\tilde{a}_{i,t}|I_{im,t}>0) + Prob(I_{im,t}>0)\frac{\partial \mathbb{E}(\tilde{a}_{i,t}|I_{im,t}>0)}{\partial \log e_t}\right]$.

[42] $\frac{\partial \mathbb{E}(g_{i,t}(D_{T,t}, D^*_{T,t}, e_t))}{\partial \log e_t} = \left[\frac{\partial Prob(I_{ix,t}=1)}{\partial \log e_t}\mathbb{E}(g_{i,t}(D_{T,t}, D^*_{T,t}, e_t)|I_{ix,t}=1) + Prob(I_{ix,t}=1)\frac{\partial \mathbb{E}(g_{i,t}(D_{T,t}, D^*_{T,t}, e_t)|I_{ix,t}=1)}{\partial \log e_t}\right]$.

4.3 Indirect-inference Estimation

Table 6 reports our preferred values for the parameters we calibrate (r, σ, ε) and the list of parameters we estimate by matching model and data statistics. For industrialized economies, we choose a real interest rate of 5%. For all other economies, we set the annual real interest rate to 10%, a reasonable value for these economies. We set the elasticity of demand σ equal to 4 (see Costinot and Rodriguez-Clare, 2014). We set the elasticity of substitution between domestic and imported intermediates equal to 4, which is in the range estimated by Halpern et al. (2015) for Hungarian firms. We provide robustness checks for these parameter choices in Section 7.

The structural estimation method that is employed in this paper is Indirect Inference (see Gouriéroux and Monfort, 1993). In this method, we first choose a set of auxiliary statistics that provide a rich statistical description of the data and then try to find parameter values such that the model generates similar values for these auxiliary statistics. More formally, let ν be the $p \times 1$ vector of data statistics and let $\nu(\Theta)$ denote the synthetic counterpart of ν with the same statistics computed from artificial data generated by the structural model. Then the indirect-inference estimator of the $q \times 1$ vector Θ, $\tilde{\Theta}$ is the value that solves

$$\min_{\Theta}(\nu - \nu(\Theta))' V (\nu - \nu(\Theta)), \tag{29}$$

where V is the $p \times p$ optimal weighting matrix (the inverse of the variance-covariance matrix of the data statistics ν). The following parameters $\tilde{\Theta}$ are estimated within the structural model: the mean export fixed cost f_x, the mean import fixed cost f_m, the mean R&D sunk cost $f_{RD,0}$, the mean R&D fixed cost f_{RD}, the credit-constraint parameter θ and the domestic and foreign aggregate demand levels D_T and D_T^*. We also estimate within the model the auto-correlation and TFP, α_1 and the standard deviation of the TFP shocks σ_u.[43]

In terms of the statistics we choose to match in order to identify the model parameters, we distinguish between cross-sectional statistics (export probability, import probability, export/sales ratio for exporters, import/sales ratio for importers, R&D probability, mean and standard deviation of the firm-size distribution (gross output)) and dynamic statistics (continuation and start rate of R&D, elasticities of R&D probability and TFPR with respect to the RER, the elasticity of R&D with respect to cash flow of the top firm-size quartile, the ratio of this statistic for the fourth relative to the second firm-size quartile, and the auto-correlation of TFPR). Overall, we estimate 10 parameters, targeting 13 statistics. Thus, the model is over-identified.

Let us briefly discuss the intuition for the econometric identification of the different structural parameters. While parameters and moments are all jointly identified, some moments are much more sensitive to certain parameters than to others. The export probability mainly identifies the distribution of export fixed costs, while the export-to-sales ratio is informative about relative foreign demand. A higher mean export fixed cost reduces export participation, while higher foreign demand increases the

[43] In principle, these parameters can be directly recovered from the production-function estimation, but there we allow for a Markov process which is a bit more general than AR(1). We do this because the production-function estimation works much better when we also allow for a square term in lagged productivity.

exports-to-sales ratio. The elasticity of TFPR with respect to the RER also plays a role for pinning down these parameters: ceteris paribus, the smaller the export fixed costs and the larger foreign demand, the higher the export participation and intensity. Thus, the average export demand elasticity with respect to the RER and the elasticity of TFPR with respect to the RER will be higher in this case.

Similarly, the import probability and the import-to-sales ratio are most sensitive to import fixed costs and the relative quality of imported intermediates. A larger mean import fixed cost reduces import participation, while a larger price-adjusted quality of imported intermediates increases import intensity. Moreover, higher import participation and import intensity also reduce the average elasticity of TFPR with respect to the RER, as for importers TFPR contains the import component which is negatively impacted by an RER depreciation.

The elasticity of R&D with respect to cash flow is informative about the credit-constraint parameter, as it governs the extent to which R&D decisions are determined by current profits rather than by the net present value of future profits. Moreover, comparing the elasticities of R&D with respect to cash flow for the fourth and second firm-size quartiles is informative about how this statistic varies with firm size, which in turn depends on the level of credit constraints (see Table 4). When credit constraints are relaxed, the relationship between the elasticity of R&D with respect to cash flow and firm size becomes shallower. In the presence of tight credit constraints and sufficiently large start-up costs of R&D, low-productivity firms do not find it worthwhile to engage in R&D, while medium to high-productivity firms are credit constrained. Thus, the R&D decisions are very sensitive to current profits for sufficiently productive firms. By contrast, with loose credit constraints, low-productivity firms do not find it profitable to engage in R&D, while high-productivity firms' decisions are determined by net-present-value considerations. Consequently, R&D choices of sufficiently productive firms are not very sensitive to changes in the level of current profits.

The identification of the parameters related to R&D is more complicated, since individual parameters impact on several moments simultaneously. Given the TFP-return to R&D, α_2, and the process for the RER, the R&D probability, the R&D start rate, the R&D continuation rate, the auto-correlation of TFPR and the firm-size distribution together identify the R&D sunk and fixed costs, the auto-correlation and the standard deviation of TFP. Other things equal, a higher R&D sunk cost reduces the R&D participation rate, increases the R&D continuation rate, reduces the R&D start rate and also impacts on the auto-correlation of TFPR and the elasticity of TFPR with respect to the RER by making R&D less sensitive to fluctuations in the RER. A higher R&D fixed cost mainly reduces the R&D participation rate. Finally, the auto-correlation and standard deviation of TFP impact on the firm-size distribution, export and import participation, the net present value of R&D and its option value and thus on the R&D participation, start and continuation rates.

The indirect-inference procedure is implemented as follows. For a given set of parameter values, we solve the value function and the corresponding policy function with a value-function iteration procedure: we first draw a set of productivity and RER shocks; we then simulate a set of firms for

Table 6: Parameters needed

Parameter	Description	Value	Parameter	Description
(*set without solving the dynamic model*)				(*estimated parameters*)
σ	demand elasticity	4	f_x	export fixed cost, mean
ε	subst. elasticity intermediates	4	f_m	import fixed cost, mean
r	interest rate (emerging)	0.10	$f_{RD,0}$	R&D sunk cost, mean
r	interest rate (industrialized)	0.05	f_{RD}	R&D fixed cost, mean
α_2	return to R&D	0.06	θ	coefficient for credit constraint
γ_1	persistence, log RER	0.93	α_1	persistence, log productivity
σ_ν	s.d., log RER	0.1	σ_u	s.d., innovation of log productivity
			$\log(D_T)$	log domestic demand
			$\log(D^*_T)$	log foreign demand

multiple countries with different realizations of the RER and compute the statistics of interest. We compare the simulated and data statistics and update the parameter values to minimize the weighted distance between them. We iterate these steps (keeping the draws of the shocks fixed) until convergence. See the Appendix for details.

5 Estimation Results

5.1 Estimates of the Return to R&D, Output Elasticities, and the RER Process

We first discuss the parameters that can be estimated without simulating the dynamic model. Table A-7 in the Appendix reports the point estimates of both the production-function parameters (equation (7)) and the parameters of the stochastic process for log-productivity (equation (18)) for the pooled sample (industrialized countries, emerging Asia, other emerging markets). In columns (1) and (2) we report unconstrained estimates of the output elasticities of factor inputs for the gross-output and value-added production functions, while in columns (3) and (4) we report estimates imposing constant returns to scale. Depending on the specification, the estimate for the R&D coefficient $\tilde{\alpha}_2$ is in the interval [0.033, 0.078], which, given a value of σ of 4, corresponds to a short-run TFP return to R&D α_2 of 4.4 to 10.4 percent. Given an auto-correlation of TFP of around 0.9, this implies a steady-state TFP difference between a firm that never engages in R&D and one that always performs R&D of 40 to 100 percent. These numbers are broadly in line with the literature (see, e.g., Aw et al., 2010). To be conservative, we set the return equal to 6 percent in the model simulation, and provide robustness checks for an even lower value.

The estimates for the output elasticities suggest increasing returns to scale for the case of the gross-output based production function and constant returns for the value-added production function.[44] In the model simulations, we scale output elasticities to add up to unity (constant returns).

In Table A-8 in the Appendix we present results for estimating the AR(1) process of the log RER $\log(e_t)$ (see equation (5)) using the period 2001-2010 and pooling all countries in the sample. The point estimate for the auto-correlation of the log RER γ_1 is 0.93. This implies that swings in the RER are very persistent, and can thus potentially have a significant effect on firms' dynamic R&D investment decisions. Finally, the estimate for the standard deviation of the log RER σ_ν is 0.1.

5.2 Estimates of Other Parameters

Tables 7-9 report the parameter values estimated using the indirect-inference procedure for our different sub-samples, as well as a comparison between the data and the simulated statistics. We report standard errors in parentheses. In general, the model performs well in terms of fitting both cross-sectional moments as well as dynamic statistics. The firms-size distribution and the import and export probabilities and intensities are always very precisely matched, while the model slightly under-predicts R&D participation rates. R&D start and continuation rates are also quite closely matched in all regions. The model qualitatively matches the difference in signs of TFPR with respect to the RER across regions. The predicted RER elasticities are slightly larger in absolute magnitudes (0.21 vs. 0.12 for emerging Asia; -0.15 vs. -0.10 for other emerging economies) and the elasticities of R&D with respect to cash flow for the top firm-size quartile display slightly more variation across regions in the model than in the data. Overall, the discrepancies between model-generated and data moments, for both for cross-sectional (R&D, export and import probabilities, export-to-sales and import-to-sales ratios, firm-size mean and standard deviation) and dynamic statistics (R&D continuation and starting probabilities, the elasticity of TFPR with respect to the RER, the auto-correlation of TFPR, the elasticity of R&D with respect to cash flow and its slope as a function of firm size), are small.

We now turn to a discussion of the magnitudes of the parameter estimates, most of which are estimated quite precisely. The mean sunk costs incurred by R&D starters are large for firms in all regions. The values are remarkable relative to average R&D benefits (17.6 percent of average R&D benefits for emerging Asia, around 28 percent for other emerging economies and 102 percent for industrialized countries).[45] The mean R&D fixed cost for continuous R&D performers is much smaller compared to R&D start-up costs: these costs correspond to roughly 0.24 to 1 percent of mean R&D benefits. Not surprisingly, the mean fixed cost for importing is relatively low compared to importers' sales and lowest for other emerging economies (4th percentile of importers' sales). The mean fixed cost for exporting is more sizable and corresponds to the 10-12th percentile of exporters' sales. The high

[44] The coefficients on labor, capital and materials in column (1) are 0.336, 0.097 and 0.681 and correspond to $\beta_L = 0.448$, $\beta_K = 0.129$ and $\beta_M = 0.899$, which suggests increasing returns to scale. By contrast, the estimates for the value-added-based output elasticities in column (2) are $\tilde{\beta}_L = 0.533$, and $\tilde{\beta}_K = 0.208$ ($\beta_L = 0.71$ and $\beta_K = 0.28$), suggesting constant returns. The estimates for the constrained coefficients in column (3) are 0.336, 0.051 and 0.363 and imply $\beta_L = 0.448$, $\beta_K = 0.068$ and $\beta_M = 0.484$.

[45] By R&D benefits we understand the net present value of the firm's expected flow of profits if R&D takes place compared to the same variable in case no R&D occurs.

export intensity of firms in emerging Asia is due to large foreign demand relative to domestic demand as shown by the values of $\log(D_T^*)$ and $\log(D_T)$.

The value of parameter A, which reflects the price-adjusted relative quality of imported intermediates, is significantly lower than one for emerging Asia and the industrialized countries (0.72 and 0.69), whereas it takes on a larger value for other emerging economies (0.97). Credit constraints are estimated to be substantial for firms in emerging Asia and other emerging economies and non-binding for most firms in industrialized countries. Firms are estimated to be able to borrow 15 (11) times current profits in the case of emerging Asia (other emerging economies), while firms in industrialized countries can borrow up to 53 times current profits. This parameter is estimated relatively precisely, except for industrialized countries. Finally, the parameters ruling the stochastic process of log-productivity ω are comparable across the three subsamples: α_1 and σ_u are in the ballpark of 0.85 and 0.45, respectively. Thus, productivity is very persistent.

In Table 10 we report how the model performs in terms of predicting the non-targeted statistics from the reduced-form regressions in Table 1. For each region, we compute the elasticity of R&D, the elasticity of cash flow and the elasticity of the export entry rate with respect to the RER from the model and compare it with the estimates from Table 1. The table also reports confidence intervals for these estimates. We first discuss results for Emerging Asia. The model somewhat under-predicts the elasticity of R&D w.r.t. the RER (0.05 compared to 0.19); it performs extremely well in terms of replicating the elasticity of cash flow (0.75 compared to 0.78); and somewhat under-predicts the elasticity of the export entry rate (0.33 compared to 0.55). In all cases, the model-generated elasticity lies within the confidence interval of the data moments. For the case of the other emerging economies, the elasticity of R&D w.r.t the RER is -0.04 compared to 0.16 in the data. However, this reduced-form point estimate is very noisy and not statistically significant, so that the model-generated elasticity is within the data confidence interval. Instead, and in line with the intuitions of the mechanisms postulated by our model, the model generates a negative elasticity of cash flow (-0.51 compared to -0.55) and an elasticity of the export entry rate w.r.t. the RER (0.21 compared to 0.06) that is similar to the corresponding data moment. Finally, for the case of industrialized countries, there are somewhat larger discrepancies between the model-predicted elasticities, which are basically zero for the R&D and cash-flow elasticities, and the corresponding estimates from the data. However, the data estimates are very noisy and not statistically significant and the zero elasticity of R&D w.r.t. the RER is well within the confidence interval. Overall, the model performs well in terms of fitting the non-targeted moments, confirming its validity.

