# International Prices and Exchange Rates*

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**Abstract**

We survey the recent empirical and theoretical developments in the literature on the relation between prices and exchange rates. After updating some of the major findings in the empirical literature we present a simple framework to interpret this evidence. We review theoretical models that generate insensitivity of prices to exchange rate changes through variable markups, both under flexible prices and nominal rigidities, first in partial equilibrium and then in general equilibrium.

**Key words:** Real exchange rate, nominal exchange rate, border prices, variable mark-ups, price rigidity, pass-through, tradeable goods.

**JEL code:** F3, F4, F15

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# Contents

## 1 Introduction

The relation between prices and exchange rates is one of the classic topics studied in international macroeconomics. This relation is of interest both from a positive and normative perspective. One basic hypothesis connecting prices and exchange rates is that of relative purchasing power parity (PPP): changes in prices of goods should be the same across locations when converted into a common currency. Deviations in relative PPP can arise because of differences in the cost of supplying the good to different locations or because firms price discriminate across locations by charging different mark-ups. Since global efficiency requires that as long as changes in the cost of making the good available to each location is the same the change in price should be the same, the sources of deviations in relative PPP shed light on the efficiency (or lack of it) in the allocation of goods across countries.

In addition to the cross country comparison of price movements, the magnitude of the response of prices to exchange rates for an individual country, exchange rate pass-through (ERPT), is also of interest to measure the extent of expenditure switching that follows exchange rate changes. This is an important ingredient to understand how a devaluation of the currency can stimulate the domestic economy by inducing substitution from foreign to domestic goods. Milton Friedman made the case for exchange rate flexibility on the grounds that if prices are rigid in the producers currency, a flexible exchange rate can bring about the same relative price movements as in a world where nominal prices are fully flexible. On the other hand, if prices in the buyer's local currency are insensitive to changes in the exchange rate there are limited expenditure switching effects. The extent of pass-through both in the short and long-run is therefore important to understand the impact of exchange rate movements not only on prices but also on quantities and therefore welfare.

The relation between prices and exchange rates also helps shed light on positive issues such as how firms' prices respond to cost shocks. This is informative of the market structure the firm operates in, the nature of the demand it faces, and the extent to which markets are segmented across countries. The gradualness (or lack of it) with which firms respond to cost-shocks, in terms of delayed adjustment, also contributes to our understanding of "real rigidities" (i.e. forces that make firms reluctant to change their price relative to other firms' prices) in the macro economy, which play an important role in propagating money non-neutralities. The advantage of international price data over the price data typically used in industrial organization or in closed economy macro is that exchange rate shocks are arguably exogenous to the firm, are easily measurable, and exhibit considerable time variation.

In this chapter we review both the empirical and theoretical work that sheds light on these positive and normative issues, focusing on developments since the last Handbook chapter by Froot and Rogoff (1995) on PPP. We first review and update the major findings in the empirical work. We distinguish between consumer prices (retail prices), producer prices (wholesale prices) and border prices (at-the-dock). The new developments mainly involve bringing more disaggregated datasets, generating new empirical facts alongside reinforcing several old ones.

After summarizing the empirical evidence we present a simple theoretical framework to help interpret the facts. We first consider the partial equilibrium problem of a firm and the impact of exchange rate movements on the pricing of the firm at the border and at the consumer level. We analyze the case of flexible prices and sticky prices. We then aggregate these prices and study the implications for aggregate price indices. Next we describe developments in the literature that endogenizes variable mark-ups. This work builds on the basic insights of Dornbusch (1987) and Krugman (1987) adding richer details such as firm heterogeneity, consumer search and matching, distribution costs and inventories. These can be connected to industry-level data on market structure as well as micro data on firms and plants. Lastly, we describe a workhorse general equilibrium model where exchange rates and wages are determined by monetary shocks and evaluate the success of the model in matching the facts. In the conclusion we discuss what we learn from the literature about the positive and normative issues raised at the start of this introduction.

The chapter is outlined as follows. Section 2 summarizes the empirical evidence, section 3 presents a simple framework to interpret the empirical evidence, sections 4 and 5 describe recent theoretical models of variable mark-ups and other mechanisms that generate insensitivity of prices to exchange rate changes. Sections 6 and 7 discuss industry equilibrium and general equilibrium respectively.

## 2 Empirical Evidence

In this section we summarize five stylized facts on the relation between international prices and exchange rates. We distinguish between international prices based on consumer prices, producer prices and border prices and update several findings using recent data (1975-2011 conditional on data availability) for eight major industrial countries (Canada, France, Germany, United Kingdom, Italy, Japan, Switzerland and the U.S.). The data appendix available on the authors websites provide details of data sources and describe how the statistics presented in this section were constructed.

The first finding characterizes the dynamics of consumer price index (CPI) based real exchange rates (RER), that is the ratio of consumer prices across countries in a common currency, and its relation to nominal exchange rates (NER).

**Empirical Finding 1** *Real exchange rates for consumer prices co-move closely with nominal exchange rates at short and medium horizons. The persistence of these RERs is large with long half lives.*

Define the change in the bilateral CPI-based RER as the log change in the ratio of the CPI in two countries $i$ and $n$ measured in a common currency:

$$\Delta rer_{in,t}^{cpi} = \Delta e_{in,t} + \Delta cpi_{i,t} - \Delta cpi_{n,t}.$$

Here, $\Delta cpi_{i,t}$ represents log changes in the CPI in country $i$ at time $t$ relative to time $t-1$. It is an expenditure weighted average of the change in retail prices consumers pay for goods and services, including both domestically produced and imported items. $\Delta e_{in,t}$ represents log changes in the NER between countries $i$ and $n$ (units of currency $n$ per unit of currency $i$). The change in the trade-weighted RER for country $n$, $\Delta rer_{n,t}^{cpi}$, is defined as a trade weighted average of bilateral RERs for country $n$ across its trade partners $i$.

Figure 1, Panel A, plots cumulative log changes in the trade-weighted NER and the trade-weighted CPI-based RER for the U.S. between 1975 and 2011. The close co-movement between the NER and the RER and the high persistence of the RER is visually apparent.

Table 1 displays standard deviations and correlations between RER and NER changes for eight major industrialized countries. We report results based on four-quarter logarithmic changes in relative prices, as well as for quarterly deviations from HP trends. The results in this table indicate that changes in NERs and RERs are roughly as large and highly correlated. For the U.S., the standard deviation of changes in the NER relative to those for the RER is 0.92, while the correlation is 0.97.

The persistence of the trade-weighted RER is estimated using an AR(5) with a constant and no time trend as in Steinsson (2008) for the 1975Q1–2011Q4 period.[1] More specifically we estimate,

$$rer_{n,t}^{cpi} = \beta + \alpha_n rer_{n,t-1}^{cpi} + \sum_{k=1}^{4} \psi_k \Delta rer_{n,t-k}^{cpi} + \varepsilon_t. \tag{1}$$

Due to the high persistence of most RER series the grid bootstrap procedure in Hansen (1999) is used to obtain a median unbiased (MU) estimate of $\alpha_n$, which is the sum of the AR coefficients. The other AR parameters are estimated by OLS conditional on the MU estimate of $\alpha_n$. In Table 2 we report estimates and 90% confidence intervals of half-lives defined as the largest time $T$ such that the impulse response function $IR$ satisfies $IR(T-1) \geq 0.5$ and $IR(T) < 0.5$. We also report the up-life that follows a similar definition with 0.5 replaced with 1 and measures the hump-shaped behavior of RER deviations.

The half life estimate for 7 of the 8 developed countries is in the range of 3-9 years, the exception being Switzerland with a half life of 1.6 years. These numbers are consistent with the survey in Rogoff (1996) that concludes that the "consensus view" for the average half-life of RER deviations is 3-5 years. Also as documented in Murray and Papell (2002) and Rossi (2005) the confidence intervals on the half live estimates are very wide. In addition CPI-based RERs exhibit hump-shaped

[1] In calculating these statistics we use the codes from Steinsson (2008).

impulse responses as documented in Eichenbaum and Evans (1995), Cheung and Lai (2000) and Steinsson (2008).

The aggregate RER is by construction a composite of more disaggregated sectoral RERs. The literature has used sectoral data to provide alternative measures of aggregate half-lives. Imbs et al. (2005) highlight the potential importance of heterogeneity in sectoral level persistence in impacting measures of aggregate RER persistence. To deal with heterogeneity they estimate the average half life for a panel of sectoral real exchange rates using the Pesaran Mean Group estimator. This estimator involves calculating (weighted) averages of AR(p) coefficients across a panel of regressions, one for each sector, and then estimating the average half life using the averaged AR(p) coefficients. They find it to be 11 months, well below the consensus estimates. Chen and Engel (2005) alternatively calculate the average half life by first estimating half lives sector by sector and taking a weighted average across these estimates. They show that the average persistence of sectoral RERs is not very different from the consensus estimates.[2]

As a reconciliation Carvalho and Nechio (2011) show that the estimation procedures in Imbs et al. (2005) and Chen and Engel (2005) measure different things. Using a model simulated to generate heterogeneity in persistence of sectoral RERs, owing to heterogeneity in the frequency of price adjustment,[3] they demonstrate that the difference between the average of sectoral half-lives and the aggregate half-life (as in Chen and Engel (2005)) is quite small. On the other hand the Pesaran Mean Group estimator (used in Imbs et al. (2005)) calculates the half life for the aggregate RER of a counterfactual one-sector economy with a frequency of price adjustment that matches the average frequency of price adjustment of the multi-sector economy. The difference between this estimate and the true estimate of the persistence of the aggregate RER for a multi-sector economy can be quite large in the presence of sectoral heterogeneity.

**Micro Data:** The fact that there is high co-movement between real and nominal exchange rates has also been established using disaggregated micro level price data for individual goods. Crucini and Telmer (2012) use annual Economist Intelligence Unit data on retail prices for goods with similar characteristics and show that on average product-level RERs co-move closely with the nominal exchange rates. Gopinath et al. (2011) and Burstein and Jaimovich (2008) find similar evidence of co-movement for the exact same UPC sold in the U.S. and Canada by the same retailer. Broda and Weinstein (2008) find similar patterns using ACNielsen's Homescan retail price database of matched goods with a common barcode.

Despite the high co-movement of the product-level RERs and NER's on average, micro level prices exhibit large idiosyncratic movements. As highlighted in Crucini and Telmer (2012) NERs

[2]Chen and Engel (2005) and Reidel and Szilagyi (2005) argue that measurement error and small sample bias can impact the estimates of Imbs et al. (2005). Imbs et al. (2004) argue against the importance of these biases.

[3]Kehoe and Midrigan (2007) document that while there is evidence in the data that the stickier the price of the good the more persistent is its RER, the amount of variation is relatively modest.

account for less than 10% of the deviations from relative purchasing power parity (PPP), defined as the time series variation in good-specific law of one price deviations. The importance of the large idiosyncratic component in goods price changes is consistent with the evidence from the closed economy literature as surveyed in Klenow and Malin (2011).[4]

**Border effect :** Several studies have also compared the behavior of cross-country RERs to within country RERs, with any differences attributed to the "border effect". Engel and Rogers (1996) is a seminal paper in this literature that documents a sizeable border effect for Canada and the U.S. Identifying the "treatment effect" of the border on prices is difficult because the distribution of prices in the absence of the border is typically not observable. Gorodnichenko and Tesar (2009) highlight that ex-ante differences in countries can be misleadingly attributed to the border.[5] In addition, Gopinath et al. (2011) show that using the information contained in price differences alone is useful only when markets are at least partly integrated. Gopinath et al. (2011) use an alternative approach by studying the response of prices to cost shocks in neighboring markets to compare market segmentation across and within countries.

Using UPC level micro data for the U.S. and Canada, Broda and Weinstein (2008) document as much variation in retail prices across as within countries, while Gopinath et al. (2011) and Burstein and Jaimovich (2008) find evidence of a sizeable border effect for consumer and wholesale prices. While the two data sets are not strictly comparable, one factor that can explain the difference in findings is that the data in Broda and Weinstein (2008) is from multiple retail chains, while the data in Gopinath et al. (2011) and Burstein and Jaimovich (2008) is from the same retail chain.[6]

**Empirical Finding 2** *Movements in RERs for tradeable goods are roughly as large as those in overall CPI-based RERs when tradeable goods prices are measured using consumer prices or producer prices, but significantly smaller when measured using border prices.*

The second stylized fact pertains to the importance of movements in relative prices of tradeable goods across countries and movements in the price of nontradeable goods relative to tradeable goods in accounting for fluctuations in the RER, motivated by the classic Salter-Swan traded/nontraded goods dichotomy. We start by describing the evidence using aggregate price indices.

[4]Crucini et al. (2005) investigate the extent of variation in the level of retail prices for similar goods across countries in the European Union. They find significant cross-country dispersion in prices that is centered around zero, and the extent of the dispersion is negatively related to the tradeability of the good. In contrast, Cavallo et al. (2012) find that online retail prices of a large number of identical goods sold in the Euro zone display no dispersion across countries.

[5]Relatedly, Burstein and Jaimovich (2008) argue that even if countries are ex-ante symmetric, a border effect can result from region-specific shocks that are more correlated within countries than across countries. For example RERs are more volatile across regions between countries than within countries because NERs are (by construction) less correlated between countries than within countries.

[6]The fact that there is large variation across retailers in pricing of the exact same good is consistent with the evidence in Boivin et al. (2012) who compare prices of books from online stores in Canada and U.S. They also conclude that international markets are segmented.

Engel (1993) and Engel (1999) propose an approach to decompose movements in CPI-based RER into two components: movements in the relative price of tradeable goods across countries, and movements in the price of non-tradeable relative to tradeable goods across countries. A standard procedure is to identify non-tradeables with services in the CPI and tradeables with goods in the CPI.[7] While these are aggregate categories, the degree of tradeability varies significantly across individual products. Based on this disaggregation, changes in the CPI-based RER can be decomposed as:

$$\Delta rer_{in,t}^{cpi} = \Delta rer_{in,t}^{tr} + \Delta rer_{in,t}^{ntr}, \tag{2}$$

where

$$\begin{aligned} \Delta rer_{in,t}^{tr} &= \Delta e_{in,t} + \Delta cpi_{i,t}^{tr} - \Delta cpi_{n,t}^{tr} \\ \Delta rer_{in,t}^{ntr} &= \Delta cpi_{i,t} - \Delta cpi_{i,t}^{tr} - \Delta cpi_{n,t} + \Delta cpi_{n,t}^{tr}. \end{aligned}$$

Here, $\Delta cpi_{n,t}^{tr}$ denotes the log changes in the component of the CPI in country $n$ that is categorized as tradeable. The term $\Delta cpi_{n,t} - \Delta cpi_{n,t}^{tr}$ is proportional to the change in the price index of nontradeable relative to tradeable categories in country $n$. Hence, equation (2) serves to quantify the importance of movements in the relative price of nontradeables to tradeables across countries in accounting for movements in the RER. It is important to note that this decomposition does not provide a causal interpretation or a structural account of the sources of fluctuations in RERs. Moreover, the two terms in equation (2) are typically not independent, so one can only calculate upper and lower bounds on the importance of each component by attributing the covariance term to one or the other component.

