The Real Exchange Rate, Innovation and Productivity: A Cross-country Firm-level Analysis*

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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 emerging Asia, real depreciations are associated with faster growth of firm-level TFP, sales and cash-flow, higher probabilities to engage in R&D and export. We find no significant effects for firms from industrialized economies and negative effects for firms in other emerging economies, which are less export intensive and more import intensive. Motivated by these facts, we build a dynamic model in which real depreciations raise the cost of importing intermediates, but increase demand and the profitability to engage in exports and R&D, thereby relaxing borrowing constraints and enabling more firms to overcome the fixed-cost hurdle for financing R&D. We decompose the effects of RER changes on productivity growth into these channels and explain regional heterogeneity in the effects of RER depreciations in terms of differences in export intensity, import intensity and financial constraints. We estimate the model and quantitatively evaluate the different mechanisms by providing counterfactual simulations.

JEL Codes: F, O.

Key Words: real exchange rate, firm level data, innovation, productivity, credit constraints

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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. Policy-makers in Asia and Latin America have expressed concerns that large capital inflows can bring about the appreciation of their exchange rates and subsequent losses of competitiveness. Similarly, in rich countries, concerns about appreciated exchange rates 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 real 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 claims that RER depreciation promotes economic growth through its positive impact on the share of tradables relative to nontradables. Still, evidence on the channels through which this positive effect operates (the individual effects of 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 doubts about the accuracy of this macro evidence (see Henry 2008, 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 mechanism and their aggregate implications

This paper revisits this important question by studying the firm-level effects of medium-term fluctuations in the real exchange rate, in particular on firm's productivity, thus shedding light on the microeconomic channels through which RER changes affect the economy. We combine several data sets on cross-country firm-level data to overcoming several 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, 1998). Our analysis uses either movements in the aggregate RER, or disaggregated trade-weighted exchange rates. In the first case, we can employ changes in world commodity prices or world capital flows as instruments for the RER. By contrast, the second measure enables us to control for country-time fixed effects thereby eliminating spurious correlation due to aggregate

[1] See Alfaro, Chari, and Kanczuk (2014), Benigno et al. (2016), Magud, Reinhart, and Rogoff (2011) and references therein for a discussion.

[2] Barattieri, Cacciatore and Ghironi (2017), for example, analyze the effects of recent trade policy, in particular anti-dumping, on macroeconomic outcomes.

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 which are exogenous to individual firms and 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 real exchange rate. We complement the Orbis data with Worldbase (Dun and Bradstreet), which provides plant-level information on export and import activity; 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 micro data: China, Colombia, Hungary, 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. By contrast, in Latin American and Eastern European countries the effects of RER depreciations on these outcomes is negative. Similarly, for manufacturing firms from industrialized countries we find also no or much less significant effects of real depreciations. When separating the effects of RER depreciations by firms' trade status, we find that the positive effects are concentrated in exporting firms, while firms importing intermediates tend to be negatively affected.

In the light of this reduced-form evidence, we construct and structurally estimate a dynamic firm-level model of exporting, importing and R&D investment. The model is based on a number of features. First, it allows for market-size effects: real depreciations increase firm-level demand, thus raising the profitability to engage in exporting and R&D.[6] Second, we model financial constraints: depreciations relax these by increasing firms' cash flow, thus enabling more firms to overcome the fixed-cost hurdle for financing R&D costs. Finally, we also consider the role of imported inputs, as real depreciations increase the cost of importing such goods, thereby counteracting the positive effect on profitability and productivity.[7]

We explain the cross-country variation in the productivity effects of real depreciations with structural differences in terms of export and import probability and intensity and the tightness of financial constraints. Real depreciations have the most positive effects on productivity growth in export-intensive economies where firms are likely to be financially constrained and do not rely much on im-

[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 the countries as examples of the different regions of study. We also use the OECD innovation survey, covering a broad sample countries.

[6] In this context, our structural model helps us disentangle the demand effects caused by a real depreciation from true productivity growth. We analyze productivity effects related to innovation and input variety and abstract from spillovers and other externalities usually mentioned in this debate.

[7] 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)).

ported intermediate inputs (emerging Asia). 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 with well developed financial markets. We use the theoretical framework to study the effects on productivity of the reduced-form evidence and quantitatively evaluate their impact. We then provide counterfactual simulation exploring the effects of temporary RER depreciations on TFP growth and innovation activity: even short-lived (temporary) real depreciations can trigger sizable (positive or negative) impacts on innovation and productivity growth in the long run because the evolution of TFP is very persistent.

An additional channel that we consider in an extension of our model relates to valuation effects associated to changes in the real exchange rate (balance sheet channel).[8] For example, when firms issue unhedged foreign-denominated liabilities, devaluations increase the domestic value of their debt, weakening their balance-sheets. In terms of foreign currency debt, data on currency composition and hedging for a wide range of countries are not easily available. We complement the analysis with information of currency denomination of foreign debt from by the World Bank Enterprise survey and cross-check the data with additional sources as explained in the next section. We find that Eastern European and Latin American firms are more exposed to foreign currency debt than firms from emerging Asia and that exporters borrow more in foreign currency compared other firms. This can partially explain why firms in emerging Asia react more positively to real depreciations than firms from other emerging economies, but cannot account for the fact that exporters experience the largest increases in R&D and TFP growth while importers are hurt most by depreciations.

In addition to the literature mentioned above on the real effects of RER, our findings relate to research based on firm-level data that studies the link between trade, innovation, and productivity growth. Regarding the link between exporting and innovation activity, Lileeva and Trefler (2010) find that CUSFTA, the free-trade agreement between Canada and the US of the late eighties, enhanced incentives to innovate and export for Canadian firms. Bustos (2011) obtains similar effects for Argentinian firms from Brazil's tariff reductions. 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 to trade shocks on innovation. As far as the link between imports and innovation is concerned, Bloom et al. (2015) find 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 financial constraints or importing of intermediate inputs.[9]

[8] Although not our main focus, a vast literature has analyzed the effects of the balance-sheet channel. For theoretical work, see Céspedes, Chang and Velasco (2004) and references therein; Salomão and Varela (2017) develop a firm-dynamics model with endogenous currency debt composition using data for Hungary and Kohn et al (2017) study the impact of financial frictions and balance-sheet effects on aggregate exports in large devaluations.

[9] A recent attempt to identify the effects of industrial policy using aggregate data is the cross-country study by Nunn

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 find large productivity losses due to reductions in imports at the product and firm level during the Argentine crisis that followed the collapse of the currency board.[10] 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.[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, 2015 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 OECD countries. In this regard, the stronger financial frictions emerging markets are subject to and the stronger prevalence of importing of intermediate inputs in OECD countries and Latin America look like a natural point of departure for our theoretical 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). The author 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 margin. 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. They provide some evidence for this with firm-level data for some eastern European countries. Aghion et al. (2012) find that R&D activity becomes procyclical for credit-constrained French firms in sectors dependent on external finance, whereas R&D is countercyclical 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 misallocation. Our paper shows that RER depreciations enable emerging-economy firms to access foreign markets, thus 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 reduced-form evidence on the relationship between RER depreciation and a number of firm-level outcomes. This helps us

and Trefler (2010). They find that countries with initial tariff structures biased towards skill-intensive manufacturing sectors subsequently grew faster. Their interpretation of this finding is that skill-intensive sectors generate local externalities. Their results suggest large growth effects of industrial policy.

[10] The role of imperfect substitution between foreign and domestic inputs has 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] See also Alessandria et al. (2010) and Burnstein and Gopinath (2014) for an overview of the effects of large devaluations.

as motivation for the theoretical model we present in Section 3. Sections 4 discuss our estimation strategy, whereas Section 5 presents the data we use and our main estimation results. In Section 6 we use our estimated model to run a number of counterfactual experiments. Section 7 presents some concluding remarks.

2 Reduced-form Empirical Evidence

2.1 Data and Sources

We combine several data sources.[12] Our main data source is Orbis (Bureau Van Dijk), which provides information for listed and unlisted firms on sales, materials, capital stock (measured as total fixed assets), cash flow (all measured in domestic currency), 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). We focus on manufacturing firms (US-SIC codes 200-399). The sample is selected according to 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-7 for descriptive statistics).

