Exchange Rates, Aggregate Productivity and the Currency of Invoicing of International Trade

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Abstract

I use novel customs data from Chile and a model of international prices with nominal rigidities to study how nominal exchange rate movements impact aggregate output and productivity. A special feature of this dataset is that it records the currency in which transactions are invoiced. I exploit this feature to estimate how exchange rate movements generate substitution across goods priced in different currencies. I show that export prices are rigid in the currency in which they are invoiced, so that, in a given destination, the relative price of products invoiced in different currencies fluctuates with the nominal exchange rate. The response in the relative quantities of these products can then be used to identify the elasticity. I find this elasticity to be low, indicating that the expenditure switching effects of exchange rates are limited. I then investigate how changes in export prices generated by exchange rate movements impact aggregate productivity by shifting the allocation of production across exporters. Guided by a quantitative open economy model disciplined by some features of my data, I show that these effects can be significant. In particular, a 10% change in the exchange rate that increases markup dispersion reduces aggregate productivity in the tradable sector by 0.5%. Alternative parameterizations that do not account for the observed heterogeneity in invoicing predict changes in productivity at least five times smaller.

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1. Introduction

Nominal exchange rates often experience dramatic fluctuations.[1] How do these movements affect the real economy? A large literature in international economics has emphasized two mechanisms through which nominal exchange rate movements can impact real output and productivity. First, exchange rate movements can stimulate (depress) output by inducing a switch in expenditures between domestic and foreign goods.[2] Second, exchange rates can affect efficiency in the allocation of factors across firms by inducing price movements that are not related to changes in marginal costs.[3] Understanding the quantitative importance of these two mechanisms is key for the design of exchange rate policy.

This paper sheds light on the strength of these forces guided by a novel dataset from Chilean customs that contains information on the currency used to invoice transactions. The first contribution of the paper is to use these data to identify the expenditure switching effects of exchange rates. The second contribution is to measure how exchange rate movements impact aggregate productivity using a quantitative model of international prices and nominal rigidities guided by the data.

A major challenge in identifying the expenditure switching effects is that exchange rates respond to shocks that simultaneously affect supply and demand conditions in the domestic and foreign economies. I am able to identify these effects in the customs data by exploiting the fact that Chilean exporters use different currencies to invoice transactions. In particular, I compare how exporters selling the same product into the same destination but invoicing in different currencies respond to changes in the exchange rate. Consistent with previous findings in the literature (Gopinath et al. (2010)) I show that export prices are rigid in the currency in which they are invoiced, so the relative price of two products invoiced in different currencies fluctuates almost one-to-one with the exchange rate. The response in relative quantities to this change in relative prices can be used to identify the elasticity.[4] I estimate an elasticity of quantities in response to the exchange rate that is in the range of -1 and -2. These values are in line with those

[1]For instance, the euro/dollar exchange rate fell 35 percent between 2002 and 2004, only to increase 16 percent in 2005. The pound/ dollar exchange rate increased 40 percent during 2008.

[2]This topic has motivated a vast literature on how exchange rate movements affect international relative prices. See Burstein and Gopinath (2012) for a summary.

[3]See Corsetti et al. (2010).

[4]This assumes that the currency of invoicing is set before the exchange rate changes, and that relative demand shocks affecting both firms are uncorrelated with nominal exchange rates. As I show in the empirical section, these assumptions are likely to hold in these data.

used by the international business cycle literature to match the observed comovements between the terms of trade and the trade balance. In contrast, my estimates are obtained directly from microdata on the response of prices and quantities to changes in the exchange rate. Such low elasticities indicate that the expenditure switching effects are limited, even when exchange rate movements change relative prices.

I then measure how movements in exchange rates impact aggregate productivity using a quantitative model of international prices with Calvo sticky prices. An extensive literature studies how exchange rates affect efficiency by inducing price movements across firms that are not driven by changes in marginal costs. This literature has been mainly theoretical in nature, and typically assumes constant desired markups and no heterogeneity in invoicing.[5] In contrast, I design a quantitative model of international relative prices that is consistent with the following three features of the Chilean data. First, there is substantial heterogeneity in the currency in which exporters invoice transactions. Second, the relative price of exports invoiced in different currencies displays persistent changes that comove with the exchange rate. Third, firms that invoice in the destination market's currency have a higher markup elasticity with respect to changes in the exchange rate than firms invoicing in U.S. dollars.[6] I show that by incorporating these assumptions into the model, I obtain very different measures of efficiency losses due to exchange rate movements than those obtained under the standard assumptions made in the literature.

I parameterize a three-country version of the model, taking the countries to represent Chile, the U.S. and Europe. I simulate an appreciation of the euro against all currencies and evaluate its effect on Chilean output per worker, where ouput per worker is calculated following the procedures used by statisticial agencies. In my baseline calibration, a 10 percent appreciation of the euro reduces Chilean productivity in the tradable sector by 0.5 percent. These effects are persistent: productivity is still 0.25 percent below the initial steady state a year after the shock. To evaluate the role of heterogeneity in invoicing, I reparameterize the model by assuming that all Chilean firms selling in each destination invoice in the same currency. I also conduct counterfactual parameteri-

[5]See for example Engel (2002, 2011) and Gali and Monacelli (2005). Dotsey and Duarte (2010) and Gust et al. (2009) are examples of richer quantitative models that evaluate the role of exchange rate pass-through on aggregate variables such as the trade balance. None of these papers focus on how exchange rates affect efficiency.

[6]Gopinath et al. (2010) provide related evidence of this fact by documenting substantial differences in pass-through into the United States of the average good priced in dollars versus non-dollars after conditioning on a price change.

zations that assume that invoicing is uncorrelated to the elasticity of desired markups. These alternative parameterizations predict changes in productivity that are at least five times smaller than my baseline results. This indicates that taking heterogeneity in invoicing into account is crucial for understanding how exchange rate fluctuations affect productive efficiency.

The response of productivity to an exchange rate shock depends on whether the shock magnifies or reduces the initial dispersion in markups. In the model, larger firms have higher desired markups. I show in the data that the invoicing is strongly correlated with firm's size and use this correlation to put discipline on the relation between desired markups and invoicing in the model. Other key parameters are the share of firms invoicing in each currency and the elasticity of substitution across products. The first of these parameters is directly observable in the data, while the elasticity is estimated in the first section of the paper.

Some final considerations are in order. First, firms may respond differently to changes in the exchange rate if they use imported intermediate inputs from different source countries.[7] In such instances, changes in the relative price of these firms would be an efficient response to the changes in input costs generated by the exchange rate. I show, however, that the changes in relative prices that I document arise from movements in relative markups rather than from relative costs. In particular, in estimating how prices respond to the exchange rate, I exploit the fact that Chilean firms sell into more than one destination and use a fixed-effect strategy to control for changes in firm level marginal costs that are common across destinations.[8]

Second, the currency in which exporters invoice their exports is exogenously determined in the model. From the observed correlation between firm size and invoicing, it seems clear that firms select into invoicing currencies. The observed correlation between size and pass-through suggests that firms with a low desired pass-through choose to invoice using the destination market's currency. This correlation between desired pass-through and invoicing is taken into account for the calibration of the model. While these invoicing decisions can be endogenized, I do not expect this modification to significantly affect the quantitative results of the paper.

Finally, it is well known that the efficiency losses from inflation are smaller when

[7] Using data from Belgium, Amiti et al. (2012) argue that about half of the lack of exchange rate pass-through into prices comes from this channel.

[8] Fitzgerald and Haller (2012) use a similar fixed effects strategy to document pricing-to-market by Irish firms selling in Ireland and the UK, for firms invoicing their exports in pounds.

price rigidities are state-dependent rather than time-dependent, as is assumed in my model.[9] In this sense, one could interpret the results from my quantitative exercises as evidence that heterogeneity in invoicing greatly amplifies the effects of exchange rates on productivity rather than focusing on the absolute numbers of the counterfactuals.

Relation to existing literature: This paper is related to various strands of literature. First, there is a growing literature that uses firm or product level data to document how international prices respond to changes in the nominal exchange rate.[10] From this literature, the paper that is the closest to mine is Gopinath et al. (2010), who document differences in pricing practices by firms importing into the U.S. in dollars vs. non-dollars. My contribution to this literature is to document how these differences in prices are reflected in quantities. This is essential for establishing how exchange rate movements affect actual allocations and for measuring the expenditure switching effects of exchange rates.

Second, the paper relates to the literature on the international elasticity puzzle (see Ruhl (2008) and Fitzgerald and Haller (2012)). This literature documents that trade flows are very responsive to changes in tariffs, but not to changes in the exchange rate. I contribute to this discussion by providing a new micro-estimate of the short run trade elasticity by exploiting special features of the Chilean data.