To implement this decomposition one must take a stand on how to measure the price index for tradable goods. The baseline approach in Engel (1993) and Engel (1999) is to measure the price index for tradeable goods from the CPI, that is based on retail prices. Alternatively, Engel (1999) and Betts and Kehoe (2006) measure changes in the price of tradeable goods using producer price indices (PPI) for manufactured goods or other output price indices. PPIs for manufactured goods differ from CPIs for tradeable goods in three major ways. First, PPIs include investment and intermediate goods, as well as consumption goods. Second, PPIs are constructed using changes in producer and wholesale prices, which on average contain a smaller local distribution margin than retail prices used in the CPI. Third, PPIs tend to exclude changes in prices for imported goods and in some countries include changes in prices for exported goods.

Burstein et al. (2005) and Burstein et al. (2006) measure the price index of tradeable goods using import price indices (IPI). IPIs tend to be constructed using changes in prices of imported goods at

[7] Non-tradeables categories include education, health, housing, among others. Tradeable categories include non-durables like food and beverages, apparel, and durables like private transportation, household furnishings, among others.

the dock (henceforth denominated *border prices*) and hence include a smaller component of local distribution margin in comparison to wholesale and consumer prices. There is large variation across countries in the procedures used to construct these indices, so one must be cautious in interpreting cross-country differences in statistics based on IPIs.[8] In the absence of data on IPIs for certain countries researchers use unit values constructed as the ratio of trade values to trade volumes. Unit values are more likely to be affected by changes in the composition of imports across goods of different price and quality than indices based on actual prices.

Figure 1, Panel B, plots cumulative log changes in the overall CPI-based RER and in the CPI-based tradeable RER for the US (trade-weighted), while Panel C adds the other two measures of tradeable RERs: the PPI-based RER using PPIs for manufactured goods and the IPI-based RER using IPIs for manufactured goods (the non-oil IPI in the US). Table 3 lists for eight countries in the period $1975-2011$ (depending on data availability) relative standard deviations, correlations, and lower and upper bounds of a variance decomposition of quarterly and annual changes in each of the three measures of tradeable RER relative to the overall CPI-based RER.

The central patterns that emerge can be summarized as follows. First, there appears to be little difference in the magnitude of fluctuations in the CPI-based RER for tradeable goods and in the magnitude of fluctuations in the overall CPI-based RER — the relative standard deviation and correlation between these two series is close to 1 in most countries. From expression (2), this implies that movements in the relative price of nontradeable to tradeable goods measured using consumer prices are not an important source of cyclical RER fluctuations (less than 3% in the U.S.). While we focus on quarterly fluctuations, Engel (1999) shows that this observation holds both at short and medium term horizons. Second, tradeable RERs computed using PPIs are on average only slightly less volatile (and less correlated) than CPI-based RERs for tradeable goods. Third, movements in tradeable RERs computed using IPIs tend to be smaller (especially in U.S., Japan, and U.K.) than the other two measures. In the U.S., in the period $1985-2011$ the IPI-based RER is roughly half as volatile as the overall CPI-based RERs, the correlation is roughly 0.5, and the upper bound of its importance in the variance decomposition is 30%.

Taken together, these observations show that a large fraction of RER fluctuations can be accounted for by movements in the relative price of tradeable goods across countries, but the extent of cyclical movements in the relative price of tradeable to nontradeable goods depends on the price measure for tradeable goods – movements in the RER for tradeable goods tend to be smaller and movements in the relative price of tradeable to nontradeable goods tend to be larger, when tradeable price indices are constructed using border prices than when constructed using consumer prices.

The observation that movements in consumer and wholesale price-based RERs for tradeable

[8] For example, Statistics Canada proxies import prices for some goods using prices from foreign sources (see the section on International Trade Price Indexes).

goods are large and highly correlated with movements in NERs has also been established using goods level data (see e.g. Crucini and Telmer (2012), Gopinath et al. (2011), and Broda and Weinstein (2008)). Crucini and Landry (2012) show that goods with a smaller non-tradeable distribution component exhibit smaller movements in RERs. This is consistent with the observation that tradeable RERs are less volatile using import prices (that contain a small non-tradeable component) than using consumer prices (that contain a larger non-tradeable component).

The fact that relative prices at the consumer level co-move more closely with the NER and are more volatile than when using border relative prices is consistent with the next empirical finding on exchange rate pass-through.

**Empirical Finding 3** *ERPT into consumer prices is lower than into border prices. ERPT into border prices is typically incomplete in the long-run, displays dynamics and varies considerably across countries.*

Pass-through regressions estimate the sensitivity of prices in a given location to exchange rates, controlling for other variables relevant for pricing. Several studies estimate dynamic lag regressions of the kind:

$$\Delta p_{in,t} = \alpha_{in} + \sum_{k=0}^{T} \beta_{in,k} \Delta e_{in,t-k} + \gamma_{in} X_{in,t} + \varepsilon_{in,t} \tag{3}$$

where $\Delta p_{in,t}$ represents either log changes in prices, price indices, or log changes in unit values for goods imported in country $n$ from country $i$, expressed in country $n$'s currency. $k > 0$ allows for lags in the pass-through of exchange rates into prices and $t$ refers to months/quarters/years. $X_{in,t}$ represents a vector of controls (including lags), besides the nominal exchange rate and typically includes a measure of the cost of production in country $i$, such as wages or producer prices.[9] $\beta_{in,0}$ measures short-run pass-through (SRPT) and long run pass-through (LRPT) is estimated as $\sum_{k=0}^{T} \beta_k$ where $T$ is typically set at 2 years.

In Table 4 we report estimates from a quarterly regression of the log import price index (in domestic currency) on lags 0 to 8 of the log trade-weighted nominal exchange rate (in units of domestic per foreign currency) and lags 0 to 8 of log trade-weighted foreign PPI (in foreign currency). The contemporaneous pass-through is given by the lag-0 coefficient on the NER, while the long-run pass-through is given by the sum of the 9 coefficients on lags of the NER.

As is evident the pass-through into consumer prices is uniformly low and well below pass-through into border prices for each country. For the U.S. both SRPT and LRPT are at least twice as high into border prices as it is into retail prices. A similar finding is documented for other countries. There is also large variation in ERPT into border prices across countries with countries like Japan, Canada, Britain, France and Germany having high LRPT while the U.S., Italy and Switzerland

[9] In certain cases a measure of prices of competitors in country $n$, such as producer prices in country $n$ and controls for local demand conditions such as local GDP are also included.

have low LRPT. The estimates of ERPT for border prices update the findings in Campa and Goldberg (2005) who provide cross-sectional and time-series estimates of ERPT for import prices.

We reiterate that unlike consumer prices, import price indices are constructed differently across countries. The large variation in ERPT estimates can also be attributed to the differing composition of import bundles since ERPT estimates differ a great deal across goods.

In the case when IPIs, NERs, and producer prices are co-integrated, dynamic lag regressions (3) are misspecified. To allow for cointegration a vector error correction model (VECM) is estimated.

$$\Delta y_t = A\left(By_{t-1} + \alpha\right) + \sum_{k=0}^{n} \Delta y_{t-k} + \delta + \epsilon_t \tag{4}$$

where $y$ is a three-dimensional VECM in the log import price index, the log NER and the log foreign PPI and $B$ is the vector of coefficients in the co-integrating relationship.[10] If the data points towards a cointegration rank of 1, the VECM is estimated by maximum likelihood. The long-run exchange rate pass-through is given by (negative) the coefficient on the exchange rate in the estimated cointegrating vector (the coefficient on import prices is normalized to 1). For four (Japan, Italy, Canada and Switzerland) of the 8 countries we cannot reject the null that the log import price index, the log of the NER and the log of foreign PPI are not cointegrated, that is for these countries the dynamic lag regression provides consistent estimates. When the log tradeable CPI is used in place of the log IPI the number of countries for which the null cannot be rejected increases to five (the previous four plus France). In general we find that the standard errors are quite large and the estimates are highly unstable in the VECM specification depending on the sample period chosen. Accordingly we decided not to report any numbers.

**Large devaluation episodes:** The ranking in ERPT across consumer and border prices is also evident in the episodes of large exchange rate devaluations. These episodes provide a particularly useful lens to study the impact of changes in exchange rates on prices.[11] Burstein et al. (2005) use basic accounting to provide a breakdown of the impact of large devaluations on border and consumer prices. Table 5 summarizes the results, reporting changes in aggregate prices for the large devaluations in Argentina 2001, Brazil 1998, Korea 1997, Mexico 1994, Thailand 1997, the European devaluations in Finland, Italy, Sweden, and UK in 1992, and the recent large depreciation of the Icelandic Krona between 2007 and 2009. Burstein et al. (2005) also present some evidence on prices for Indonesia 1997, Malaysia 1997, Philippines 1997, and Uruguay 2002.

[10] The lag length $n$ is determined by the Akaike information criteria and the cointegration rank is estimated by the Johansen trace statistic using a significance level of 95%. Standard errors are based on the usual asymptotic normal approximation.

[11] Unlike episodes of regular sized exchange rate movements, large devaluations tend to be associated with large declines in output, consumption and imports. Those factors inducing contractions in economic activity before or after large devaluations can play an important role in shaping the small observed increase in wages and prices of nontradeable goods, as discussed in e.g. Burstein et al. (2007) and Kehoe and Ruhl (2009). For a survey of the literature on currency and financial crises we refer the reader to the chapter by Guido Lorenzoni in this handbook.

The central patterns of prices in the aftermath of these devaluation episodes can be summarized as follows. The increase in prices of nontradeable goods and services tends to be low relative to the large exchange rate depreciation. The increase in prices of tradable goods is higher, with the extent of the increase depending critically on whether prices are measured at the retail level (CPI) or at the border (IPI). In particular, the rise in prices of imports at the dock is significantly higher than the increase of tradeable consumer prices. In Argentina, Brazil, and Mexico, ERPT for the IPI in the first year is close to complete. In the European devaluations of 1992, ERPT for import prices is lower than in the other countries, but significantly higher than ERPT for consumer prices of tradeable goods. Note that, consistent with the importance of distribution costs, consumer prices of imported goods in Argentina rise by far less than import prices at the dock (130% compared to 204% in the first year after the 244% NER devaluation).

Based on the RER decomposition in expression (2), Burstein et al. (2005) show that for all devaluation episodes, movements in tradeable RERs are much larger measured using consumer prices than measured using import prices. In many episodes, movements across countries in the price of non-tradeable goods relative to border prices of tradeable goods comprise the most important source of RER movements.

**Empirical Finding 4** *Border prices, in whatever currency they are set in, respond partially to exchange rate shocks at most empirically estimated horizons.*

Incompleteness in ERPT can arise because prices are completely rigid for a period of time in the local currency and/or because when prices change they respond only partially to exchange rate changes. Aggregate pass-through regressions of the kind described above are a combination of the two phenomenon. Gopinath and Rigobon (2008) and Gopinath et al. (2010) use the micro price data underlying the construction of U.S. import and export price indices to document the extent of price rigidity and pass-through conditional on price change of actual traded goods.[12] Fitzgerald and Haller (2012) provide evidence using data for Irish producers. We describe below the findings on the frequency of price adjustment in the invoicing currency and pass-through conditional on a price change.[13]

**Frequency**: Gopinath and Rigobon (2008) document that the weighted median duration of border prices in their currency of pricing is 11 months for U.S. imports and 13 months for U.S. exports. Fitzgerald and Haller (2012) find that for Irish exporters the weighted mean duration is 6.2 months.

The higher degree of stickiness in border prices in comparison to consumer prices is consistent with evidence on prices in the PPI as documented in Nakamura and Steinsson (2008) for the U.S.

[12] These findings are further explored in Gopinath and Itskhoki (2010b) and Gopinath and Itskhoki (2010a).

[13] Given limited data availability of actual traded goods prices there is limited country coverage for the facts on frequency and conditional pass-through.

and Gautier et al. (2007) for 6 European countries.[14] Eichenbaum et al. (2009) estimate reference price durations for wholesale prices from a retail chain that are similar to that found from border prices for comparable categories of goods.[15]

**Conditional on price change:** A "Medium-run pass-through" (MRPT) regression takes the form

$$\Delta p_{in,t} = \alpha_{in} + \beta \Delta_c e_{in,t} + \gamma X_{in,t} + \varepsilon_{in,t}.$$

$\Delta p_{in,t}$ is the the change in the log price (in local currency) of the good imported in country $n$ from country $i$, where the sample is restricted to those observations that have a non-zero price change in their currency of pricing. $\Delta_c e_{in,t}$ is the cumulative change in the bilateral nominal exchange rate over the duration for which the previous price was in effect. $X_{in,t}$ are controls that include the cumulative change in the foreign consumer/producer price level. Gopinath et al. (2010) also provide estimates of "life-long pass-through" (LLPT) that involves cumulating price changes and exchange rate changes over the entire life of the good in the sample. We report in Table 6 estimates from medium-run and life-long pass-through regressions for U.S. import prices by country of origin of goods. These numbers update the results in Gopinath et al. (2010) and Gopinath and Rigobon (2008) to cover the period 1994-2009. Overall, MRPT is 20% and LLPT is 28%.

Conditional on changing, prices in their currency of pricing respond only partially to exchange rate shocks. This is why MRPT of dollar priced goods is low at 16% while that of non-dollar priced goods is high at 80%. Further there are dynamics in pass-through estimates with life-long pass-through significantly exceeding MRPT for dollar priced goods.[16]

As one would expect ERPT in the short-run is higher for goods with a higher frequency of price change, but Gopinath and Itskhoki (2010a) document that this correlation is evident even for the longer-run based on LLPT estimates.

Finding 4 offers one potential explanation for Finding 3 regarding the large dispersion in estimates of border ERPT across countries. In a pure accounting sense the observation that ERPT to border prices for developing countries is high is consistent with the fact that the vast majority of imports into these countries is priced in foreign currencies. Similarly ERPT into import prices for

[14]One has to be cautious in comparing measures of price stickiness across producer/border goods and consumer goods. First, the coverage of goods is very different with the former including intermediate and capital goods that are not included in the CPI bundle. Second, producer/border prices include many business-to-business transactions and contracts that may incorporate non-price features, while goods consumer prices cover mostly list (spot) prices. Friberg and Wilander (2008) use survey data for Swedish exporters and find that even for exporters that list a price the median price adjustment is once per year.

[15]Gagnon (2009), Gagnon et al. (2012a) and Alvarez et al. (2011) document the state contingent behavior of pricing with sharp increases in the frequency of price adjustment of consumer prices during episodes of high inflation and large devaluations.