In Table 11 we use equation (28) to decompose the short-run elasticity of TFPR with respect to the RER into its various components for each of the regions. For emerging Asia, the overall elasticity is 0.21: a one-percent depreciation leads to a 0.266 percent increase in demand; a 0.055 percent loss in TFPR due to less importing and a 0.013 increase in productivity associated to the innovation channel due to more R&D. Thus, in the short run, even in emerging Asia physical productivity gains are more than compensated by productivity losses from importing. However, this result is reversed in the

Table 7: Estimated parameters and model fit: emerging Asia

Parameter	Description	Value (sd)	Moments	Data	Model
			(*Cross-sectional moments*)		
f_x	log export fixed cost,mean	7.98 (0.01) (11th pctile of exporters' sales)	R&D probability	0.25	0.19
$f_{RD,0}$	log R&D sunkcost, mean	13.38 (0.53) (17.6 pct. of avg. R&D benefit)	Export probability	0.26	0.26
f_{RD}	log R&D fixed cost, mean	9.06 (0.43) (0.24 pct. of avg. R&D benefit)	Export/sales Ratio, mean	0.60	0.64
f_m	import fixed cost, mean	7.99 (0.03) (5th pctile of importers' sales)	Import probability	0.17	0.19
A	quality of imported intermediates	0.72 (0.01)	Import/sales ratio	0.17	0.19
$\log(D_T)$	log domestic demand	5.56 (0.01)	Mean firm size (log revenue)	6.6	6.7
$\log(D_T^*)$	log foreign demand	6.53 (0.01)	Sd, firm size (log revenue)	3.23	3.19
α_1	persistence, productivity	0.86 (0.003)	(*Dynamic moments*)		
σ_u	sd, innovation of productivity	0.44 (0.006)	R&D, continuation prob.	0.90	0.86
θ	credit constraint	15.11 (7.94)	R&D, start prob.	0.06	0.04
			autocorrelation, TFPR	0.91	0.86
			Elasticity of TFPR w.r.t RER	0.12	0.21
			Elasticity of R&D prob. w.r.t c.f. (4th firm-size quantile)	0.041	0.054
			Elasticity of R&D prob. w.r.t c.f. (difference of 4th and 2nd firm-size quantile)	0.030	0.034

Table 8: Estimated parameters and model fit: other emerging economies

Parameter	Description	Value (sd)	Moments	Data	Model
			(*Cross-sectional moments*)		
f_x	log export fixed cost,mean	4.17 (2.18) (10th pctile of exporters' sales)	R&D probability	0.25	0.22
$f_{RD,0}$	log R&D sunkcost, mean	11.24 (0.31) (28 pct. of avg. R&D benefit)	Export probability	0.35	0.30
f_{RD}	log R&D fixed cost, mean	7.84 (0.32) (1 pct. of avg. R&D benefit)	Export/sales Ratio, mean	0.10	0.12
f_m	log import fixed cost, mean	5.88 (0.81) (4th pctile of importers' sales)	Import probability	0.39	0.35
A	quality of imported intermediates	0.97 (0.35)	Import/sales ratio	0.24	0.25
$\log(D_T)$	log domestic demand	4.88 (0.30)	Mean firm size (log revenue)	5.97	5.98
$\log(D_T^*)$	log foreign demand	3.02 (2.01)	Sd, firm size (log revenue)	2.63	2.67
α_1	persistence, productivity	0.84 (0.01)	(*Dynamic moments*)		
σ_u	sd, innovation of productivity	0.40 (0.06)	R&D, continuation prob.	0.90	0.83
θ	credit constraint	11.02 (2.80)	R&D, start prob.	0.06	0.05
			autocorrelation, TFPR	0.84	0.85
			Elasticity of TFPR w.r.t RER	-0.10	-0.15
			Elasticity of R&D prob. w.r.t c.f. (4th firm-size quantile)	0.048	0.072
			Elasticity of R&D prob. w.r.t c.f. (difference of 4th and 2nd firm-size quantile)	0.035	0.039

Table 9: Estimated parameters and model fit: industrialized countries

Parameter	Description	Value (sd)	Moments	Data	Model
			(*Cross-sectional moments*)		
f_x	log export fixed cost,mean	6.82 (1.35) (12th pctile of exporters' sales)	R&D probability	0.56	0.40
$f_{RD,0}$	log R&D sunkcost, mean	13.75 (0.47) (102 pct. of avg. R&D benefit)	Export probability	0.23	0.24
f_{RD}	log R&D fixed cost, mean	9.11 (0.46) (1 pct. of avg. R&D benefit)	Export/sales Ratio, mean	0.17	0.15
f_m	log import fixed cost, mean	8.42 (1.28) (5th pctile of importers' sales)	Import probability	0.20	0.19
A	quality of imported intermediates	0.69 (0.33)	Import/sales ratio	0.14	0.13
$\log(D_T)$	log domestic demand	6.66 (0.14)	Mean firm size (log revenue)	7.64	7.64
$\log(D_T^*)$	log foreign demand	4.99 (1.30)	Sd, firm size (revenue)	2.91	2.91
α_1	persistence, productivity	0.79 (0.003)	(*Dynamic moments*)		
σ_u	sd, innovation of productivity	0.54 (0.04)	R&D, continuation prob.	0.90	0.90
θ	credit constraint	53 (27.17)	R&D, start prob.	0.06	0.07
			autocorrelation, TFPR	0.90	0.81
			Elasticity of TFPR w.r.t RER	-0.03	-0.02
			Elasticity of R&D prob. w.r.t c.f.(4th firm-size quantile)	0.027	0.049
			Elasticity of R&D prob. w.r.t c.f. (difference of 4th and 2nd firm-size quantile)	0.022	0.001

Table 10: Non-targeted moments

	Model	Data	Confidence interval data moments
Emerging Asia			
elasticity of R&D w.r.t RER	0.052	0.190	[0.004, 0.376]
elasticity of cash flow w.r.t RER	0.745	0.783	[0.560, 1.006]
elasticity of export entry rate w.r.t RER	0.326	0.552	[0.146, 0.958]
Other emerging			
elasticity of R&D w.r.t RER	-0.043	0.160	[-0.085, 0.405]
elasticity of cash flow w.r.t RER	-0.514	-0.557	[-0.839, -0.275]
elasticity of export entry rate w.r.t RER	0.217	0.063	[-0.053, 0.179]
Industrialized			
elasticity of R&D w.r.t RER	-0.0002	-0.168	[-0.460, 0.124]
elasticity of cash flow w.r.t RER	-0.041	-0.319	[-0.566, -0.072]
elasticity of export entry rate w.r.t RER	0.264	-0.275	[-0.812, 0.262]

medium run, as we show below, because productivity gains from R&D are persistent, while productivity losses due to reduced importing are temporary. In the set of other emerging economies a one-percent depreciation is associated with a 0.153 percent loss in TFPR, which is composed of a 0.051 increase in demand, a 0.207 percent loss in TFPR due to reduced imports, and a 0.009 percent productivity gain from increased R&D. Intuitively, the large import dependence relative to the export orientation of these economies exacerbates the negative effects of the depreciation. Finally, the elasticity of TFPR is basically zero in industrialized countries (-0.017) and consists of a 0.051 percent increase in demand, a 0.069 productivity loss due to reduced imports and a 0.013 productivity gain from increased R&D. Thus, our model highlights very different effects of real depreciations on TFPR and its components across regions due to the regional differences in the underlying structure of these economies.

Table 11: Elasticity of TFPR (G.O) w.r.t RER, Decomposition

	Innovation (R&D)	Imports	Demand	Total Elasticity
Emerging Asia	0.013	-0.055	0.266	0.21
Other emerging	0.009	-0.207	0.051	-0.153
Industrialized	0.013	-0.069	0.051	-0.017

6 Counterfactuals

In this section, we perform a number of counterfactual exercises with the estimated model in order to understand its quantitative implications. As a benchmark exercise, we first simulate an unanticipated temporary depreciation of the RER. We allow for a yearly depreciation of 5% for five years with a subsequent sudden 25% appreciation back to the initial level of the RER (Figure 2). This magnitude corresponds roughly to a one-standard-deviation change in the RER over a five-year interval (see

Appendix Table A-1 Panel D). All along the exercise we keep firms' beliefs about the exchange-rate process constant. We then simulate a similar RER depreciation of smaller magnitude (12.5%) to show that the impact of depreciations is non-linear. Finally, we explore the asymmetries of firms' responses by simulating a 25% appreciation. We perform each of these exercises separately for the samples of emerging Asia, other emerging economies and industrialized countries.

6.1 Benchmark: 25% Depreciation

Emerging Asia Figure 3 plots the simulation results for outcomes averaged over the firm distribution. We depict the time paths of the percentage-point deviations of the RER, revenue TFP and its components (physical TFP, import effects on TFPR, demand effects on TFPR) from their original steady-state levels. The continuous red lines plot the effects of the benchmark 25% real depreciation.[46] The impact of a depreciation on TFPR is positive: it leads to up to a 6.5% increase in average firm-level TFPR. The positive demand effect of the depreciation on TFPR is even larger (up to 8%), while the negative impact on TFPR through the import channel is relatively small (with a minimum of -1%). Physical TFP increases by up to 0.5% due to the depreciation.

These effects are expected in a sub-sample of countries with relatively export-intensive firms: in this case, the increase in profits due to higher demand for firms' exports is larger than the decrease in profits due to the fact that intermediate inputs become more expensive. The resulting net increase in profits leads to more R&D investment and an increase in physical productivity. Notice that the increase in physical productivity persists much longer than the other effects, which disappear as soon as the RER appreciates back to its initial level: temporary RER movements can have very long-lasting effects on TFP growth.

Finally, there is both a direct and an indirect impact of the depreciation working through innovation and physical TFP growth. The direct effect comes through more R&D participation, while the indirect impact works through the additional exporting and importing in the future (at the extensive and intensive margins) induced by the additional R&D. These changes influence future trade participation and thus the import and demand components of TFPR.[47]

Other Emerging Economies The overall impact of the depreciation on TFPR is negative: the depreciation leads roughly to a 3% decline in TFPR. (See Figure 4.) The negative effect of the depreciation on TFPR through the import channel (-4.3%) dominates the positive effect operating through the demand channel (1.6%). Physical productivity falls by up to 0.3%. Again, changes in physical productivity are much more long lasting than those of the other components of TFPR. Moreover, the direct impact of the decline in physical TFP explains only around 10% of the reduction in TFPR.[48]

[46]The blue dashed-dotted lines plot the effect of a 12.5% depreciation. The gray dashed lines lines corrrespond to the effects of a 25% appreciation.

[47]Quantitatively, the indirect effect on average TFPR growth turns out to be relatively small: it accounts for at most 0.1 percentage points (around the time the RER re-appreciates back to the initial level).

[48]The indirect impact of changes in R&D on TFPR via less exports and imports accounts for a TFPR reduction of -0.05%.

Figure 2: Unexpected real depreciation (25%, 12.5%) and real appreciation (25%).

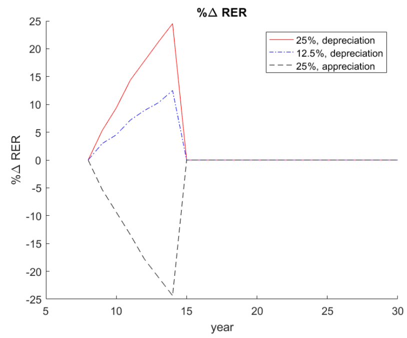


Figure 3: Effect of an unexpected real depreciation (25%, 12.5%) and appreciation (25%) for emerging Asia.

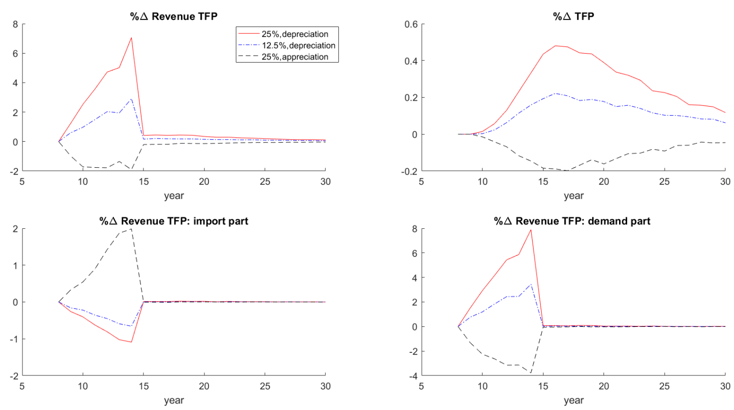


Figure 4: Effect of an unexpected real depreciation (25%, 12.5%) and appreciation (25%) for other emerging economies.

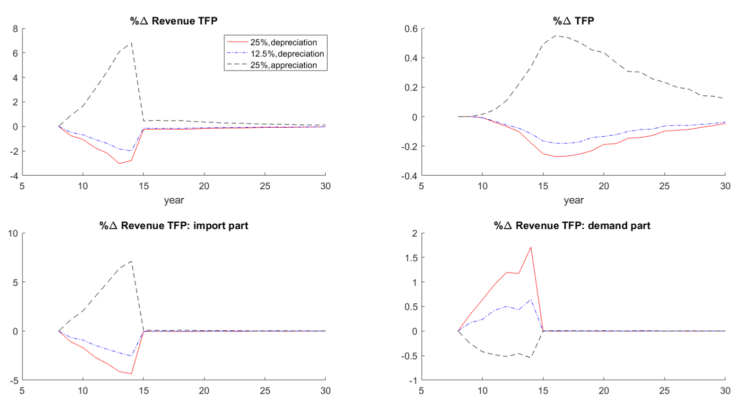
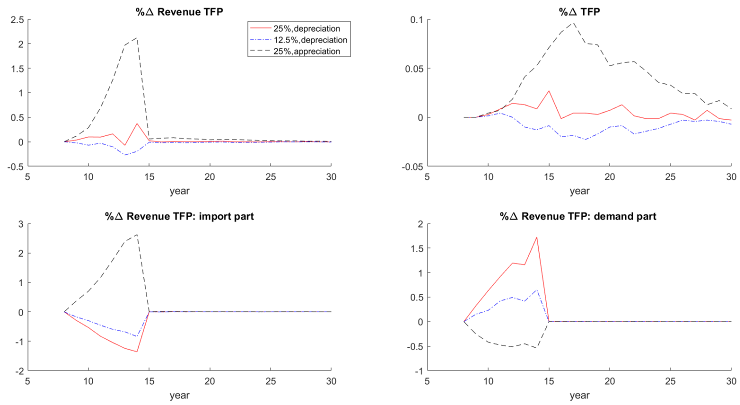


Figure 5: Effect of an unexpected real depreciation (25%, 12.5%) and appreciation (25%) for industrialized economies.