Finally, as discussed above, there is an extensive literature that uses open economy models with sticky prices to study the transmission of monetary shocks across countries.[11] In contrast, I use a quantitative model calibrated to microdata to measure the effects of exchange rate movements on productivity. In doing so, I provide evidence linking invoicing to firm characteristics. This evidence can shed light on the determinants of invoicing practices.[12]

The rest of the paper is organized as follows. The empirical evidence is presented in the next section. Section 3 introduces the model. Section 4 describes the parameterization and the quantitative exercises, and the last section concludes.

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[9] See Golosov and Lucas (2007) and Burstein and Hellwig (2008). Time dependent (Calvo) pricing is the common assumption in open economy literature with price rigidities.

[10] Some of these papers are Berman et al. (2012), Amiti et al. (2012), Fitzgerald and Haller (2012), Burstein and Jaimovich (2012), and Burstein and Gopinath (2012). See Goldberg and Knetter (1997) for a summary of an older literature measuring exchange rate pass-through using sector level data.

[11] A non-exhaustive list of these papers is Obstfeld and Rogoff (1995), Corsetti-Pesenti (2001), Devereux and Engel (2006), Gali and Monacelli (2005) and Engel (2002, 2011).

[12] See for example Goldberg and Tille (2008, 2009), Baccheta and van Wincoop (2005), Engel (2006).

2. Empirical Evidence

2.1. Data

I use two different datasets from Chilean customs. The first dataset contains all export shipments between the years 2009 and 2011. The second dataset only covers wine export shipments, but spans more years, from 2003 to 2011. I use both datasets in the empirical section below.

The data contain information on each export shipment originating in Chile during these periods. Before shipping their products abroad, Chilean exporters, to be authorized by customs, must file an export authorization form.[13] This form records, among other information, the date, the value and quantity of the shipment, the exporter tax id, the destination port and country, the HS8 category of the product, and the product brand and description.[14] The form records the currency in which the transaction was settled, for which the exporter must provide the receipt. I refer to this as the currency of invoicing.

As it is typically the case with customs data, I use firm-product-destination level unit values as proxy for prices. A disadvantage of using unit values is that I cannot measure price stickiness directly, because I do not observe the frequency at which firms adjust prices. On the other hand, an important advantage of the data relative to survey data on prices is that it records values and quantities of actual transactions.

Finally, I take the period average nominal exchange rate from the IMF International Financial Statistics. Data on nominal GDP and domestic inflation are taken from the same source.

2.1.1. Summary Statistics

Table 1 provides summary statistics for the manufacturing and wine datasets. There were over 3 million manufacturing shipments between 2009 and 2011, and over a million wine shipments between 2003 and 2011. These were made by 11,596 and 816 exporters respectively. Finally, note that Chilean exporters sold a wide variety of products (almost 6000 HS8 products) to over 170 destinations during this period.

[13] More precisely, exporters need to get a "Documento Unico de Salida" or "DUS" authorized by customs to be able to get their products out of the country.

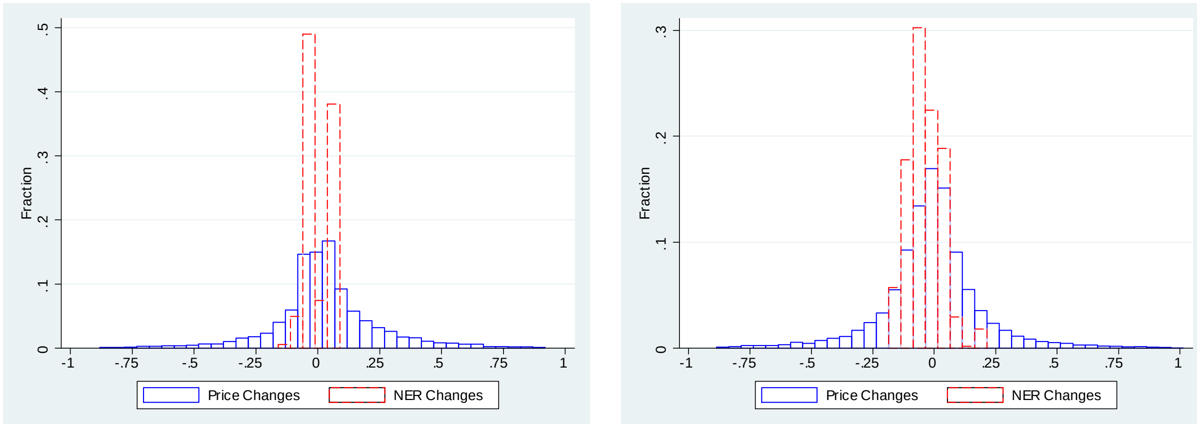
[14] HS8 is a very detailed classification system that Chilean customs uses to impose tariffs. This classification contains over 6000 products and has a level of dissagregation that is equivalent to the HS10 classification used in the US or the CN8 classification used in Europe.

The second and third panels of the table show the distribution of price and nominal exchange rate changes used in the estimations (both computed as log differences). The distributions are plotted in Figure 1. First, note that there is significant heterogeneity in how firms change prices. Second, note that the changes in exchange rates during this period are significant relative to this variation in prices. The median change in the exchange rate in each sample is -0.04, indicating that this was a period during which currencies appreciated relative to the dollar.

Table 1: Summary Statistics

	Manufacturing	Wines
Number of Shipments	3,142,211	1,388,131
Number of exporters	11,596	816
Number of HS8 products	5,746	26
Number of destinations	171	140
Number of currencies used	27	16
Distribution of price changes, expressed in destination's currency*		
10%	-0.19	-0.21
25%	-0.06	-0.09
50%	0.02	0.00
75%	0.12	0.07
90%	0.29	0.18
Distribution of NER changes, destination's currency per U.S. dollar*		
10%	-0.05	-0.10
25%	-0.05	-0.09
50%	-0.04	-0.04
75%	0.05	0.01
90%	0.05	0.05
*Computed for the observations used in the benchmark estimation		

Figure 1: Distribution of Price Changes



Manufacturing Wines

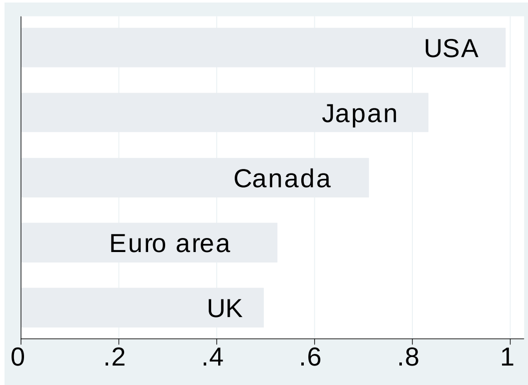
Invoicing: I summarize some important features of the data before proceeding with the econometric analysis. First, most of the invoicing by Chilean exporters is done using the U.S. dollar, while the Chilean peso is seldom used. This is in line with what previous studies have found in developing countries.[15] Figure 2 shows the predominance of the dollar in selected destination countries. We can see that in some markets a significant fraction of the invoicing is done in the currency of the destination country. For instance, about 50 percent of the exports to the UK and Europe are invoiced in pounds and euros respectively. In a given destination, Chilean exporters typically use either the dollar or the destination's currency, while exports in a third currency are extremely infrequent. In addition, over 85 percent of the exporters in my sample use only one currency in a given destination during the period. This suggests that i) exporters play a major role in determining the currency in which international transactions are invoiced, and ii) exporters rarely switch currencies over time in a particular destination. Finally, the volume of exports of firms invoicing in the destination market's currency is 82 percent larger on average than that of firms invoicing in U.S. dollars.

2.2. Empirical Strategy

In this section I describe the empirical strategy for estimating the expenditure switching effects of exchange rates. I compare how exporters selling the same product into the same destination but invoicing in different currencies respond to changes in the ex-

[15] See Goldberg and Tille (2008) for some aggregate facts on how countries invoice their exports.

Figure 2: Share of Sales Invoiced in U.S. dollars



change rate. Assuming that: (i) the invoicing currency is set before the exchange rate changes, and (ii) differences in the shocks to exporters invoicing in different currencies are not correlated with the bilateral exchange rate, the response in relative quantities to changes in relative prices generated by the exchange rate can be used to identify the elasticity. Both assumptions are likely to hold in this setting. The first assumption holds since exporters do not change their invoicing currency during the period. The second assumption is also likely to hold, since exporters from the same country who sell the same product into the same destination are likely to be affected by the same set of aggregate shocks.