[16]The average size of price adjustment conditional on a change is large, consistent with the importance of idiosyncratic factors in pricing. Gopinath and Rigobon (2008) document that the weighted median absolute size of price change is 8.2% for U.S. imports and 7.9% for U.S. exports.

the U.S. is one of the lowest across countries because 92% of U.S. imports are priced in dollars.[17]

**Empirical Finding 5** *There are large deviations from relative PPP for traded goods produced in a common location and sold in multiple locations. On average, these deviations co-move with exchange rates across locations.*

Findings 1 and 2 summarized the evidence on deviations from relative PPP across countries (i.e. movements in product-level RERs) for tradeable goods, without distinguishing whether goods are produced in a common location or not. Finding 5 summarizes the evidence on deviations from relative PPP for actual traded goods that are produced in one location and sold in multiple locations. Under the assumption that changes in marginal costs for individual goods produced in a common location are independent of the destination to which the good is shipped this evidence can be used to quantify the extent of the practice of *pricing-to-market* by exporters through which they vary markups systematically across destinations. This evidence is mostly based on producer and wholesale prices, which in principle contain a smaller local cost component than retail prices.

To quantify deviations from relative PPP for traded goods, researchers have used price data that differs in the degree of disaggregation. Consider first the use of aggregate price data (see e.g. Atkeson and Burstein (2008) and Drozd and Nosal (2012b)). Applied to aggregate price data, the hypothesis of relative PPP implies that import prices that consumers in one country pay for another country's goods should move one-for-one with the producer prices for goods in those countries that are the sources of those imports, when all of these prices are expressed in a common currency. Likewise, a country's export prices should move one-for-one with that country's producer prices. Relative PPP thus implies that the terms of trade (the ratio of export and import at-the-dock prices for a country relative to its trading partners) should be as volatile as the PPI-based RER, as can be seen in the following accounting identity:

$$\Delta rer_{in,t}^{ppi} = (\Delta ipi_{in,t} - \Delta epi_{ni,t}) + (\Delta ppi_{i,t} + \Delta e_{in,t} - \Delta ipi_{in,t}) + (\Delta epi_{ni,t} - \Delta ppi_{nt}), \quad (5)$$

Here, $\Delta epi_{in,t}$ denotes the log change in the export price index (EPI) for goods produced in country $i$ and sold in country $n$ measured in country $i$'s currency, $\Delta ipi_{in,t} = \Delta epi_{in,t} + \Delta e_{in,t}$ denotes the import price index (IPI) in country $n$ for goods imported from country $i$, and $(\Delta ipi_{in,t} - \Delta epi_{ni,t})$ denotes the bilateral terms of trade between these two countries. Relative PPP applied to aggregate price data implies that the second term and third terms should be zero, so that the bilateral terms

[17] An argument in favor of using micro price data as opposed to aggregate price indices is that one can condition on an observable price change. As pointed out in Gopinath et al. (2010) and Nakamura and Steinsson (2011) in the BLS import/export series for the U.S. there are several goods that exit the BLS sample without a single price change, either because of product substitution or resampling or lack of reporting and consequently estimates of long-run pass-through using aggregate indices will be biased. Nakamura and Steinsson (2011) provide a bias correction factor for such index based numbers under certain assumptions and claim that it is large. Gagnon et al. (2012b) under alternative assumptions claim that the correction factor is small.

of trade moves one-to-one with the bilateral PPI-based RER. Averaging over country $i$'s trade partners, expression (5) implies that the overall terms of trade for this country should move one to one with its trade-weighted PPI-based RER.

Data on international relative price fluctuations for major industrialized countries reveal that the terms of trade for manufactured goods are substantially less volatile than the corresponding PPI-based RER for manufactured goods, as can be see in Panel D of Figure 1 for the U.S., and Table 7 for our set of industrialized countries. In the U.S., the standard deviation of annual changes in the manufacturing terms of trade is half as large as that of the manufacturing PPI-based RER. This observation arises because, at the aggregate level, changes in export and import price indices deviate systematically from changes in source country producer prices. In particular, an increase in home producer prices relative to foreign producer prices is typically associated with an increase in home producer prices relative to export prices, and an increase in home import prices relative to foreign producer prices. In other words, all three components in the identity (5) tend to be positively correlated, as shown in Table 7.

Figure 2 illustrates these aggregate deviations from relative PPP using U.S. manufacturing import price data by source country. Between the years 2006 and 2008, the appreciation of the Euro against the U.S. dollar resulted in an increase of Germany's manufacturing PPI measured in U.S. dollars ($\Delta ppi_{i,t}+\Delta e_{in,t}$) of more than 0.3 log points. Import prices in the U.S. for manufactured goods from Germany ($\Delta ipi_{in,t}$) rose by less than 0.1 log points. The extent of aggregate deviations from relative PPP displayed in Figure 2 varies by source country.

Other studies use data on unit values (ratios of export or import values to export or import volumes evaluated at border prices) at the level of goods categories or industries to quantify the extent of deviations from relative PPP, see e.g. the survey in Goldberg and Knetter (1997). The typical regression is of the form

$$\Delta p_{in,t} = \lambda_t + \theta_n + \beta_n \Delta e_{in,t} + \varepsilon_{in,t} \ ,$$

where $\Delta p_{in,t}$ is the log change in the export unit value of a good produced in country $i$ and sold in destination $n$. If changes in unit values (measured in country $i$'s currency) are uncorrelated with changes in the nominal exchange rate across destination countries, then $\beta = 0$. The typical finding in the literature, as surveyed in Goldberg and Knetter (1997), is that $\beta$ is significantly negative, meaning that an appreciation of the Euro (country $i$) against the U.S. dollar (country $n$), $\Delta e_{in,t} > 0$, results in a decline in the export price of a German firm in the U.S. relative to the price in other destinations. There is substantial variation in $\beta$ across industries and across exporting countries. Knetter (1989) and Knetter (1993) use this type of regression to show that pricing-to-market by U.S. exporters is less prevalent than pricing-to-market by exporters from other major industrialized countries.

In order to infer deviations from relative PPP for individual goods from aggregate price indices or unit values, one has to worry that movements in international relative aggregate prices can result from differences in the product and quality composition of the indices, and not from changes in relative price across locations for common goods. To address this concern, recent work measure deviations from relative PPP using relative price movements for individual products sold in multiple locations.

Burstein and Jaimovich (2008) and Fitzgerald and Haller (2012) focus on products produced in a common location and sold in multiple destinations to identify the extent of pricing-to-market. Fitzgerald and Haller (2012) use domestic and export prices at the plant level from Ireland's PPI monthly survey. Burstein and Jaimovich (2008) use wholesale prices of individual products produced in a common location and purchased by a large retailer in Canada and the U.S. Both papers find that, on average, export prices relative to domestic prices (measured in the same currency) follow closely movements in the bilateral exchange rate.

In Fitzgerald and Haller (2012), a 10% appreciation of the Pound Sterling against the Euro results in a roughly 10% increase in the price charged by Irish exporters in the U.K. relative to the domestic price. In Burstein and Jaimovich (2008), a 10% appreciation of the Canadian dollar against the US dollar results in a roughly 8% increase in prices charged by exporters in Canada relative to the price charged in the US. Both papers find that these large movements in relative prices are also observed conditional on nominal price adjustment. Burstein and Jaimovich (2008) show that, while on average movements in product-level RERs for traded goods produced in a common location track changes in nominal exchange rates, there are large idiosyncratic movements in product-level RERs: movements in international product-level RERs are three to four times as large as movements in the Canada-US nominal exchange rate.

## 3 A simple framework to interpret empirical findings

The facts in the empirical section provide a model-free description of the data. However, understanding what might be generating these facts and their implications for how firms price requires the use of models. In this section we use a simple model to interpret the evidence. This model, as well as those presented in sections 4-6 are in partial equilibrium in that wages and exchange rates are taken as given. The general equilibrium model in section 7 endogenizes wages and exchange rates.

Let $p_{in}$ represents the log border price and $p^r_{in}$ the log retail (consumer) price of a good exported from country $i$ (Germany) to country $n$ (U.S.), where all prices are expressed in the buyer's local currency (dollars). To sell the good, a retailer combines the physical good with local distribution services according to some constant returns to scale technology, and then adds a markup. For simplicity, we lump together wholesale and retail costs and markups. Up to a first-order approximation, the log change in the consumer price, $\Delta p^r_{in}$, is given by

$$\Delta p^r_{in} = \left(1 - s^d_{in}\right) \Delta p_{in} + s^d_{in} \Delta p^d_n + \Delta \mu^r_{in}, \tag{6}$$

where $\Delta p^d_n$ denotes the log change in the price of distribution services in country $n$, $\Delta \mu^r_{in}$ denotes the log change in the gross retail markup, and $s^d_{in}$ denotes the share of distribution costs in the pre-markup retail price, $s^d_{in} = 1 - \exp\left(p_{in} + \mu^r_{in} - p^r_{in}\right)$.

A number of papers have measured the "distribution wedge" as the difference between producer and retail prices as a fraction of retail prices, $1 - \exp\left(p_{in} - p^r_{in}\right)$, or similarly, the sum of wholesale and retail gross margins relative to retail sales.[18] In our specification, the distribution wedge is equal to $s^d_{in} + \left(1 - s^d_{in}\right)\left(\exp\left(\mu^r_{in}\right) - 1\right) / \exp\left(\mu^r_{in}\right)$, and hence combines distribution costs and retail markups. Burstein et al. (2003) and Campa and Goldberg (2010) calculate the distribution wedge for consumer goods in the U.S. and other OECD countries using Input-Output tables, while Berger et al. (2009) use matched micro price data in the U.S. This distribution wedge is found to be large ranging between 40% and 70% across tradeable goods (i.e. not including services) and is quite stable over time.

Aggregating changes in consumer prices across all tradeables goods consumed in country $n$ (domestically produced and imported) in two consecutive time periods, we obtain the log change in the tradeables CPI:

$$\Delta cpi^{tr}_n = \left(1 - s^d_n\right)\left(1 - s^m_n\right) \Delta ppi_{nn} + \left(1 - s^d_n\right) s^m_n \Delta ipi_n + s^d_n \Delta p^d_n + \Delta \mu^r_n, \tag{7}$$

where $s^m_n$ denotes the share of expenditures (exclusive of distribution costs) on imported goods in country $n$, $s^d_n$ denotes the aggregate share of distribution costs in country $n$, $\Delta ipi_n$ is a weighted average of import border prices, $\Delta ppi_{nn}$ denotes the log change in the producer price index in country $n$ including only goods sold domestically (we do not use $ppi_n$ for this since the PPI in some countries include prices of exported goods), and $\Delta \mu^r_n$ denotes the average change in retail markups in country $n$. The change in the CPI-based RER for tradeables goods for two ex-ante symmetric countries, country 1 and country 2 can be expressed as:

$$\begin{aligned} \Delta rer^{tr}_{12} &= \left(1 - s^d\right)\left(1 - 2s^m\right)\left(\Delta ppi_{11} + \Delta e_{12} - \Delta ppi_{22}\right) \\ &\quad + s^d \left(\Delta p^d_1 + \Delta e_{12} - \Delta p^d_2\right) + \left(\Delta \mu^r_1 - \Delta \mu^r_2\right) \\ &\quad + \left(1 - s^d\right) s^m \left(\Delta epi_2 - \Delta ppi_{22} - \Delta epi_1 + \Delta ppi_{11}\right). \end{aligned} \tag{8}$$

We can use equations (6), (7) and (8) to interpret Findings 1, 2, 3 and 5. Consider first ERPT for goods imported in country $n$ from country $i$. The fact that for imported goods, ERPT for

[18] The distribution wedge can also be calculated as the gap between total goods consumption at purchaser prices (from NIPA) and goods production attributed to consumption, at producer prices, as reported in Input-Output Tables.

consumer prices is lower than for border prices (Finding 3) can be the result of two forces as seen from equation (6). First, for a given ERPT into border prices, wholesale and retail markups may fall in response to an exchange rate shock, $\Delta\mu_{in}^r/\Delta e_{in} < 0$. Second, the price of local distribution services, $p_n^d$, may respond partially (less than border prices) to exchange rate movements.

While there is ample evidence of high distribution wedges, measures of changes in the price of local distribution services and measures of changes in retail and wholesale markups are less readily available. This has led to an active literature quantifying the role of local distribution costs and variable wholesale and retail markup, using different approaches. Berger et al. (2009) find that changes in distribution wedges are not correlated with exchange rate changes, which from our expression above is consistent with constant distribution cost shares $s_{in}^d$ and constant markups $\mu_{in}^r$. Gopinath et al. (2011) show using Canada-US scanner data from a large retail chain that changes in retail markups have low correlation with changes in the Canada-US exchange rate.[19] Goldberg and Hellerstein (2006) estimate a structural IO model featuring local distribution costs, variable wholesale and retail markups, and menu costs, using U.S. data on the beer industry. They show through counterfactuals that, because retail markups do not vary much with exchange rate changes, local costs must be insensitive to exchange-rate movements and play a significant role in generating incomplete pass-through to consumer prices.[20] Alessandria et al. (2010) consider the role of inventory management frictions of retailers as an important ingredient of retail distribution costs. We discuss this model in Section 4.

To sum up, lower ERPT for consumer prices than for border prices of imported goods can be mechanically explained by the presence of significant local costs that are insensitive to exchange-rate movements. There is less support for the role of variable retail mark-ups in inducing low ERPT for consumer prices. Given this conclusion, for the remainder of the chapter we assume that retail markups are constant, $\Delta\mu_{in}^r = 0$.

Finding 3 that ERPT is low for consumer prices of tradeable goods (which include domestic and imported goods) can be understood using (7). If tradeable consumption includes a large portion of domestically produced goods and services (stemming from a combination of $s_m < 0.5$ and $s^d > 0$) and prices of domestically produced goods and services are not very sensitive to exchange rates, then ERPT for the tradeable CPI is low even if ERPT at the border is high. The high share of domestically produced goods in the tradeable CPI can also explain, using equation (8), Finding 2 that movements in the CPI-based RER for tradeable goods are almost as large as the relative price of domestically produced goods (the PPI-based RER) and also as large as movements in the overall CPI-based RER (which combines the CPI-based RER for tradeable goods and non-tradeable

[19]Eichenbaum et al. (2009) also find, using the same data, that on average retail markups are quite insensitive over time exclusive of temporary sales.