Recall that firms in this sub-sample are, in comparison with firms in emerging Asia, relatively import intensive. This reverses the net effect of the depreciation on firms' profits, which becomes negative and induces firms to reduce their investment in R&D and a subsequent decrease in physical TFP.

Industrialized Countries The pattern of long-lasting changes in physical productivity growth and merely transitory reactions of the other two components of revenue TFP repeats itself once more. (See Figure 5.) The overall effect of the depreciation on revenue TFP growth is positive but tiny in comparison with the magnitudes of our previous two counterfactual exercises. In this case, demand and import TFPR growth are of similar magnitude. The increase in profits induced by a larger volume of exports is compensated by the decrease in profits due to more expensive intermediate-input imports. Since the positive and negative effects of the depreciation on profits roughly cancel each other, R&D investment barely differs from zero: changes in physical TFP are positive but very close to zero.

6.2 Non-linearities: 12.5% Depreciation

We now simulate a 12.5% depreciation (blue dashed-dotted lines in Figures 2-5).

Emerging Asia In Figure 3 one can see that TFPR increases by slightly more than 2% (compared to more than 6% for the 25% depreciation), physical TFP expands by 0.2% (compared to around 0.5%); the demand component of TFP rises by around 3% (compared to 8%) and the import component of TFPR decreases by less than 0.5% (compared to more than 1%). The overall impact of the 25% depreciation on firm-level outcomes is more than double than that of the 12.5% depreciation.

Given the high relative export intensity of this region's firms, the losses from more expensive imported inputs are compensated by the profits from better access to export markets. Moreover, the cost of intermediates rises less than proportionally with a depreciation due to the possibility of replacing imported inputs with domestic ones (see Section 3.3). Larger depreciations therefore bring about more than proportional increases in profitability compared to smaller depreciations. Moreover, higher profitability due to larger exports induces more firms to import through the complementarities between these two choice variables, which counterbalances the negative effect of higher import costs to some extent. Finally, since profitability increases disproportionately more with a larger depreciation, physical TFP also rises disproportionately more, as the number of firms that start investing in R&D is higher with the larger depreciation.

Other Emerging Economies The total (negative) effect of a 12.5% depreciation on total revenue TFP (-2% compared to -3%), physical TFP (-0.2% compared to -0.3%) and the import component of TFPR (-3% compared to -4.5%) is proportionally smaller in absolute magnitude than the one of a 25% depreciation, whereas the impact on the demand component of TFPR (1.8% compared to 0.6%) is relatively larger for a depreciation of larger magnitude. Thus, the impact of a smaller depreciation in other emerging economies is comparatively large, whereas for emerging Asia it is the impact of a larger depreciation that is relatively large.

Since this region's firms feature a high relative import intensity, depreciations reduce their profitability. Given the non-linear effect of the real exchange rate on import costs, imports fall disproportionately less with a larger depreciation. Thus, exports increase disproportionately more due to the complementarities between the two activities. Finally, since the average firm's profitability is reduced disproportionately less with the larger depreciation, innovation and thus physical TFP also fall disproportionately less.

Industrialized Countries The negative impact of the 12.5% depreciation is larger in absolute terms than the one of the 25% depreciation. Import and export intensities are very similar, so that the larger profitability induced by a depreciation through the export channel is roughly offset by higher import costs. Because of the non-linear effect of a depreciation on the import costs, import costs fall disproportionately less with a larger depreciation. It turns out that for the 12.5% depreciation the import component of TFPR dominates the export component, so that firms become slightly less profitable and thus perform slightly less innovation, reducing physical TFP. By contrast, with the 25% depreciation the increase in profits via the export channel dominates the import component and profitability and thus physical TFP increase slightly.

6.3 Asymmetries: 25% Appreciation

We now simulate an unanticipated temporary yearly appreciation of 5% for five years with a subsequent sudden 25% depreciation back to the initial level of the RER (see the gray dashed lines in Figures 2-5).

Emerging Asia The effects of an appreciation on average firm-level TFPR and its components are qualitatively opposite to those of a depreciation. (See Figure 3.) The reduction in TFPR through lower exports and lower physical TFP due to less innovation dominates the positive effect on TFPR through more imports. However, the quantitative impact on TFPR and its components (TFPR falls by at most 2%, which can be decomposed into a 4% drop in demand, a 1.8% increase in TFPR due to cheaper imported inputs and a 0.2% reduction in physical TFP) is just around a third of the size of the corresponding effects of a depreciation of the same absolute magnitude.

Due to the large magnitude of R&D sunk costs relative to that of fixed costs, firms respond more to a positive shock to the net present value of innovation than to a negative one. They try to avoid paying the sunk costs of re-starting innovation in case they stop performing R&D. In other words, R&D has an option value in the face of a negative shock. This effect relates to the classical hysteresis argument made by Baldwin (1988), Baldwin and Krugman (1989) and Dixit (1989). For firms in this region, a depreciation corresponds to a positive shock to R&D profitability, while an appreciation corresponds to a negative one. Thus, in this region physical TFP responds more to a depreciation than to an appreciation.[49]

Moreover, a depreciation triggers a reduction in imports that is smaller than the increase associated to an appreciation. This is the result of three feedback effects: (i) for a depreciation, the positive change in physical TFP due to more innovation mitigates the impact of higher import costs; (ii) the import component of TFPR decreases less during a depreciation than it increases for an appreciation of the same magnitude due to substitution effects; (iii) complementarities between exporting and importing activities: since in emerging Asia export intensity is high compared to import intensity, the pull effects of higher exports on imports are larger than the other way round. Finally, a depreciation triggers an increase in exports larger than the decline in exports caused by an appreciation: the extensive margin of exports responds more to a depreciation because of the stronger selection into exporting triggered by the more sizable change in physical TFP.

Other Emerging Economies In stark contrast to emerging Asia, the impact of the appreciation on TFPR is in this case positive and more than twice as large as the negative effect of the depreciation. As seen in Figure 4, TFPR increases by around 6.5%, compared to the three-percent decline of the depreciation. This effect on TFPR is composed of a 6.5% increase in TFPR through increased imports, a 0.5% decline through reduced exports and a 0.5% increase via larger physical TFP. A positive shock to profitability has a larger impact on innovation and thus on physical TFP growth than a negative one.

The explanation of these effects is the mirror image of the emerging-Asia case: since for other emerging economies an appreciation increases the profitability of R&D, while a depreciation reduces it, an appreciation has a larger effect on physical TFP growth compared to a depreciation due of the option-value effect. Besides, due to complementarities between exporting and importing decisions, the larger import orientation and the smaller export orientation of these economies, the positive effects of importing on exporting via the appreciation are more sizable than the negative effects of less exporting on importing via the depreciation. Moreover, the increase in physical TFP due to the appreciation leads more firms to select into exporting and importing and thus also raises TFPR through these channels. Finally, the non-linearity of $\tilde{a}_t$ leads to larger import increases with an appreciation than export declines with a depreciation.

[49] There is also an additional channel via credit constraints: credit constraints are relaxed for more firms during a depreciation than they are tightened during an appreciation because R&D continuation costs are smaller than start-up costs. However, this effect turns out to be quantitatively small compared to the asymmetries induced by the option value.

Industrialized Countries In this case, the impact of RER movements on TFPR is quantitatively small compared to the other regions and qualitatively similar to the case of other developing countries. (See Figure 5.) The effect of the 25% appreciation on TFPR is positive and larger in magnitude compared to the one of a depreciation of equal size. In the case of a depreciation, the negative impact on TFPR via the import channel is almost exactly offset by the positive effect through more exports, so that innovation and physical TFP are almost unchanged. For an appreciation, the positive effects through cheaper inputs and increased profitability of R&D dominate the negative effects on TFPR through reduced exports so that the net effects on TFPR are positive but small (TFPR increases by two percent and physical TFP by 0.1%). The intuition is very similar to the case of other developing countries.

The model's predictions for the asymmetric effects of RER depreciations and appreciations are consistent with the corresponding reduced-form estimates, as we show in Appendix Table A-9. In these specifications, we allow for differential impacts of RER depreciations and appreciations on firm-level outcomes for each region. In emerging Asia, the impact of RER depreciations is positive, large and highly statistically significant, while RER appreciations have no significant impact on firm-level outcomes. In the other emerging economies, the impact of RER appreciations on firm-level outcomes is instead positive, large and highly significant, while depreciations have no statistically significant effect. Finally, for industrialized countries, neither depreciations nor appreciations have significant effects.

6.4 Decomposition of Productivity Growth

Finally, we decompose the effect of the 25% temporary depreciation on physical TFP growth into (i) market-size effects and (ii) relaxed credit constraints.We provide numbers for the five-year depreciation period. Table 12 indicates that in emerging Asia the R&D participation rate increases by 2.6 percentage points during the depreciation. 87% of the new R&D performers start this activity due to a relaxation of credit constraints (firms that found it profitable to do R&D in net-present-value terms, for which the credit constraint was initially binding), while only 13% of the new R&D investment is due to an increase in market size (firms that were initially unconstrained but found it unprofitable to engage in R&D in net-present-value terms, for which it now becomes profitable to perform R&D). By contrast, in the other emerging economies, the R&D participation rate falls by 1.7 percentage points. This drop can be decomposed into a 82% reduction due to an increase in credit constraints and a 18% reduction due to reduced market size effects.[50]

[50]We do not report the decomposition for industrialized countries, as the R&D participation rate hardly reacts to the depreciation.

Table 12: Elasticity of R&D w.r.t RER, decomposition into market size and financial constraints (25% over 5-year depreciation period).

	Innovation Channel (Change in R&D prob.)	Market size	Financial constraints
emerging Asia	2.6%	13%	87%
Other emerging	-1.7%	18%	82%

7 Extensions and Robustness

7.1 Foreign-currency Borrowing

An alternative explanation for the heterogeneity of RER effects on firm-level outcomes across regions lies in the fact that firms, in particular in emerging economies, often borrow in foreign currency. In this case, a RER depreciation makes foreign borrowing more expensive and may thus discourage R&D investment for firms that finance a large share of their debt in foreign currency. While firms in industrialized countries mostly borrow in their own currency, we employ the Worldbank's World Enterprise Survey to show that firms in Latin America and Eastern Europe are far more exposed to foreign-currency borrowing than firms in emerging Asia. As explained in the data section, we cross-checked the data with several alternative local sources.[51]

In the first column of Table 13, we report the OLS regression results from running the share of manufacturing firms' foreign-currency liabilities in total liabilities on dummies for emerging Asia and other emerging economies (Latin America and Eastern Europe). The latter's average share of foreign borrowing is roughly twice as large as that of the former (around 20% compared to 10%). In column (2) we add interactions of region dummies with exporter and importer status dummies. Not surprisingly, in both regions exporting firms exhibit a much larger average share of foreign-currency borrowing than importing firms or firms that do not engage in international trade. Still, the overall effect suggests that firms from emerging Asia are much less dependent on foreign-currency borrowing than firms from other emerging countries. Thus, it is possible that RER depreciations lead to different effects across regions not only because of differences in export and import orientation, but also because of differential exposure of firms to foreign-currency borrowing. Given their stronger reliance on such sources of financing, firms from other emerging economies experience an increase in borrowing costs in the event of a depreciation in comparison with firms from emerging Asia.[52]

We now extend our structural model to consider foreign-currency borrowing. In order to assess the importance of this channel, we assume that firms contract loans for period t in period $t-1$. Lenders loan a multiple θ of the firms' period-t expected profits $E_{t-1}\Pi_{i,t}$. A share λ is borrowed by the firm

[51] For our time period, we analyze as well foreign currency patterns in Hungary and Colombia. For France, according to BIS, most firms tend to borrow in local currency.

[52] The more positive effects of depreciations on exporters and the more negative effects on importers found above cannot be rationalized with differential foreign currency exposure, since exporters borrow more in foreign currency, while importers are not different from firms that do not trade.

Table 13: Foreign debt shares by region

	(1) foreign debt share	(2) foreign debt share
emerging Asia$_c$	10.61***	4.820***
	(0.338)	(0.462)
emerging Asia$_c$× exporter$_f$		18.21***
		(0.876)
emerging Asia$_c$× importer$_f$		0.433
		(0.626)
other emerging$_c$	19.09***	14.15***
	(0.386)	(0.581)
other emerging$_c$× exporter$_f$		24.90***
		(1.073)
other emerging$_c$× importer$_f$		-0.919
		(0.759)
Observations	14,554	14,554
R-squared	0.201	0.271
Cluster	Firm	Firm

Notes: The dependent variable in columns (1)-(5) is the foreign debt share for manufacturing firms in emerging Asia and other emerging economies (Latin America, Eastern Europe) in the 2016 World Enterprise Survey.

in domestic consumption units and a share $1-\lambda$ is borrowed in foreign consumption units, where λ is an exogenous parameter that we allow to vary by region and trade status.[53] In the event of a RER depreciation (that is, $e_{t-1}/e_t < 1$), the corresponding credit constraint becomes tighter, as a given amount of expected profits in domestic consumption units elicits a smaller amount of credit in foreign consumption units. (Implicit is the assumption that lenders, at the moment in which e_t is realized, do not have time to revise expectations.) The credit constraint now is as follows:[54]

$$\theta\left[\lambda+(1-\lambda)\frac{E_{t-1}(e_t)}{e_t}\right]E_{t-1}\Pi_{i,t}\geq I_{iRD,t}\left[f_{RD,0}\left(1-I_{iRD,t-1}\right)+f_{RD}I_{iRD,t-1}\right]. \tag{30}$$

We calibrate the model by setting the foreign debt shares equal to the estimated ones for each region and trade-participation status and re-simulate a 25% depreciation. We find that the positive effects of depreciations are slightly smaller than in the baseline model for the case of emerging Asia, but the balance-sheet effects are dominated by the increase in expected profitability from exporting.[55] Similarly, the negative impact of depreciations on TFP in other emerging economies becomes a bit larger, but the most important channel continues to be importing. Thus, our results are robust to introducing foreign-currency borrowing.