I proceed by estimating the following equation at the firm-product-destination level:

$$\begin{aligned}\Delta \log Y_{fpd,t} &= \beta_{dc} \times D_{fpd} \times \Delta \log NER_{d,t} + \beta_{\$} \times [1 - D_{fpd}] \times \Delta \log NER_{d,t} \\ &\quad + \gamma Z'_{d,t} + \upsilon_{fp,t} + \gamma_d + \varepsilon_{fd,t}.\end{aligned} \tag{1}$$

Here, $\Delta \log Y_{fpd,t}$ is the dependent variable, which can be either the log change in the price (expressed in the destination market's currency) or the quantity sold by firm f into destination d in year t. $\Delta \log NER_{d,t}$ is the log change in the destination market's nominal exchange rate, expressed in units of the destination market's currency per U.S. dollar. D_{fpd} is a dummy that takes the value of 1 if the good is priced in the destination market's currency and zero if it is priced in dollars. $Z'_{d,t}$ includes controls for the change in the destination's price level and nominal GDP. γ_d is a set of destination fixed effects. $\upsilon_{fp,t}$ are firm-product-year fixed effects that control for changes in firm-product level marginal costs or demand that are common across destinations. The coefficients of interest are β_{dc} and $\beta_{\$}$, and capture the elasticity of prices or quantities to changes in nominal exchange rates for firms invoicing in the destination's currency and dollars, respectively.

Since I am interested in the differential response of firms that invoice in different currencies, I exclude from the sample those firms that use multiple currencies in the same destination. In addition, I follow Gopinath et al. (2010) by focusing on product-destination pairs where multiple currencies are used. Finally, I aggregate shipments by year to obtain a more accurate interpretation of quantities and avoid seasonality issues.

Below I present my benchmark results using both the manufacturing and the wine datasets. To mitigate concerns about selection, the baseline regressions only include exporters that are active in a destination during the entire period. Subsection 2.3.3 presents robustness checks using different samples and different fixed effects estimators.

2.3. Results

2.3.1. Exchange Rates and Prices

The results from estimating equation (1) using the change in price as the dependent variable, $\Delta \log Y_{fpd,t} = \Delta \log P_{fpd,t}$, are presented in Table 2. Columns 1 and 5 show my benchmark results using the manufacturing and the wine datasets respectively. Note first that the coefficient β_{dc} is not statistically different from zero in either sample. This coefficient captures the price elasticity with respect to the exchange rate for exporters that invoice using the destination's currency. Since prices are denominated in the destination's currency, a zero coefficient indicates that these firms do not change nominal prices in response to changes in the destinations' nominal exchange rate.

In contrast, the elasticity for firms invoicing in U.S. dollars, $\beta_{\$}$, is close to one in both the manufacturing and wine samples. In fact, we cannot reject the null hypothesis that $\beta_{\$} = 1$ in either sample. This implies that nominal prices for these firms are rigid in U.S. dollars, so that these prices move one-to-one with the destination's exchange rate once they are denominated in the destination market's currency. This evidence suggests that prices are very rigid in the currency in which they are invoiced. This rigidity implies that relative prices move one-to-one with the nominal exchange rate. This result is in line with Gopinath et al. (2010), who document a similar finding for firms importing into the U.S. using dollars vs. non-dollars.[16]

A possible interpretation for such an extreme difference in relative prices may be that firms invoicing in different currencies use intermediate inputs sourced from different countries, so that exchange rate changes affect relative marginal costs across firms.[17] An important characteristic of my data is that I can include fixed effects at the firm-product-year level to control for changes in marginal costs that are common across destinations. Assuming that each firm uses the same set of inputs to source every destination, the difference in the coefficients can be attributed to changes in relative markups rather than to changes in marginal costs brought forth by the exchange rate.[18]

Table 2: Exchange Rates and Prices

	Manufacturing				Wines	
	(1)	(2)	(3)	(4)	(5)	(6)
β_{dc}	-0.213	-0.215	-0.061	-0.089	-0.045	-0.043
	(0.189)	(0.188)	(0.117)	(0.115)	(0.087)	(0.066)
$\beta_{\$}$	1.249***	1.128***	1.287***	1.280***	0.889***	0.911***
	(0.21)	(0.21)	(0.116)	(0.111)	(0.10)	(0.061)
Cty FE	Yes	Yes	No	No	Yes	Yes
Continuing	Yes	No	Yes	No	Yes	No
Observations	9,113	9,891	9,113	9,891	9,637	21,282

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Note also that this rigidity seems to be beyond what can be explained by price stickiness. Table 3 repeats the regressions aggregating the wine dataset over periods of two years.[19] Although the coefficient β_{dc} in these estimations turns out to be positive, there continues to be a significant difference between the response of firms invoicing in U.S. dollars relative to those using the destination's currency. The literature on nominal

[16] Fitzgerald and Haller (2012) also document extreme pricing to market (i.e., an elasticity close to zero) for Irish firms selling in pounds into the UK.

[17] Using data from Belgium, Amiti et al. (2012) argue that about half of the lack of exchange rate pass-through into prices comes from this channel.

[18] Fitzgerald and Haller (2012) use a similar fixed effects strategy to document pricing to market by Irish firms.

[19] Unfortunately, the manufacturing dataset does not span enough years to do this exercise.

rigidities documents a median price duration of a year. In contrast, I find a difference in markups that moves one-to-one with the exchange rate over a period of a year, and that is still significant over a period of two years. Such stark responses are in line with those reported by Gopinath et al. (2010) and Fitzgerald and Haller (2012).

Table 3: Wines Sample

	(1)	(2)
β_{dc}	0.134	0.167**
	(0.096)	(0.078)
$\beta_{\$}$	0.929***	0.961***
	(0.097)	(0.069)
Cty FE	Yes	Yes
Continuing	Yes	No
Observations	6,172	11,067
Robust standard errors in parentheses		
*** p<0.01, ** p<0.05, * p<0.1		

2.3.2. Exchange Rates and Quantities

I now present the results for quantities. Table 4 displays the results from estimating equation (1) using the change in quantities as the dependent variable, $\Delta \log Y_{fpd,t} = \Delta \log Q_{fpd,t}$. My benchmark results are presented in columns 1 and 5 for the manufacturing and wine samples, respectively. There is no significant response in quantities for firms invoicing with the destination market's currency, and I cannot reject that the null that the elasticity β_{dc} equals zero in either sample. These are the firms whose price in the destination market did not change in response to the exchange rate. On the other hand, the coefficient for the firms that invoice in dollars, $\beta_{\$}$, comes out negative and significant as expected. These are the firms whose price was rigid in dollars and increased in the destination market's currency when the destination's currency depreciated, as shown in Table 2. The difference in the coefficients is statistically significant and equals 1.35 in our benchmark specification. Note that although relative quantities move in the expected direction, the implied elasticity is low. As mentioned above, such low elasticities are in line with those used by the international business cycle literature to match the observed comovements between the terms of trade and the trade balance. Here, the elasticity is identified from the variation in prices across firms invoicing in different currencies in response to a change in the exchange rate.

Table 4: Exchange Rates and Quantities

	Manufacturing				Wines	
	(1)	(2)	(3)	(4)	(5)	(6)
β_{dc}	-0.519	-0.381	0.335	0.482	-0.408	-0.366
	(0.746)	(0.735)	(0.463)	(0.455)	(0.348)	(0.287)
$\beta_{\$}$	-1.873**	-1.320*	-1.369***	-1.395***	-1.784***	-0.996***
	(0.823)	(0.795)	(0.436)	(0.417)	(0.464)	(0.290)
$\beta_{\$} - \beta_{dc}$	1.35**	0.95	1.704***	1.877***	1.37**	0.63
Cty FE	Yes	Yes	No	No	Yes	Yes
Continuing	Yes	No	Yes	No	Yes	No
Observations	9,113	9,891	9,113	9,891	9,637	21,282
Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1						

2.3.3. Robustness

I now conduct several robustness checks for the results established in the previous two sections. In particular, I conduct the following exercises: First, I repeat the regressions including the entire sample of firms, instead of using only continuing firms. These results are displayed in columns 2 and 6 of Tables 2 and 4 for the manufacturing and wine datasets, respectively. The results are robust to these alternative samples, although the difference in coefficients for the quantity regression is somewhat smaller. Second, I run the regressions controlling for different types of fixed effects. The results of these estimates are presented in columns 3 and 4 of the tables. None of these changes modify the conclusions of the previous subsections.

2.3.4. Discussion

The data presented in this section establish that: i) relative prices across firms that invoice using different currencies fluctuate one-to-one with the exchange rate, ii) these price fluctuations can be attributed to variations in destination specific markups, as opposed to changes in firm level marginal costs that are common across destinations, and iii) relative quantities respond to the exchange rate in the expected direction, with an implied elasticity that is between -1 and -2. Such low elasticities are indicative of limited expenditure switching effects of changes in the exchange rates. The elasticities estimated in this section are for goods in the same product category that were sourced from the same country (Chile). To the extent that goods from different source countries are less substitutable than goods from the same country, the expenditure switching effects would be even weaker than those implied by these estimates.

In addition, the evidence provided so far shows that exchange rate changes affect relative markups and the allocation of production across firms invoicing in different currencies. The model developed in the next section provides a framework for evaluating how these changes in nominal exchange rates translate to aggregate output per worker.