[20]Nakamura and Zerom (2010) considers a similar exercise for the case of the coffee market in the U.S. in response to changes in the world price of coffee grain and find rapid pass-through of changes in producer prices to consumer prices.

services)[21][22]. Moreover, based on Finding 5, firms price-to-market. In response to an exchange rate depreciation in country 1, relative prices for traded goods tend to increase in country 2 relative to country 1: $\Delta ppi_2 > \Delta epi_2$ and $\Delta epi_1 > \Delta ppi_1$ – both of which imply that the terms of trade move less than the PPI-based RER. Deviations from relative PPP for traded goods, the third term in the expression on the RHS of equation (8), therefore contribute to larger movements in $rer_{12}^{tr}$. In sum, the evidence points to all three terms on the right hand side of the equality in equation (8) co-moving with the exchange rate and are contributing factors that explain Findings 2 that the CPI-based RER for tradeable goods is roughly as volatile as the RER for domestically produced goods. Given the evidence on large home bias and important distribution shares the volatility of $rer_{12}^{tr}$ appears to be driven mainly by the first two terms, with the third term playing a smaller role.

Finding 2 that for many countries the RER for tradeable goods constructed using import price indices move less closely with nominal exchange rates than the RER for tradeables constructed using consumer price indices can be understood by the higher share of distribution costs and local goods in the CPI than in the IPI.[23]

Throughout this discussion, we have taken as given the fact that prices of domestically produced goods and services are not very sensitive to NERs. If the share of these domestically produced goods and services in the CPI is high, then Finding 1 that movements in the overall CPI-based RER co-move closely with nominal exchange rates follows. This begs the question, why are prices of domestically produced goods and services so insensitive to NERs nominal exchange rate. We discuss this further in the general equilibrium section 7.

We now consider the pricing of goods at the border (at-the-dock). We first consider an environment with flexible prices and then allow for nominal rigidities in pricing. We use the model with nominal rigidities to interpret Finding 4.

[21] Burstein et al. (2005) and Fitzgerald (2008) perform accounting exercises of this form to explain the link between exchange rates and CPI and CPI-based RER for a number of countries, using measures of trade shares in consumption. Hau (2002) shows that more open economies tend to display less volatile RERs.

[22] Here we are abstracting from changes in the relative price between domestically produced tradeable goods and domestically produced services. These are potentially important to understand lower frequency trends in relative prices (see e.g. Asea and Mendoza (1994)) and movements in RERs in certain episodes such as exchange-rate based stabilizations (see e.g. Rebelo and Vegh (1995)).

[23] Note that if countries import different sets of commodities, we should *not* expect the RER constructed using IPIs to be constant over time even if relative PPP holds for each commodity (in a two-country world, for example, the IPI-based RER is equal to the terms of trade). Similarly, even if relative PPP holds for each commodity, we should *not* expect the RER constructed using PPIs to be constant over time if countries specialize in the production of a different set of commodities. In contrast, in the absence of home bias in consumption and if relative PPP holds for each good, it follows from equation (8) that the RER constructed using tradeable CPIs should be constant over time because the set of tradeable goods consumed in each country is identical.

### 3.1 Flexible prices

Suppose that firms face segmented markets in each country so that they can charge a different price by destination. The optimal flexible log border price can be expressed as the sum of the log marginal cost and gross markup:

$$p_{in} = \mu_{in} + mc_{in}. \tag{9}$$

We assume that the mark-up depends on the price charged by the exporting (German) firm relative to the (log) aggregate industry price level in the destination country $n$ (U.S.), $p_n$. That is, $\mu_{in} = \mu_{in}(p_{in} - p_n)$. We describe in section 4 a number of models that produce this reduced-form relationship between markups and relative price, where the exact specification of $\mu_{in}(.)$ as well as the definition of the relevant aggregate industry price index $p_n$ depends on model. The dollar marginal cost is given by $mc_{in} = mc_{in}(q_{in}, w_i, e_{in})$, where $q_{in}$ is the quantity sold by the German firm in the U.S. markets and $w_i$ summarizes those variables that impact the costs of production incurred by the German firm that are local to Germany such as German wages in euros and total factor productivity.

Log-differentiating (9), we have that the log change in price, $\Delta p_{in}$, can be approximated as

$$\Delta p_{in} = -\Gamma_{in}(\Delta p_{in} - \Delta p_n) + mc_q \Delta q_{in} + \Delta w_i + \alpha_{in}\Delta e_{in} \ ,$$

where $\Gamma_{in} \equiv -\frac{\partial \mu_{in}(.)}{\partial(p_{in} - p_n)}$ is the elasticity of the mark-up with respect to the relative price, $mc_q \equiv \frac{\partial mc_{in}(.,.,.)}{\partial q}$ is the elasticity of marginal cost with respect to output (which we assume is common across firms), and $\alpha_{in} \equiv \frac{\partial mc_{in}(.,.,.)}{\partial e_{in}}$ is the partial-elasticity of the marginal cost (expressed in the destination country's currency) to the exchange rate. Note that we have assumed, without loss of generality, that $\frac{\partial mc_{in}(.,.,.)}{\partial w_i} = 1$. In the case of constant mark-ups, $\Gamma_{in} = 0$. When the production technology is constant returns to scale then $mc_q = 0$, with decreasing returns to scale $mc_q > 0$. When all production costs for a German firm are in euros $\alpha_{in} = 1$.

Log demand is given by $q_{in} = \mathbf{q}(p_{in} - p_n) + q_n$ where $q_n$ denotes the log of aggregate quantities/demand in country $n$. Log-differentiating,

$$\Delta q_{in} = -\varepsilon_{in}(\Delta p_{in} - \Delta p_n) + \Delta q_n$$

where $\varepsilon_{in} \equiv -\frac{\partial \mathbf{q}(.)}{\partial p_{in}} > 0$ is the price elasticity of demand. Combining these two equations and collecting terms we obtain:

$$\Delta p_{in} = \frac{1}{1 + \Gamma_{in} + \Phi_{in}} \left[\Delta w_i + \alpha_{in}\Delta e_{in} + (\Gamma_{in} + \Phi_{in})\Delta p_n + mc_q \Delta q_n\right] \tag{10}$$

where $\Phi_{in} = mc_q \varepsilon_{in} \geq 0$ is the partial elasticity of marginal cost with respect to the relative price.

Consider a change in the bilateral exchange rate, $\Delta e_{in}$, assuming for now that $\Delta w_i = 0$. The resulting change in the price charged by firm $i$ in country $n$ implied by expression (10) can be decomposed into a direct effect at fixed aggregate prices and quantities in country $n$ (i.e. $\Delta p_n = \Delta q_n = 0$), and an indirect effect induced by changes in aggregate prices and quantities in country $n$ . The direct effect can be thought of as the overall effect when country $i$ is very small relative to country $n$ in that changes in the bilateral exchange rate do not affect aggregate outcomes in country $n$. The following proposition characterizes the direct component of exchange-rate pass-through.

**Proposition 1** *Exchange rate pass-through, when $\Delta w_i = \Delta p_n = \Delta q_n = 0$, is given by*

$$\frac{\Delta p_{in}}{\Delta e_{in}} = \frac{\alpha_{in}}{1 + \Gamma_{in} + \Phi_{in}}.$$

*If $\Gamma_{in} = 0$, $\Phi_{in} = 0$, and $\alpha_{in} = 1$, then ERPT is 1.*

Intuitively, when the dollar depreciates relative to the euro this raises the dollar marginal costs of the German firm, all else equal. The sensitivity of dollar marginal costs to the exchange rate movement depends on $\alpha_{in}$. Suppose the German firm sources some of its production inputs globally and these inputs are priced in dollars, whose dollar price is unaffected by the exchange-rate movement. In this case, only a fraction of the firm's marginal cost is affected, so $\alpha_{in} < 1$ and ERPT is less than 1. In response to the rise in dollar marginal cost, the firm considers raising the dollar export price. The increase in the profit-maximizing price depends on two factors.

The first factor is the degree to which marginal costs increase in the firm's scale of production. If $mc_q > 0$, as the firm raises its prices the quantity sold declines, this reduces the marginal cost of the firm and dampens the initial desire to raise prices. The extent to which this happens depends not only on the extent of decreasing returns to scale, but also on the elasticity of demand the firm faces $\varepsilon_{in}$, since that determines the magnitude of the quantity response. A higher value of $\Phi_{in} = mc_q \varepsilon_{in}$ works to reduce ERPT below 1.

The second factor determining ERPT is the degree to which desired markups depend on a firm's price relative to the aggregate price. Suppose that desired markups are decreasing in the relative price set by the firm, $\Gamma_{in} > 0$. As the price of the German firm relative to the aggregate industry price in the U.S. increases, that reduces its desired mark-up, another reason to dampen price increase and reduce pass-through.

Proposition 1 displays the direct effect on German prices in the U.S. resulting from a change in the Euro/dollar exchange rate when aggregate industry prices and quantities in the U.S. remain unchanged to this exchange rate movement (i.e. $\Delta p_n = \Delta q_n = 0$). In practice, however, changes in the Euro/dollar bilateral exchange rate may be associated with changes in U.S. aggregate prices and quantities, which give rise to additional indirect effects from exchange rate changes on German prices in the U.S. At this point we do not discuss what generates this association and take it as given.

**Proposition 2** *ERPT including both direct and indirect effects, when* $\Delta w_i = 0$*, is given by*

$$\frac{\Delta p_{in}}{\Delta e_{in}} = \frac{\alpha_{in}}{1+\Gamma_{in}+\Phi_{in}} + \frac{\Gamma_{in}+\Phi_{in}}{1+\Gamma_{in}+\Phi_{in}}\frac{\Delta p_n}{\Delta e_{in}} + \frac{mc_q}{1+\Gamma_{in}+\Phi_{in}}\frac{\Delta q_n}{\Delta e_{in}}.$$

The indirect effects of changes in aggregate prices and quantities in country $n$ on country $i$'s prices charged in country $n$ can be understood as follows. An increase in the U.S. aggregate industry price, $\Delta p_n > 0$, increases the price charged by German firms if $\Gamma_{in} + \Phi_{in} > 0$. Intuitively, an increase in the U.S. aggregate price increases the German firm's desired markup (when $\Gamma_{in} > 0$) and increases quantity sold and marginal cost (when $\Phi_{in} > 0$), both of which result in a higher price. Moreover, an increase in U.S. aggregate quantities, $\Delta q_n > 0$, increases the German firm's demand and marginal cost (when $mc_q > 0$), resulting in an increase in the German firm's price. These results imply that, unless markups are independent of relative prices ($\Gamma_{in} = 0$) and marginal costs are independent of quantities ($mc_q = 0$), the overall degree of ERPT depends crucially on the details of how aggregate prices and quantities respond to exchange rate movements.

**Interpretation of results of ERPT regressions:** The ERPT regressions reported under the empirical Finding 3 provide a useful way of summarizing the response of border prices to movements in exchange rates. Here we discuss to what extent ERPT estimates can be used to shed light on the underlying forces that shape ERPT in our model. Propositions 1 and 2 point out that incompleteness of ERPT into border prices can arise either because of the lack of sensitivity of the exporters cost to the exchange rate shocks, variability of mark-ups or decreasing returns to scale. ERPT also depends on the specifics of the regression being estimated, whether direct and indirect effects are considered.

The direct effects reported in Proposition 1 can be viewed as the estimated ERPT assuming that changes in other components of marginal cost, aggregate quantities and aggregate prices can be "controlled for" in those regressions. Shocks that affect the exchange rate can simultaneously induce movements in marginal cost components (such as foreign wages or global commodity prices) that impact pricing. If these costs are not well measured then the ERPT estimate includes the affect of these omitted variables on prices.[24] The precise definitions of marginal cost and the aggregate price index depend on model details. For example, in the CES model with a finite number of firms per sector described below, the price index $p_n$ only includes the subset of prices of firms in the sector that directly compete with firm $i$. Empirical work trying to estimate the degree of ERPT typically lacks data on prices of a firm's direct competitors.[25] Using the PPI as a proxy for this price index may be highly imperfect. Given the difficulties in measuring $p_n$, ERTP regressions may be effectively estimating the "uncontrolled" degree of ERPT (which include both the direct and

[24] Corsetti and Leduc (2008) use a GE model to investigate possible biases from omitted variables and measurement error in ERPT regressions.

[25] There are exceptions, such as Auer and Schoenle (2012), that construct structural measures of competitors' price indices using micro price data.

the indirect effects).

The sensitivity of $p_n$ to the exchange rate, which determines the indirect effect of ERPT, depends on important details such as the source of the shock to the exchange rate (which shapes the response of e.g. costs and prices of domestic producers competing with foreign exporters). It also depends on whether the exchange rate shock being considered is idiosyncratic to the bilateral country pair or is a common shock, for instance where the dollar simultaneously depreciates relative to the currencies of all its trading partners. In the latter case the movement in $p_n$ will tend to be larger and the estimated ERPT will be large. Consistent with this implication, Gopinath and Itskhoki (2010b) document that for the U.S. ERPT for border prices is higher when the trade weighted NER is used compared to when the bilateral NER is used. Auer and Schoenle (2012) and Pennings (2012) document a similar finding at the sectoral level using the same micro price data. Note that $\alpha_{in}$ is also sensitive to the scope of the exchange rate shock. If the shock is common across countries and the German firm uses inputs from other countries affected by the shock then $\alpha_{in}$ can be higher.

To re-emphasize, while measures of ERPT provide a simple reduced form way of summarizing the response of prices to exchange rates, there is no single measure of ERPT that is independent of model details and driving shocks. One needs to be cautious when comparing estimates across studies, countries, and time periods and drawing implications for model parameters of pricing models, without knowledge of details of the environment.

**Pricing to market:** Next, consider the evidence summarized in Finding 5 on deviations from relative PPP for individual goods produced in a common location and sold in multiple destinatons. The change in the relative price of a good produced in country $i$ and sold in countries $n$ and $m$, both expressed in the same currency, is given by

$$(\Delta p_{in} + \Delta e_{ni}) - (\Delta p_{im} + \Delta e_{mi}) = (\Delta mc_{in} + \Delta e_{ni} - \Delta mc_{im} - \Delta e_{mi}) + (\Delta \mu_{in} - \Delta \mu_{im}) .$$

If the change in marginal cost is independent of where the good is sold, then changes in relative prices across countries are given by $(\Delta \mu_{in} - \Delta \mu_{im})$. Note that to obtain pricing to market one requires not just variable mark-ups but the response of mark-ups should vary across locations. Therefore, incomplete pass-through arising from variable mark-ups in and of itself is not sufficient to generate pricing-to-market.

Data on deviations from relative PPP for individual goods without information on the country of production of individual goods and based on retail prices that have a substantial local cost component are not informative enough to separate movements in relative markups from movements in relative marginal costs across locations. The evidence summarized in Finding 5, based on producer and wholesale prices for goods produced in a common location for sales in multiple destination, suggests a substantial role for variable markups in generating deviations from relative PPP.[26] The

[26] While Burstein and Jaimovich (2008) use wholesale prices, which are not free of local distribution costs, they

fact that relative markups move even conditional on price adjustment, as documented in Fitzgerald and Haller (2012), suggest that movements in markups are not purely driven, mechanically, by sticky prices in the buyer's local currency.