[53] We abstract from the firm's endogenous choice in terms of the currency denomination of its debt. See, e.g., Salomão and Varela, 2017.

[54] Under the assumption that the firm makes repayments so as to keep a fraction λ of domestic debt and a fraction $1-\lambda$ of foreign debt, the firm's budget constraint needs to be modified as follows:

$$B_{i,t+1}+\Pi_{i,t}-I_{iRD,t}\left[f_{RD,0}\left(1-I_{iRD,t-1}\right)+f_{RD}I_{iRD,t-1}\right]=(1+r)\left[\lambda+(1-\lambda)\,e_t/e_{t-1}\right]B_{i,t},\ B_{i,t}>0.$$

The term e_t/e_{t-1} represents the effect of a RER depreciation on the value of the firm's outstanding debts in terms of domestic consumption. Notice, however, that our assumptions on the firm's behavior regarding dividends and debt repayment prevent RER changes from affecting the firm's credit constraint via the firm's stock of outstanding debt.

[55] Only with a significantly higher foreign debt share than present in the data the tightening of the credit constraint through valuation effects becomes dominant and innovation and physical TFP decline initially.

7.2 Sensitivity Checks

We now present robustness checks regarding the values of the calibrated parameters. We consider different values for the elasticity of demand (σ), the elasticity of substitution between domestic and imported intermediates (ε) and the return to R&D (α_1). We vary each of these parameters one by one and re-estimate the structural model given the new parameter value. We report results for the indirect-inference parameter estimates and the simulated model statistics in Appendix Tables A-10 to A-12.

We first consider a higher value for the elasticity of demand within the reasonable range for this parameter ($\sigma = 6$ instead of $\sigma = 4$), while leaving the other preset parameters at their baseline values. Increasing σ makes the sales distribution more sensitive to the underlying TFP differences and thus reduces the estimate of the standard deviation of the TFP process σ_u required to fit the firm-size distribution. To keep the R&D continuation and start probabilities fixed, this then requires a lower estimate of the R&D sunk cost $f_{RD,0}$. The remaining parameter estimates are not affected much and the fit of the model is overall similar to the baseline case.

Next, we change the elasticity of substitution between intermediates ε and consider a value of 6 instead of 4, which is still within the range of values estimated by Halpern et al., 2015. Increasing ε makes imports more sensitive to price-adjusted quality and thus requires us to adjust downward the estimate of the quality of imported intermediates A to keep the import to sales ratio fixed. This then requires a lower estimate for the import fixed cost f_m in order to hold the import probability constant. The remaining parameter estimates are not significantly altered and the model fit is overall not changed much compared to the baseline case.

Third, we reduce the short-run return to R&D from 6 to 4 percent (this is the lower bound of our estimates from the production-function estimation). A lower return to R&D mainly requires a downward adjustment in the R&D sunk cost $f_{RD,0}$ to keep the R&D start and continuation rates roughly similar. However, with a lower R&D sunk cost the R&D continuation rate is reduced and too low compared to the targeted rate.

Finally, our results are also robust to considering higher or lower real interest rates (15% and 5%) for discounting firm-level profits. As the estimated parameters are hardly affected, we do not report these results for brevity. The decomposition of innovation responses into credit constraints and market size slightly shifts (results available upon request).

Overall, the model fit is robust to altering the value of these calibrated parameters – alternative values give similar model fit. In addition, this robustness also implies that these parameters need to be set outside of the indirect-inference procedure because the targeted statistics are not very informative about their values.

8 Conclusions

This paper evaluates firms' responses to changes in the real exchange rate. We limit the analysis to manufacturing firms as we exploit a detailed firm-level dataset for a large set of countries for the period 2001-2010. Our focus on the firm level enables us to tease the micro channels through which the aggregate economic effects of changes in the real exchange rate operate. Further, we establish that the relative strength of these channels varies across regions and types of firms.

For the average firm in emerging Asia, real depreciations are associated with faster growth in revenue-based productivity, sales and cash flow; a higher probability to engage in R&D; and higher export entry rates. In other emerging markets (Latin America and Eastern Europe), real depreciations have instead a significantly negative effect on firm-level outcomes. Finally, in industrialized countries real depreciations have no significant effects on average firm-level outcomes. When conditioning on trade participation, we find that exporters are positively affected by real depreciations, while importers are hurt. We show that firms in emerging Asia are relatively more likely to export and relatively more export intensive than firms in other emerging economies and industrialized countries. Our firm-level evidence also establishes that a firm's R&D choice depends on the level of internal cash flow, and the more so the less developed local financial markets are.

Motivated by these facts, we build and estimate a dynamic firm-level model in which real depreciations raise the cost of importing intermediates, but increase demand and the profitability to engage in exports and R&D. The latter effect relaxes borrowing constraints and allows firms to overcome the fixed-cost hurdle for financing R&D. The model enables us to decompose the effects of RER changes on productivity growth into these channels; explain regional heterogeneity in the effects of RER changes in terms of differences in the parameters that affect export and import intensities and financial constraints; and quantitatively evaluate the different mechanisms by providing counter-factual simulations.

Regarding the latter, we obtain a number of interesting results. First, as in our reduced-form evidence, RER changes have different impacts depending on the relative export orientation of regions and the prevalence of credit constraints: while in emerging Asia a real depreciation leads to more R&D and an increase in physical productivity, other emerging economies experience effects with the opposite sign; finally, in industrialized economies opposing effects operating through the export and import channels largely offset each other. Second, the effects on physical productivity are rather persistent, extending far beyond the length of the real depreciation. Finally, we also show that depreciations and appreciations yield asymmetric effects due to the presence of sunk costs to R&D, which we also uncover in our reduced-form evidence.

Our analysis remains silent about welfare effects, as we take the real exchange rate as given. We also take the origins of the regional differences in export and import behavior and financial constraints as the result of exogenously determined parameters. Still, the huge heterogeneity of effects across regions for similar changes in RER suggests that some aspects of our work may be informative for policy-making. Triggering a depreciation would perhaps seem to be a reasonable policy for (export-intensive) emerging

Asia but certainly not for (import-intensive) Latin America and Central and Eastern Europe, where engineering an appreciation may potentially have positive effects on productivity growth. However, as emerging-country firms follow the path of industrialized-country firms and become ever more integrated into global value chains, manipulating the RER will be less effective, as effects of different signs will offset each other. At the same time, increased use of hedging through simultaneous participation in exporting and importing may allow firms to become less vulnerable to exchange-rate shocks. Finally, the non-linearities and asymmetries in the effects of RER appreciations and depreciations we have uncovered suggest that the link between RER changes and macroeconomic performance might be much more nuanced than usually thought.

We limited the analysis to manufacturing firms due to data restrictions. Future work should aim to study the response of firms in the services industry, too, as it is becoming the most important sector both in industrialized and many emerging markets.

References

[1] Aghion, Philippe, Philippe Askenazy, Nicolas Berman, Gilbert Cette and Laurent Eymard, 2012, "Credit Constraints and the Cyclicality of R&D Investment: Evidence from France," Journal of the European Economic Association, 10(5), 1001-1024.

[2] Aghion, Philippe, Antonin Bergeaud, Matthieu Lequien and Marc Melitz, 2017, "The Impact of Exports on Innovation: Theory and Evidence," working paper.

[3] Alessandria, George, Joseph P. Kaboski and Virgiliu Midrigan, 2010, "Inventories, Lumpy Trade, and Large Devaluations," American Economic Review, 100(5), 2304-2339.

[4] Alfaro, Laura, Anusha Chari and Fabio Kanczuk, 2017, "The Real Effects of Capital Controls: Firm-Level Evidence from a Policy Experiment," Journal of International Economics, 108, 191-210.

[5] Alfaro, Laura, Paola Conconi, Harald Fadinger, and Andrew Newman, 2016, "Do Price Determine Vertical Integration?" Review of Economic Studies, 83(3), 855-888.

[6] Alfaro, Laura, and Maggie X. Chen, 2018, "Selection and Market Reallocation: Productivity Gains from Multinational Production" American Economic Journal: Economic Policy, 10(2), 1-38.

[7] Alvarez and Hansen, Erwin, 2017, "Corporate Currency Risk and Hedging in Chile: Real and Financial Effects," Inter-American Development Bank Working Paper Series IDB-WP-769. Washington DC, February.

[8] Amiti, Mary, Oleg Itskhoki and Jozef Konings, 2014, "Importers, Exporters, and Exchange Rate Disconnect," American Economic Review, 104(7), 1942-78.

[9] Amiti, Mary and Jozef Konings, 2007, "Trade Liberalization, Intermediate Inputs, and Productivity: Evidence from Indonesia," American Economic Review, 97(5), 1611-1638.

[10] Autor, David, David Dorn, Gordon H. Hanson, Pian Shu and Gary Pisano, 2016, "Foreign Competition and Domestic Innovation: Evidence from U.S. Patents," NBER WP #22879.

[11] Aw, Bee, Mark Roberts and Daniel Xu, 2011, "R&D Investment, Exporting and Productivity Dynamics," American Economic Review, 101(4), 1312-44.

[12] Baldwin, Richard, 1988, "Hysteresis in Import Prices: The Beachhead Effect," American Economic Review, 78(4), 773-785.

[13] Baldwin, Richard and Paul Krugman, 1989, "Persistent Trade Effects of Large Exchange Rate Shocks," Quarterly Journal of Economics, 104(4), 635-654

[14] Barajas et al., 2016, "Balance Sheet Effects in Colombian Non-Financial Firms,"Inter-American Development Bank Working Paper Series IDB-WP-740. Washington DC, October.

[15] Barattieri, Alessandro, Matteo Cacciatore, and Fabio Ghironi, 2017, "Protectionism and the Business Cycle,"Working Paper.

[16] Benigno, Gianluca, Huigang Chen, Christopher Otrok, Alessandro Rebucci, and Eric Young, 2016, "Optimal Capital Controls and Real Exchange Rate Policies: A Pecuniary Externality Perspective," Journal of Monetary Economics, 84(C),147-165.

[17] Berman, Nicolas, Philippe Martin and Thierry Mayer, 2012, "How Do Different Exporters React to Exchange Rate Changes?" Quarterly Journal of Economics, 127(1), 437-492.

[18] Blaum, Joaquin, Claire LeLarge and Michael Peters, 2015, "The Gains from Input Trade in Firm-Based Models of Importing," NBER WP #21504

[19] Bloom, Nicholas, Mirko Draca, and John van Reenen, 2015, "Trade Induced Technical Change? The Impact of Chinese Imports on innovation, IT and Productivity," Review of Economic Studies, 83(1), 87-117.

[20] Burstein, Ariel, and Gita Gopinath, 2014, "International Prices and Exchange Rates," in Gopinath, G., Helpman, E., and Rogoff, K. (Eds.): Handbook of International Economics Volume 4, Amsterdam: Elsevier

[21] Bussière, Matthieu, Claude Lopez, and Cédric Tille, 2015, "Do real exchange rate appreciations matter for growth?," Economic Policy, 30(81), 5-45.

[22] Bustos, Paula, 2011, "Trade Liberalization, Exports and Technology Upgrading: Evidence on the Impact of MERCOSUR on Argentinean Firms," American Economic Review, 101(1), 304-340.

[23] Cavallo, Alberto, 2017 "Retail Prices and the Real Exchange Rate," working paper.

[24] Céspedes, Luis F., Roberto Chang and Andrés Velasco, 2004 "Balance Sheets and Exchange Rate Policy," American Economic Review 94(4), 1183-1193.

[25] Chinn, Menzie D. and Hiro Ito, 2006, "What Matters for Financial Development? Capital Controls, Institutions, and Interactions," Journal of Development Economics, 81(1), 163-192.

[26] Corsetti, Giancarlo, Luca Dedola, and Sylvain Leduc, 2014, "The International Dimension of Productivity and Demand Shocks in the US Economy," Journal of the European Economic Association, 12(1), 153-176.

[27] Cosar, Kerem, Nezih Guner and James Tybout, 2016 "Firm Dynamics, Job Turnover, and Wage Distributions in an Open Economy, " American Economic Review, 106(3), 625-63.

[28] Costinot, Arnaud, and Andrés Rodríguez-Clare, 2014, "Trade Theory with Numbers: Quantifying the Consequences of Globalization" in Gopinath, G., Helpman, E., & Rogoff, K. (Eds.): Handbook of International Economics Volume 4, Amsterdam: Elsevier

[29] Defever, Fabrice, and Alejandro Riaño, 2017 "Twin Peaks," working paper.

[30] De Loecker, Jan, 2011, "Product Differentiation, Multi-Product Firms and Estimating the Impact of Trade Liberalization on Productivity," Econometrica, 79(5), 1407-1451.

[31] Dix-Carneiro, Rafael, 2014, "Trade Liberalization and Labor Market Dynamics," Econometrica, 82(3).

[32] Dixit, Avinash, 1989, "Entry and Exit Decisions under Uncertainty," Journal of Political Economy, 97(3), 620-638

[33] Ekholm, Karolina, Andreas Moxnes and Karen Helene Ulltveit-Moe, 2012, "Manufacturing Restructuring and the Role of Real Exchange Rate Shocks: A Firm-Level Analysis," Journal of International Economics, 86(1), 101-117.

[34] Feenstra, Robert C., Robert Inklaar and Marcel P. Timmer, 2015. " The Next Generation of the Penn World Table," American Economic Review, 105(10), 3150-82.

[35] Fernandes, A., Freund, C. and M. Pierola, 2016. " Exporter Behavior, Country Size and Stage of Development: Evidence from the Exporter Dynamics Database," Journal of Development Economics, 119, 121-137.

[36] Fitzgerald, Doireann, and Stefanie Haller, 2014, "Pricing-to-Market: Evidence From Plant-Level Prices," Review of Economic Studies, 81(2), 761-786.

[37] Gopinath, Gita and Brent Neimann, 2014, "Trade Adjustment and Productivity in Large Crises," American Economic Review, 2014, 104(3), 793-831.

[38] Gorodnichenko, Yuriy and Monika Schnitzer, 2013, "Financial Constraints and Innovation: Why Poor Countries Don't Catch Up," Journal of European Economic Association, 11, 1115-1152

[39] Gouriéroux, Christian, Montfort, Alain and Eric Renault, 1993, "Indirect Inference," Journal of Applied Econometrics, 8, 85-118.