3. Model

This section introduces a quantitative open economy model of international relative prices to measure how exchange rates affect aggregate productivity.

Preliminaries: The structure of the model is relatively standard. There are three countries indexed by $i = c, s, e$. Each country is inhabited by n_i agents and produces n_i goods. I normalize the world population and the number of available goods in the world to 1. Identical households in each country consume a final good and supply labor. In addition, in each country there is a continuum of n_i monopolistically competitive intermediate producers, each producing a differentiated good. These producers use labor as their sole input of production and differ in their productivities. The output of these intermediate producers is aggregated by the consumers into a final good with a Dixit-Stiglitz CES aggregator. I introduce endogenous variable markups in a tractable way by assuming that intermediate goods must be combined with nontradable distribution services in fixed proportions to be delivered to consumers.[20] How distribution costs affect desired markups is explained below. Finally, money is introduced in the model assuming a cash-in-advance constraint.

[20]One interpretation is that all goods use the same "shelf space", regardless the technology used for production. This way of generating endogenous variables markups was first introduced by Corsetti and Dedola (2005).

Households: The utility function of a household in country i is given by

$$U_{i,t} = E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_{i,t}^{1-\sigma}}{1-\sigma} - \frac{N_{i,t}^{1+\phi}}{1+\phi} \right],$$

where $C_{i,t}$ is an aggregate bundle of tradable and nontradable consumption goods and $N_{i,t}$ denotes labor effort. The parameters σ and ϕ control the intertemporal elasticity of substitution for consumption and the Frisch elasticity of the labor supply, respectively. I assume that households in each country can trade a full set of state contingent nominal bonds. This gives rise to two familiar optimality conditions: the intratemporal consumption-leisure condition,

$$C_{i,t}^{\sigma} N_{i,t}^{\phi} = W_{i,t}/P_{i,t},$$

and the risk sharing condition,

$$\left(\frac{C_{i,t}}{C_{j,t}} \right)^{\sigma} = \frac{E_{ij,t} P_{j,t}}{P_{i,t}} \equiv Q_{ij,t}.$$

Here, $W_{i,t}$ and $P_{i,t}$ denote the nominal wage and the consumption price index in country i, respectively. $E_{ij,t}$ denotes the bilateral nominal exchange rate, expressed as units of country $i's$ currency per currency unit of country $j's$ currency. The first condition states that households equalize the ratio of the marginal utilities between consumption and leisure to the real wage. The risk sharing condition states that the marginal utility of a dollar is equalized across countries. This means that the ratio of marginal utilities between countries i and j must equal the real exchange rate between country i and country j, denoted by $Q_{ij,t}$. Finally, the cash-in-advance constraint implies

$$P_{i,t} C_{i,t} \leq M_{i,t}.$$

Preferences and demands: Aggregate consumption in each country is a composite of nontradable and tradable goods. We break down this bundle in steps. First, aggregate consumption is given by $C_{i,t} = C_{iT,t}^{\alpha} C_{iN,t}^{1-\alpha}$, where $C_{iT,t}$ and $C_{iN,t}$ are bundles of tradable and nontradable goods, respectively. The tradable good bundle is a composite of intermediate tradable goods produced in each country:

$$C_{iT,t} = \sum_j \left[\nu_{ji}^{\frac{1}{\xi}} C_{jiT,t}^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}}.$$

Here, $C_{jiT,t}$ is a composite of consumption goods sold from country j into country i, and ξ is the elasticity of substitution across tradable varieties. The weights that composites from different source countries receive in the aggregate bundle are given by $\nu_{ji} \equiv n_j \lambda$ and $\nu_{ii} \equiv 1 - (1 - n_i)\lambda$. This specification allows weights ν_{ji} to depend on a parameter λ that determines home bias, and on the number of goods n_j produced in the source country j. Hence, consumption shares depend directly on country size n_j. This is a tractable way of making the size of the Chilean economy arbitrarily small in the quantitative exercises below.[21] In addition, the consumption composites $C_{jiT,t}$ are aggregate bundles of the intermediate goods produced in each country. These bundles are given by

$$C_{jiT,t} = \left[\left(\frac{1}{n_j} \right)^{\frac{1}{\xi}} \int_0^{n_j} C_{jiT,t}(f)^{\frac{\xi-1}{\xi}} \, df \right]^{\frac{\xi}{\xi-1}},$$

where, $C_{jiT,t}(f)$ denotes consumption of good f. Finally, the nontradable bundle in each country is a composite of domestically produced intermediate goods, given by:

$$C_{iN,t} = \left[\left(\frac{1}{n_i} \right)^{\frac{1}{\rho}} \int_0^{n_i} C_{iN,t}(f)^{\frac{\rho-1}{\rho}} \, df \right]^{\frac{\rho}{\rho-1}},$$

where ρ is the elasticity of substitution across nontradable intermediate goods.

Cost minimization implies that demands for tradable and non-tradable goods are given by:

$$C_{iT,t} = \frac{\alpha P_{i,t} C_{i,t}}{P_{iT,t}}; \quad C_{iN,t} = \frac{(1-\alpha) P_{i,t} C_{i,t}}{P_{iN,t}} \;;$$

where $P_{iT,t}$ and $P_{iN,t}$ are the price indexes for tradable and nontradable consumption. Demand for goods originating in country j is:

$$C_{jiT,t} = \nu_{ji} \left[\frac{P_{jiT,t}}{P_{iT,t}} \right]^{-\xi} C_{iT,t}.$$

[21] This specification has previously been used in Sutherland (2005) and Di Paoli (2009).

while the demands for individual varieties are:

$$C_{jiT,t}(f) = \frac{1}{n_j}\left[\frac{P_{jiT,t}(f)}{P_{jiT,t}}\right]^{-\xi} C_{jiT,t}; \quad C_{iN,t}(f) = \frac{1}{n_i}\left[\frac{P_{iN,t}(f)}{P_{iN,t}}\right]^{-\rho} C_{iN,t};$$

where $P_{jiT,t}(f)$ is the consumer price in country i of good f produced in country j, and $P_{jiT,t}$ is the ideal consumer price index for goods sold in from country i into country j. $P_{iN,t}(f)$ is the price of nontradable intermediate f in country i. The relative consumption between goods being sourced from different countries is given by:

$$C_{ijT,t}/C_{jjT,t} = \left(P_{ijT,t}/P_{jjT,t}\right)^{-\xi}.$$

I refer to changes in this ratio following a change in the nominal exchange rate $E_{ij,t}$ as expenditure switching effects. These are determined by changes in retail prices and the elasticity of substitution ξ.

Pricing: There are two sources of price rigidities in the model. First, producer prices are sticky in the currency in which they are invoiced. Second, there are endogenous variable markups. To introduce endogenous variable markups in a tractable way, I follow Corsetti and Dedola (2005) and assume that competitive retailers combine the intermediate goods with local nontradable goods in fixed proportions to deliver these goods to consumers. This implies that the consumer price in country j for tradable good f produced in country i is given by:

$$P_{ijT,t}(f) = P^{p}_{ijT,t}(f) + \eta P_{jNt}.$$

Here, $P_{ijT,t}(f)$ is the consumer price of good f in country j, $P^{p}_{ijT,t}(f)$ is the producer price of good f denoted in $j's$ currency, and η controls the share of distribution costs in the consumer's price. Note that distribution costs use nontradables from the destination country. Below I describe how the introduction of distribution costs affects the pricing problem of the firm.

Flexible prices: I start by solving for the optimal price under flexible prices. The problem of producer f from country i selling into country j is given by:

$$\max_{P^{pl}_{ijT,t}(f)} \left[P^{p}_{ijT,t}(f)\, E_{ij,t} - \frac{W_{i,t}}{z(f)}\right] \left[\frac{P_{ijT,t}(f)}{P_{ijT,t}}\right]^{-\xi} C_{ijT,t},$$

where $z(f)$ denotes the productivity of firm f. The optimal flexible price expressed in the producer's currency is a markup over the marginal costs

$$P^{p}_{ijT,t}\left(f\right)E_{ij,t}=\mu_{ij,t}\left(f\right)\frac{W_{i,t}}{z\left(f\right)},$$

where the markup is given by:

$$\mu_{ij,t}\left(f\right)\equiv\frac{\xi}{\xi-1}\left[1+\frac{\eta}{\xi}\frac{z\left(f\right)P_{jN,t}E_{ij,t}}{W_{i,t}}\right].$$

To provide intuition on why markups $\mu_{ij,t}\left(f\right)$ vary by source country, destination and firm, note that the elasticity of demand faced by the producer is:

$$\varepsilon_{ij,t}\left(f\right)\equiv-\frac{d\log C_{ijT,t}\left(f\right)}{d\log P^{p}_{ijT,t}\left(f\right)}=\xi\left(1-s_{ij,t}\left(f\right)\right),$$

where $s_{ij,t}\left(f\right)\equiv\frac{\eta P_{jNt}}{P^{p}_{ijT,t}(f)+\eta P_{jNt}}$ is the share of distribution services in the consumer price. Note also that the elasticity of markups with respect to the producer price is given by:

$$\Gamma_{ij,t}\left(f\right)\equiv-\frac{d\log\mu_{ij,t}\left(f\right)}{d\log P^{p}_{ijT,t}\left(f\right)}=\left[\left(\xi-1\right)\frac{1-s_{ij,t}\left(f\right)}{s_{ij,t}\left(f\right)}+1\right]^{-1}.$$

Markups depend on the demand elasticity with respect to the producer price, $\varepsilon_{ij,t}\left(f\right)$, which depends on the share that the producer price has in the price paid by consumers $s_{ij,t}\left(f\right)$. This share is determined by the firm's productivity $z\left(f\right)$. More productive firms have lower marginal costs, higher $s_{ij,t}\left(f\right)$, and higher desired markups $\mu_{ij,t}\left(f\right)$. In addition, these firms have a higher markup sensitivity to changes in the price, $\Gamma_{ij,t}\left(f\right)$.