What determines how markups for goods produced in a common location change across destinations in model considered above? To ensure that changes in marginal costs are the same across destinations, we assume $mc_q = 0$ and $\alpha_{ij} = 1$. The following proposition derives the change in relative prices (and relative markups) under the assumption that the markup elasticity for this good is equal in the two destinations.

**Proposition 3** *If* $\Gamma_{in} = \Gamma_{im}$*, then the change in the markup across destinations for a good produced in country* $i$ *is given by*

$$\Delta\mu_{in} - \Delta\mu_{im} = \frac{\Gamma_{in}}{1+\Gamma_{in}} \left[ (\Delta p_n + \Delta e_{ni}) - (\Delta p_m + \Delta e_{mi}) \right]. \tag{11}$$

According to expression 11, the change in the relative markup set by a country $i$ firm in countries $n$ and $m$ is proportional to the change in the aggregrate (industry-wide) real-exchange rate between these two countries. In response to a change in marginal cost of production faced by the German exporter that does not affect the Germany-U.S. industry-wide real exchange rate, relative markups between Germany and the U.S. are unchanged, even if $\Gamma_{in} > 0$ (in which case ERPT is incomplete). On the other hand, if the aggregate industry price level in U.S. rises relative to that in Canada (both prices measured in a common currency), then a German exporter will increase the markup it charges in U.S. relative to that in Canada. The relative markup more closely tracks the aggregate real exchange rate, the higher is the elasticity of markup with respect to the relative price $\Gamma_{in}$. More generally, if the markup elasticity $\Gamma_{in}$ varies across destination markets, then the size and direction of pricing-to-market depends on the specific shape of $\Gamma_{in}$, which is determined by model details.

We now consider the environment when prices adjust infrequently consistent with the evidence surveyed in Finding 4.

## 3.2 Nominal rigidities in pricing

When prices are sticky the sensitivity of prices to exchange rate changes depends on the currency in which prices are rigid and pass-through of shocks display dynamics over time. Infrequent price adjustments can be modeled in different ways, under the assumption of Calvo pricing (Calvo (1983)), using menu costs and state contingent pricing or with imperfect information and rational inattention.[27] To present some insights we use the Calvo environment that lends itself to analytical

report that the average gross margin as a percentage of wholesale sales for groceries and related products in the U.S. is only 16%.

[27]See e.g. Midrigan (2007) for a menu cost model of international relative price fluctuations, and see e.g. Crucini et al. (2010) for a model with imperfect information.

characterizations using first order approximations. Given that this pricing model is dynamic, we must re-introduce time notation.

Once again consider a German firm $i$ selling in the country $n$, the U.S. For now let us assume that firm $i$ prices in currency $n$, that is it follows local currency pricing and prices in U.S. dollars when selling in the U.S. Define the desired (or flexible) price of firm $i$, $\tilde{p}_{in,t}$, as the logarithm of the price it would set if it could flexibly adjust its price in every state, that is,

$$\tilde{p}_{in,t} = \arg\max_{p_{in}} \Pi(p_{in}|s_t), \tag{12}$$

where $s_t$ summarizes the firm's relevant state at time $t$. The logarithm of the reset price by a firm from country $i$ selling in country $n$ is denoted by $\bar{p}_{in,t}$. The observed price is $p_{in,t} = \bar{p}_{in,t}$ when prices change and $p_{in,t} = p_{in,t-1}$ when it does not. The optimal reset price in a Calvo environment is determined by the first order condition

$$\textstyle\sum_{\ell=0}^{\infty} \kappa^{\ell} \mathbb{E}_t \Theta_{t+\ell} \Pi_p\left(\bar{p}_{in,t}|s_{t+l}\right) = 0 \tag{13}$$

where $\kappa$ is the constant probability of non-adjustment at each date, $\Pi_p$ denotes the partial derivative of the profit function with respect to $p$, and $\Theta_{t+\ell}$ represents the stochastic discount factor. In steady-state with zero inflation, $\Theta_{t+\ell} = \beta^l$, where $\beta < 1$ is the discount factor. Log-linearizing equation (13) around the flexible price first-order condition, as shown in Gopinath et al. (2010), the optimal reset price can be approximated as:

$$\bar{p}_{in,t} = (1 - \beta\kappa) \sum_{\ell=0}^{\infty} (\beta\kappa)^{\ell} \mathbb{E}_t \tilde{p}_{in,t+\ell}. \tag{14}$$

That is, the reset price $\bar{p}_{in,t}$ can be expressed as a weighted-average of expected desired prices where the weights depend on the probability of non-adjustment and the discount factor.

We now derive the reset price under the assumptions of section 3.1 and, for expositional simplicity, constant returns to scale in production, $mc_q = \Phi = 0$. Starting from equation (9) and approximating the level of the mark-up and the marginal cost around their steady-state levels, the desired price is, up to a first order approximation:

$$\tilde{p}_{in,t+\ell} = \frac{1}{1 + \Gamma_{in}} \left[ w_{i,t+\ell} + \alpha_{in} e_{in,t+\ell} + \Gamma_{in} p_{n,t+\ell} + const_{in} \right], \tag{15}$$

where $const_{in}$ contains steady state values. Combining (14) and (15), the reset price is, up to a first order approximation:

$$\bar{p}_{in,t} = \frac{(1 - \beta\kappa)}{1 + \Gamma_{in}} \sum_{\ell=0}^{\infty} (\beta\kappa)^{\ell} \mathbb{E}_t \left[ w_{i,t+\ell} + \alpha_{in} e_{in,t+\ell} + \Gamma_{in} p_{n,t+\ell} + const_{in} \right]. \tag{16}$$

In the instances when the German firm $i$ does not change its dollar price then clearly ERPT is 0. When it does adjust, ERPT is determined by the change in the reset price. The following proposition derives ERPT conditional on price adjustment when the exchange rate follows an AR(1) process and aggregate prices are constant.

**Proposition 4** *If the exchange rate follows an AR(1) with persistence parameter* $0 \leq \rho_e \leq 1$ *and* $w_{i,t}$ *and* $p_{n,t}$ *are constant for all* $t$*, ERPT for a firm, conditional on changing price (MRPT) equals:*

$$\frac{\Delta p_{in,t}}{\Delta_c e_{in,t}} = \frac{(1-\beta\kappa)}{(1-\beta\kappa\rho_e)} \frac{\alpha_{in}}{1+\Gamma_{in}}, \tag{17}$$

where we use the same notation as in the empirical section. Expression (17) follows immediately from equation (16) and the assumption that the NER follows an AR(1) process.[28] When $\rho_e = 1$, that is the NER follows a random walk, then ERPT conditional on price change is the same as that in the static section. With $\rho_e < 1$, ERPT is less that 1 even conditional on a price change, and even if flexible price ERPT is complete (i.e. $\alpha_{in} = 1$, $\Gamma_{in} = \Phi_{in} = 0$). When the NER change is not expected to last firms choose to adjust only partially since they will be stuck with the new price for a period of time within which the NER can revert back to its original value.

In the case when $p_n$ is impacted by the exchange rate change and $\Gamma_{in}$ is non-zero, ERPT depends on the response of the aggregate price index $p_n$ to the exchange rate change. As long as there is staggered price adjustment, the aggregate price index will depend on lagged exchange rate shocks even prior to the last round of price adjustment. This implies that, if $\Gamma_{in}$ is non-zero, $\frac{\Delta p_{in,t}}{\Delta_c e_{in,t}}$ will depend on lagged exchange rates prior to the last round of price adjustment, in contrast to the result in Proposition 4. There will be dynamics in pass-through with one price adjustment being insufficient to attain long-run pass-through.[29]

We now calculate the change in the aggregate price in country $n$ for goods imported from country $i$, i.e. the import price index $\Delta ipi_{int}$, assuming that all firms from country $i$ selling in country $n$ are symmetric except for the timing of price adjustment. Since a random fraction $(1-\kappa)$ of firms change prices and they all choose the same price (given symmetry), the change in the import price index is given by:

$$\Delta ipi_{in,t} = (1-\kappa)(\bar{p}_{in,t} - ipi_{in,t-1}).$$

Short-run pass-through into the import price index is a combination of the fraction of firms changing prices and desired pass-through.

In the next sub-section we explore the role of the currency in which prices are set on ERPT.

[28] The proof is as follows: For a good that changes prices at time $t$ and time $t-j$, $\frac{\Delta p_{in,t}}{\Delta_c e_{in,t}} = \frac{\bar{p}_{in,t} - \bar{p}_{in,t-j}}{e_{in,t} - e_{in,t-j}}$. Equation (16) implies

$$\bar{p}_{in,t} - \bar{p}_{in,t-j} = (1-\beta\kappa)\frac{\alpha_{in}}{1+\Gamma_{in}}\left[\mathbb{E}_t \sum_{\ell=0}^{\infty} (\beta\kappa)^{\ell} e_{in,t+\ell} - \mathbb{E}_{t-j} \sum_{\ell=0}^{\infty} (\beta\kappa)^{\ell} e_{in,t-j+\ell}\right]$$

Using $\mathbb{E}_t e_{in,t+\ell} = \rho_e^{\ell} e_{in,t}$ we obtain the equation in (17).

[29] Note that when $p_n$ changes over time in response to the shock, controlling only for the contemporaneous affect on $p_n$ will not suffice to arrive at the direct component of ERPT, unlike the case of flexible prices. This is because lags of changes in $p_n$ will impact ERPT in addition to the direct effect, derived in proposition 4.

#### 3.2.1 Currency of pricing and exchange rate pass-through

Most countries import goods that are priced in multiple currencies. Let $\bar{p}_{in}^{j}$ represent the reset price of imports into country $n$ from country $i$ priced in the currency of country $j \in (n, i)$. Suppose a fraction $(1-\vartheta)$ of firms from Germany price in euros ($i$) and $\vartheta$ in dollars ($n$), and that the frequency of price adjustment $(1-\kappa)$ is equal for both groups of firms. Assuming symmetry across all firms within a particular currency pricing category, the change in the aggregate import price index (in dollars) is given by:

$$\Delta ipi_{in,t} = (1-\kappa)\left[\vartheta(\bar{p}_{in,t}^{n} - ipi_{in,t-1}^{n}) + (1-\vartheta)\left(\bar{p}_{in,t}^{i} - ipi_{in,t-1}^{i} + \Delta e_{in,t}\right)\right] + \kappa(1-\vartheta)\Delta e_{in,t}$$

where $ipi_{in,t}^{j}$ denotes the import price index for goods priced in the currency of country $j$. By construction, ERPT for firms that do not adjust price is zero for dollar pricing firms and is 1 for euro pricing firms. The following proposition characterizes short-run ERPT into the import price index.

**Proposition 5** *Short run ERPT into the aggregate import price index is given by:*

$$\frac{\Delta ipi_{in,t}}{\Delta e_{in,t}} = (1-\vartheta) + (1-\kappa)\left[\vartheta\frac{\Delta\bar{p}_{in,t}^{n}}{\Delta e_{in,t}} + (1-\vartheta)\frac{\Delta\bar{p}_{in,t}^{i}}{\Delta e_{in,t}}\right] \tag{18}$$

*assuming symmetry across all firms within a particular currency pricing category.*

The first term on the right hand side of equation (18) indicates that the larger the fraction of goods priced in euros, $(1-\vartheta)$, the higher the short-run pass-through. The second term captures price changes in the currency of invoicing.

The dollar reset price $\bar{p}_{in,t}^{n}$ is given by equation (14) replacing for notation sake $\tilde{p}_{in,t+\ell}$ with $\tilde{p}_{in,t+\ell}^{i}$ to represent desired prices in dollars. A similar derivation gives the euro reset price $\bar{p}_{in,t}^{i}$ as:

$$\bar{p}_{in,t}^{i} = (1-\beta\kappa)\sum_{\ell=0}^{\infty}(\beta\kappa)^{\ell}\mathbb{E}_{t}\tilde{p}_{in,t+\ell}^{i}$$

where $\tilde{p}_{in,t+\ell}^{i}$ is the desired price in euros. In the case when flexible desired prices are the same regardless of currency of invoicing, that is $\tilde{p}_{in,t+\ell}^{i}+e_{in,t}=\tilde{p}_{in,t+\ell}^{n}$, we obtain the following proposition linking the two reset prices, as derived in Gopinath et al. (2010):

**Proposition 6** *If the NER follows a random walk and flexible desired prices are the same across firms regardless of the currency of pricing, then the reset price and ERPT conditional on changing price is equal across firms, up to the first order:*

$$\bar{p}_{in,t}^{n} = \bar{p}_{in,t}^{i} + e_{in,t}$$

$$\frac{\Delta p_{in,t}^{n}}{\Delta_{c} e_{in,t}} = \frac{\Delta p_{in,t}^{i}}{\Delta_{c} e_{in,t}} + 1$$

That is, the law of one price holds for the reset price if the fundamentals are the same. Note that ERPT conditional on price change is the same across firms including both the direct and indirect effects as well as any other change in costs.

We now discuss the findings in the empirical section in the context of the current framework. In the absence of micro price data pass-through estimates using import price indices typically combine the effect of sticky prices and pass-through conditional on a price change as discussed earlier. Proposition 4 discusses the conditions under which pass-through conditional on a price change (MRPT) as estimated in the empirical section for Finding 4 is a measure of life-long pass-through (LLPT). It requires $\rho_e = 1$ and $\Gamma_{in} = 0$. In the case when $\Gamma_{in} \neq 0$, the indirect effects of ERPT arising from changes in the aggregate price level show up dynamically over time and one would require multiple rounds of price adjustment to arrive at LLPT. As documented in Gopinath et al. (2010), the fact that MRPT is lower than LLPT is consistent with an important role for $\Gamma_{in} \neq 0$.

The combination of the fact that prices adjust infrequently in the currency in which they are priced in, and that even conditional on a price change they respond only partially to the NER, as documented in Finding 4, implies that aggregate pass-through estimates are heavily determined by the currency composition of the import bundle, in the short and medium run. This is evident from the expression in proposition 5.

As demonstrated in proposition 6, if firm fundamentals (that is, desired flexible prices) are the same and the NER follows a random walk, MRPT should be the same conditional on a price change regardless of the currency in which goods are priced. As documented in Finding 4 this is not the case in the data. Pass-through of dollar priced imports into the U.S. is significantly lower than for non-dollar priced imports even conditional on a price change. As demonstrated in Engel (2006) (for one period ahead price stickiness) and Gopinath et al. (2010) (for Calvo pricing) this is consistent with a model where firms optimally choose what currency to set their prices in. If prices adjust every period, currency choice is irrelevant. However when prices are sticky, the firm can choose its currency to keep its preset price closer to it's desired price.