[40] Gourinchas, Pierre-Olivier, 1999, "Exchange Rates and Jobs: What Do We Learn from Job Flows?," in Ben S. Bernanke and Julio Rotemberg, editors, NBER Macroeconomics Annual 1998, 153-222.

[41] Henry, Peter Blair, 2008, "Comment," Brookings Papers on Economic Activity, Fall, 413-420.

[42] Halpern, László, Miklós Koren and Adam Szeidl, 2015, "Imported Inputs and Productivity," American Economic Review, 105(12), 3660-3703.

[43] Kohn David, Fernando Leibovici, and Michal Szkup, 2017, "Financial Frictions and Export Dynamics in Large Devaluations," Working Paper.

[44] Lerner, Josh, and Bronwyn H Hall, 2010, "The Financing of R&D and Innovation." In Handbook of the Economics of Innovation. Vol. 1, edited by Bronwyn Hall and Nathan Rosenberg. Elsevier.

[45] Lileeva, Alla and Daniel Trefler, 2010, "Improved Acces to Foreign Markets Raises Plant-Level Productivity... For Some Plants," Quarterly Journal of Economics, 125(3), 1051-1099.

[46] Magud, Nicolas, Carmen Reinhart, and Kenneth Rogoff, 2011, "Capital Controls: Myth and Reality? A Portfolio Balance Approach, " NBER Working Paper No. 16805.

[47] Manova, Kalina, 2013, "Credit Constraints, Heterogeneous Firms, and International Trade," Review of Economic Studies 80, 711-744.

[48] Mendoza, Enrique and Viven Yue, 2012, "A General Equilibrium Model Of Sovereign Default and Business Cycles" Quarterly Journal of Economics, 127(2), 889-946.

[49] Midrigan, Virgiliu, and Daniel Yi Xu, 2014, "Finance and Misallocation: Evidence from Plant-Level Data," American Economic Review, 104(2), 422-458.

[50] Rodrik, Dani, 2008, "The Real Exchange Rate and Economic Growth," Brookings Papers on Economic Activity, Fall, 365-412.

[51] Salomão, Juliana, and Liliana Varela, 2017, "Exchange Rate Exposure and Firm Dynamics," Working paper.

[52] Valle et al. 2017, "The Correlation Effect between Commodity Prices and Exchange Rate for Brazilian Firms' Balance Sheets," Inter-American Development Bank Technical Note IDB-TN-1168. Washington DC, January.

[53] Verhoogen, Eric, 2008, "Trade, Quality Upgrading and Wage Inequality in the Mexican Manufacturing Sector," Quarterly Journal of Economics, 123(2), 489-530

[54] Woodford, Michael, 2008, "Comment," Brookings Papers on Economic Activity, Fall, 420-437.

Appendix

A-1.1 Model

This appendix presents the small-open-economy model that leads to a number of results we have used implicitly in section 3.

A-1.1.1 Preferences, Technologies and Market Environment

Each country has a representative consumer who maximizes a Cobb-Douglas per-period utility:

$$U_t = \left(\frac{C_{NT,t}}{\alpha_{NT}}\right)^{\alpha_{NT}} \left(\frac{D_{O,t}}{\alpha_O}\right)^{\alpha_O} \left(\frac{D_{T,t}}{\alpha_T}\right)^{\alpha_T}, \tag{A-1.1}$$

$\alpha_j \in (0,1)$ for all j, $\sum_j \alpha_j = 1$. $C_{NT,t}$, $D_{O,t}$ and $D_{T,t}$ denote consumption of, respectively, a non-traded, a numéraire and a manufacturing good; t denotes time. The non-traded and numéraire sectors are perfectly competitive. The manufacturing sector features differentiated varieties produced under monopolistic competition. The consumption-based price index associated to this utility function is $P_t = P_{NT,t}^{\alpha_{NT}} P_{O,t}^{\alpha_O} P_{T,t}^{\alpha_T}$. We take a small-open-economy approach whereby countries face given foreign prices and a given foreign price index P_t^*. Stars denote foreign variables. The RER is defined as P_t^*/P_t. Thus, given our assumptions, changes in P_t also reflect changes in the real exchange rate.

A-1.1.2 Numéraire and Non-traded Sectors

The numéraire good is freely traded and produced with technology

$$Y_{O,t} = e_t^{-1} \left(K_{O,t}/\beta_k\right)^{\beta_k} \left(L_{O,t}/\beta_l\right)^{\beta_l} \left(X_{O,t}/\beta_m\right)^{\beta_m}, \tag{A-1.2}$$

$\beta_h > 0$, $\{h = k, l, m\}$, $\sum_h \beta_h = 1$. $K_{O,t}$, $L_{O,t}$, and $X_{O,t}$ respectively denote capital, labor and a domestically produced intermediate input employed by the numéraire sector. e_t is a shifter inversely related to the sector's productivity. All countries produce the numéraire good. Since $P_{O,t} = 1$, an increase in e_t makes domestic production factors cheaper. The non-traded sector is produced with technology $Y_{NT,t} = \left(K_{NT,t}/\beta_k\right)^{\beta_k} \left(L_{NT,t}/\beta_l\right)^{\beta_l} \left(X_{NT,t}/\beta_m\right)^{\beta_m}$. We assume that non-tradables can be used for final non-traded consumption or as the domestic intermediate input X_t, which implies $P_{NT,t} = P_{X,t} = e_t^{-1}$.

A-1.1.3 Aggregate Prices and the Real Exchange Rate

The domestic consumption-based price of the manufacturing CES aggregator is

$$P_T = \left[\int_{i\in\Omega_{T,NI}} p_i^{1-\sigma} di + \int_{i\in\Omega_{T,I}} p_i^{1-\sigma} di + \int_{i\in\Omega_T^*} p_i^{*1-\sigma} di\right]^{\frac{1}{1-\sigma}}. \tag{A-1.3}$$

Define the price of imported goods $P_T^* = \left[\int_{i\in\Omega_T^*} p_i^{*1-\sigma} di\right]^{\frac{1}{1-\sigma}}$ and the price of domestic goods

$$P_{TH} = P_{T,NI}\left[1 + \left(P_{T,I}/P_{T,NI}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}, \tag{A-1.4}$$

where $P_{T,NI} = e^{-1}\Delta_{T,NI}$, $P_{T,I} = e^{-1}\left(P_M/P_X\right)^{\beta_m}\Delta_{T,I}$, $\Delta_{T,NI} \equiv \frac{\sigma}{\sigma-1}\left[\int_{i\in\Omega_{T,NI}} \exp\left[\omega_i\left(\sigma-1\right)\right] di\right]^{\frac{1}{1-\sigma}}$ and $\Delta_{T,I} \equiv \frac{\sigma}{\sigma-1}\left[\int_{i\in\Omega_{T,I}} \exp\left[\omega_i\left(\sigma-1\right)\right] di\right]^{\frac{1}{1-\sigma}}$. One can express P_T as

$$P_T = P_{T,NI}\left[1 + \left(P_{T,I}/P_{T,NI}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}\left[1 + \frac{P_T^{*1-\sigma}}{\left(P_{T,NI}\right)^{1-\sigma}\left[1 + \left(P_{T,I}/P_{T,NI}\right)^{1-\sigma}\right]}\right]^{\frac{1}{1-\sigma}}. \tag{A-1.5}$$

Substituting from the definitions of $P_{T,NI}$, $P_{T,I}$, and P_T^*, imposing $\varepsilon = \sigma$ and manipulating the resulting expression yields $P_T = e^{-1}\Delta_{T,NI}\Gamma^{\frac{1}{1-\sigma}}$, where

$$\Gamma \equiv \left[1 + \left[1 + \left(\frac{e}{A}\right)^{1-\sigma}\right]^{\beta_m}\left(\frac{\Delta_{T,I}}{\Delta_{T,NI}}\right)^{1-\sigma} + \left(\frac{eP_T^*}{\Delta_{T,NI}}\right)^{1-\sigma}\right]. \tag{A-1.6}$$

e has a *direct* negative effect on P_T via e^{-1}, and a number of *indirect* effects that operate through (1) the prices of imported final goods, eP_T^*, and intermediate inputs, $\left[1 + \left(Ae^{-1}\right)^{\sigma-1}\right]$, and (2) the extensive margins of $\Delta_{T,NI}$ and $\Delta_{T,I}$. Changes in ω_i only have lagged effects on P_T, as they operate with a time lag via the innovation process.

Taking logs, $\ln P_T = -\ln(e) + \ln\Delta_{T,NI} + \frac{1}{1-\sigma}\ln\Gamma$. Define $\widetilde{X} = \ln X - \ln\overline{X}$ as the log deviation of variable X from its steady state $\overline{X}$:

$$\widetilde{P}_T = -\widetilde{e} + \widetilde{\Delta}_{T,NI} + \frac{1}{1-\sigma}\widetilde{\Gamma}. \tag{A-1.7}$$

Log-linearizing $\Gamma(\cdot)$,

$$\widetilde{\Gamma} \approx (1-\sigma)\left[\left[\overline{\Gamma}_2\frac{\beta_m\left(\overline{e}/A\right)^{1-\sigma}}{1 + \left(\overline{e}/A\right)^{1-\sigma}} + \overline{\Gamma}_3\right]\widetilde{e} + \overline{\Gamma}_2\widetilde{\Delta}_{T,I} - \left(\overline{\Gamma}_2 + \overline{\Gamma}_3\right)\widetilde{\Delta}_{T,NI}\right], \tag{A-1.8}$$

where

$$\overline{\Gamma}_2 \equiv \left[1 + \left(\overline{e}/A\right)^{1-\sigma}\right]^{\beta_m}\left(\overline{\Delta}_{T,I}/\overline{\Delta}_{T,NI}\right)^{1-\sigma} = \left(\overline{P}_{T,I}/\overline{P}_{T,NI}\right)^{1-\sigma}, \tag{A-1.9}$$

$$\overline{\Gamma}_3 \equiv \left(\overline{e}\overline{P_T^*}/\overline{\Delta}_{T,NI}\right)^{1-\sigma} = \left(\overline{P_T^*}/\overline{P}_{T,NI}\right)^{1-\sigma}, \tag{A-1.10}$$

$$\overline{\Gamma} \equiv 1 + \overline{\Gamma}_2 + \overline{\Gamma}_3. \tag{A-1.11}$$

Plugging back into (A-1.7),

$$\widetilde{P}_T \approx \overline{\Gamma}^{-1}\left[-\left[1+\overline{\Gamma}_2\left(1-\frac{\beta_m\left(\overline{e}/A\right)^{1-\sigma}}{1+\left(\overline{e}/A\right)^{1-\sigma}}\right)\right]\widetilde{e}+\widetilde{\Delta}_{T,NI}+\overline{\Gamma}_2\widetilde{\Delta}_{T,I}\right]. \tag{A-1.12}$$

Notice that the direct effect $-\widetilde{e}$ is of a larger magnitude than the indirect effects provided changes in e do not bring about large changes in the extensive margins of $\Delta_{T,NI}$ and $\Delta_{T,I}$. If we therefore ignore the last two terms of this equation and $1+\overline{\Gamma}_2$ is large relative to $\overline{\Gamma}_3$, then $\widetilde{P}_T \approx -\widetilde{e}$.

Finally, plugging the results obtained above for P_T into aggregate consumption-based price index $P = P_{NT}^{\alpha_{NT}} P_O^{\alpha_O} P_T^{\alpha_T}$ yields

$$\ln P = -\left(\alpha_{NT}+\alpha_T\right)\ln e + \alpha_T \ln \Delta_{T,NI} + \alpha_T \frac{1}{1-\sigma}\ln \Gamma. \tag{A-1.13}$$

$$\widetilde{P} = -\left(\alpha_{NT}+\alpha_T\right)\widetilde{e} + \alpha_T\widetilde{\Delta}_{T,NI} + \alpha_T\frac{1}{1-\sigma}\widetilde{\Gamma} = \tag{A-1.14}$$

$$\approx \quad -\left[\alpha_{NT}+\alpha_T\frac{\left[1+\overline{\Gamma}_2\left(1-\beta_m\frac{(\overline{e}/A)^{1-\sigma}}{1+(\overline{e}/A)^{1-\sigma}}\right)\right]}{\overline{\Gamma}}\right]\widetilde{e}+\alpha_T\frac{1}{\overline{\Gamma}}\widetilde{\Delta}_{T,NI}+\alpha_T\frac{\overline{\Gamma}_2}{\overline{\Gamma}}\widetilde{\Delta}_{T,I}.$$

Notice that both $\alpha_T/\overline{\Gamma}$ and $\alpha_T\overline{\Gamma}_2/\overline{\Gamma}$ are close to zero. As for the coefficient of $\widetilde{e}$, it can be approximated by $\alpha_{NT}+\alpha_T$, which we assume close to 1: $\widetilde{P} \approx -\widetilde{e}$. We can therefore think of an increase in e_t as a real depreciation.

A-1.2 Production-function Estimation

In this Appendix we explain the details of the production-function estimation we use to construct the gross-output-based and the value-added based productivity measures. In the exposition we focus on the model consistent gross-output-based measure. For the case of value added, we substract material expenditure from gross output and use it as the dependent variable. Most steps are analogous to the case of gross output.