Finally, with flexible prices, firms set the same price regardless of the currency that is used for invoicing. That means that the flexible price for a producer that invoices in currency l, $P^{pl}_{ijT,t}\left(f\right)$, is given by:

$$P^{pl}_{ijT,t}\left(f\right)E_{lj,t}=\mu_{ij,t}\left(f\right)\frac{W_{i,t}}{z\left(f\right)}.$$

Nominal rigidities: I now introduce Calvo-style nominal rigidities. In particular, intermediate producers in the tradable sector can reset their price with probability $1-\theta_T$, and producers in the nontradable sector reset their prices with probability $1-\theta_N$. I assume that producer prices are rigid in the currency in which they are invoiced. This gives rise to the familiar pricing equations in logs:

$$\bar{p}^{pl}_{ijT,t}(f) = (1-\beta\theta_T)\sum_{k=0}^{\infty}(\beta\theta_T)^k E_t\left[\tilde{p}^{pl}_{ijT,t+k}(f)\right].$$

Here $\bar{p}^{pl}_{ijT,t}(f)$ is the log of the reset producer price of firm f selling from country i to country j invoicing in currency l. $\tilde{p}^{pl}_{ijT,t}(f)$ is the log of the price that the firm would set if prices were flexible, which to a first order approximation is given by:

$$\tilde{p}^{pl}_{ijT,t} = \frac{1}{1+\Gamma(f)}\left[\hat{w}_{i,t} - e_{il,t} + \Gamma(f)\left[\tilde{p}_{jN,t} + e_{lj,t}\right]\right].$$

Finally, retail prices are flexible.

Money supply: The law of motion for the money supply follows: $\Delta \log M_{i,t} = \upsilon_{it}$, where $\upsilon_{it} \sim N(0,\sigma_m)$.

Market clearing: Goods market clearing in the tradable and nontradable sector implies:

$$Y_{iT,t} = \frac{1}{n_i}\sum_j n_j C_{ijT,t}, \tag{2}$$

and:

$$Y_{iN,t} = C_{iN,t} + D_{iN,t}.$$

Here $D_{iN,t} \equiv \frac{1}{\eta}\sum_j \int_0^{n_j} c_{ji,t}(f)\,df$ denotes the amount of nontradable goods used for distribution services.

The amount of labor used in the tradable sector is given by:

$$n_i N_{iT,t} = \int_0^{n_i} N_{iT,t}(f)\,df,$$

we can write this condition as:

$$N_{iT,t} = \frac{1}{n_i}\sum_j n_j C_{ijT,t} V_{ijT,t}, \tag{3}$$

where $V_{ijT,t} \equiv \left[\frac{1}{n_i}\int_0^{n_i}\left[\frac{p_{ijT,t}(f)}{P_{ijT,t}}\right]^{-\xi}\frac{1}{z(f)}df\right]$ is a term capturing the dispersion in tradable prices. The amount of labor used in the non-tradable sector is:

$$N_{iN,t} = \left[C_{iN,t} + D_{iN,t}\right]V_{iN,t},$$

with $V_{ijN,t} \equiv \left[\frac{1}{n_i}\int_0^{n_i}\left[\frac{p_{ijN,t}(f)}{P_{ijN,t}}\right]^{-\rho} df\right]$. Labor market clearing implies:

$$N_{i,t} = N_{iT,t} + N_{iN,t}$$

I solve the model by log-linearizing the equilibrium conditions around the steady-state and solving the resulting system of linear difference equations.

Measuring aggregate output per worker: I define the change in define output per worker in the tradable sector as:

$$TFP_{iT,t}/TFP_{iT,0} = \left[RGDP_{iT,t}/N_{iT,t}\right] / \left[RGDP_{iT,0}/N_{iT,0}\right],$$

where $RGDP_{iT,t}$ is real GDP in the tradable sector. I will compute $RGDP_{iT,t}$ following as closely as possible the procedures used in the United States' National Income and Product Accounts (NIPA) by the Bureau of Economic Analysis to compute real GDP.[22] In particular, I use a Fisher formula, which is a geometric average of a Laspeyres and a Paasche quantity index. For example, real GDP in period t relative to period $t-1$ is given by

$$\frac{RGDP_{iT,t}}{RGDP_{iT,t-1}} = \left[\frac{\sum_j n_j \int_0^{n_i} p_{ijT,t-1}(f)\, c_{ijT,t}(f)\, df}{\sum_j n_j \int_0^{n_i} p_{ijT,t-1}(f)\, c_{ijT,t-1}(f)\, df} \times \frac{\sum_j n_j \int_0^{n_i} p_{ijT,t}(f)\, c_{ijT,t}(f)\, df}{\sum_j n_j \int_0^{n_i} p_{ijT,t}(f)\, c_{ijT,t-1}(f)\, df}\right]^{0.5}, \tag{4}$$

where $p_{ijT,t-1}(f)$ and $c_{ijT,t}(f)$ denote prices and quantities in period t of the detailed components of GDP.[23] The first term in expression (4) is a Laspeyres quantity index (based on $t-1$ prices), while the second term is a Paasche quantity index (based on t prices).[24] Real GDP in period L relative to period 0 is given by:

$$\frac{RGDP_{iT,L}}{RGDP_{iT,0}} = \prod_{t=1}^{L} \frac{RGDP_{iT,t}}{RGDP_{iT,t-1}}. \tag{5}$$

I assume there are two types of firms; z_H and z_L. Using the equilibrium conditions, I show in the appendix that the log-linearized versions of (3) and (4)can be combined as:

[22] See, e.g. Concepts and Methods of the U.S. National Income and Product Accounts (2009). The procedures that we consider are broadly consistent with the recommendations by the United Nations in their System of National Accounts.

[23] See Burstein and Cravino (2012) for a more detailed discussion of these measures.

[24] The implicit GDP deflator is calculated as the ratio of current-dollar GDP to real GDP, $\left(\sum p_t q_t / \sum p_{t-1} q_{t-1}\right) / \left(RGDP_t / RGDP_{t-1}\right)$, which is equal to a geometric average of a Laspeyres and a Paasche *price* index.

$$\hat{v}_{iT,t} = \hat{y}_{iT,t} - \hat{n}_{iT,t},$$

where a $\hat{x}$ denotes log deviations from the non-stochastic steady state. Here $\hat{v}_{iT,t}$ denotes the log change in change in tradable productivity. I the appendix, I show that $\hat{v}_{iT,t}$ can be writen as:

$$\hat{v}_{iT,t} \equiv -\xi \left(\omega^{v} - \omega\right) \sum_{j} \nu_{ij} \left[\hat{p}^{H}_{ijT,t} - \hat{p}^{L}_{ijT,t}\right], \tag{6}$$

where $\omega \equiv \left[1 + \left(\frac{1-\kappa}{\kappa}\right)\left[\frac{\bar{p}_{ijT}(L)}{\bar{p}_{ijT}(H)}\right]^{1-\xi}\right]^{-1}$ and $\omega^{v} \equiv \left[1 + \left(\frac{1-\kappa}{\kappa}\right)\left[\frac{\bar{p}_{ijT}(L)}{\bar{p}_{ijT}(H)}\right]^{-\xi} \frac{z(H)}{z(L)}\right]^{-1}$. In the following sections we will focus on how changes in no nominal exchange rates affect productivity in the tradable sector, $\hat{v}_{iT,t}$, in Chile.

3.1. Exchange Rates, Markups and Productivity

This section describes how exchange rates affect markup dispersion and productivity in the model. Exchange rate fluctuations affect markup dispersion through three different channels. First, since producer prices are sticky, relative markups across firms invoicing in different currencies fluctuate with the exchange rate. Second, for the firms that are able to reset prices each period, there is dispersion across exporters with different productivities and different desired markups. Finally, there is dispersion originating from the staggered price adjustment caused by the Calvo price stickiness.