We present the argument in a one period ahead sticky price environment as in Engel (2006). A risk neutral firm chooses to price in the local ($n$) currency as opposed to the producer ($i$) currency if $\mathbb{E}_{t-1}\Pi(\bar{p}^n_{in,t}) > \mathbb{E}_{t-1}(\Pi(\bar{p}^i_{in,t})$.[30] Taking a second order approximation to the profit function around the flexible price at date $t$ we have that,

$$\mathbb{E}_{t-1}\left[\Pi(\bar{p}^n_{in,t}) - \Pi(\bar{p}^i_{in,t})\right] \approx \mathbb{E}_{t-1}\frac{1}{2}\tilde{\Pi}_{pp}\left[(\bar{p}^n_{in,t} - \tilde{p}^n_{in,t})^2 - (\bar{p}^i_{in,t} + e_{in,t} - \tilde{p}^n_{in,t})^2\right] \tag{19}$$

[30]The result is unchanged if the firm is risk averse as long as the discount factor is exogenous to the decisions of the firm as pointed out by Engel (2006).

where $\tilde{\Pi}_{pp} < 0$ is the second derivative of the profit function evaluated at the date $t-1$ price. Here we have used the fact that flexible price profits are the same regardless of currency, that $\tilde{p}^n_{in,t} = \tilde{p}^i_{in,t} + e_{in,t}$, and that the first derivative of the profit function equals zero when evaluated at the flexible price. Expanding the right hand side of (19) and taking the expectation we have:[31]

$$\mathbb{E}_{t-1}\left[\Pi(\bar{p}^n_{in,t}) - \Pi(\bar{p}^i_{in,t})\right] \approx \frac{1}{2}\tilde{\Pi}_{pp} Cov_{t-1}(-e_{in,t}, e_{in,t} - 2\tilde{p}^n_{in,t}) \tag{20}$$

The firm will therefore choose LCP if:

$$\frac{Cov_{t-1}(\tilde{p}^n_{in,t}, e_{in,t})}{Var_{t-1}(e_{in,t})} < \frac{1}{2}, \tag{21}$$

that is if its desired pass-through is low enough. The cut-off of 0.5 follows from the second order approximation. Intuitively, if a firm desires low exchange rate pass-through in the short run before it has a chance to adjust prices, the firm is better off choosing local currency pricing that results in 0% pass-through in the short run. Conversely, if short-run desired pass-through is high, the firm should choose producer currency pricing that results in complete (100%) pass-through prior to price adjustment.

A number of papers in the literature fit into this simple framework. Devereux et al. (2004) consider an environment with one period ahead price stickiness, constant mark-ups and constant returns to scale. They show that an exporter will price in local currency if $Cov_{t-1}(w_{i,t} + e_{in,t}, e_{in,t})/Var_{t-1}(e_{in,t}) < 0.5$. It follows from equation (15), that if $\Gamma = 0$, $\Phi = 0$ and $\alpha = 1$ then $Cov_{t-1}(w_{i,t} + e_{in,t}, e_{in,t}) = Cov_{t-1}(\tilde{p}^n_{in,t}, e_{in,t})$. The cut-off rule is the same as (21). Bacchetta and van Wincoop (2005) assume constant mark-ups ($\Gamma = 0$) and decreasing returns to scale ($\Phi > 0$). They show that all else equal a marginal exporter selling to a country where all local firms price in the local currency will choose to price in local currency the higher the elasticity of demand it faces. This again fits into condition (21). To see this, recall that $\Phi = mc_q\varepsilon$, therefore for a given $mc_q$ the higher is the elasticity of demand $\varepsilon$ the larger is $\Phi$ and the lower is desired pass-through.

In the case of Calvo pricing, as derived in Gopinath et al. (2010), the currency choice rule depends on the average desired pass-through over the period of non-adjustment. This depends both on the dynamic path of desired pass-through and the duration of non-adjustment.[32] Gopinath et al. (2010) also show that MRPT, that is pass-through conditional on the first adjustment to the exchange rate shock, as estimated in the empirical section, is a good measure of this average desired pass-through.

[31] To derive equation (20), the right hand side of (19) can be expressed as:

$$\mathbb{E}_{t-1}\frac{1}{2}\tilde{\Pi}_{pp}\left[(\bar{p}^n_{in,t} - \bar{p}^i_{in,t} - e_{in,t})(\bar{p}^n_{in,t} + \bar{p}^i_{in,t} + e_{in,t} - 2\tilde{p}^n_{in,t})\right] = \mathbb{E}_{t-1}\frac{1}{2}\tilde{\Pi}_{pp}\left[(\mathbb{E}_{t-1}e_{in,t} - e_{in,t})(\bar{p}^n_{in,t} + \bar{p}^i_{in,t} + e_{in,t} - 2\tilde{p}^n_{in,t})\right]$$

The equality follows because $\bar{p}^n_{in,t} = \bar{p}^i_{in,t} + \mathbb{E}_{t-1}e_{in,t}$ up to the first order. Using the definition of the covariance and the fact that $\mathbb{E}_{t-1}(\mathbb{E}_{t-1}e_{in,t} - e_{in,t}) = 0$ we arrive at the cut-off rule (21).

[32] An implication of this point is that currency choice cannot be predicted solely by long-run pass-through or desired pass-through on impact of the exchange rate shock. A firm, for instance, with a high flexible price (long-run) pass-through can well choose local currency pricing if desired pass-through is low in the medium-run.

In terms of empirical evidence linking currency choice to primitives of desired pass-through, Goldberg and Tille (2008) find evidence in support of the role of strategic complementarities in pricing in the currency decison using data on currency invoicing of international trade for 24 countries. Consistent with Gopinath et al. (2010) they find that more homogenous goods are priced in dollars, given the predominance of the dollar in trade transactions. Goldberg and Tille (2009) use disaggregated data for Canadian imports and find that exporters tend to use the currency of the country that dominates their industry. In addition they find that the Canadian dollar is used more for larger shipments into Canada.[33]

Lastly, Bacchetta and van Wincoop (2005), Devereux et al. (2004), and Gopinath et al. (2010) highlight the potential for multiple equilibria in the currency choice decision. Consider an environment where firms have an incentive to keep their price relative to their competitors prices stable (high $\Gamma$). The currency choice decision depends on the currency of choice of the other firms. So for instance if the marginal firm selling to the U.S. competes with firms that price in dollars, then in response to movements in the U.S. NER its desired pass-through in dollars is low and it will choose to price in dollars. If on the other hand its competitors all price in euros then its desired pass-through in dollars will be high and it will be choose to price in euros.

## 4 Models with desired variable markups

We now illustrate a number of alternative models that have been used in the literature on international pricing in macroeconomic models that produce a negative relationship between markups and relative price $p_{in} - p_n$, so that $\Gamma_{in} > 0$ in the model presented in the previous section.

To start, as a benchmark, we briefly describe the case of monopolistic competition and CES demand. A continuum of intermediate goods, that in an abuse of notation we index by $i$ are combined in country $n$ in amounts $Q_{in}$ to produce a final good $Q_n$ (or utility) according to the constant returns to scale technology

$$Q_n = \left[ \int_{\Omega_n} A_{in}^{\frac{1}{\theta}} Q_{in}^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}} , \theta > 1,$$

where $\Omega_n$ denotes the set of available varieties in country $n$, and $A_{in}$ denotes a taste parameter for good $i$ in country $n$. We introduce these taste parameters to allow for home-bias in consumption if $A_{in} < A_{nn}$ for $i \neq n$. Cost minimization by the final good producer (or, equivalently, utility maximization by households) gives rise to the demand for variety $i$ of the form $Q_{in} = A_{in} \left( \frac{P_{in}}{P_n} \right)^{-\theta} Q_n$, where $P_{in}$ is the price of variety $i$ in country $n$, and $P_n$ is the cost-minimizing aggregate price index in country $n$ given by $P_n = \left[ \int_{\Omega_n} A_{in} (P_{in})^{1-\theta} di \right]^{\frac{1}{1-\theta}}$. The demand elasticity is $\varepsilon_{in} = \theta$. Profit maximization by a monopolistic producer $i$ gives rise to a simple pricing rule with a constant markup

[33] To explain this finding Goldberg and Tille (2008) build a pricing and currency choice model based on bargaining between the exporter and an importer that gets higher utility when facing stable prices in local currency.

given by

$$\mu_{in} = \log\left(\frac{\varepsilon_{in}}{\varepsilon_{in}-1}\right) = \log\left(\frac{\theta}{\theta-1}\right).$$

Given that markups are constant, $\Gamma_{in} = 0$.

### 4.1 Non-CES demand

Kimball (1995) introduces a simple departure from CES using a homothetic aggregator over individual varieties implicitly defined by:

$$\frac{1}{|\Omega_n|}\int_{\Omega_n} A_{in}\Upsilon\left(\frac{|\Omega_n|\,Q_{in}}{A_{in}Q_n}\right)di = 1,$$

The function $\Upsilon$ satisfies the constraints $\Upsilon(1) = 1$, $\Upsilon'(.) > 0$ and $\Upsilon''(.) < 0$. Under CES, $\Upsilon\left(\frac{|\Omega_n|Q_{in}}{A_{in}Q_n}\right) = \left(\frac{Q_{in}}{A_{in}Q_n}\right)^{\frac{\theta-1}{\theta}}$. Cost minimization (or utility maximization) gives rise to the following first-order-condition:

$$P_{in} = \Upsilon'\left(\frac{|\Omega_n|\,Q_{in}}{A_{in}Q_n}\right)\frac{\lambda_n}{Q_n},$$

where $\lambda_n$ denotes the Lagrange multiplier. Expenditures over all varieties are given by

$$P_nQ_n = \int_{\Omega_n} Q_{in}P_{in}di = \lambda_n D_n,$$

where $P_n$ is the price index and $D_n \equiv \int_{\Omega_n}\Upsilon'\left(\frac{|\Omega_n|Q_{in}}{A_{in}Q_n}\right)\frac{Q_{in}}{Q_n}di$. Hence, the inverse demand function for variety $i$ in country $n$ is

$$\Upsilon'\left(\frac{|\Omega_n|\,Q_{in}}{A_{in}Q_n}\right) = D_n\frac{P_{in}}{P_n},$$

which can we inverted to obtain

$$Q_{in} = A_{in}\psi\left(D_n\frac{P_{in}}{P_n}\right)Q_n,$$

where $\psi(.) = \Upsilon'^{-1}(.)/|\Omega| > 0$ and $\psi'(.) < 0$ applying the inverse derivative theorem and $\Upsilon''(.) < 0$. In logs,

$$q_{in} = a_{in} + \log\left(\psi\left(\exp\left(x_{in}\right)\right)\right) + q_n,$$

where $x_{in} = \log(D_n) + p_{in} - p_n$ and $a_{in} = \log(A_{in})$. The demand elasticity is:

$$\varepsilon_{in} = -\frac{\psi'(.)}{\psi(.)}\frac{D_nP_{in}}{P_n},$$

which can vary across firms depending on the shape of $\psi(.)$. Note that $a_{in}$ does not directly affect the demand elasticity.[34]

[34] Starting around an equilibrium in which $\varepsilon_{in}$ is equal across all firms selling in country $n$, it is straightforward to show that $dD_n = 0$ up to a first-order-approximation.

To put more structure on the dependance of $\varepsilon_{in}$ on the relative price, Klenow and Willis (2006) choose a specification $\Upsilon$ that results in a demand function:

$$\log(\psi(x)) = \frac{\theta}{\eta}\log[1-\eta x].$$

The limit of $\log(\psi x)$ as $\eta \longrightarrow 0$ is $-\theta x$ as under CES. The demand elasticity is

$$\varepsilon_{in} = -\frac{\partial \log \psi(x)}{\partial x} = \frac{\theta}{1-\eta x_{in}}$$

which is constant when $\eta = 0$ and increasing in $x$ when $\eta > 0$. The log markup is

$$\mu_{in} = \log\left(\frac{\theta}{\theta - 1 + \eta x_{in}}\right)$$

and the elasticity of the markup with respect to the relative price is

$$\Gamma_{in} = \frac{\eta}{\theta - 1 + \eta x_{in}}.$$

Hence, when $\eta > 0$ markups are decreasing in the relative price. Note that the elasticity of the markup with respect to relative price, $\Gamma_{in}$, varies systematically across firms. Specifically, markups are more sentitive to relative prices $p_{in} - p_n$ (i.e. $\Gamma_{in}$ is higher) the lower is a firm's relative price.

A similar relationship between markups and relative prices is implied by other commonly used non-CES utility functions over a continuum of products such as quadratic (e.g. Melitz and Ottaviano (2008)) or translog utility (e.g. Bergin and Feenstra (2001)).[35]

## 4.2 Strategic complementarities in pricing with CES demand

We now describe a setting with CES demand and a discrete number of products which gives rise to variable markups of the form assumed above. This setting was originally studied in Dornbusch (1987) and more recently in Atkeson and Burstein (2008).

Final sector output is modeled as a CES of the output of a continuum of sectors with elasticity of substitution $\eta$ and sector output is CES over a *finite* number of differentiated products with elasticity $\theta$, where $1 \leq \eta \leq \theta$. Firms own single products within each sector and compete in prices (Bertrand). Taking as given prices of other firms in its sector, the elasticity of demand for good $i$ selling in country $n$ in any given sector is

$$\varepsilon_{in} = \eta s_{in} + \theta(1 - s_{in}),$$

where $s_{in} = \exp(a_{in} + (1-\theta)(p_{in} - p_n))$ represents the expenditure share of product $i$ with taste parameter $a_{in}$ in that sector and $p_n = \frac{1}{1-\theta}\log\left(\sum_i \exp(a_{in} + (1-\theta)p_{in})\right)$ is the log of the aggregate

[35] For other models of non-CES demand over a continuum of products, see e.g. Simonovska (2010) and Gust et al. (2010). Arkolakis et al. (2012) consider the effects of international trade on markups in a general class of models featuring a decreasing relationship between markups and relative prices.

sector price. Note that, if $\eta < \theta$, $\varepsilon_{in}$ is decreasing in the expenditure share of the firm in that sector. A firm with a small share assigns a larger weight to competitors in its same sector (high elasticity of substitution) than to competitors in other sectors (low elasticity of substitution). A firm with a higher share assigns a larger weight to firms in other sectors whose products are less substitutable, thus facing a lower price-elasticity of demand.