The analysis exploits several additional firm-level data sources. Worldbase (Dun and Bradstreet) provides plant-level information of production activities and export and import status for the same set of countries as Orbis.[13] We use an algorithm to match firms in the two datasets 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 179,000 firms.

The World Bank's Exporter Dynamic Database reports entry/exit rates into/from exporting by country for a large set of industrialized and developing countries computed from underlying census customs microdata 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 region, to complete the analysis. In particular, as explained in the next section, we use information on sales, exports, and imports, employment form their detailed administrative plant level data.

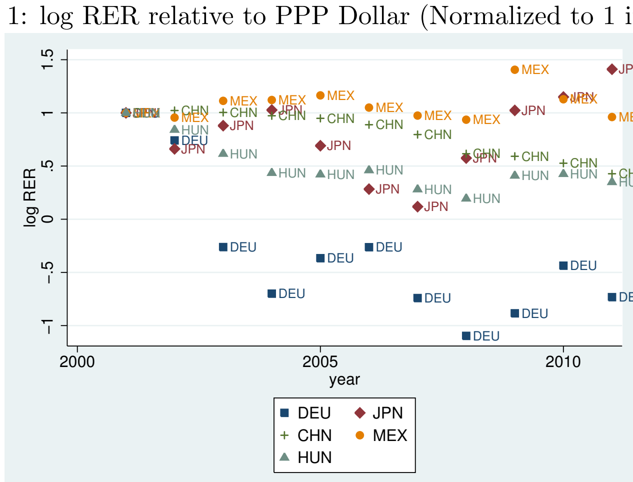
[12] A detailed explanation of the datasets we use can be found in the Appendix.

[13] Worldbase 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, and export 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.

We obtain data on the exposure of firms to foreign-currency borrowing from various sources. We use the 2002-2006 version of the World Entreprise Survey . The advantage of this dataset is 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.[14]

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.[15] 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 1 in 2001)



[14]We thank Liliana Valera for help with Hungary. 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).

[15]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 indepth discussion.

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 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.[16] 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: industrialized economies; emerging Asia; other emerging economies.[17] 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:

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

where I_r is a dummy for country c belonging to region r, δ_{sc} is a 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,[18] while we control for real GDP growth because open-economy macro

[16] In other specifications, we also control for country-sector-time fixed effects.

[17] The set of countries in each region and the corresponding numbers of observations are listed in Table A-1.

[18] We use domestic currency values and not dollar values to avoid that nominal exchange-rate changes can have

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 autocorrelated.

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;[19] 3) the growth rate of sales; 4) the growth rate of cash flow; 5) the change of an indicator variable for R&D.[20] 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 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. Instead, in emerging Asia, a one-percent depreciation of the RER increases value-added TFP growth by 0.24 percent, gross-output TFP 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. Finally, in the other emerging economies, real depreciations are associated with significantly slower TFP and sales growth, while there is no significant effect on cash flow, R&D probabilities and export entry. These results are robust to excluding the years of the global financial crisis from our sample (see Table A-2 in the Appendix).

In Table A-3 in the Appendix we show that these results are robust and statistically significant 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.[21] 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.[22]

Alternatively, 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 and

valuation effects.

[19] We construct our TFP measures by adapting the methodology of De Loecker (2013) and Halpern et al. (2015). We explain our approach in detail in Section 4.

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

[21] 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.

[22] 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 above 9, which indicates that the instrumental variable estimates might be slightly biased due to a somewhat 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$_{ct}$
$\Delta \log e_{ct} \times$	0.0196	-0.031	-0.282	-0.319**	-0.168	-0.275
industrialized$_c$	(0.103)	(0.0309)	(0.217)	(0.126)	(0.149)	(0.274)
$\Delta \log e_{ct} \times$	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)
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: industrialized economy; emerging Asia; other emerging 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.

thereby to directly control for aggregate shocks to the manufacturing sector that might be correlated with firm-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-4 in the Appendix presents the corresponding results, which are similar to those in Table 1. In industrialized countries, depreciations of the export-weighted RER have no significant effects on firm-level outcomes. In emerging Asia instead, real depreciations of the export-weighted RER are highly significant and are associated with faster TFP, sales and cash flow growth an higher R&D probabilities. Finally, in the set of other emerging economies, real depreciations of the export-weighted RER have an insignificantly negative impact 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.

Finally, we show that our results are not driven by short-term business-cycle fluctuations: we find very similar results using specifications in 3-year annualized differences, which we report in Appendix Table A-5.[23]

[23] Results are to be interpreted as average annual changes. To maximize sample coverage we choose 2002, 2005, 2008 and 2010.

2.3 Trade Status and Foreign-currency Borrowing

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

Table 2 provides evidence for differential 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 datasets for four countries for which we have detailed administrative plant-level data available: China, Colombia, Hungary, France.[24] We find that China (representative for emerging Asia) has a lower import propensity and intensity than the other countries, while Colombia and Hungary (representative for the other developing countries) are very import intensive. At the same time Chinese exporters have a very high export intensity compared to the other countries. Firms in France (representative for industrialized countries) have intermediate export and import propensities and intensities.[25] 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.[26]

In order to provide direct evidence that the effect of RER changes on firm-level outcomes depends on the firms' trade status, we now 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).[27] Remember that our micro data do not contain information on import and export values by firm, so even conditional on exporting, we expect the positive effects of RER changes to be strongest for exporters in emerging Asia (which are most export intensive).

[24]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.

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

[26]The Worldbank's Enterprise Survey does not cover 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 East Asia, other emerging, industrialized) for the years 2000, 2005 and 2009. Results from Worldbase confirm that plants in emerging East Asia are much less likely to import than plants in the other regions. Similarly, the export propensity is also somewhat lower in emerging East Asia than in the other regions.

[27]To avoid endogeneity of the trade status, we keep the firms' trade status fixed over the sample period and equal to the trade 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
Avg. export intensity (conditional)	0.6	0.10	0.10	0.23
Avg. import intensity (conditional)	0.13	0.14	0.24	0.14

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

$$\Delta \log(Y_{ic,t}) = \beta_0 + \sum_{r\in R} \beta_r \Delta \log(e_{c,t}) I_r + \sum_{r\in R,\ } \sum_{T\in exp,imp} \beta_{Tr} \Delta \log(e_{c,t}) I_T I_r + \beta_2 X_{c,t} + \sum_{r\in R,\ } \sum_{T\in exp,imp} I_T I_r + \delta_{sc} + \delta_t + u_{ic,t} \tag{3}$$

Table 3 reports the corresponding results. Again, for firms in industrialized countries the baseline effect on outcomes is insignificant, while the interaction effect with export status is positive and mostly statistically significant (but small). By contrast, the interaction with import status is not significant. Differently, in emerging Asia the baseline effect RER depreciations is significantly positive, the interaction effects with export status is also positive and large, while the interaction with import status is negative. Finally, for firms in other emerging countries the baseline effect is negative, while the interaction effect with export status is positive and the interaction effect with import status is negative and large. Observe also that the probability to engage in R&D is significantly positively affected only for exporters in emerging Asia. In Appendix Table A-7 we show that results are robust to including country-time fixed effects (which absorb the baseline category) in these regressions.

An alternative explanation for the heterogeneity of regional RER effects lies in the fact that firms, in particular, in non-industrialized countries 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 (France), we now employ the Worlbank'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. In columns (1) and (2) of Table 4 we report the OLS regression output from running the share of a manufacturing firms' foreign-currency liabilities in total liabilities on dummies for emerging Asia and other emerging economies.[28] The latter's average share of foreign borrowing is roughly twice as large as that of the former (around 20 compared to 10 percent). In

[28] 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, see BIS foreign debt database.