Consider an appreciation of the euro against all currencies. Distribution costs in Europe increase relative to production costs in Chile following the appreciation, so all Chilean firms exporting to Europe increase markups. The effects are larger for more productive firms, since they have a higher markup elasticity. Second, since prices are sticky and firms invoice in different currencies, an appreciation of the euro increases relative markups of firms invoicing in euros relative to those invoicing in U.S. dollars. Markup dispersion affects productivity in much the same way that inflation affects efficiency in closed economy models with staggered price adjustment. This is captured by the term $V_{ij,T}$ in equation (3). How exchange rate movements affect productivity depends on how invoicing and desired markups correlate with the initial markup dispersion. This implies that productivity can move in either direction in response to an exchange rate shock depending on whether the shock magnifies or reduces the initial markup dispersion. Finally, the shock generates markup dispersion across identical firms that reset prices at different times, as is usual with Calvo pricing. In the next section, I calibrate the model using the Chilean data and evaluate the strength of these mechanisms.

4. Quantitative Results

In this section, I parameterize the model using the Chilean data and evaluate the impact of exchange rate movements in aggregate output per worker. In what follows, I describe what aspects of the data identify the key parameters in my model. I next present my baseline quantitative results. Finally, I conduct alternative parameterizations and sensitivity analyses to show the importance of different assumptions regarding invoicing for the effects of exchange rates in productivity.

4.1. Parameterization

I parameterize the model assuming that there are two types of firms, z_H and z_L. Then, the parameters that I must choose are the elasticity of substitution across varieties, ξ, the share of firms invoicing in each currency in each country, the ratio of productivities across firms, $z_r = z_H/z_L$, the steady state share of distribution costs in the retail price, $\frac{\eta P_N}{P_T}$, the degree of price stickiness in the tradable and nontradable sectors, θ_T and θ_N, the share of goods that are exported, λ, and the relative country sizes, n_i. I also need to assign values for the parameters in the utility function σ and ϕ, the share of nontradables in consumption α, and the discount factor β. I now provide an overview of my baseline parameterization procedure, the results of which are summarized in Table 5.

The calibration of most of these parameters is standard. I take the consumption, output, and trade shares in manufacturing for Chile from the OECD-STAN Input-Output Database. This results in setting $\alpha = 0.37$ and $\lambda = 0.4$. I set the country sizes to $n_c \to 0$, and $n_s = 0.52$, $n_e = 0.48$, so that the size of Chile in the world economy is negligible and to match the share of Chilean manufacturing exports to the US and Europe respectively. Since I use unit values as proxy for prices, I cannot observe the frequency of price changes in my data. Hence, I take the price stickiness parameters θ_N and θ_T from the literature on nominal rigidities and set both of these parameters to equal 0.75, which implies a median price duration of a year. Finally, I set the parameters in the utility function to be $\sigma = 1$ and $\phi = 0$. These choices are made purely for convenience, to ensure that a monetary shock does not generate an overshooting of the nominal exchange rate, and that the change in the exchange rate following the shock is permanent. The values of these parameters do not affect the response of productivity for a given path of the nominal exchange rate.

The remaining parameters are calibrated to the microdata. I first need to establish the currency in which the invoicing is done. I set the share of Chilean firms using the dollar to sell into the U.S. equal to one. I set the share of firms using euros when exporting to Europe equal to 0.38. Both of these shares are directly observable in the Chilean customs data. I assume that the H firms invoice in euros, while the L firms invoice in U.S. dollars in Europe to match the correlation between invoicing and size in the data. Although I do not observe the currency used to sell into the domestic country, I assume that Chilean firms use the Chilean peso when selling into Chile. Finally, I assume that all U.S. firms invoice in dollars and that all European firms invoice in euros in every destination. I will not be focusing on how invoicing affects productivity in these countries.

Finally, there are 3 key parameters that need to be jointly calibrated. These are the elasticity of substitution ξ, the relative productivities between firms, z_r, and the share of distribution costs in the final price $\frac{\eta P_N}{P_T}$. I choose these parameters to target the following three moments: i) the response of relative quantities to the exchange rate, ii) the relative size of firms invoicing in different currencies, and iii) the average share of distribution costs in the retail price. I take the first two moments from the data, while I take the last moment from the literature and set it equal to 0.5.

Table 5: Baseline Calibration

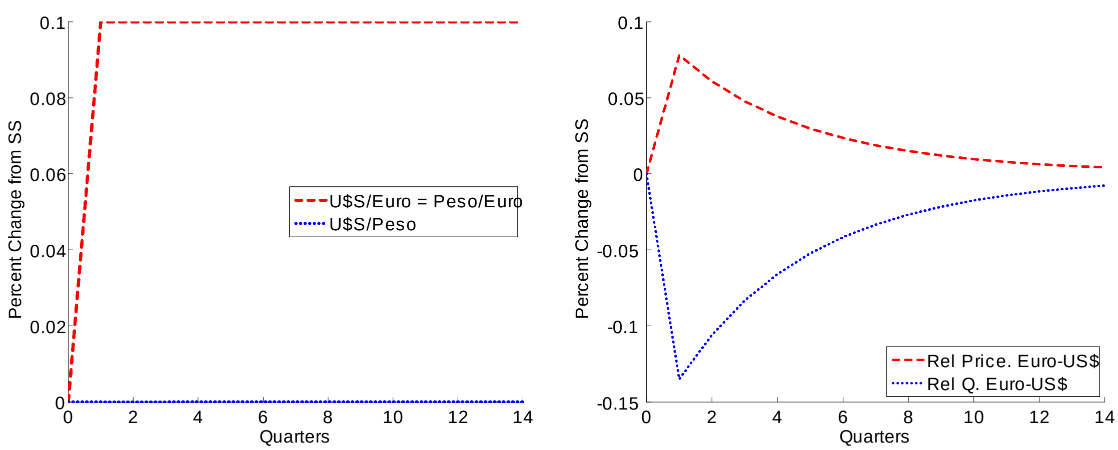
Parameter	Value	Parameter	Value
n_c, n_s, n_e	$0, 0.52, 0.48$	$\kappa_{cs}, \kappa_{ce}, \kappa_{cc}$	$1, 0.38, 1$
σ	1	ξ	2.53
ϕ	0	z_r	2.18
β	0.99	λ	0.4
θ	0.75	α	0.37
θ_N	0.75	$\frac{\eta \bar{P}_N}{P_T(H)}$	0.55
		$\frac{\eta \bar{P}_N}{P_T(L)}$	0.44

Note that the low level of the elasticity implies an extremely high level of markups. However, the level of markups does not enter the log-linear system of equations that characterize the solution of the model.

4.2. Baseline Results

I simulate a change in European money supply that generates a permanent appreciation of the euro against all other currencies. The first panel of Figure 3 depicts the nominal exchange rate shock. The responses of relative prices and quantities of Chilean firms invoicing in different currencies are displayed in the second panel. The dashed red line displays the change in the relative price of firms invoicing in euros relative to those invoicing in U.S. dollars. The dotted blue line shows the corresponding relative quantities. The shock increases the relative price of firms invoicing in euroz relative to those invoicing in U.S. dollars, and decreases the relative quantities between these two types of firms. Since the elasticity is low in the baseline calibration, the resulting change in quantities is small. This corresponds to the limited expenditure switching effect described in first part of the paper.

Figure 3: Exchange Rate Shock, Baseline Calibration

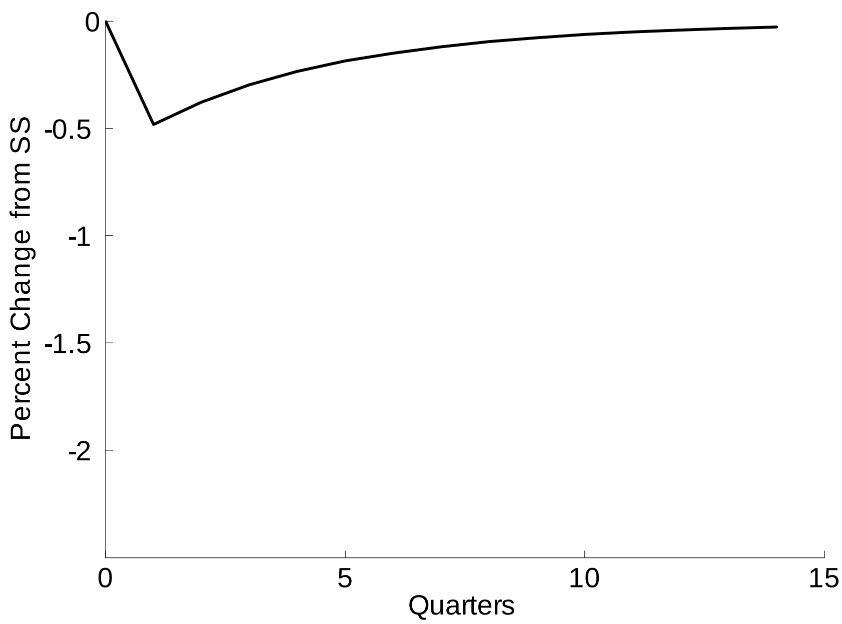


Nominal Exchange Rates | Relative Prices and Quantities

Notice that the persistence of the change in prices is lower than in the data. This is a common feature of models with sticky prices. One way to generate higher persistence would be to introduce a larger degree of price stickiness. In that case, the resulting change in productivity would be even larger and more persistent than those in the results reported below.