The optimal markup (obtained by choosing price to maximize profits taking prices of other firms in the sector as given) is

$$\mu_{in} = \log\left(\frac{\eta s_{in} + \theta\left(1 - s_{in}\right)}{\eta s_{in} + \theta\left(1 - s_{in}\right) - 1}\right),$$

which is increasing in $s_{in}$ (and decreasing in $p_{in} - p_n$ for a fixed $a_{in}$) if $\theta > \eta$.[36] The elasticity of the markup with respect to relative price is

$$\Gamma_{in} = \left(\theta - \eta\right)\left(\theta - 1\right)\frac{s_{in}}{\left[\eta s_{in} + \theta\left(1 - s_{in}\right)\right]\left[\eta s_{in} + \theta\left(1 - s_{in}\right) - 1\right]}. \tag{22}$$

which is positive if $\eta < \theta$. That is firms with lower relative price, $p_{in} - p_n$, and higher expenditure share, $s_{in}$, set higher markups. Markups are more sensitive to relative prices $p_{in} - p_n$ the higher is a firm's market share $s_{in}$. These results are qualitatively unchanged if firms compete in quantities (Cournot).[37] Finally, note that with a finite number of positive-mass firms per sector, any change in a product's price $p_{in}$ has a non-zero effect on the aggregate sector price $p_n$, so that in expression (24) $\Delta p_n$ directly depends on $\Delta p_{in}$. Taking into account this effect, equation (10) becomes (assuming constant returns to scale)

$$\Delta p_{in} = \frac{1}{1 + \left(1 - s_{in}\right)\Gamma_{in}}\left[\Delta w_i + \alpha_{in}\Delta e_{in} + \left(1 - s_{in}\right)\Gamma_{in}\Delta p_{-in}\right]$$

where $\Delta p_{-in}$ is an expenditure-weighted average of price changes in the sector exclusive of firm or product $i$ (in models with a continuum of firms, $s_{in} = 0$). Markups are constant if $s_{in} = 0$ or if $s_{in} = 1$. Hence, ERPT (both the direct effect and the sum of the direct and indirect effects) is non-monotonic in size.

## 4.3 Distribution costs

We now consider a simple model of pricing with CES demand and additive distribution costs which gives rise to variable markups of the form assumed above. This setting was originally explored in Corsetti and Dedola (2005).

[36] See de Blas and Russ (2012) for an analytical characterization of the distribution of mark-ups as a function of primitives in a related model.

[37] Under Cournot competition, $\varepsilon_{in} = \left(\frac{s_{in}}{\eta} + \frac{1 - s_{in}}{\theta}\right)^{-1}$ and $\Gamma_{in} = \left(\theta - 1\right)\left(\frac{1}{\eta} - \frac{1}{\theta}\right)\mu_{in}s_{in}$, where $s_{in}$ and $p_n$ are given by the same expressions as under Bertrand competition, and $\mu_{in} = \log\left(\varepsilon_{in}/\left(\varepsilon_{in} - 1\right)\right)$. Once again, $\Gamma_{in}$ is decreasing in $p_{in} - p_n$ and increasing in $s_{in}$.

When country $i$ firms sell to country $n$ there is a retail (and wholesale) sector that bundles the imported good with distribution services to bring it to the final consumer. Assuming that the retail sector is competitive and combines the good and distribution services at fixed proportions, the retail price (in levels) $P^r_{in}$ is given by:

$$P^r_{in} = P_{in} + \eta_{in} P^d_n$$

where $\eta_{in}$ denotes the fixed distribution cost per good. We assume that production of one unit of distribution services uses one unit of the industry bundle, which implies $P^d_n = P_n$.[38]

In this setup, the presence of local distribution services immediately implies that retail prices move less than one-to-one with changes in producer prices. Corsetti and Dedola (2005) show that the presence of additive distribution costs can lead to variable markups at the producer level. To see this, consider a CES demand at the retail level with elasticity of substitution $\theta$: $Q_{in} = A_{in} \left(\frac{P^r_{in}}{P_n}\right)^{-\theta} Q_n$, where $P_n$ denotes the aggregate CES price inclusive of distribution costs. The elasticity of demand country $i$ firm faces when selling in country $n$ is

$$\varepsilon_{in} = -\frac{\partial \log Q_{in}}{\partial \log P_{in}} = \theta \left(1 - s^d_{in}\right)$$

where $s^d_{in} = \frac{\eta_{in} P_n}{P_{in} + \eta_{in} P_n}$ denotes the share of distribution services in the retail price. The distribution share and the elasticity of demand are both decreasing in the ratio of the firm's producer price to the local cost component $P_{in}/P_n$. The optimal mark-up for a monopolistic price-setter is:

$$\mu_{in} = \log \left[\frac{\theta \left(1 - s^d_{in}\right)}{\theta \left(1 - s^d_{in}\right) - 1}\right] = \log \left[\frac{\theta}{\theta - 1 - \eta_{in} \exp\left(-\left(p_{in} - p_n\right)\right)}\right].$$

The elasticity of the markup with respect to the relative price $p_{in} - p_n$ is

$$\Gamma_{in} = \frac{1}{\frac{\theta - 1}{\eta_{in} \exp(-(p_{in} - p_n))} - 1} = \frac{1}{(\theta - 1)\frac{1 - s^d_{in}}{s^d_{in}} - 1}. \tag{23}$$

Clearly $\Gamma_{in} = 0$ if $s^d_{in} = 0$ and $\Gamma_{in} > 0$ if $s^d_{in} > 0$. Intuitively, as the firm raises its relative price, that raises the elasticity of demand it faces and reduces its desired mark-up.[39]

Note from expression 23 that the elasticity of the markup with respect to relative price, $\Gamma_{in}$, varies systematically across firms. Specifically, markups of firms with lower relative price $p_{in} - p_n$ (or higher distribution share $s^d_{in}$) are more sensitive to relative price.

[38] An alternative, standard assumption is that distribution services are produced using local labor instead of the industry bundle. In such case, the markup is a decreasing function of the price relative to the wage, $p_{in} - w_n$, instead of $p_{in} - p_n$. Markups in this case respond to changes in local wages and not directly to changes in the local aggregate price. If there are positive trade costs or home bias in preferences (so that relative aggregate prices across countries comove relative wages), the two models behave similarly.

[39] A necessary condition for $\Gamma_{in} > 0$ in this model is that the elasticity of substitution in the retail technology between the good and distribution services be less than one. In the Cobb-Douglas case, $\Gamma_{in} = 0$.

The specific models discussed above produce systematic differences in the elasticity of markup to relative price $\Gamma_{in}$ across firms from country $i$ selling in country $n$. To recap, in the first model (non-CES demand), the markup elasticity is higher for low relative price firms. In the second model (CES demand with a finite number of firms), the markup elasticity is higher for higher market share firms. In the third model (distribution costs), the markup elasticity is higher for firms with higher distribution share. In all of these models, everything else the same, more productive firms have a lower relative price, a higher expenditure share, and a higher markup elasticity.

What are the implied differences in the degree of ERPT across firms? From expression in Proposition 2, we can see that, ceteris paribus, firms with higher markup elasticity, $\Gamma_{in}$, have a smaller ERPT stemming from direct effects (changes in exchange rate at fixed aggregate prices and quantities) but higher ERPT stemming from indirect effects (from changes in the aggregate prices and quantities in the destination country). The net effect of a higher $\Gamma_{in}$ on ERPT is ambiguous.[40] If firms have a non-trivial effect on the industry aggregate price (as in the CES model with a finite number of firms), there is an additional source of non-monotonicity of ERPT across firms described above.

These model implications for how ERPT varies across heterogeneous firms have recently motivated empirical work using detailed micro data that merges measures of ERPT and firm characteristics. Berman et al. (2012) find evidence that higher productivity firms in France have lower ERPT than low productivity firms.[41] Similarly, Amiti et al. (2012) find evidence that Belgian exporters with higher expenditures shares in the destination market have lower ERPT. This is both because of the the markup channel (i.e. $\Gamma_{in}$) and because larger exporters import a larger fraction of intermediate inputs that in turn lowers their sensitivity to bilateral exchange rate shocks, that is they have a lower $\alpha_{in}$.

Goldberg and Hellerstein (2006), Hellerstein (2008), Goldberg and Verboven (2001), and Nakamura and Zerom (2010) develop structural models of international pricing featuring heterogeneous consumer choosing among horizontally differentiated varieties that better suit their preferences. These models, which give rise to richer and more flexible demand systems, are simulated and estimated using detailed micro data and econometric methods that are standard in the field of industrial organization. Goldberg and Hellerstein (2008) provide a recent survey of this work. These flexible demand models typically do not generate simple closed form solutions for $\Gamma_{in}$ or $\varepsilon_{in}$ and, in contrast to the models presented in this section, are less tractable to embed in general equilibrium setups like the one presented in Section 7. Consumer heterogeneity gives rise to a potentially important effect that is not present in the models described in this section. Specifically, when prices increase,

[40] Auer and Chaney (2009) present a model of pricing-to-market under perfect competition that features consumers with heterogeneous preferences for quality. In equilibrium, ERPT is lower for high quality goods.

[41] Chatterjee et al. (2012), using Brazilian data, find similar results on ERPT across individual products exported by multi-product firms.

consumers with high demand elasticity exit the market causing average demand elasticity to fall and mark-ups to rise. Hence, pass-through can be larger than 100%.

# 5 Other models of incomplete pass-through

We now discuss a number of alternative models of incomplete pass-through considered in the literature that do not directly fit into the framework used above.

## 5.1 Consumer search

Search models, as formulated by Burdett and Judd (1983) in a closed-economy context and by Alessandria (2009) in an international context, provide an alternative approach to obtaining variable markups of a similar form of those in the framework above. Consumer-search limits consumer arbitrage and can hence provide one rationalization for the observed dispersion of prices across locations for identical products at a point of time.

In the model of Alessandria (2009), firms from each country produce a single good at a constant, common marginal cost. Search is a costly activity that buyers in each country undertake to reduce the expected cost of purchasing the good from each source country. In equilibrium, for every good there is a distribution of prices in each country. Firms are indifferent between charging different prices in the distribution: a higher price entails a higher markup but a lower expected quantity sold. Alessandria (2009) shows that the average price posted by country $i$ producers in country $n$ is

$$P_{in} = MC_{in} + \eta P_n^s,$$

where $MC_{in}$ denotes the marginal cost of all country $i$ producers for sales to country $n$ (expressed in the currency of country $n$), $P_n^s$ denotes the cost of a unit of search effort for a country $n$ consumer, and $\eta$ is a parameter shaped by the search technology parameters.[42] The higher is the consumer's cost of search effort, $\eta P_n^s$, the higher is the average markup. The logarithm of the average markup for country $i$ producers selling to country $n$ can be represented in terms of the notation used above as

$$\mu_{in} = \log\left(\frac{P_{in}}{MC_{in}}\right) = \log\left(1 + \eta \frac{1}{1 - \exp\left(p_n^s - p_{in}\right)}\right).$$

If the cost of search effort is in terms of the aggregate good in each country (so that $p_n^s = p_n$) we obtain a negative relationship between the average markup and the average price of country $i$ producers in country $n$ relative to the aggregate price in country $n$, as in the previous models.[43]

[42] A similar relation hold for the average transacted prices, with a different mapping between parameters and $\eta$.

[43] If the search effort is in terms of time, then the negative relationship is between the average markup and the price-wage ratio.

Note that, since firms are indifferent between charging different markups in the distribution, the markup elasticity $\Gamma_{in}$ is not uniquely determined for each individual firm.[44]

## 5.2 Customer accumulation

Incomplete pass-through from costs to prices may arise if firms face adjustment costs to expand sales in any destination market. These adjustment costs may arise from investments in distribution infrastructure, marketing, or other costs to the firm of expanding its customer base. In response to a depreciation of the Euro against the U.S. dollar, a German exporter to the U.S. will not find it optimal to fully reduce its dollar price if there is no capacity to meet additional demand. This insight was initially developed in Krugman (1987) and later embedded in dynamic general equilibrium models by Kasa (1992) and Lapham (1995).

More recently, Drozd and Nosal (2012b) build an international business cycle model in which producers face costs to match with additional retailers in each market, while retailers search in an undirected way for domestic and foreign producers. Once matched, Nash bargaining between producers and retailers result in a producer price given by

$$P_{in} = (1 - \eta)\, MC_{in} + \eta P^{r}_{in},$$

where $MC_{in}$ denotes the marginal of production expressed in country $n$'s currency, $P^{r}_{in}$ the retail price, and $0 < \eta < 1$ the bargaining power of retailers. That is, as in previous models, there is an additive local component ($P^{r}_{in}$) that disconnects prices from costs. An appreciation of the Euro that increases marginal costs of a German exporter in U.S. dollars relative to the retail price in the U.S., results in incomplete ERPT into border prices. Deviations from relative PPP for German goods sold in Germany and the U.S. occur if retail prices $P^{r}_{in}$ change across countries when measured in a common currency. Drozd and Nosal (2012b) show that changes in relative retail prices across countries arise from two forces. First, from changes across countries in the local cost of increasing the number of matches (this destination-specific cost component operates similarly to distribution costs described above). Second, from adjustment costs to the accumulation of matches. Intuitively, if adjustment costs are large, retail quantities do not change much in the short-run, and neither do retail prices. Over time, as quantities adjust, deviations from relative PPP become smaller. Drozd and Nosal (2012b) discipline the degree of adjustment costs to account for the observed differences between (low) short-run and (high) long-run price elasticity of international trade flows (see e.g. Ruhl (2008)).

Relatedly, and building on the partial equilibrium models of pricing-to-market with consumer switching costs developed in Froot and Klemperer (1989), Ravn et al. (2007) present a dynamic

[44] Alessandria and Kaboski (2011) argue that the search mechanism can partly account for differences in price levels between rich and poor countries.

model of pricing-to-market stemming from preferences with habit formation at the level of individual varieties. In particular, preferences are given by

$$Q_{n,t} = \left[\int_{\Omega_n} \left(Q_{in,t} - \eta\overline{Q}_{in,t-1}\right)_{in,t}^{\frac{\theta-1}{\theta}} di\right]^{\frac{\theta}{\theta-1}} ,$$

where $\overline{Q}_{in,t} = \rho\overline{Q}_{in,t-1} + (1-\rho)\widetilde{Q}_{in,t}$ denotes the stock of habit for good $i$ in country $n$, and $\widetilde{Q}_{in,t}$ denotes average consumption of this good (which each consumer takes parametrically and equals $Q_{in,t}$ in a symmetric equilibrium). Utility maximixation results in demand for good $i$ in country $n$ at time $t$ of the form

$$Q_{in,t} = \left(\frac{P_{in,t}}{P_{n,t}}\right)^{-\theta} Q_{n,t} + \eta\overline{Q}_{in,t-1}.$$

The price-elasticity $\varepsilon_{in}$ is a weighted average of $\theta$ and 0, where the weight on $\theta$ is increasing in expected future sales. When the present value of future sales rises in a country, firms selling there have incentives to invest in market share by lowering current markups. Any shock that increases the present value of sales in U.S. relative to Germany reduces markups in U.S. relative to Germany for any traded good. Ravn et al. (2006) show that, in response to an increase in government spending in the U.S., the CPI-based RER depreciates in the U.S., and prices for any traded good rise in Germany relative to the U.S., consistent with the correlations summarized in Finding 5. Drozd and Nosal (2012a) show, however, that the ability of this model to reproduce the correlations in Finding 5 are sensitive to the source of aggregate shocks.[45]

## 5.3 Inventories

Alessandria et al. (2010), as discussed previously, show that in the case of goods that are storable the retail or wholesale price of imported goods can be disconnected from the border price. Pass-through from changes in import prices into retail or wholesale prices can be incomplete even with CES preferences that in the baseline model without inventories generate full pass-through. Specifically, when a good is storable and firms face shipping lags and fixed costs of importing, they choose to import infrequently and hold inventories. These frictions are carefully documented in Alessandria et al. (2010). Holding inventories is not costless because goods depreciate if not sold. As derived in Alessandria et al. (2010) the retail or wholesale price charged by a monopolist is given by

$$p_{in}^{r} = \frac{\theta}{\theta-1} V_s(s)$$

where $V_s$ is the value of an additional increment of stock of inventories. Therefore, prices in general depend on the firm's current stock of inventories. When the firm decides to import goods to add to inventories, then $V_s = p_{in}$, where $p_{in}$ is the marginal cost of importing another unit. In this case

[45] Dynamics models of incomplete pass-through have implications in terms of how the degree of pricing-to-market varies with the permanence of movements in exchange rates.

there is 100% pass-through from changes in border prices into wholesale or retail prices. When the level of inventories is high, $V_s < p_{in}$, that is the firm will choose to price at lower than the replacement cost because its inventories are too high. In response to an increase in the border price $p_{in}$, a firm may find itself with too much inventories, in which case $V_s < p_{in}$ and pass-through is incomplete. Note that in response to a decline in the border prices, pass-through will be complete if firms choose to sell more or to replenish their inventories. Hence, this model generates an asymmetry in the extent of pass-through to increases and decreases in the border price $p_{in}$.