A-1.2.1 Firm-level Productivity Measures

Rewriting the demand function (11), $d_{i,t} = \left(p_{i,t}/P_{T,t}\right)^{-\sigma} D_{T,t}$ as $d_i = \left(\frac{p_i}{P_T}\right)^{-\sigma} D_T$, we get the inverse demand function $p_i = d_i^{\frac{-1}{\sigma}} D_T^{\frac{1}{\sigma}} P_T$. Using optimal pricing $p_i = \frac{\sigma}{\sigma-1} MC_i$, it is easy to show that the fraction of domestic sales is given by $\nu_i(e) \equiv \frac{d_i}{d_i+d_i^*}$. Since $d_i = \nu_i Y_i$, we have that $d_i^{\frac{\sigma-1}{\sigma}} = \nu_i^{\frac{\sigma-1}{\sigma}} Y_i^{\frac{\sigma-1}{\sigma}}$. For the case of an exporting firm, we can then write total revenue $R_i = p_{it}d_{it} + p_{it}^* d_{it}^*$ as $R_i = Y_i^{\frac{\sigma-1}{\sigma}}\left[\nu^{\frac{\sigma-1}{\sigma}} D_T^{\frac{1}{\sigma}} P_T + (1-\nu)^{\frac{\sigma-1}{\sigma}} (D_T^*)^{\frac{1}{\sigma}} (P_T^*)\right] \equiv Y_i^{\frac{\sigma-1}{\sigma}} G_i\left(D_T, D_T^*, e\right)$. Total revenue can be expressed as:

$$R_{i,t} = p_{i,t}d_{i,t} + I_{iX,t}p^*_{i,t}d^*_{i,t} = (Y_{i,t})^{\frac{\sigma-1}{\sigma}} G_{i,t}\left(D_{T,t}, D^*_{T,t}, e_t\right),$$

where $Y_{i,t}$ is physical output and $G_{i,t}$ captures the state of aggregate demand, which depends on the RER e_t. $G_{i,t}$ varies by firm only through $I_{iX,t}$, which is an indicator that equals one if the firm exports and thus allows the firm to also attract foreign demand. Taking logs and plugging in production function (10),

$$r_{i,t} = \frac{\sigma-1}{\sigma}\left[\beta_0 + \beta_k k_{i,t} + \beta_l l_{i,t} + \beta_m \tilde{m}_{i,t} - \beta_m \log(P_{X,t}) + \beta_m \tilde{a}_{it}(e_t) + \omega_{it} + \epsilon_{i,t}\right] + g_{i,t}\left(D_{T,t}, D^*_{T,t}, e_t\right). \tag{A-1.15}$$

A-1.2.2 First Stage

Materials are chosen conditional on observing ω_{it}, the capital stock k_{it}, the export and import status $I_{ix,t}$, $I_{im,t}$, the RER e_t and aggregate demand $D_{T,t}$, $D^*_{T,t}$. Since material expenditure $\tilde{m}_{i,t} = \tilde{m}_{i,t}\left(\omega_{i,t}, k_{i,t}, D_{T,t}, D^*_{T,t}, e_t\right)$ is strictly increasing in $\omega_{i,t}$,[56] we can express $\omega_{i,t}$ as a function of capital $k_{i,t}$, material expenditure $\tilde{m}_{i,t}$ and aggregate demand $(D_{T,t}, D^*_{T,t}, e_t)$.

$$\begin{aligned} r_{i,t} &= \tilde{\beta}_l l_{i,t} + \tilde{\beta}_0 + \tilde{\beta}_k k_{i,t} + \tilde{\beta}_m \tilde{m}_{i,t} + \tilde{\beta}_m \tilde{a}_{i,t}(e_t) - \tilde{\beta}_m \log(P_{X,t}) + \tilde{\omega}_{i,t}\left(k_{i,t}, \tilde{m}_{i,t}, D_{T,t}, D^*_{T,t}, e_t\right) + g_{i,t}\left(D_{T,t}, D^*_{T,t}, e_t\right) + \epsilon_{i,t} = \\ &= \tilde{\beta}_l l_{i,t} + \Phi\left(k_{i,t}, \tilde{m}_{i,t}, D_{T,t}, D^*_{T,t}, e_t\right) + \epsilon_{i,t}, \end{aligned} \tag{A-1.16}$$

where $\tilde{\beta} = \frac{\sigma-1}{\sigma}\beta$ and $\tilde{\omega} = \frac{\sigma-1}{\sigma}\omega$. $\Phi\left(k_{i,t}, \tilde{m}_{i,t}, D_{T,t}, D^*_{T,t}, e_t\right)$ is a function that captures a combination of $\tilde{\omega}_{i,t}$, the import channel $\tilde{a}_{i,t}$ and the demand channel $g_{i,t}$. It is approximated using a flexible polynomial:

$$\begin{aligned} \Phi\left(k_{i,t}, \tilde{m}_{i,t}, D_{T,t}, D^*_{T,t}, e_t\right) &= \lambda_0 + \lambda_1 k_{i,t} + \lambda_2 \tilde{m}_{i,t} + \lambda_3 k_{i,t}\tilde{m}_{i,t} + \lambda_4 k^2_{i,t} + ... + \lambda_9 \tilde{m}^3_{i,t} + \\ &+ \sum_{j=1}^{J} \lambda_j^{EXP} \log(e^{EXP}_{s,t}) + \sum_{j=1}^{J} \lambda_j^{IMP} \log(e^{IMP}_{s,t}) + D_{c,t} + D_s \end{aligned}$$

Here, $D_{c,t}$ are country-time dummies that absorb aggregate demand shocks, the price of domestic materials, $P_{X,t}$, and also correct for the fact that output and inputs are measured in nominal terms, while D_s are sector dummies. The terms $\sum_{j=1}^{J} \lambda_j^{EXP} \log(e^{EXP}_{s,t})$ and $\sum_{j=1}^{J} \lambda_j^{IMP} \log(e^{IMP}_{s,t})$ are interactions of sector-specific export and import-weighted RERs with dummies for firm-size bins λ_j^{EXP}, λ_j^{IMP}. They control for the impact of firms' export and import decisions on their demand and productivity. By interacting RERs with dummies for firm size, we allow the impact of RER changes to affect firms differentially depending on their size.[57] Larger firms are much more likely to export and/or import and should thus be more affected by RER changes. We prefer these firm-size-bin interactions with the

[56] The dependence on the export and import status is indicated by making the function $m_{i,t}$ firm specific. Strictly speaking, the production function estimation procedure requires material choices to be made after the other input choices are made. In our theoretical model we assume for convenience that all inputs are chosen simultaneously so that firms operate on their long-run marginal cost curve. We have also experimented with material choices to be made after the other inputs are chosen, leading to very similar results.

[57] In the estimation we use 4 firm-size bins: ≤ 20 employees; $20-50$ employees $50-200$ employees ≥ 200 employees.

RERs to interactions with export and import status, since the firm-level trade status is not available for around 60% of the observations.[58] Since $\epsilon_{i,t}$ is uncorrelated with the covariates given our timing assumptions, OLS estimation of (A-1.16) allows us to recover a consistent estimate for the labor coefficient $\widehat{\beta}_l$ and predicted values for $\widehat{\Phi}\left(k_{i,t}, \tilde{m}_{i,t}, D_{T,t}, D^*_{T,t}, e_t\right)$ from the first stage.

A-1.2.3 Second Stage

In the second stage we obtain consistent estimates for the capital and material coefficients $\tilde{\beta}_k$ and $\tilde{\beta}_m$, the return to R&D $\tilde{\alpha}_2$ and for the stochastic process of TFP. To obtain a better fit, we allow the Markov-process to be a second-order polynomial of lagged TFP, with parameters α_0, α_1 and α_3. To do this, we plug our estimates $\widehat{\beta}_l$ and $\widehat{\Phi}\left(k_{i,t}, \tilde{m}_{i,t}, D_{T,t}, D^*_{T,t}, e_t\right)$ into the equation resulting from combining the stochastic process for TFP (18) with (A-1.16).

$$
\begin{aligned}
& r_{i,t} - \widehat{\beta}_l l_{i,t} = \tilde{\beta}_0 + \tilde{\beta}_k k_{i,t} + \tilde{\beta}_m \tilde{m}_{i,t} + \tilde{\alpha}_0 + \\
& +\alpha_1 \left[\widehat{\Phi}\left(k_{i,t-1}, \tilde{m}_{i,t-1}, D_{T,t}, D^*_{T,t}, e_{t-1}\right) - \tilde{\beta}_k k_{i,t-1} - \tilde{\beta}_m \tilde{m}_{i,t-1}\right] \\
& +\alpha_3 \left[\widehat{\Phi}\left(k_{i,t-1}, \tilde{m}_{i,t-1}, D_{T,t}, D^*_{T,t}, e_{t-1}\right) - \tilde{\beta}_k k_{i,t-1} - \tilde{\beta}_m \tilde{m}_{i,t-1}\right]^2 + \tilde{\alpha}_2 I_{iRD,t-1} + \epsilon_{i,t} + \tilde{u}_{i,t}.
\end{aligned}
$$

Since $\mathbb{E}(\tilde{m}_{i,t}\tilde{u}_{i,t}) \neq 0$ we need to instrument for $\tilde{m}_{i,t}$ using the 2-period lag of materials. The moment conditions are given by $\mathbb{E}(Z'_{i,t}(\varepsilon_{i,t} + \tilde{u}_{it})) = 0$, where $Z_{i,t} = (\tilde{m}_{i,t-1}, \tilde{m}_{i,t-2}, k_{i,t-1}, I_{iRD,t-1})$. We use a 2-step GMM estimator to obtain consistent estimates of $\tilde{\beta}_k$, $\tilde{\beta}_m$, $\tilde{\alpha}_0$, α_1, α_3 and $\tilde{\alpha}_2$.[59] We obtain standard errors using a bootstrap. In some specifications we impose constant returns to scale in the second stage of the estimation procedure (i.e., given $\sigma = 4$, the input coefficients need to sum to 3/4). Results are reported in Table A-7. TFPR is then constructed using equation (25). In the baseline results (all Tables except Table A-3) we do not impose constant returns to scale (we use estimates from columns (1) and (3) of Table A-7) and we do not correct for the markup term. We report results imposing constant returns in Table A-3, columns (3) and (6). We report results imposing constant returns and multiplying $\tilde{\beta}$ with $(\sigma - 1)/\sigma$ in Table A-3, columns (4) and (7).

A-1.3 Dataset Construction

Our main data source for firm-level information is Orbis (Bureau Van Dijk). We combine data from two CDs (2007 and 2014) and the web version of Orbis. Orbis provides firm-level balance sheet data of listed and unlisted firms.

We drop firm-year observations without firm identifiers, company names, information on revenue or sales, total assets, employees and observations with missing accounting units. We replace as missing any

[58] We obtain similar results for the first-stage coefficients when instead interacting RERs with export and import status.

[59] For the case of the value added production function materials do not appear on the right-hand side, so the equation can be consistently estimated by non-linear least squares.

negative reported values for sales, revenue, number of employees, total assets, current liabilities, total liabilities, long-term debt, tangible fixed assets, intangible fixed assets, current assets, material costs, R&D expenditure. We convert variables into common units (thousands of current local currency). We compute the capital stock as the sum of tangible fixed assets and intangible fixed assets. We compute value added as revenue minus material costs. We keep firms with a primary activity in the manufacturing sector (US SIC 1997 codes 200-399). See Alfaro and Chen (2018) for further description of the data.

Dun & Bradstreet's WorldBase is a database covering millions of public and private companies in more than 200 countries and territories. The unit of observation in Worldbase is the establishment/plant. Among other variables, Worldbase reports for each plant the full name of the company, location information (country, state, city, and street address) basic operational information (sales and employment), and most importantly, information on the plant's trade status (exporting/not exporting/importing/not importing). See Alfaro et al (2016) for a detailed description.

For those manufacturing firms in Orbis that report revenue, number of employees, capital stock and material costs, we merge by names with the Worldbase datasets for the years 2000, 2005, 2007 and 2009. When common id were not provided by the datasets, we use the Jaro-Winkler string distance algorithm to match the datasets by company names. We condition on the firms being located in the same country and then match by names and require a match score of at least 0.93, which turns out to provide a very good match in manual checks. For our main analysis we disregard the year information of the trade status to maximize sample coverage. We thus assign a fixed trade status to each firm, giving priority to earlier years.

We drop outliers, by removing the top and bottom one percent of observations in terms of (log) capital stock, materials, value added, sales, employment in the TFP estimation. After the production function coefficients have been estimated on this restricted sample, we expand sample size and compute TFP also for observations with missing material costs, by proxying for the material cost as (median material share in revenue)$\times$revenue. Finally, we drop the top and bottom one percent of observations in terms of TFP growth before running the reduced-form regressions reported in the paper.

Appendix Table A-1 (Panel B) reports descriptive statistics of firm-level variables (for comparability across countries in thousands of 2004 US-Dollars).

A-1.4 Numerical Solution Algorithm

This Appendix describes the computational details of the algorithm used in the estimation. Denote Θ as the vector of parameters to be estimated. The estimation follows the following routine:

(1) For a given value of Θ, solve the dynamic problem of firms, captured by the Bellman equation described in Section 3.7. This step yields the value functions for the firms.

(2) Simulate the decisions (for a panel of 8000 firms for 80 periods) for a set of firms. Calculate the desired moments from the simulated data.

(3) Update Θ to minimize the (weighted) distance between the simulated statistics and the data statistics.

Step 1. Solving the Bellman equation.

First we use Tauchen's method to discretize the state space for the continuous state variables that include productivity ω_{it} and the RER e_t. We choose 50 grids for each state variable. The transition matrix of productivity conditional on doing or not doing R&D is calculated accordingly.

We first derive the per-period revenue, profit, static export and import choices at each state in the grid as described in Section 3. The discrete R&D choice is the only dynamic decision. Each firm maximizes the sum of its current and discounted future profits. We iterate on the value function until numerical convergence. We do not get a deterministic R&D decision since only the mean R&D costs are known to the firms when solving the Bellman equation. However, we can calculate the value of doing R&D at any given state. In step 2, after firms observe their cost draws, they can then make deterministic R&D investment decisions.

Step 2 Simulating firms' decisions.

We then simulate the decisions for a panel of 8000 firms and 80 periods: 400 firms, each for 20 countries and 80 periods. Each country gets a unique series of exchange rates shocks simulated following the same AR(1) process and mapped to the grids of the state space. The shocks in the initial period are drawn from the steady-state distribution implied by the AR(1) process. All the cost shocks are drawn from their respective distributions.

With respect to firms' idiosyncratic productivity shocks, we assume that no firm does R&D in period 1, and draw the initial-period productivity shocks from the steady-state distribution without R&D. In each subsequent period, given the beginning-of-period productivity and other shocks, each firm then makes the static export and import decisions, and also the dynamic R&D decisions by comparing their associated fixed or sunk cost draws with the value of doing R&D computed in step 1 (taking into account the credit constraint). After knowing each firm's R&D decision, we simulate its end-of-period productivity shock following the respective AR(1) process. The moments of interest are then calculated from the simulated data on exporting, importing, sales, cash flow, etc. The first 10 periods are considered as burn-in periods and not used to calculate the data moments.

Step 3. Indirect Inference.

Steps 1 and 2 together generate the moments of interest for any given Θ. In step 3, Θ is updated to minimize a weighted distance between the data statistics and the simulated statistics (see below). After each optimization step, we return to steps 1 and 2 using the updated guess of Θ. The minimization is performed using the genetic algorithm.