Exchange rates and output per worker: Figure 4 shows the response of Chilean output per worker in the tradable sector, given by equation 6, to the change in the European exchange rate. The y-axis shows the deviation in output per worker from the initial steady state. Output per worker falls by 0.5 percent on impact and is still 0.25 percent below the initial steady state four quarters after the shock. Following an appreciation of the euro there are two effects. First, most firms cannot change their nominal price, so the markups of firms invoicing in U.S. dollars decline relative to the markups of the firms invoicing in euros. Second, as the appreciation of the euro increases the share of distribution costs in Europe, all Chilean firms increase markups, in particular large firms. Since large firms are precisely those invoicing in euros, these two effects reinforce each other in increasing the relative markups of the larger firms. Since large firms had higher markups before the exchange rate shock, the shock increases the initial dispersion in markups, generating the drop in productivity. In contrast, a depreciation of the euro would close the initial dispersion in markups and have the opposite effect on productivity.

Figure 4: Exchange Rates and Productivity



4.3. Alternative Parameterizations

I now evaluate the role of variable markups and heterogeneity in invoicing in driving these results. For each of the following exercises, I recalibrate the entire model to be consistent with the corresponding assumptions.

Endogenous variable markups: I first solve a version of the model with multiplicative distribution costs to analyze the importance of variable markups.[25] Under this assumption, markups are constant, with the only effects of the monetary shock on productivity being those arising from the staggered price setting. I repeat the counterfactual exercise and show the results in Figure 5. This is the case depicted by the dashed light blue line labeled "no variable markups." Note that the productivity losses in this case are minuscule. It is worth emphasizing that these are the losses typically studied in the literature. By starting from an inefficient allocation, heterogeneity in markups makes the effects of exchange rates in productivity an order of magnitude larger.

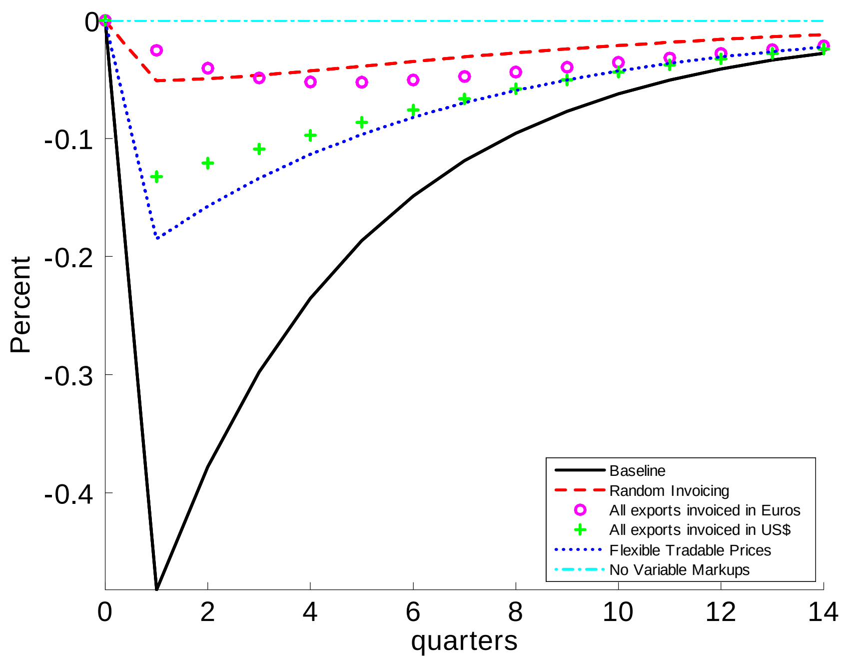
Flexible tradable prices: I now analyze the role of sticky prices in the tradable sector. Even without sticky prices in the tradable sector, changes in the nominal exchange rate generate a change in productivity because of the markup dispersion induced by the endogenous markup channel. This is depicted by the dotted blue line in Figure 5. The figure shows, however, that price stickiness in the currency of invoicing is important: the change in productivity when prices are sticky is only a third of those in the baseline calibration.

Heterogeneity in invoicing: Figure 5 shows the case in which there is no heterogeneity in invoicing. I consider the cases in which all Chilean firms export using either euros or dollars. These correspond to the circled and crossed lines in Figure 5. The figure shows that the response in either case is about five times smaller than in the benchmark scenario. As in the case of flexible tradable prices, exchange rates still affect markup dispersion through the endogenous markup channel despite their lack of heterogeneity in invoicing. However, the effects are even smaller than with flexible tradable prices, since only a small fraction of the firms have the opportunity to reset markups in response to the exchange rate under this specification.

Random invoicing: Finally, I repeat the counterfactual in an environment of multiple invoicing currencies, but where invoicing is uncorrelated to desired markups. That is, the calibration ignores the correlation between invoicing and firm size in the data. This case is shown by the dashed red line in Figure 5. The response of productivity under this scenario is significantly smaller, as firms that increase markups are not necessarily those that had higher markups before the change in the exchange rate.

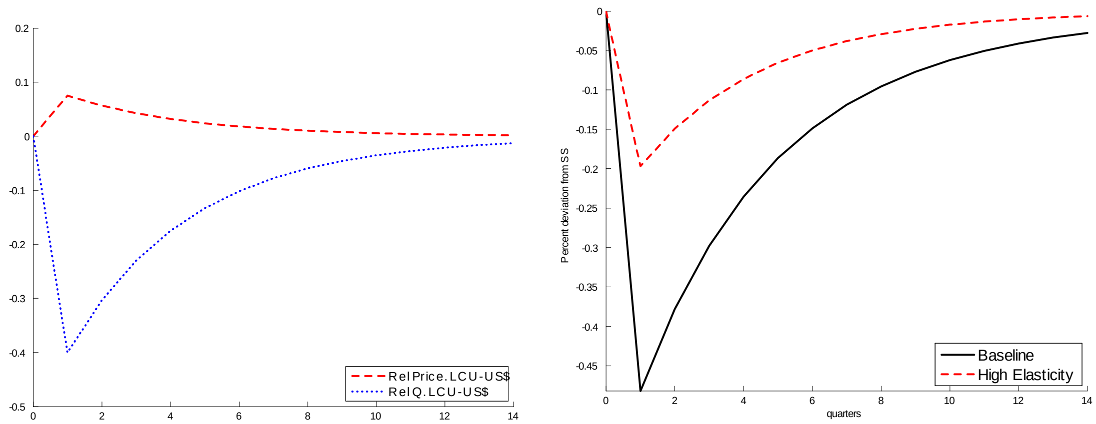
[25] In particular, I assume that the consumer price is given by $P_{ijT,t}(f) = \left[P^{p}_{ijT,t}(f)\right]^{1-\eta} \left[P_{jNt}\right]^{\eta}$. In this case, the share of distribution costs in the retail price is constant and all firms set the same constant markup $\xi/(\xi-1)$.

Figure 5: Alternative Parameterizations



Role of elasticity: Finally, I recalibrate the model assuming an elasticity of quantities to the exchange rate equal to 4. Such high elasticities are common in the international trade literature (typically using trade elasticities in the range of 5 and 10, see Eaton and Kortum (2002)). Figure 6 shows the results. Not surprisingly, the first panel shows that the expenditure switching effects of exchange rates would be much higher under a higher elasticity. The second panel shows the response of aggregate output per worker. A higher trade elasticity implies a higher elasticity of substitution ξ. Then, for a given change in relative quantities, the response in productivity would be smaller.

Figure 6: Exchange Rate Shock, High Elasticity



Expenditure Switching   Output per Worker

4.4. Discussion

The counterfactual parameterizations in this section show that models that ignore heterogeneity in invoicing, endogenous variable markups, or the correlation between markups and invoicing, greatly understate how changes in the exchange rate affect productivity. The intuition is that if firms invoice in different currencies and prices are sticky, changes in the exchange rate have a dramatic impact on relative markups. This effect is reinforced when the invoicing currency is correlated with the initial dispersion in markups. As mentioned above, these features are typically absent in models used to evaluate optimal exchange rate policy.