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

	(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.$_{it}$
$\Delta \log e_{ct} \times$	0.054	-0.018	-0.086	-0.658***	-0.243
industrialized$_c$	(0.087)	(0.035)	(0.140)	(0.128)	(0.177)
$\Delta \log e_{ct} \times$	0.062*	0.021*	0.024	0.367***	0.021
industrialized$_c \times$exporter$_f$	(0.037)	(0.011)	(0.059)	(0.118)	(0.038)
$\Delta \log e_{ct} \times$	0.052	0.012*	0.026	0.037	-0.035
industrialized$_c \times$importer$_f$	(0.038)	(0.007)	(0.038)	(0.076)	(0.060)
$\Delta \log e_{ct} \times$	0.301***	0.117***	0.193	0.857***	0.231
emerging Asia$_c$	(0.079)	(0.027)	(0.142)	(0.115)	(0.153)
$\Delta \log e_{ct} \times$	0.150*	0.007	0.100***	-0.065	0.0945**
emerging Asia$_c \times$exporter$_f$	(0.086)	(0.026)	(0.036)	(0.173)	(0.045)
$\Delta \log e_{ct} \times$	-0.155***	-0.019	-0.053	-0.265	-0.062**
emerging Asia$_c \times$importer$_f$	(0.049)	(0.014)	(0.037)	(0.184)	(0.030)
$\Delta \log e_{ct} \times$	-0.220**	-0.053*	-0.404**	-0.188	0.481
other emerging$_c$	(0.085)	(0.031)	(0.199)	(0.307)	(0.294)
$\Delta \log e_{ct} \times$	0.212***	0.046**	-0.101	0.944***	-0.509
other emerging$_c \times$exporter$_f$	(0.072)	(0.021)	(0.213)	(0.099)	(0.411)
$\Delta \log e_{ct} \times$	-0.129*	-0.023	0.164	-1.015***	0.0626
other emerging$_c \times$importer$_f$	(0.069)	(0.025)	(0.158)	(0.169)	(0.154)
Observations	514,971	514,971	485,433	317,395	37,689
R-squared	0.053	0.04	0.098	0.024	0.038
Country-sector FE	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES
Trade status controls	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 2001-2010: 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 firm-level indicators for exporting and importing, and with dummies for: industrialized economy; emerging Asia; other emerging economy. The regressions also control for the firms' trade status. Standard errors are clustered at the country level.

columns (3) and (4) 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[29] 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 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.[30]

Table 4: 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$_c\times$		18.21***
exporter$_f$		(0.876)
emerging Asia$_c\times$		0.433
importer$_f$		(0.626)
other emerging$_c$	19.09***	14.15***
	(0.386)	(0.581)
other emerging$_c\times$		24.90***
exporter$_f$		(1.073)
other emerging$_c\times$		-0.919
importer$_f$		(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.

2.4 Financial Constraints

Finally, we provide some reduced-form evidence for the role of financial constraints on R&D decisions and First, in order to understand the effect of financial constraints on R&D decisions, we check if the probability to engage in R&D is affected by the availability of internal cash flow. We thus run the

[29]Presumably due to their ability to hedge exchange-rate risk with their export revenue.

[30]Cash flow is the difference in amount of cash available at the beginning and end of a period. We obtain similar results when analyzing the effect of net worth when conditioning on trade status. The cash flow effects on R&D were stronger. Note also that 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.

following regression for the firms in the Orbis dataset:

$$I_{RDi,t} = \beta_0 + \beta_1 financialdev._c + \beta_2 \log(cashflow)_{i,t} + \beta_3 \log(cashflow)_{i,t} \times financialdev._c + \beta_4 X_{ic,t} + \nu_{i,t}, \quad (4)$$

where $I^{RD}_{i,t}$ is an indicator that equals one if firm i performs R&D in year t. *log(cash flow)*$_{i,t}$ is the plant's cash flow (in logs) 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 the context of intangible investments such as R&D, as these are difficult to pledge as collateral. We always include the following set of controls: employment and 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, country-sector or firm). 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.[31]

We report results for these specifications in Table 5. The coefficient on (log) cash flow, which measures the impact of cash flow on R&D when financial development is zero, is between 0.01 and 0.052 and always highly statistically significant. Moreover, the interaction term between (log) cash flow and financial development is negative and also highly significant: the role of internal cash flow for R&D is smaller when the country has more developed capital markets. Table 6 reports the predicted marginal effects of (log) cash flow for each region. Its impact on R&D is largest for the set of other emerging economies (around 0.036), intermediate for emerging Asia (0.025), and basically zero for industrialized countries. For firms from emerging Asia, the estimates imply that a one-percent increase in cash flow increases the probability of performing R&D by 0.025 percentage points.

We will show using the structural model that in emerging Asia and the other emerging economies financial constraints can amplify the positive (or negative) effects of RER movements on R&D and productivity growth depending on whether profitability of the typical firm increases or decreases (which depends on export and import orientation and exposure to foreign currency borrowing).

2.5 Summary of Stylized Facts

- For exporting 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; higher export entry rates. Smaller positive effects of real depreciations are also present for firms that do not participate in international trade, while the effect of real depreciations on firm-level outcomes for importers is most modest.

- In industrialized countries real depreciations have no significant effects on firm-level outcomes,

[31] 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 5: R&D sensitivity to cash flow by level of financial development

	(1) R&D prob.$_{it}$	(2) R&D prob.$_{it}$	(3) R&D prob.$_{it}$	(4) R&D prob.$_{it}$
financial development$_c$	0.589***			
	(0.019)			
log(cash flow)$_{ft}$	0.044***	0.048***	0.052***	0.015***
	(0.00222)	(0.003)	(0.003)	(0.003)
log(cash flow)$_{ft}\times$	-0.028***	-0.028***	-0.032***	-0.004***
financial development$_c$	(0.001)	(0.002)	(0.002)	(0.001)
R-squared	0.250	0.338	0.375	0.790
Observations	117,403	117,394	117,142	108,826
Time FE	YES	YES	YES	YES
Sector FE	NO	YES	NO	NO
Country FE	NO	YES	NO	NO
Sector-country FE	NO	NO	YES	NO
Firm FE	NO	NO	NO	YES
Cluster	Firm	Firm	Firm	Firm

Notes: The dependent variable is an indicator for the firm's R&D status. Explanatory variables are cash flow (in logs), financial development (measured as private credit/GDP) and their interaction. Further controls (not reported): employment, capital (both in logs), the real GDP growth rate (from PWT 8.0) and the inflation rate (from IMF).

Table 6: 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	0.025	0.036	0.006

Notes: Predicted marginal effects of (log) cash flow for each region.

independently of their trade status.

- In other emerging markets (Latin America and Eastern Europe), real depreciations have a significantly negative effect on firm-level outcomes for firms that do not engage in trade and an even larger negative effect for importers, while there is no significant effect on exporters.
- Firms in emerging Asia are less likely to import and less import intensive than firms located in other emerging economies and in industrialized countries; moreover, firms in emerging Asia have a higher export intensity than firms in other emerging economies and industrialized countries. Firms in located in other emerging economies are most likely to import and most import intensive.
- Firms in other emerging economies are most exposed to foreign currency borrowing, followed by firms from emerging Asia. Exporters borrow a larger share in foreign currency compared to other firms.
- Firms' R&D choice 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 a significant 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 impacting on 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 a 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 $\omega_{it} + \varepsilon_{it}$. Here $\omega_{i,t}$ follows a Markov process defined below and $\varepsilon_{i,t}$ is independently drawn from $N(0, \sigma_\varepsilon^2)$. We assume that $\omega_{i,t}$ is realized before firms make decisions in each period, while $\varepsilon_{i,t}$ is realized after decisions have been made.

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

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

$K_{i,t}$, $L_{i,t}$, 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

$$P_{M,t} = P_{X,t} \left[1 + \left(B^* P_{X,t} / P_{X,t}^* \right)^{\varepsilon-1} \right]^{\frac{1}{1-\varepsilon}} = e_t^{-1} \left[1 + \left(A_t e_t^{-1} \right)^{\varepsilon-1} \right]^{\frac{1}{1-\varepsilon}}, \tag{9}$$

where $P_{X,t}$ is the price of domestically produced intermediates and $A_t \equiv B^*/P_{X,t}^*$ is the quality-adjusted relative cost of imported intermediates. As we show in the Appendix, a higher e_t leads to lower domestic factor prices, a lower price of domestic intermediates and thus a higher relative price of imported intermediates.[32] Defining the cost reduction from importing (resulting from a combination of relative price, quality and imperfect substitution) as $\tilde{a}_t(e_t) = (\varepsilon - 1)^{-1} \ln\left[1 + \left(A_t e_t^{-1}\right)^{\varepsilon-1}\right]$, one can see that cost reductions from importing are increasing in the quality of foreign inputs and decreasing in e_t. It is easy to see that $P_{M,t} = P_{X,t} exp\left[-\tilde{a}_t(e_t)\right]$: 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 $\tilde{M}_t = P_{X,t} exp\left(-\tilde{a}_t(e_t)\right) M_t$. Substituting this into the production function and taking logs, and using $z \equiv \log Z$, $Z = K, L, \tilde{M}$,

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

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

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

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.[33] Firm i's domestic revenue is

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

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

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

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

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

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

effect on revenue (and profits) through the effect of the price of imported intermediates on the price these firms charge:

$$R_{i,t}^{d}\left(\omega_{i,t}\right)=\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}\exp\left[\left(\sigma-1\right)\omega_{i,t}\right]e_{t}^{\sigma-1}exp\left[-\tilde{a}_{t}\left(e_{t}\right)\right]^{(1-\sigma)\beta_{m}}P_{T,t}^{\sigma-1}\left(P_{T,t}D_{T,t}\right). \tag{14}$$

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

3.5 Exports

If a firm with log-productivity level ω_{it} chooses to export,[34] 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 on 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.[35]

3.6 Exporter and Importer Status

Importing and exporting decisions involve per-period fixed costs f_m and f_x, respectively.[36] Each firm's fixed costs are iid 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 $\varepsilon_{i,t}$ 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

[34] This decision is also discussed below.