Let ν be the $p\times 1$ vector of data statistics and let $\nu(\Theta)$ denote the synthetic counterpart of ν with the statistics computed from artificial data generated by the structural model. Then the indirect-inference estimator of the $q \times 1$ vector Θ, $\tilde{\Theta}$ is the value that solves

$$\min_{\beta}(\nu - \nu(\Theta))' V (\nu - \nu(\Theta)), \tag{A-1.17}$$

where V is the $p \times p$ optimal weighting matrix (the inverse of the variance-covariance matrix of the data statistics ν). Since the data statistics are computed from different datasets, we set the off-diagonal elements of the variance-covariance matrix to zero. (See Cosar et al., 2016 and Dix-Carneiro, 2014 for a similar approach.) One can show that under certain regularity conditions, the estimates are consistent and asymptotically normal. (See Gouriéroux et al., 1993 for details.)

A-1.5 Additional Figures and Tables

Table A-1: Panel A - Sample Frame

Country	Freq.	Percent	Cum.	Country	Freq.	Percent	Cum
ARG*	98	0.01	0.01	KEN*	13	0	88.28
AUS+	1,004	0.08	0.08	KOR-	101,267	7.63	95.91
AUT+	5,895	0.44	0.53	KWT*	33	0	95.91
BEL+	25,908	1.95	2.48	LBN*	1	0	95.91
BGD-	36	0	2.48	LKA-	126	0.01	95.92
BGR*	24,114	1.82	4.3	LTU*	64	0	95.92
BHR*	6	0	4.3	LUX+	38	0	95.93
BIH*	15,580	1.17	5.47	LVA*	64	0	95.93
BOL*	32	0	5.48	MAR*	15	0	95.93
BRA*	2,030	0.15	5.63	MEX*	152	0.01	95.94
BRB*	1	0	5.63	MKD*	73	0.01	95.95
BWA*	1	0	5.63	MLT*	3	0	95.95
CAN+	30	0	5.63	MUS+	8	0	95.95
CHE+	538	0.04	5.67	MWI*	1	0	95.95
CHL*	5	0	5.67	MYS+	3,210	0.24	96.19
CHN-	213,230	16.07	21.74	NAM*	4	0	96.19
COL*	125	0.01	21.75	NGA*	168	0.01	96.21
CPV*	4	0	21.75	NLD+	4,111	0.31	96.52
CRI*	8	0	21.75	NOR+	11,227	0.85	97.36
CYP*	204	0.02	21.76	NZL+	41	0	97.36
CZE*	5,216	0.39	22.16	OMN*	158	0.01	97.38
DEU+	100,801	7.59	29.75	PAK*	134	0.01	97.39
DMA*	4	0	29.75	PAN*	14	0	97.39
DNK+	915	0.07	29.82	PER*	151	0.01	97.4
DOM*	6	0	29.82	PHL-	216	0.02	97.41
ECU*	18	0	29.82	POL*	11,174	0.84	98.26
EGY*	70	0.01	29.83	PRT+	137	0.01	98.27
ESP+	291,219	21.94	51.77	PRY*	8	0	98.27
EST*	16,559	1.25	53.02	QAT*	10	0	98.27
FIN+	30,996	2.34	55.35	ROU*	27	0	98.27
FJI*	3	0	55.35	SAU*	33	0	98.27
FRA+	168,756	12.71	68.07	SGP-	1,462	0.11	98.38
GBR+	37,491	2.82	70.89	SLV*	4	0	98.38
GHA*	4	0	70.89	SRB*	3	0	98.38
GRC+	24,076	1.81	72.7	SVK*	9	0	98.38
GRD*	1	0	72.71	SVN*	21	0	98.39
GTM*	7	0	72.71	SWE+	9,262	0.7	99.08
HKG-	351	0.03	72.73	THA-	3,677	0.28	99.36
HRV*	35,905	2.71	75.44	TTO*	1	0	99.36
HUN*	28	0	75.44	TUN*	3	0	99.36
IDN-	1,055	0.08	75.52	TUR*	81	0.01	99.37
IND-	303	0.02	75.54	TWN-	7,369	0.56	99.92
IRL+	2,120	0.16	75.7	TZA*	4	0	99.92
IRN*	126	0.01	75.71	UGA*	1	0	99.92
IRQ*	15	0	75.71	UKR*	307	0.02	99.95
ISL+	25	0	75.71	URY*	5	0	99.95
ISR*	696	0.05	75.77	VEN*	2	0	99.95
ITA+	107,685	8.11	83.88	VNM-	528	0.04	99.99
JAM*	4	0	83.88	ZAF*	174	0.01	100
JOR*	229	0.02	83.9	ZMB*	8	0	100
JPN+	58,096	4.38	88.27	ZWE*	3	0	100
KAZ*	25	0	88.28	Total	1,333,986	100	

Notes: + indicates industrialized economies, - indicates emerging Asia, * indicates other emerging economies. The number of observations for each country correspond to those of Table 1, columns (1) and (2). These numbers correspond to those observations included in the estimation that are not absorbed by the fixed effects.

Table A-1: Panel B - Firm-level descriptive statistics. Mean values of firm-level variables by trade status (in thousands of constant 2004 Dollars)

	sales	va	capital	materials	empl.	tfp	R&D exp.	R&D prob.	exp. prob.	imp. prob.	firms
full sample	18.015	5.871	5.960	7.082	110.685	0.406	6.767	0.341	0.290	0.221	494,652
with trade data	24.688	8.675	7.889	8.954	123.687	0.540	10.837	0.423	0.290	0.221	177,358
domestic firms	15.439	5.924	4.691	5.842	81.437	0.428	5.699	0.327	0.000	0.000	127,943
exporters	46.459	14.984	15.407	15.948	223.573	0.806	18.064	0.551	1.000	0.644	43,766
importers	47.162	13.534	15.452	15.337	223.240	0.803	18.898	0.543	0.847	1.000	32,935

Table A-1: Panel C - Firm-level descriptive statistics. Growth rates of firm-level outcomes.

	Mean	Median	S.D.	Pct. 10	Pct. 90	Observations
Δ log TFPR $_{VA,it}$	0.062	0.032	0.401	-0.323	0.459	1,333,986
Δ log TFPR$_{GO,it}$	0.014	0.009	0.149	-0.127	0.155	1,333,986
Δ log sales$_{it}$	0.083	0.045	0.421	-0.280	0.458	1,275,606
Δ log c. f.$_{it}$	0.032	0.033	0.810	-0.770	0.835	772,970
Δ R&D prob.$_{it}$	0.018	0	0.245	0	0	148,367

Table A-1: Panel D - Percentage changes in aggregate/trade-weighted real exchange rates (computed from PWT 8.0).

	Mean	Median	S.D.	Pct.10	Pct. 90	Observations
$\Delta \log(e_{ct})$ (sample weights)	-0.022	-0.026	0.077	-0.106	0.069	1,333,986
$\Delta \log(e^{exp}_{sct})$ (sample weights)	-0.009	-0.001	0.037	-0.054	0.036	1,285,833
$\Delta \log(e^{imp}_{sct})$ (sample weights)	-0.010	-0.001	0.038	-0-061	0.028	1,286,033
$\Delta \log(e_{ct})$ (unweighted)	-0.034	-0.040	0.119	-0.160	0.086	1,832
$\Delta \log(e_{ct})$ (5-year differences)	-0.189	-0.211	0.248	-0.478	-0.196	333

Table A-2: The aggregate RER and firm-level outcomes: excluding crisis years

	(1)	(2)	(3)	(4)	(5)
	Δ log TFPR$_{VA,it}$	Δ log TFPR$_{GO,it}$	Δ log sales$_{it}$	Δ log c. f.$_{it}$	Δ R&D prob.$_{it}$
$\Delta \log e_{ct} \times$	0.209***	0.124***	0.410**	0.660***	0.164***
emerging Asia$_c$	(0.062)	(0.017)	(0.164)	(0.246)	(0.058)
$\Delta \log e_{ct} \times$	-0.217*	-0.0438	-0.0828	0.173	0.00822
other emerging$_c$	(0.130)	(0.048)	(0.207)	(0.336)	(0.007)
$\Delta \log e_{ct} \times$	0.094*	0.0105	0.162	-0.258	0.0104
industrialized$_c$	(0.055)	(0.022)	(0.105)	(0.326)	(0.023)
Observations	871,672	871,672	816,686	528,152	86,859
R-squared	0.053	0.031	0.076	0.022	0.012
Country-sector FE	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES
Business cycle controls	YES	YES	YES	YES	YES
Cluster	Country	Country	Country	Country	Country

Notes: The dependent variable in columns (1)-(5) is the annual log difference in the following firm-level outcomes computed from Orbis for manufacturing firms for the years 2001-2008: revenue-based TFP computed from value-added (column 1), revenue-based TFP computed from gross output (column 2), nominal sales (column 3), cash flow (column 4), an indicator for R&D status (column 5). The construction of TFP is explained in section 4 of the paper. The main explanatory variable of interest is the annual log difference in the real exchange rate from the PWT 8.0 interacted with dummies for: emerging Asia; other emerging economy; industrialized economy. The regressions also control for the real growth rate of GDP in PPP (from PWT8.0) and the inflation rate (from IMF).

Table A-3: The aggregate RER and productivity growth – alternative productivity measures

	(1) Δ log lab. prod.$_{it}$	(2) Δ log TFPR$_{VA,it}$	(3) Δ log TFPR$_{VA,CRS,it}$	(4) Δ log TFPR$_{VA,CRS,markup,it}$	(5) Δ log TFPR$_{GO,it}$	(6) Δ TFPR$_{GO,CRS,it}$	(7) Δ TFPR$_{GO,CRS,markup,it}$
$\Delta \log e_{ct} \times$	0.245*	0.239***	0.242***	0.835**	0.120***	0.106	0.152**
emerging Asia$_c$	(0.144)	(0.090)	(0.087)	(0.366)	(0.020)	(0.113)	(0.060)
$\Delta \log e_{ct} \times$	-0.483**	-0.546***	-0.542***	0.277	-0.105**	-0.376***	-0.234***
other emerging$_c$	(0.190)	(0.185)	(0.185)	(0.390)	(0.043)	(0.126)	(0.083)
$\Delta \log e_{ct} \times$	-0.13	0.0196	0.021	0.304	-0.031	-0.118	-0.0773
industrialized$_c$	(0.139)	(0.103)	(0.102)	(0.245)	(0.031)	(0.109)	(0.063)
Observations	1,275,606	1,333,986	1,333,986	1,333,986	1,333,986	1,333,986	1,333,986
R-squared	0.052	0.057	0.056	0.012	0.038	0.066	0.058
Country-sector FE	YES	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES	YES
Business cycle controls	YES	YES	YES	YES	YES	YES	YES
Cluster	Country	Country	Country	Country	Country	Country	Country

Notes: The dependent variable in columns (1)-(7) is the annual log difference in the following firm-level productivity measures computed from Orbis for manufacturing firms for the years 2001-2010: labor productivity (sales/employment) (column 1), revenue-based TFP computed from value-added (column 2), revenue-based TFP computed from value added, imposing constant returns to scale (column 3), revenue-based TFP computed from value added, imposing constant returns to scale and correcting for markups (column 4), revenue-based TFP computed from gross output (column 5), revenue-based TFP computed from gross output, imposing constant returns to scales (column 6), revenue-based TFP computed from gross output, imposing constant returns to scale and correcting for markups (column 7). The construction of TFP is explained in section 4 of the paper and in Appendix A-1.2. The main explanatory variable of interest is the annual log difference in the real exchange rate from the PWT 8.0 interacted with dummies for: emerging Asia; other emerging economy; industrialized economy. The regressions also control for the real growth rate of GDP in PPP (from PWT 8.0) and the inflation rate (from IMF).

Table A-4: The aggregate RER and firm-level outcomes: IV estimates

	(1) Δ log TFPR$_{VA,it}$	(2) Δ log TFPR$_{GO,it}$	(3) Δ log sales$_{it}$	(4) Δ log c. f.$_{it}$	(5) Δ R&D prob.$_{it}$
$\Delta \log e_{ct} \times$	0.286***	0.140***	0.267	0.895***	0.668***
emerging Asia$_c$	(0.078)	(0.023)	(0.190)	(0.060)	(0.245)
$\Delta \log e_{ct} \times$	-0.922***	-0.337**	-2.114*	-0.906	-4.076
other emerging	(0.354)	(0.137)	(1.241)	(0.560)	(2.836)
$\Delta \log e_{ct} \times$	-0.009	-0.054	-0.353	-0.105	-5.169
industrialized$_c$	(0.258)	(0.099)	(0.686)	(0.520)	(5.424)
Observations	1,310,509	1,310,509	1,252,483	758,623	142,093
R-squared	0.011	0.011	0.028	0.014	-0.006
Country-sector FE	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES
Business cycle controls	YES	YES	YES	YES	YES
Cluster	Country	Country	Country	Country	Country
Kleibergen-Paap F-Statistic	9.146	9.146	9.919	4.759	8.304
Cragg-Donald P-value	(0.011)	(0.011)	(0.041)	(0.312)	(0.081)
Hansen	3.333	1.88	3.951	2.625	2.642
P-value	(0.343)	(0.597)	(0.267)	(0.453)	(0.452)

Notes: The dependent variable in columns (1)-(5) is the annual log difference in the following firm-level outcomes computed from Orbis for manufacturing firms for the years 2001-2010: revenue-based TFP computed from value-added (column 1), revenue-based TFP computed from gross output (column 2), nominal sales (column 3), cash flow (column 4), an indicator for R&D status (column 5). The construction of TFP is explained in section 4 of the paper. The main explanatory variable of interest is the annual log difference in the real exchange rate from the PWT 8.0 interacted with dummies for: emerging Asia; other emerging economy; industrialized economy. The regressions also control for the real growth rate of GDP in PPP (from PWT8.0) and the inflation rate (from IMF). The set of excluded instruments consists of: regional dummies interacted with (i) trade-weighted world commodity prices and (ii) world capital flows interacted with the Chinn-Ito index for financial account openness. Standard errors are clustered at the country level.