Some final considerations on how to interpret these results are in order: First, in the model, all changes in relative prices arise from changes in markups rather than from changes in marginal costs. This is consistent with the fixed effects method for estimating changes in relative prices in the empirical section of the paper. Second, although the currency in which exporters invoice their exports is exogenously determined in the model, the correlation between invoicing and desired markups in the baseline parameterization is in line with the predictions of models of endogenous currency choice (see Engel 2006). While I expect to endogenize these decisions in future versions of the paper, I do not expect this modification to significantly affect my quantitative results. Finally, the nominal rigidities in the model arise from Calvo pricing. A more realistic assumption is that firms must incur in menu costs to be able to reset prices. The nominal rigidities literature indicates that losses from inflation are smaller when price rigidities are state-dependent rather than time-dependent. In light of this concern, my results can be interpreted as evidence that heterogeneity in invoicing greatly amplifies the effects of exchange rates on productivity.

5. Conclusions

A large literature in international economics has emphasized expenditure switching and misallocation effects as mechanisms through which nominal exchange rates can affect real output and productivity. This paper provides a quantitative exploration of these mechanisms guided by a novel dataset from Chilean customs and a quantitative model of international prices with nominal rigidities. I exploited differences in the response of Chilean firms invoicing exports in different currencies to identify an elasticity of export quantities in response to the exchange rate that is in the range of -1 and -2. Such a low elasticity indicates that the expenditure switching effects of exchange rates are limited not only because price rigidities limit exchange rate pass-through into prices, but also because quantities are not very responsive to these changes in prices.

I then designed a quantitative model of international relative prices that is consistent with the salient features of the Chilean data to measure how exchange rates affect aggregate productivity. I have shown that by incorporating these features, I obtain very different measures of efficiency losses due to exchange rate movements than those obtained under the standard assumptions made in the literature. As noted above, both the currency of invoicing and the timing of price changes are exogenous in the model. I intend to endogeneize both of these decisions in future versions of the paper. The results presented here show that taking heterogeneity in invoicing and endogenous variable markups into account is key for the discussion in optimal exchange rate policy.

Finally, in light of my results, a natural question is how developing countries should design exchange rate policy. This question has received surprisingly little attention in the literature of optimal exchange rate policy, which typically focuses on cases where all the invoicing is done either in the producer's currency (PCP) or the destination's currency (LCP) (Corsetti et al. 2010). The available evidence suggests that, as in Chile, developing countries use the dollar to invoice a large fraction of their exports. The results in this paper suggest that this is a fruitful area for future research.

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Appendix

Measuring output per worker

In this appendix I derive equation (6) in the paper. I start by approximating $RGDP_{iT,L}/RGDP_{iT,0}$ around the non stochastic steady state. A first order approximation to equation (4) gives:

$$\begin{aligned} y_{iT,t}-y_{iT,t-1} &= \int_0^{n_i}\frac{\sum_j n_j\bar{P}_{ijT}(f)\bar{C}_{ijT}(f)}{\int_0^{n_i}\sum_j n_j\bar{P}_{ijT}(f)\bar{C}_{ijT}(f)}\left(c_{ijT,t}(f)-c_{ijT,t-1}(f)\right)df \\ &= \sum_j\frac{n_j\bar{P}_{ijT}\bar{C}_{ijT}}{\sum_j n_j\bar{P}_{ijT}\bar{C}_{ijT}}\int_0^{n_i}\frac{\bar{P}_{ijT}(f)\bar{C}_{ijT}(f)}{\bar{P}_{ijT}\bar{C}_{ijT}}\left(c_{ijT,t}(f)-c_{ijT,t-1}(f)\right)\bar{d}f \\ &= \sum_j\nu_{ij}\left(c_{ijT,t}-c_{ijT,t-1}\right), \end{aligned}$$

where $y_{iT,t}$ denotes the log of real GDP, and we used $c_{ijT,t}=\int_0^{n_i}\frac{\bar{P}_{ijT}(f)\bar{C}_{ijT}(f)}{\bar{P}_{ijT}\bar{C}_{ijT}}c_{ijT,t}(f)$ in the derivation. We can then write the log-linear version of (5) as:

$$\hat{y}_{iT,t}=\sum_j\nu_{ij}\hat{c}_{ijT,t}.$$

In addition, equation (3) can be approximated as:

$$n_{iT,t}=\sum_j\frac{n_j\bar{C}_{ijT}\bar{V}_{ijT}}{\sum_j n_j\bar{C}_{ijT}\bar{V}_{ijT}}\left(c_{ijT,t}+v_{ijT,t}\right).$$

In a symmetric SS, $\bar{V}_{ij,T}=\bar{V}$ and $\bar{P}_{ijT}=\bar{P}_T$. Then,

$$\begin{aligned} \hat{n}_{iT,t} &= \sum_j\nu_{ij}\left(\hat{c}_{ijT,t}+\hat{v}_{ijT,t}\right) \\ &= \hat{y}_{iT,t}-\hat{v}_{iT,t}, \end{aligned}$$

where: $v_{iT} \equiv -\sum_j \nu_{ij} v_{ijT,t}$. Finally, approximating $V_{ij,T}$ we obtain:

$$
\begin{aligned}
V_{ij,T} &\equiv \left[\frac{1}{n_i}\int_0^{n_i}\left[\frac{p_{ijT,t}(f)}{P_{ijT,t}}\right]^{-\xi}\frac{1}{z(f)}df\right] \\
v_{ij,t} &= \xi\left[\int_0^{n_i}\frac{\left[\bar{p}_{ijT}(f)\right]^{-\xi}\frac{1}{z(f)}}{\int_0^{n_i}\left[\bar{p}_{ijT}(f)\right]^{-\xi}\frac{1}{z(f)}df}\left[p_{ijT,t}(f)-P_{ijT,t}\right]df\right] \\
&= \xi\int_0^{n_i}\left[\frac{\left[\bar{p}_{ijT}(f)\right]^{-\xi}\frac{1}{z(f)}}{\int_0^{n_i}\left[\bar{p}_{ijT}(f)\right]^{-\xi}\frac{1}{z(f)}df}-\int_0^{n_i}\frac{\left[\bar{p}_{ijT}(f)\right]^{1-\xi}}{\int_0^{n_i}\left[\bar{p}_{ijT}(f)\right]^{1-\xi}df}\right]p_{ijT,t}(f) \\
&= \xi\left[\begin{array}{c}\frac{\kappa\left[\bar{p}_{ijT}(H)\right]^{-\xi}\frac{1}{z(H)}}{\kappa\left[\bar{p}_{ijT}(H)\right]^{-\xi}\frac{1}{z(H)}+(1-\kappa)\left[\bar{p}_{ijT}(L)\right]^{-\xi}\frac{1}{z(L)}} \\ -\frac{\kappa\left[\bar{p}_{ijT}(H)\right]^{1-\xi}}{\kappa\left[\bar{p}_{ijT}(H)\right]^{-\xi}\frac{1}{z(H)}+(1-\kappa)\left[\bar{p}_{ijT}(L)\right]^{-\xi}\frac{1}{z(L)}}\end{array}\right]p_{ijT,t}(H) \\
&\quad+\left[\begin{array}{c}\frac{(1-\kappa)\left[\bar{p}_{ijT}(L)\right]^{-\xi}\frac{1}{z(L)}}{\kappa\left[\bar{p}_{ijT}(H)\right]^{-\xi}\frac{1}{z(H)}+(1-\kappa)\left[\bar{p}_{ijT}(L)\right]^{-\xi}\frac{1}{z(L)}} \\ -\frac{(1-\kappa)\left[\bar{p}_{ijT}(L)\right]^{1-\xi}}{\kappa\left[\bar{p}_{ijT}(H)\right]^{-\xi}\frac{1}{z(H)}+(1-\kappa)\left[\bar{p}_{ijT}(L)\right]^{-\xi}\frac{1}{z(L)}}\end{array}\right]p_{ijT,t}(L) \\
&= \xi\left[\begin{array}{c}\left[1+\left(\frac{1-\kappa}{\kappa}\right)\left[\frac{\bar{p}_{ijT}(L)}{\bar{p}_{ijT}(H)}\right]^{-\xi}\frac{z(H)}{z(L)}\right]^{-1} \\ -\left[1+\left(\frac{1-\kappa}{\kappa}\right)\left[\frac{\bar{p}_{ijT}(L)}{\bar{p}_{ijT}(H)}\right]^{1-\xi}\right]^{-1}\end{array}\right]\left[p_{ijT,t}(H)-p_{ijT,t}(L)\right]
\end{aligned}
$$

then, the change in productivity is:

$$\hat{y}_{iT,t}-\hat{n}_{iT,t}=\hat{v}_{iT,t}=-\xi\left(\omega^v-\omega\right)\sum_j \nu_{ij}\left[\hat{p}^H_{ijT,t}-\hat{p}^L_{ijT,t}\right],$$

where ω and ω^v are defined in the text.