[35] As in the case of domestic sales, export revenues and profits of importers and non-importers differ by term $exp\left[-\tilde{a}_{t}\left(e_{t}\right)\right]^{(1-\sigma)\beta_{m}}$.

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

that does not import materials; $\Pi_{i,t}^{(0,m)}(\omega_{i,t}) = \Pi_{i,t}^{d}[\omega_{i,t}, exp[-\tilde{a}_t(e_t)]]$ are the profits of an importing non-exporter; and $\Pi_{i,t}^{(0,0)}(\omega_{i,t}) = \Pi_{i,t}^{d}(\omega_{i,t}) > 0$ 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 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 the previous period's profits:

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

Parameter $\theta \in [1, \bar{\theta}]$ reflects the quality of the financial system: the lower θ, the more financially constrained the firms.[37]

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.[38] 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 downpayment).[39] 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

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

[37] The factor $1+r$ values period-$(t-1)$ consumption units in period-t consumption units.

[38] 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.

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

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

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

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

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

where $\beta=\left(1+r\right)^{-1}$. 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.
To summarize, the timing of decision making we assume is the following:

1. Observe $s_{i,t}=(\omega_{i,t},e_t,I_{iRD,t-1},\Pi_{i,t-1})$.
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 $\varepsilon_{i,t}$.
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 $\log\left(e_t\right)$ 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)[40] are estimated by using an indirect inference approach that matches model and data statistics.[41]

[40] 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.

[41] We re-estimate the persistence parameter of the log-productivity process α_1 again in the model, as we want to allow for some flexibility in order to match the moments. (The persistence of productivity affects innovation choices.) In the

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, total revenue can be expressed as:[42]

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

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), we obtain a log-linear expression of firm revenue in terms of physical output and aggregate demand:

$$r_{i,t} = \left[\tilde{\beta}_0 + \tilde{\beta}_k k_{i,t} + \tilde{\beta}_l l_{i,t} + \tilde{\beta}_m \tilde{m}_{i,t} - \tilde{\beta}_m \log(P_{X,t}) + \tilde{\beta}_m \tilde{a}_{it}(e_t) + \tilde{\omega}_{it} + \tilde{\varepsilon}_{i,t}\right] + g_{i,t}\left(D_{T,t}, D^*_{T,t}, e_t\right), \tag{23}$$

where x indicates the natural log of the variable and $\tilde{x}$ indicates multiplication by $\frac{\sigma-1}{\sigma}$. In the Appendix we show how to combine (23) with the Markov process for log productivity (18) in order to consistently estimate output elasticities β_i and the return to R&D α_2.

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

$$tfpr_{i,t} \equiv r_{i,t} - \tilde{\beta}_l l_{i,t} - \tilde{\beta}_k k_{i,t} - \tilde{\beta}_m m_{i,t} = \left[\tilde{\beta}_0 + \tilde{\omega}_{i,t} + \tilde{\varepsilon}_{i,t} + \tilde{\beta}_m \tilde{a}_{i,t} - \tilde{\beta_m} \log P_{X,t}\right] + g_{i,t}\left(D_{T,t}, D^*_{T,t}, e_t\right). \tag{24}$$

Notice that measured revenue-based productivity is a combination of physical productivity $\beta_0 + \omega_{i,t} + \varepsilon_{it}$, import effects on productivity $\beta_m \tilde{a}_{i,t}(e_t)$ 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.

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 elasticities into its different components. Remember that in the reduced-form regressions we used the following econometric specification:

$$\mathbb{E}(tfpr_{ic,t}|X_{ic,t}) = \beta_0 + \beta_1 \log e_{c,t} + \beta_2 X_{ic,t} + \delta_i + \delta_t \tag{25}$$

end, however, the two estimates for α_1 are almost identical.

[42]See the Appendix for detailed derivation.

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

$$\Delta tfpr_{ic,t} = \beta_1 \Delta \log e_{ct} + \beta_2 \Delta X_{ic,t} + \Delta\delta_t + \Delta u_{ic,t} \tag{26}$$

Taking expectations of (24) and derivatives with respect to RER, we now compute the model counterpart to the reduced-form regression coefficient β_1, the expected elasticity of TFPR with respect to RER:

$$\beta_1 \equiv \frac{\partial \mathbb{E}(tfptr_{i,t})}{\partial \log e_t} = \underbrace{\tilde{\alpha}_2 \frac{\partial Prob(I_{iRD,t-1}=1)}{\partial \log e_t}}_{\text{innovation}} + \underbrace{\tilde{\beta}_m \frac{\partial \mathbb{E}(\tilde{a}_{i,t})}{\partial \log e_t}}_{\text{imports}} + \underbrace{\frac{\partial \mathbb{E}(g_{i,t}(D_{T,t}, D^*_{T,t}, e_t))}{\partial \log e_t}}_{\text{demand}} \tag{27}$$

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 more innovation through a larger net present value of future profits and the *financial constraints channel*, which operates through an increase of current profits and a relaxation 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 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).[43] This channel, which impacts negatively on the elasticity of TFPR, 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.[44] 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 RER into these three components.

4.3 Model Estimation

Table 7 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 emerging Asia, and the other emerging economies, we set the annual real interest rate to 15%, which corresponds to a reasonable value for these economies. For industrialized economies, we choose a real interest rate of 5%. We set the elasticity of demand σ equal to 4, which is a plausible value for this parameter (see e.g. Costinot

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

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

and Rodriguez-Clare, 2015). 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 below.

The structural estimation method that is employed in this paper is Indirect Inference (see Gourieroux and Monfort, 1996). 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, $\tilde{\beta}$ is the value that solves

$$\min_{\Theta}(\nu - \nu(\Theta))' V (\nu - \nu(\Theta)), \tag{28}$$

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}, and the credit-constraint parameter θ. We also estimate within the model the autocorrelation and TFP, α_1 and the standard deviation of the TFP shocks σ_u.[45]

In terms of statistics we choose to match in order to identify the model parameters, we distinguish between cross-sectional statistic (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, the autocorrelation of TFPR).

Let us briefly discuss the intuition for the econometric identification of the different structural parameters. The export probability mainly identifies the distribution of export fixed costs, while the export-to-sales ratio is informative about relative foreign demand. Higher mean export fixed costs reduce export participation, while higher foreign demand increases the exports-to-sales ratio. Also the elasticity of TFPR with respect to RER plays a role for pinning down these parameters: ceteris paribus, a higher value of this elasticity corresponds to a larger export elasticity with respect to the RER. This elasticity will be larger, the smaller the export fixed costs and the larger foreign demand. Similarly, the import probability and the import-to-sales ratio are sensitive to the import fixed costs, the elasticity of substitution between intermediates and the relative quality of imported intermediates. A larger import fixed costs reduces import participation, while a larger price-adjusted quality of imported intermediates and a larger elasticity of substitution across inputs increase import intensity. Moreover, smaller import fixed costs and a higher value for the elasticity of substitution across inputs also impact negatively

[45] 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.