Table A-5: Export-and import-weighted RERs and firm-level outcomes

	(1)	(2)	(3)	(4)	(5)
	Δ log TFPR$_{VA,it}$	Δ log TFPR$_{GO,it}$	Δ log sales$_{it}$	Δ log c. f.$_{it}$	Δ R&D prob.$_{it}$
$\Delta \log e_{sct}^{exp} \times$	0.627***	0.212***	0.953***	1.441***	0.218***
emerging Asia$_c$	(0.188)	(0.066)	(0.229)	(0.514)	(0.048)
$\Delta \log e_{sct}^{exp} \times$	0.0154	0.100	0.222	0.171	0.342
other emerging$_c$	(0.239)	(0.078)	(0.395)	(0.487)	(0.369)
$\Delta \log e_{sct}^{exp} \times$	0.827	0.069	0.391	0.751	-0.737***
industrialized$_c$	(0.587)	(0.081)	(0.385)	(0.679)	(0.189)
$\Delta \log e_{sct}^{imp} \times$	0.0507	0.0352	-0.0697	-0.692*	0.053
emerging Asia$_c$	(0.181)	(0.0624)	(0.207)	(0.400)	(0.048)
$\Delta \log e_{sct}^{imp} \times$	-0.397	-0.145	-0.330	-0.925	0.253
other emerging$_c$	(0.324)	(0.102)	(0.596)	(0.680)	(0.345)
$\Delta \log e_{sct}^{imp} \times$	-0.193	6.32E-05	-0.289	-0.557	0.510***
industrialized$_c$	(0.354)	(0.0674)	(0.326)	(0.616)	(0.169)
Observations	1,285,693	1,285,693	1,228,253	746,330	140,048
R-squared	0.054	0.037	0.104	0.025	0.03
Country-time FE	YES	YES	YES	YES	YES
Country-sector FE	YES	YES	YES	YES	YES
Cluster	Country-sector	Country-sector	Country-sector	Country-sector	Country-sector

Notes: The dependent variable in columns (1)-(5) is the annual log difference in the following firm-level outcomes computed from Orbis for manufacturing firms for the years 2001-2010: revenue-based TFP computed from value-added (column 1), revenue-based TFP computed from gross output (column 2), nominal sales (column 3), cash flow (column 4), an indicator for R&D status (column 5). The construction of TFP is explained in section 4 of the paper. The main explanatory variables of interest are the annual log differences in the export- and import-weighted sector-level real exchange rates computed from PWT 8.0 and bilateral export and import shares at the 3-digit USSIC level (from UN-Comtrade data), interacted with dummies for: industrialized economy; emerging Asia; other emerging economy. Standard errors are clustered at the country-sector level.

Table A-6: Import and export propensity/intensity of manufacturing plants (Worldbank's 2016 Enterprise Survey)

	Emerging Asia	other emerging
Export prob.	0.20	0.26
Import prob.	0.19	0.33
Avg. export intensity (exporters)	0.58	0.25
Avg. import intensity (importers)	0.13	0.14

Notes: Emerging Asia is defined as emerging East Asia and South Asia; other emerging economies are defined as Eastern Europe and Latin America.

Table A-7: Production function: coefficient estimates

	(1) gross output	(2) value added	(3) gross output constant returns	(4) value added constant returns
labor $\tilde{\beta}_l$	0.336***	0.533***	0.336***	0.533***
	(0.002)	(0.002)	(0.002)	(0.002)
capital $\tilde{\beta}_k$	0.093***	0.210***	0.051***	0.217***
	(0.018)	(0.010)	(0.008)	(0.002)
materials $\tilde{\beta}_m$	0.682***		0.363***	
	(0.022)		(0.008)	
R&D return $\tilde{\alpha}_2$	0.079***	0.033**	0.060***	0.033**
	(0.013)	(0.016)	(0.009)	(0.016)
$\log(e^{EXP}_{sct})\times \lambda^{EXP}_1$	0.001	-0.149***	0.001	-0.149***
	(0.021)	(0.034)	(0.021)	(0.034)
$\log(e^{EXP}_{sct})\times \lambda^{EXP}_2$	0.426***	0.729***	0.426***	0.729***
	(0.025)	(0.039)	(0.025)	(0.039)
$\log(e^{EXP}_{sct})\times \lambda^{EXP}_3$	0.345***	0.755***	0.345***	0.755***
	(0.027)	(0.046)	(0.027)	(0.046)
$\log(e^{EXP}_{sct})\times \lambda^{EXP}_4$	0.178***	0.445***	0.178***	0.445***
	(0.068)	(0.117)	(0.068)	(0.117)
$\log(e^{IMP}_{sct})\times \lambda^{IMP}_1$	-0.073***	0.110***	-0.073***	0.110***
	(0.020)	(0.032)	(0.020)	(0.032)
$\log(e^{IMP}_{sct})\times \lambda^{IMP}_2$	-0.561***	-0.838***	-0.561***	-0.838***
	(0.025)	(0.034)	(0.025)	(0.034)
$\log(e^{IMP}_{sct})\times \lambda^{IMP}_3$	-0.700***	-1.142***	-0.700**	-1.142***
	(0.027)	(0.045)	(0.027)	(0.045)
$\log(e^{IMP}_{sct})\times \lambda^{IMP}_4$	-0.827***	-1.240***	-0.827***	-1.240***
	(0.066)	(0.117)	(0.066)	(0.117)
Observations	33,252	49,183	33,252	49,183
Country-time FE	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES

Notes: Details of the production-function estimation are explained in Appendix A-1.2. The terms $\lambda^{EXP}_j \times \log(e^{EXP}_{s,t})$ and $\lambda^{IMP}_j \times \log(e^{IMP}_{s,t})$ are interactions of sector-specific export and import-weighted RERs with dummies for firm-size bins for ≤ 20 employees; $20-50$ employees $50-200$ employees ≥ 200 employees. Standard errors clustered at the firm level reported in parentheses.

Table A-8: Estimation of log RER, AR (1) process

	(1)	(2)
intercept	-0.000	-0.032
	(0.009)	(0.020)
$\log e_{c,t-1}$	0.930***	0.935***
	(0.015)	(0.015)
Observations	1,832	1,832
R-squared	0.931	0.947
s.d. residuals	0.105	0.0924
Cluster	Country	Country
Time dummies	NO	YES

Notes: AR (1) process of log RER. The explanatory variable of interest is the 1-year lag of the log RER from the PWT 8.0. Standard errors are clustered at the country level.

Table A-9: The aggregate RER and firm-level outcomes: separating depreciations and appreciations

	(1) Δ log TFPR$_{VA,it}$	(2) Δ log TFPR$_{GO,it}$	(3) Δ log sales$_{it}$	(4) Δ log c. f.$_{it}$
$\lvert\Delta \log e_{ct}\rvert \times I^{+}_{ct} \times$	0.740***	0.243***	1.209***	1.580***
emerging Asia$_c$	(0.152)	(0.077)	(0.285)	(0.238)
$\lvert\Delta \log e_{ct}\rvert \times I^{-}_{ct} \times$	0.159	-0.020	0.657**	0.153
emerging Asia$_c$	(0.124)	(0.057)	(0.323)	(0.310)
$\lvert\Delta \log e_{ct}\rvert \times I^{+}_{ct} \times$	-0.231	0.020	-0.739	0.136
other emerging$_c$	(0.402)	(0.128)	(0.449)	(0.299)
$\lvert\Delta \log e_{ct}\rvert \times I^{-}_{ct} \times$	0.864***	0.219***	1.039**	1.124**
other emerging$_c$	(0.234)	(0.077)	(0.427)	(0.528)
$\lvert\Delta \log e_{ct}\rvert \times I^{+}_{ct} \times$	-0.056	-0.072	-0.790	-0.225
industrialized$_c$	(0.198)	(0.094)	(0.544)	(0.313)
$\lvert\Delta \log e_{ct}\rvert \times I^{-}_{ct} \times$	-0.026	0.011	-0.062	0.430
industrialized$_c$	(0.143)	(0.048)	(0.251)	(0.290)
Observations	1,333,986	1,333,986	1,275,606	772,970
R-squared	0.057	0.038	0.104	0.024
Country-sector FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
Business cycle controls	YES	YES	YES	YES
Cluster	Country	Country	Country	Country

Notes: The dependent variable in columns (1)-(5) is the annual log difference in the following firm-level outcomes computed from Orbis for manufacturing firms for the years 2001-2010: revenue-based TFP computed from value-added (column 1), revenue-based TFP computed from gross output (column 2), nominal sales (column 3), cash flow (column 4). We do not present results for R&D status, which are not statistically significant. The construction of TFP is explained in section 4 of the paper. The main explanatory variable of interest is the absolute value of the annual log difference in the real exchange rate from the PWT 8.0 interacted with dummies for depreciation (I^{+}_{ct}) and appreciation (I^{-}_{ct}) and emerging Asia; other emerging economy; industrialized economy. The regressions also control for the real growth rate of GDP in PPP (from PWT8.0) and the inflation rate (from IMF).

Table A-10: Sensitivity analysis: Emerging Asia

Parameter	Value Baseline	Value σ=6	Value ε=6	Value α_2=0.04	Moments (Cross-sectional moments)	Data	Model Baseline	Model $\sigma = 6$	Model ϵ=6	Model α_2=0.04
					(Cross-sectional moments)					
f_x	7.99	7.57	7.99	7.84	R&D probability	0.26	0.19	0.20	0.20	0.22
$f_{RD,0}$	13.38	12.75	13.38	12.63	Export probability	0.26	0.26	0.25	0.26	0.26
f_{RD}	9.07	9.07	9.07	9.07	Export/Sales ratio, mean	0.60	0.64	0.65	0.64	0.60
f_m	7.99	8.23	7.35	8.12	Import probability	0.17	0.19	0.18	0.19	0.17
A	0.72	0.68	0.78	0.70	Import/Sales ratio, mean	0.13	0.14	0.14	0.12	0.13
$\log(D_T)$	5.56	5.35	5.56	5.59	Mean firm size (log revenue)	6.60	6.69	6.78	6.71	6.64
$\log(D_T^*)$	6.53	6.48	6.53	6.38	Sd, firm size (log revenue)	3.23	3.19	3.26	3.27	3.20
α_1	0.86	0.86	0.87	0.87	(Dynamic moments)					
σ_u	0.44	0.25	0.44	0.44	R&D, continuation probability	0.90	0.86	0.85	0.87	0.84
θ	15.11	15.12	15.08	15.09	R&D, start probability	0.06	0.03	0.04	0.03	0.05
					autocorrelation, TFPR	0.91	0.86	0.87	0.88	0.87
					Elasticity of TFPR w.r.t RER	0.12	0.21	0.21	0.20	0.20
					Elasticity of R.D w.r.t c. f. (4th firm-size quantile)	0.03	0.03	0.04	0.03	0.04
					Elasticity of R.D w.r.t c. f. (dif of 4th and 2nd firm-size quantile)	0.04	0.05	0.06	0.05	0.07

Table A-11: Sensitivity analysis: other emerging economies

Parameter	Value Baseline	Value σ=6	Value ε=6	Value α_2=0.04	Moments (Cross-sectional moments)	Data	Model Baseline	Model $\sigma = 6$	Model ϵ=6	Model α_2=0.04
					(Cross-sectional moments)					
f_x	4.17	2.92	3.97	3.74	R&D probability	0.25	0.22	0.22	0.24	0.25
$f_{RD,0}$	11.24	11.03	11.18	10.78	Export probability	0.35	0.30	0.36	0.33	0.35
f_{RD}	7.84	7.72	7.76	7.84	Export/Sales ratio, mean	0.10	0.12	0.14	0.13	0.12
f_m	5.88	5.88	5.29	5.70	Import probability	0.39	0.35	0.35	0.37	0.37
A	0.97	0.98	1.03	0.97	Import/Sales ratio, mean	0.24	0.24	0.28	0.27	0.24
$\log(D_T)$	4.88	4.36	4.87	4.90	Mean firm size (log revenue)	5.97	5.98	5.92	5.97	5.96
$\log(D_T^*)$	3.02	2.55	3.03	3.02	Sd, firm size (log revenue)	2.63	2.67	2.65	2.63	2.63
α_1	0.84	0.84	0.84	0.84	(Dynamic moments)					
σ_u	0.40	0.20	0.40	0.40	R&D, continuation probability	0.90	0.83	0.84	0.83	0.80
θ	11.02	14.03	12.02	11.02	R&D, start probability	0.06	0.05	0.04	0.05	0.06
					autocorrelation, TFPR	0.87	0.85	0.85	0.85	0.84
					Elasticity of TFPR w.r.t RER	-0.11	-0.15	-0.20	-0.19	-0.16
					Elasticity of R.D w.r.t c. f. (4th firm-size quantile)	0.04	0.04	0.04	0.03	0.04
					Elasticity of R.D w.r.t c. f. (dif of 4th and 2nd firm-size quantile)	0.05	0.07	0.07	0.07	0.08

Table A-12: Sensitivity analysis: industrialized economies

Parameter	Value Baseline	Value σ=6	Value ε=6	Value α_2=0.04	Moments (Cross-sectional moments)	Data	Model Baseline	Model $\sigma = 6$	Model ϵ=6	Model α_2=0.04
					(Cross-sectional moments)					
f_x	6.82	6.04	6.82	6.90	R&D probability	0.56	0.40	0.41	0.40	0.45
$f_{RD,0}$	13.76	13.38	13.76	12.95	Export probability	0.23	0.24	0.23	0.24	0.24
f_{RD}	9.12	8.54	9.12	9.12	Export/Sales ratio, mean	0.17	0.15	0.16	0.15	0.17
f_m	8.43	8.38	7.85	8.28	Import probability	0.20	0.19	0.20	0.20	0.21
A	0.69	0.68	0.79	0.69	Import/Sales ratio, mean	0.14	0.13	0.14	0.13	0.13
$\log(D_T)$	6.66	6.31	6.66	6.73	Mean firm size (log revenue)	7.64	7.64	7.65	7.63	7.64
$\log(D_T^*)$	4.99	4.43	4.99	5.21	Sd, firm size (log revenue)	2.91	2.91	2.88	2.89	2.93
α_1	0.79	0.79	0.79	0.79	(Dynamic moments)					
σ_u	0.54	0.30	0.54	0.55	R&D, continuation probability	0.90	0.90	0.91	0.90	0.88
θ	53.05	53.05	53.17	53.05	R&D, start probability	0.06	0.07	0.06	0.07	0.10
					autocorrelation, TFPR	0.91	0.81	0.82	0.81	0.80
					Elasticity of R.D w.r.t c. f. (4th firm-size quantile)	0.02	0.00	0.00	0.00	-0.01
					Elasticity of R.D w.r.t c. f. (dif of 4th and 2nd firm-size quantile)	0.03	0.05	0.04	0.05	0.05