Table 7: 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)	0.15	$f_{RD,0}$	R&D sunk cost, mean
r	interest rate (industrialized)	0.05	f_{RD}	R&D fixed cost, mean
			θ	coefficient for credit constraint
			α_1	persistence, productivity
			σ_u	s.d., innovation of productivity
			D_T	log domestic demand
			D_T^*	log foreign demand

on the elasticity of TFPR with respect to RER, as firms make larger adjustments to their sourcing decisions in response to fluctuations in RER. The elasticity of R&D with respect to cash flow should be informative about the credit-constraint parameter, as it governs to what extent R&D decisions are determined by current profits rather than by the net present value of future profits. The identification of the parameters governing 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 autocorrelation of TFPR and the firm-size distribution together identify the R&D sunk and fixed costs, the autocorrelation and the standard deviation of TFP. Other things equal, a higher R&D fixed cost mainly reduces the R&D participation rate. 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 autocorrelation of TFPR and the elasticity of TFPR with respect to RER.

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 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 for Output elasticities, returns to R&D and the RER process

Table 8 reports the estimates of both the production-function parameters (equation (7)) and the stochastic process for log-productivity (equation (18)) for the pooled sample (industrialized countries, emerging Asia, other emerging markets). The estimate for $\tilde{\alpha}_2$ is 0.078 (0.033), which, given a σ of 4, corresponds to a return of R&D of 0.104 (0.044). These numbers are broadly in line with the literature (see, e.g., Aw et al., 2010). The coefficients on labor, capital and materials 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 constrast, the estimates for the value-added-based output elasticities are $\tilde{\beta}_L = 0.533$, and $\tilde{\beta}_K = 0.208$ ($\beta_L = 0.71$ and $\beta_K = 0.28$), suggesting constant returns. Finally, note that the size-bin interactions with the export- and import-weighed RERs, λ_j^{EXP} and λ_j^{IMP}, have the expected signs and become larger for larger firms, which are more likely to export and/or import.

In Table 9 we present results from estimating the AR(1) process for the RER e_t (see equation (5)) using the period 2001-2010. The RER has an autocorrelation coefficient of 0.93. This implies that swings in e_t are very persistent, and can thus potentially have a significant effect on firms' dynamic R&D investment decisions. The R-squared of fitting this process is also 0.93.

5.2 Estimates of Other Model Parameters

Tables 10-12 report the parameter values estimated using the Indirect Inference procedure for our different sub-samples (standard errors are reported in parentheses), as well as a comparison between the data and the simulated statistics. 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 also qualitatively matches the difference in signs of TFPR with respect to RER across regions. The predicted RER elasticities are slightly larger in absolute magnitudes (0.2 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 display less 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 and the autocorrelation of TFPR), are small.

We now turn to a discussion of the parameter estimates, which are all estimated quite precisely with the exemption of credit constraints. 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 and around 28 percent for other emerging and 102 percent for industrialized countries). The mean R&D fixed cost for R&D continuers are much smaller compared

Table 8: Production function: coefficient estimates

	(1)	(2)
labor $\tilde{\beta}_l$	0.33621***	0.53342***
	(0.00170)	(0.00245)
capital $\tilde{\beta}_k$	0.09272***	0.20844***
	(0.01782)	(0.01046)
materials $\tilde{\beta}_m$	0.68178***	
	(0.02238)	
R&D return $\tilde{\alpha}_2$	0.07854***	0.03306**
	(0.01306)	(0.01644)
$\log(e^{EXP}_{sct})\times$	0.00125	-0.14872***
λ_1^{EXP}	(0.02131)	(0.03440)
$\log(e^{EXP}_{sct})\times$	0.42624***	0.72894***
λ_2^{EXP}	(0.02462)	(0.03941)
$\log(e^{EXP}_{sct})\times$	0.34517***	0.75503***
λ_3^{EXP}	(0.02741)	(0.04605)
$\log(e^{EXP}_{sct})\times$	0.17792***	0.44537***
λ_4^{EXP}	(0.06777)	(0.11737)
$\log(e^{IMP}_{sct})\times$	-0.07311***	0.10997***
λ_1^{IMP}	(0.02015)	(0.03286)
$\log(e^{IMP}_{sct})\times$	-0.56088***	-0.83792***
λ_2^{IMP}	(0.02471)	(0.03454)
$\log(e^{IMP}_{sct})\times$	-0.70016***	-1.14283***
λ_3^{IMP}	(0.02682)	(0.04461)
$\log(e^{IMP}_{sct})\times$	-0.82707***	-1.24005***
λ_4^{IMP}	(0.06633)	(0.11686)
Observations stage 1	1,001,593	1,001,593
Observations stage 2	33,252	49,183
Country-time FE	YES	YES
Sector FE	YES	YES

Notes: The terms $\lambda_j^{EXP}\log(e^{EXP}_{s,t})$ and $\lambda_j^{IMP}\log(e^{IMP}_{s,t})$ 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.

Table 9: Estimation of log RER, AR (1) process

	(1)	(2)
intercept	-0.000472	-0.0315
	(0.0095)	(0.0201)
$\log e_{c,t-1}$	0.930***	0.935***
	(0.015)	(0.015)
Observations	657	657
R-squared	0.931	0.947
s.d. residuals	0.105	0.0924
Cluster	Country	Country
Time dummies	NO	YES

Table 10: 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 (1.63) (17.6 pct. of avg. R&D benefit)	Export probability	0.26	0.26
f_{RD}	log R&D fixed cost, mean	9.06 (1.25) (0.24 pct. of avg. R&D benefit)	Export/sales Ratio, mean	0.60	0.64
f_m	import fixed cost, mean	7.99 (0.04) (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
D_T	log domestic demand	5.56 (0.01)	Mean firm size (log revenue)	6.6	6.7
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 (23.97)	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.	0.025	0.032

with R&D start-up costs: they are roughly 0.25 to 1 percent of mean R&D benefits. Not surprisingly, the mean fixed costs for importing are relatively low compared to importers' sales and lowest for other emerging economies (4th percentile of importers' sales). The mean fixed cost for exporting are more sizable and correspond to the 10-12th percentile of exporters' sales. The high 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, reflecting the price-adjusted relative quality of imported intermediates, is significantly lower than one for emerging Asia and the industrialized countries (0.71 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 East Asia (other emerging economies), while firms in industrialized countries can borrow up to 53 times current profits. Note however that this parameter is estimated with substantial noise in all regions. 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.

In Table 13 we use equation (27) to decompose the short-run elasticity of TFPR with respect to RER into its various components for each of the regions. For emerging Asia the overall elasticity is 0.21. This is composed as follows: a 1-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 productivty associated to the innovation channel due to more R&D. Thus, in the short run, even in emerging Asia physical productivity gains are swamped by productivity losses from importing. However, this result will reverse in the medium run, as we will 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 1-percent depreciation is associated with a 0.153 percent loss in TFPR, which

Table 11: 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 (2.19) (10th pctile of exporters' sales)	R&D probability	0.25	0.22
$f_{RD,0}$	log R&D sunkcost, mean	11.24 (1.95) (28 pct. of avg. R&D benefit)	Export probability	0.35	0.30
f_{RD}	log R&D fixed cost, mean	7.84 (1.68) (1 pct. of avg. R&D benefit)	Export/sales Ratio, mean	0.10	0.12
f_m	log import fixed cost, mean	5.88 (0.77) (4th pctile of importers' sales)	Import probability	0.39	0.35
A	quality of imported intermediates	0.97 (0.32)	Import/sales ratio	0.24	0.25
D_T	log domestic demand	4.88 (0.29)	Mean firm size (log revenue)	5.97	5.98
D_T^*	log foreign demand	3.02 (2.05)	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 (21.19)	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.	0.036	0.044

Table 12: 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 (1.68) (12th pctile of exporters' sales)	R&D probability	0.56	0.40
$f_{RD,0}$	log R&D sunkcost, mean	13.75 (1.76) (102 pct. of avg. R&D benefit)	Export probability	0.23	0.24
f_{RD}	log R&D fixed cost, mean	9.11 (1.85) (1 pct. of avg. R&D benefit)	Export/sales Ratio, mean	0.17	0.15
f_m	log import fixed cost, mean	8.42 (1.47) (5th pctile of importers' sales)	Import probability	0.20	0.19
A	quality of imported intermediates	0.69 (0.38)	Import/sales ratio	0.14	0.13
D_T	log domestic demand	6.66 (0.17)	Mean firm size (log revenue)	7.64	7.64
D_T^*	log foreign demand	4.99 (1.61)	Sd, firm size (revenue)	2.91	2.91
α_1	persistence, productivity	0.79 (0.006)	(*Dynamic moments*)		
σ_u	sd, innovation of productivity	0.54 (0.04)	R&D, continuation prob.	0.90	0.90
θ	credit constraint	53 (114.41)	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.	0.006	0.041

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. 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.

Table 13: 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

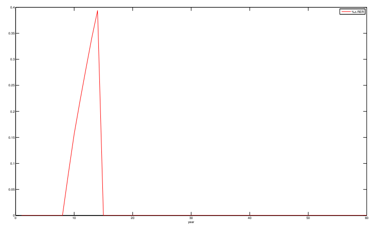
6 Counterfactuals

In this section, we use the estimated model to perform a number of counterfactual exercises: we simulate an unanticipated temporary depreciation of the exchange rate, allowing for a yearly depreciation of 8% for five years with a subsequent appreciation back to the initial level of the RER (Figure 2). All along the exercise, we keep firms' beliefs about the exchange-rate process constant. We do this for the samples of emerging Asia, other emerging economies and industrialized countries.

The top panels of Figure 3 plot the simulation results for emerging Asia. We plot the time paths of the percentage deviations of the exchange rate, revenue TFP and its components from their original steady-state levels. The positive demand effect of the depreciation on demand revenue TFP is quite large relative to the negative effect on import revenue TFP, as expected in a sub-sample of countries with export-intensive firms that import relatively small volumes of intermediate inputs. In this case, the increase in profits due to higher demand for the firms' exports is larger than the decrease in profits due to the fact that intermediate inputs are now more expensive. The resulting net increase in profits leads to R&D investments that trigger an increase in physical productivity. Notice that this increase in physical productivity persists for much longer than the other effects, which are purely transitory. This suggests that temporary exchange rate movements can have very long-lasting effects on productivity growth. The quantitative effect on average physical TFP growth is relatively small: the maximum increase in the growth rate is by 0.1 percentage points (around the time the RER reappreciates back to the initial level).

The middle panels of Figure 3 plot the results of our simulation for other emerging economies. Recall firms in this sub-sample are much more import intensive than East Asian firms. The negative effect of a depreciation on import revenue TFP dominates the positive effect on demand revenue TFP. Similarly, the net effect of the depreciation on firms' profits is negative, inducing them to reduce their

Figure 2: Unexpected real depreciation (8%)



investment in R&D with the subsequent decrease in physical productivity. (Again as above, changes in physical productivity are much more long-lasting than those of the other components of revenue TFP.) In contrast with the East-Asian sub-sample, in this case the overall effect of the depreciation on revenue TFP is negative (but quantitatively very small).

Finally, the bottom panels of Figure 3 display the simulation results for the industrialized-country case. 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. 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 revenue TFP growth are of comparable 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: physical TFP growth is positive but very close to zero.

Lastly, we decompose the effect of the temporary depreciation on physical TFP growth into (i) market-size effects and (ii) relaxed credit constraints. Table 14 indicates that in emerging Asia the R&D participation rate increases by 3.9 percentage points due to the depreciation. More than 80% 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 binding), while only 18% 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 1.3 percentage points. This drop can be decomposed into a 60% reduction due to an increase in credit constraints and a 26% reduction due to reduced market size effects. Finally, in industrialized countries, the R&D participation rate hardly reacts. and the entire change is due to market size effects. Thus, the role of credit constraints for the R&D channel differs vastly across regions and is most important in emerging Asia.

Figure 3: Effect of an unexpected real depreciation on the components of revenue-based TFP by region (emerging Asia (top), other emerging (center), industrialized (bottom)).

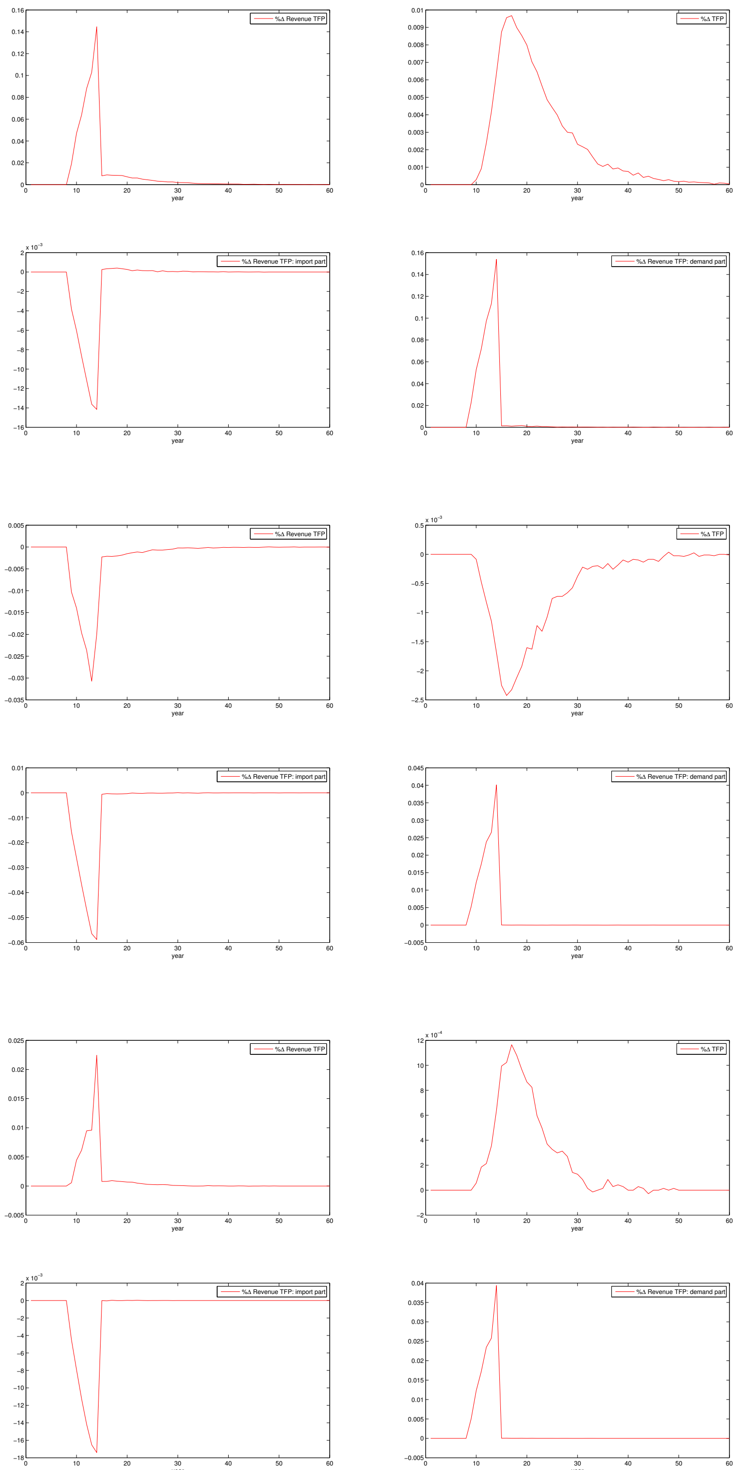


Table 14: Elasticity of R&D w.r.t RER, decomposition into market size and credit constraints.

	Innovation Channel (Change in R&D prob.)	Current Profits	Relaxation Borrowing Constraints
emerging Asia	0.039	18%	82%
Other emerging	-0.013	26%	74%
Industrialized	0.003	-50%	150%

7 Robustness

7.1 Foreign Debt

In an extension of our model, we consider foreign borrowing, which opens up another avenue for the RER to affect firms' behavior. In order to asses its importance in a simple way, we require firms to put a share $1-\lambda$ of their profits in period $t-1$ as a downpayment in foreign consumption units for credit in that currency rather than in domestic consumption units. In the event of a real depreciation from period $t-1$ to period t (that is, $e_{t-1}/e_t < 1$), the corresponding credit constraint becomes tighter, as a given amount of period-$(t-1)$ profits in domestic units elicit a smaller amount of foreign credit:[46]

$$\theta\left(1+r\right)\left[\lambda+\left(1-\lambda\right)\frac{e_{t-1}}{e_t}\right]\Pi_{i,t-1} \geq I_{iRD,t}\left[f_{RD,0}\left(1-I_{iRD,t-1}\right)+f_{RD}I_{iRD,t-1}\right]. \quad (29)$$

8 Conclusions

[46] 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, equation (21) needs to be modified as follows:

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

The term e_t/e_{t-1} represents the effect of a RER depreciation on the value of the firm's outstanding debt 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 by changing the value of the firm's stock of outstanding debt.

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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:

$$U_t = \left(\frac{C_{NT,t}}{\alpha_{NT}}\right)^{\alpha_{NT}} \left(\frac{D_{O,t}}{\alpha_O}\right)^{\alpha_O} \left(\frac{D_{T,t}}{\alpha_T}\right)^{\alpha_T}, \tag{30}$$

$\alpha_j \in (0,1)$ 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 $\frac{P_t^*}{P_t}$. 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

$$Y_{O,t} = e_t^{-1} \left(K_{O,t}/\beta_k\right)^{\beta_k} \left(L_{O,t}/\beta_l\right)^{\beta_l} \left(X_{O,t}/\beta_m\right)^{\beta_m}, \tag{31}$$

$\beta_h > 0$, $\{h = k, l, m\}$, $\sum_h \beta_h = 1$. $K_{O,t}$, $L_{O,t}$, 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

$$P_{O,t} = e_t r_t^{\beta_k} w_t^{\beta_l} P_{X,t}^{\beta_m} = e_t h_t = 1, \tag{32}$$

$h_t \equiv r_t^{\beta_k} w_t^{\beta_l} P_{X,t}^{\beta_m} = e_t^{-1}$: an increase in e_t makes domestic production factors cheaper.[47] 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 $P_{NT,t} = P_{X,t} = e_t^{-1}$.[48]

[47] Note that $P_t \propto e_t^{-1}$. We can therefore think of an increase in e_t as a real depreciation.

[48] This implies $h_t = \left(r_t^{\beta_k} w_t^{\beta_l}\right)^{1/(1-\beta_m)}$ and $P_{X,t} = P_{NT,t} = h_t = \left(r_t^{\beta_k} w_t^{\beta_l}\right)^{1/(1-\beta_m)} = e_t^{-1}$: $P_{NT,t}$, $P_{X,t}$, and $\left(r_t^{\beta_k} w_t^{\beta_l}\right)^{1/(1-\beta_m)}$ move in lockstep.

A-1.1.3 Aggregate Prices and the Real Exchange Rate

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

$$P_T = \left[\int_{i\in\Omega_{T,NI}} p_i^{1-\sigma} di + \int_{i\in\Omega_{T,I}} p_i^{1-\sigma} di + \int_{i\in\Omega_T^*} p_i^{*1-\sigma} di\right]^{\frac{1}{1-\sigma}}. \tag{33}$$

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

$$P_{TH} = P_{T,NI}\left[1 + \left(P_{T,I}/P_{T,NI}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}, \tag{34}$$

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

$$\begin{aligned} P_T &= \left[P_{TH}^{1-\sigma} + P_T^{*1-\sigma}\right]^{\frac{1}{1-\sigma}} = P_{TH}\left[1 + \left(P_T^*/P_{TH}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} = \\ &= P_{T,NI}\left[1 + \left(P_{T,I}/P_{T,NI}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}\left[1 + \frac{P_T^{*1-\sigma}}{\left(P_{T,NI}\right)^{1-\sigma}\left[1 + \left(P_{T,I}/P_{T,NI}\right)^{1-\sigma}\right]}\right]^{\frac{1}{1-\sigma}}. \end{aligned} \tag{35}$$

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

$$\Gamma \equiv \left[1 + \left[1 + \left(\frac{e}{A}\right)^{1-\sigma}\right]^{\beta_m}\left(\frac{\Delta_{T,I}}{\Delta_{T,NI}}\right)^{1-\sigma} + \left(\frac{eP_T^*}{\Delta_{T,NI}}\right)^{1-\sigma}\right]. \tag{36}$$

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 $\overline{X}$:

$$\widetilde{P}_T = -\widetilde{e} + \widetilde{\Delta}_{T,NI} + \frac{1}{1-\sigma}\widetilde{\Gamma}. \tag{37}$$

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

$$\widetilde{\Gamma} \approx (1-\sigma)\left[\left[\overline{\Gamma}_2\frac{\beta_m\left(\overline{e}/A\right)^{1-\sigma}}{1+\left(\overline{e}/A\right)^{1-\sigma}} + \overline{\Gamma}_3\right]\widetilde{e} + \overline{\Gamma}_2\widetilde{\Delta}_{T,I} - \left(\overline{\Gamma}_2 + \overline{\Gamma}_3\right)\widetilde{\Delta}_{T,NI}\right], \tag{38}$$

where

$$\overline{\Gamma}_2 \equiv \left[1 + (\overline{e}/A)^{1-\sigma}\right]^{\beta_m} \left(\overline{\Delta}_{T,I}/\overline{\Delta}_{T,NI}\right)^{1-\sigma} = \left(\overline{P}_{T,I}/\overline{P}_{T,NI}\right)^{1-\sigma}, \tag{39}$$

$$\overline{\Gamma}_3 \equiv \left(\overline{e}\overline{P^*_T}/\overline{\Delta}_{T,NI}\right)^{1-\sigma} = \left(\overline{P^*_T}/\overline{P}_{T,NI}\right)^{1-\sigma}, \tag{40}$$

$$\overline{\Gamma} \equiv 1 + \overline{\Gamma}_2 + \overline{\Gamma}_3. \tag{41}$$

Plugging back into (37),

$$\widetilde{P}_T \approx \overline{\Gamma}^{-1} \left[- \left[1 + \overline{\Gamma}_2 \left(1 - \frac{\beta_m (\overline{e}/A)^{1-\sigma}}{1 + (\overline{e}/A)^{1-\sigma}} \right) \right] \widetilde{e} + \widetilde{\Delta}_{T,NI} + \overline{\Gamma}_2 \widetilde{\Delta}_{T,I} \right]. \tag{42}$$

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

$$\ln P = -\left(\alpha_{NT} + \alpha_T\right) \ln e + \alpha_T \ln \Delta_{T,NI} + \alpha_T \frac{1}{1-\sigma} \ln \Gamma. \tag{43}$$

$$\widetilde{P} = -\left(\alpha_{NT} + \alpha_T\right) \widetilde{e} + \alpha_T \widetilde{\Delta}_{T,NI} + \alpha_T \frac{1}{1-\sigma} \widetilde{\Gamma} = \tag{44}$$

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

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: $\widetilde{P} \approx -\widetilde{e}$.

A-1.1.4 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:

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

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),

$$r_{i,t} = \frac{\sigma-1}{\sigma}\left[\beta_0 + \beta_k k_{i,t} + \beta_l l_{i,t} + \beta_m \tilde{m}_{i,t} - \beta_m \log(P_{X,t}) + \beta_m \tilde{a}_{it}(e_t) + \omega_{it} + \varepsilon_{i,t}\right] + g_{i,t}\left(D_{T,t}, D^*_{T,t}, e_t\right). \tag{45}$$

A-1.2 Production-function Estimation

A-1.2.1 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 $\omega_{i,t}$,[49] we can express $\omega_{i,t}$ as a function of capital $k_{i,t}$, material expenditure $\tilde{m}_{i,t}$ and aggregate demand $(D_{T,t}, D^*_{T,t}, e_t)$.

$$\begin{aligned} r_{i,t} &= \tilde{\beta}_l l_{i,t} + \tilde{\beta}_0 + \tilde{\beta}_k k_{i,t} + \tilde{\beta}_m \tilde{m}_{i,t} + \tilde{\beta}_m \tilde{a}_{i,t}(e_t) - \tilde{\beta}_m \log(P_{X,t}) + \tilde{\omega}_{i,t}\left(k_{i,t}, \tilde{m}_{i,t}, D_{T,t}, D^*_{T,t}, e_t\right) + g_{i,t}\left(D_{T,t}, D^*_{T,t}, e_t\right) + \varepsilon_{i,t} = \\ &= \tilde{\beta}_l l_{i,t} + \Phi\left(k_{i,t}, \tilde{m}_{i,t}, D_{T,t}, D^*_{T,t}, e_t\right) + \varepsilon_{i,t}, \end{aligned} \tag{46}$$

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.[50] 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 RERs to interactions with export and import status, since the firm-level trade status is not available

[49] 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.

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

for around 60% of the observations.[51] Since $\varepsilon_{i,t}$ is uncorrelated with the covariates given our timing assumptions, OLS estimation of (46) 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-1.2.2 Second Stage

In the second stage we obtain consistent estimates for the capital and labor coefficients $\tilde{\beta}_k$ and $\tilde{\beta}_m$, for the autocorrelation of TFP α_1 and the return to R&D $\tilde{\alpha}_2$. 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 (46).

$$\begin{aligned} r_{i,t} - \widehat{\beta}_l l_{i,t} &= \tilde{\beta}_0 + \tilde{\beta}_k k_{i,t} + \tilde{\beta}_m \tilde{m}_{i,t} + \tilde{\alpha}_0 + \\ &+\alpha_1 \left[\widehat{\Phi}\left(k_{i,t-1}, \tilde{m}_{i,t-1}, D_{T,t}, D^*_{T,t}, e_{t-1}\right) - \tilde{\beta}_k k_{i,t-1} - \tilde{\beta}_m \tilde{m}_{i,t-1}\right] + \tilde{\alpha}_2 I_{iRD,t-1} + \varepsilon_{i,t} + \tilde{u}_{i,t}. \end{aligned} \tag{47}$$

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, and $\tilde{\alpha}_2$. We obtain standard errors using a bootstrap.

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 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 (2015) 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 ex-

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

porting/importing/not importing). See Alfaro, Conconi, Fadinger and Newman (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)×revenue. Finally, we drop the top an bottom one percent of observations in terms of TFP growth before running the reduced-form regressions reported in the paper.

Appendix Table A-6 reports descriptive statistics of firm-level variables.

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

$$\min_{\beta}(\nu - \nu(\Theta))' V (\nu - \nu(\Theta)), \tag{48}$$

where V is the $p \times p$ optimal weighting matrix (the inverse of the variance-covariance matrix of the data statistics ν). Under certain regularity conditions

$$\sqrt(N)(\tilde{\Theta} - \Theta) \rightarrow N(0, (1 + 1/T)(J' V^{-1} J)^{-1}) \tag{49}$$

where $J = E(\partial\nu(\Theta)/\partial\Theta)$ is a $q \times p$ matrix.

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
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
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 developing countries.

Table A-1: Panel B-Firm-level descriptive statistics. Mean values 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-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.$_{it}$
$\Delta \log e_{ct} \times$	0.094*	0.0105	0.162	-0.258	0.0104
industrialized$_c$	(0.055)	(0.022)	(0.105)	(0.326)	(0.023)
$\Delta \log e_{ct} \times$	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)
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: industrialized economy; emerging Asia; other emerging 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 firm-level outcomes: IV estimates

	(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.$_{it}$
$\Delta \log e_{ct} \times$	-0.009	-0.054	-0.353	-0.105	-5.169
industrialized$_c$	(0.258)	(0.099)	(0.686)	(0.520)	(5.424)
$\Delta \log e_{ct} \times$	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)
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: industrialized economy; emerging Asia; other emerging 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-4: Export-and import-weighted RERs 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.$_{it}$
$\Delta \log e_{sct}^{exp} \times$	0.827	0.069	0.391	0.751	-0.737***
industrialized$_c$	(0.587)	(0.081)	(0.385)	(0.679)	(0.189)
$\Delta \log e_{sct}^{exp} \times$	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	0342
other emerging$_c$	(0.239)	(0.078)	(0.395)	(0.487)	(0.369)
$\Delta \log e_{sct}^{imp} \times$	-0.193	6.32E-05	-0.289	-0.557	0.510***
industrialized$_c$	(0.354)	(0.0674)	(0.326)	(0.616)	(0.169)
$\Delta \log e_{sct}^{imp} \times$	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)
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. 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 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-5: Export- and import-weighted RERs and firm-level outcomes – long differences

	(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}
$\Delta \log e^{exp}_{sct} \times$	0.540**	0.0471	1.061	-0.241	5.460***
industrialized_c	(0.258)	(0.0815)	(0.673)	(1.676)	(1.175)
$\Delta \log e^{exp}_{sct} \times$	0.322**	0.0714	2.841***	3.717**	3.557***
emerging Asia_c	(0.156)	(0.125)	(1.023)	(1.547)	(0.578)
$\Delta \log e^{exp}_{sct} \times$	-0.0838	0.0369	-0.199	-0.493	-1.01
other emerging_c	(0.123)	(0.113)	(0.861)	(1.188)	(2.073)
$\Delta \log e^{imp}_{sct} \times$	-0.247	0.13	1.891**	-0.342	-2.304**
industrialized_c	(0.214)	(0.0837)	(0.745)	(1.42)	(1.023)
$\Delta \log e^{imp}_{sct} \times$	0.0457	-0.109	1.04	0.199	3.234***
emerging Asia_c	(0.149)	(0.119)	(0.918)	(1.451)	(0.739)
$\Delta \log e^{imp}_{sct} \times$	-0.202*	-0.101	-0.658	-1.928*	1.085
other emerging_c	(0.117)	(0.105)	(0.81)	(1.03)	(2.275)
Observations	298,664	298,570	297,402	195,921	37,983
R-squared	0.085	0.06	0.212	0.115	0.086
Country-sector FE	YES	YES	YES	YES	YES
Time 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 three-year averaged log difference in the following firm-level outcomes computed from Orbis for manufacturing firms for the years 2002, 2005, 2008, 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 3-year-averages of 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 US SIC level (from UN-Comtrade data), interacted with dummies for: industrialized economy; emerging Asia; other emerging economy. The regressions also include business cycle controls: the 3-year-averaged real growth rate of GDP in PPP (from PWT8.0) and the inflation rate (from IMF). 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 (conditional)	0.58	0.25
Avg. import intensity (conditional)	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: The aggregate RER and firm-level outcomes by firm's trade participation status and region: country-sector-time FE

	(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.$_{it}$
$\Delta \log e_{ct} \times$	0.009	-0.002	0.031	0.284***	-0.007
industrialized$_c \times$exporter$_f$	(0.019)	(0.008)	(0.025)	(0.077)	(0.057)
$\Delta \log e_{ct} \times$	0.0483**	0.0128	0.0711***	-0.0457	-0.0498
industrialized$_c \times$importer$_f$	(0.021)	(0.008)	(0.026)	(0.080)	(0.052)
$\Delta \log e_{ct} \times$	0.193***	0.030	0.127**	0.243	0.064***
emerging Asia$_c \times$exporter$_f$	(0.064)	(0.021)	(0.058)	(0.177)	(0.022)
$\Delta \log e_{ct} \times$	-0.142**	-0.0119	-0.081***	-0.122	-0.101*
emerging Asia$_c \times$importer$_f$	(0.071)	(0.023)	(0.062)	(0.193)	(0.055)
$\Delta \log e_{ct} \times$	0.394***	0.0833*	0.360**	1.182***	0.168
other emerging$_c \times$exporter$_f$	(0.141)	(0.048)	(0.163)	(0.417)	(0.162)
$\Delta \log e_{ct} \times$	-0.251*	-0.076	0.009	-0.789*	-0.127*
other emerging$_c \times$importer$_f$	(0.149)	(0.047)	(0.156)	(0.408)	(0.069)
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
Trade status controls	YES	YES	YES	YES	YES
Cluster	Firm	Firm	Firm	Firm	Firm

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 firm-level indicators for exporting and importing (no trade participation is the omitted category absorbed by country-time FE), and with dummies for: industrialized economy; emerging Asia; other emerging economy. The regressions also control for the firms' trade status. Standard errors are clustered at the firm level.

Table A-8: Robustness of 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 (1.63) (17.6 pct. of avg. R&D benefit)	Export probability	0.26	0.26
f_{RD}	log R&D fixed cost, mean	9.06 (1.25) (0.24 pct. of avg. R&D benefit)	Export/sales Ratio, mean	0.60	0.64
f_m	import fixed cost, mean	7.99 (0.04) (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
D_T	log domestic demand	5.56 (0.01)	Mean firm size (log revenue)	6.6	6.7
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 (23.97)	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.	0.025	0.032