Thus far we have mainly focused on the partial equilibrium problem of a firm from country $i$ selling in country $n$. We now examine the industry equilibrium and a general equilibrium environment.

# 6 Industry equilibrium

How does the aggregate industry price respond to exchange rate movements? We calculate the log change in the aggregate price index in country $n$, $\Delta p_n$, as an expenditure-weighted average of changes in all prices of goods sold in country $n$. This definition corresponds to the change in the CPI for an industry calculated at producer prices, as well as the change in the aggregate industry price, up to a first order approximation, in the type of models described in section 4.

To calculate the first-order change in the aggregate price index, we make some simplifying assumptions: there are constant returns to scale ($mc_q = 0$) and in the initial equilibrium all firms within each country are homogeneous so that $\Gamma_{in}$ is equal across all producers from country $i$ selling in country $n$ and $\alpha_{in} = \alpha_{ni} = 1$. The following proposition presents the change in the aggregate price when prices are flexible:

**Proposition 7** *If all firms within each country are homogeneous and $mc_q = 0$, then the log change in the aggregate price, when prices are flexible, is*

$$\Delta p_n = \left[ \sum_j \frac{s_{jn}}{1 + \Gamma_{jn}} \right]^{-1} \sum_i \frac{s_{in}}{1 + \Gamma_{in}} \left( \Delta w_i + \Delta e_{in} \right), \tag{24}$$

*and the change in quantity sold from country $i$ to country $n$ is*

$$\Delta q_{in} = \frac{\varepsilon_{in}}{1 + \Gamma_{in}} \left( \Delta w_i + \Delta e_{in} - \Delta p_n \right) + \Delta q_n, \tag{25}$$

where $s_{in}$ denotes the total expenditure share of country $i$ producers selling in country $n$. From expression (24) we can observe that an increase in the marginal cost (in U.S. dollars) affecting a larger expenditure share of firms selling into the U.S. results in a larger increase in the aggregate price and, through the indirect effects on ERPT, a higher increase in any country $j$'s prices into country $n$.

If markets in countries $m$ and $n$ are not segmented in the sense that $s_{jn} = s_{jm}$, $\Gamma_{jn} = \Gamma_{jm}$ for all $j$, then the industry aggregate RER is constant, $\Delta p_m + \Delta e_{mn} - \Delta p_n = 0$. According to expression (11), relative markups between these two countries are constant for any traded good, even if $\Gamma_{in} > 0$. Hence, trade costs or home bias in preferences that segment markets across countries are essential to obtain pricing-to-market, as discussed in Atkeson and Burstein (2008).

From expression (24) we can also observe that if $\Gamma_{jn} = \Gamma_n$, then for given changes in wages and exchange rates, the change in the aggregate price is independent of $\Gamma_n$ and hence is the same as if markups are constant, $\Gamma_n = 0$. To understand why $\Gamma_n$ does not affect the change in aggregate prices, suppose that country $n$'s currency depreciates against country $i$'s currency, $\Delta e_{in} > 0$, while $\Delta w_j = 0$. The higher is $\Gamma_n$, the lower is ERPT in country $n$ for imports from country $i$, but the higher is the increase in prices by all other producers selling to country $n$.

This result can be related to expression (8) for movements in CPI-based RERs for tradeable goods. A higher markup elasticity $\Gamma_n$ increases the movements in export prices relative to producer prices, $\Delta epi_n - \Delta ppi_n$, contributing to larger movements in $rer_{in}^{tr}$, but also reduces movements in PPI's across countries, $\Delta ppi_{ii} + \Delta e_{in} - \Delta ppi_{nn}$, contributing to smaller movements in $rer_{in}^{tr}$. When $\Gamma_{jn} = \Gamma_n$, these effects exactly offset each other and movements in $rer_{in}^{tr}$ are not affected by the markup elasticity for given changes in wages and exchange rates.

While the markup elasticity does not affect the response in aggregate prices to given changes in wages and exchange rates across countries, it does affect the response of quantities as can be seen in expression (25). In particular, a higher markup elasticity $\Gamma_{in}$ reduces the effects of a change in exchange rates on relative quantities in the same way as a reduction in the price elasticity of demand, $\varepsilon_{in}$, does.

The irrelevance of $\Gamma_{in}$ for aggregate price movements is an outcome of flexible prices. When prices adjust infrequently, as in the data, $\Gamma_{in}$ affects the price response. Assume that there are only two countries $i$ and $n$. Reset prices are given by (16). The aggregate price in country $n$ is given by:

$$p_{n,t} = \kappa p_{n,t-1} + (1-\kappa)\overline{p}_{n,t} \tag{26}$$

where

$$\overline{p}_{n,t} = s^m \overline{p}_{in,t} + (1-s^m)\overline{p}_{nn,t} + constant \tag{27}$$

and $s^m$ represents the import share of spending in each country ($s^m = s_{21}$ in country 1 and $s^m = s_{12}$ in country 2). Assuming that countries are symmetric, $s^m = s_{21} = s_{12}$, $\Gamma_{in} = \Gamma_{nn} = \Gamma_{ni} = \Gamma$, after some algebraic manipulation (derived in the appendix) we arrive at the following expressions for the evolution of producer price inflation in country $n$:[46]

$$\Delta p_{n,t} - \beta \mathbb{E}_t \Delta p_{n,t+1} = \frac{(1-\kappa)(1-\beta\kappa)}{\kappa(1+\Gamma)} \left[ s^m (w_{i,t} + e_{in,t}) + (1-s^m)\, w_{n,t} - p_{n,t} \right] \tag{28}$$

[46] These assumptions allow for home bias in consumption stemming from differences in preference parameters, $A_{in} < A_{nn}$.

Using the definition of the real exchange rate, $rer_{in,t} = e_{in,t} + p_{i,t} - p_{n,t}$ and combining the previous two expressions we arrive at the following expression for the evolution of the real exchange rate:

$$\begin{aligned} \Delta rer_{in,t} - \beta \mathbb{E}_t \Delta rer_{in,t+1} &= \Delta e_{in,t} - \beta \mathbb{E}_t \Delta e_{in,t+1} \\ &+ \frac{(1-\kappa)(1-\beta\kappa)}{\kappa(1+\Gamma)} \left[ (1-2s^m)(w_{i,t} + e_{in,t} - w_{n,t}) - rer_{in,t} \right] \end{aligned} \tag{29}$$

For given paths of wages and exchange rates, a higher $\Gamma$ works the same way as a higher $\kappa$, as it reduces the response of the firm changing prices to the exchange rate shock.

# 7 General equilibrium

In the previous sections we described mechanisms through which prices adjust incompletely and gradually to exchange rate shocks and generate relative price movements for the same good across different markets. We adopted a partial equilibrium approach, focusing on the problem of a firm and solving for industry equilibrium. We modeled the cost components of the firm including the exchange rate shock and wages as exogenous variables. In this section we describe one standard form of closing the model to endogenize wages and exchange rates. Movements in real and nominal exchange rates are driven by monetary shocks, motivated by the evidence presented in Mussa (1986). This is the approach adopted in Chari et al. (2002), Kehoe and Midrigan (2007), Carvalho and Nechio (2011), among others.

Here we sketch the main features of the general equilibrium model and spell out more details in the appendix. There are two ex-ante symmetric countries. Households in each country derive utility from leisure and consumption of tradeable and non-tradeable goods, and have access to a complete set of state-contingent assets. To sell tradeable goods, a competitive distribution sector combines them with nontradeable goods. Tradeable and non-tradeable consumption goods are each composed of a continuum of differentiated goods according to a non-CES aggregator of the form described in section 4.1. Differentiated goods are produced using a symmetric technology that is linear in labor so that marginal cost is $(w_i + e_{in})$. We consider two alternative assumptions on price and wage rigidity. In section 7.1 we consider the case of flexible wages and price rigidity in local currency and in section 7.2 we present the case of rigid wages and flexible prices.

## 7.1 Local currency pricing

Monopolistically competitive firms set prices in each country that are sticky in the currency of the buyer. For a given path of wages and exchange rates, the dynamics of prices and RER for tradeable (at the producer level) and non-tradeable goods is represented by equations (28) and (29), where $s^m = 0$ for nontradeable goods.

Labor supply is determined by the consumers' intra-temporal labor-leisure decisions, which under a utility function of the form $U(C,N)=\frac{C_i^{1-\sigma}}{1-\sigma}-\frac{L_i^{1+\gamma}}{1+\gamma}$ is given by

$$\sigma c_{i,t}+\gamma l_{i,t}=w_{i,t}-p_{i,t}^{c} \tag{30}$$

where $1/\gamma$ is the Frisch elasticity of labor supply, and $p_{i,t}^{c}$ is the aggregate consumer price in country $i$ (including tradeable and nontradeable goods). Up to a first-order approximation, $\Delta p_{i,t}^{c}=\Delta cpi_{i,t}$.

With complete asset markets, risk sharing implies

$$\sigma\left(c_{n,t}-c_{i,t}\right)=e_{in,t}+p_{i,t}^{c}-p_{n,t}^{c}=rer_{in,t} \tag{31}$$

where $rer_{in,t}$ is the consumer price based RER. Combining risk sharing and labor supply, we obtain:

$$w_{i,t}+e_{in,t}-w_{n,t}=\gamma\left(l_{i,t}-l_{n,t}\right). \tag{32}$$

The nominal side of the economy is modeled using a money growth ($\Delta m_{i,t}$) rule and a cash-in-advance constraint:

$$\Delta m_{i,t}=\rho_m\Delta m_{i,t-1}+\sigma_{\epsilon_m}\epsilon_{i,t}$$

where $\varepsilon_{i,t}$ are *iid* shocks. The cash in advance constraint is given by,

$$p_{i,t}^{c}+c_{i,t}=m_{i,t} \tag{33}$$

The following proposition, derived in Carvalho and Nechio (2011), analytically characterizes the first-order dynamics of RERs (taking into account the endogenous determination of wages and exchange rates) under certain parameter restrictions.[47]

**Proposition 8** *When $\sigma=1$, $\gamma=0$, $\alpha_{in}=\alpha_{ni}=1$ and $\Gamma=0$, the real exchange rate is given by*

$$(1-\rho_m L)(1-\kappa L)rer_{in,t}=\left(\kappa-(1-\kappa)\frac{\rho_m\beta\kappa}{1-\rho_m\beta\kappa}\right)u_{in,t}$$

*and the nominal exchange rate follows*

$$\Delta e_{in,t}=\rho_m\Delta e_{in,t-1}+u_{in,t}$$

*where $u_{in,t}\equiv\sigma_{\epsilon_m}(\epsilon_{n,t}-\epsilon_{i,t})$.*

One measure of the persistence of the real exchange rate is given by the sum of autoregressive roots: $\mathcal{P}=1-(1-\rho_m)(1-\kappa)$. The persistence of the RER is increasing in the persistence of the money growth rate and in the frequency of non-adjustment $\kappa$.[48] When $\rho_m=0$ there is a one-to-one

[47] Kehoe and Midrigan (2007) derive a similar expression for the case when $\rho_m=0$.

[48] Carvalho and Nechio (2011) show that a multi-sector model with sectoral heterogeneity in the frequency of price adjustment will tend to generate larger aggregate RER persistence than a one sector model with the average sectoral frequency of price adjustment.

mapping between the RER persistence and the frequency $\kappa$. Kehoe and Midrigan (2007) find a positive but weak relationship between these two statistics using data for a number of developed countries. However, as is evident in the case when $\rho_m$ is high the effect of variations in $\kappa$ can be small.

More generally, when $\Gamma \neq 0$ and $\gamma \neq 0$ there is no simple closed form solution for the real exchange rate that evolves according to (29). In Figure 3 we graph the half-life (in quarters) for the RER as a function of $\Gamma$.[49] As expected, the higher is $\Gamma$ the longer is the half life.

With only price rigidity and with flexible wages this model implies a close tie between exchange rates and relative wages at high frequencies. According to (32), if the Frisch elasticity is infinite, relative wages (measured in a common currency) are constant, independent of the source of the shock. If the Frisch elasticity is finite, countries that expand experience an increase in relative wages. It is difficult to reconcile these movements (or lack of) in relative wages with Findings 1,2 and 3 that relied on the disconnect between non-traded prices (and hence wages) and exchange rates. In addition, with sticky local currency prices a devaluation leads to an increase in export prices relative to import prices and the real trade balance deteriorates in the case when prices are rigid in the local currency and wages are flexible. One standard way of disconnecting wages and non-traded good prices from exchange-rates in the short run is to allow for sticky wages. We describe this extension in the next subsection.

The impulse responses to a permanent money growth shock that induces a 1% depreciation of the nominal exchange rate in country 1 in the new steady state are depicted in Figure 4. The values represent log percentage deviations from the initial steady state. Relative wages (measured in a common currency) remain constant across countries. With local currency prices adjusting sluggishly, the terms of trade (price of imports relative to exports) appreciates and the real trade balance (defined as the difference between the quantity of exports and imports) deteriorates for the country that experiences an exchange rate depreciation (country 1). This is because, with local currency pricing, there is limited expenditure switching in the short-run so the standard channel that generates an improvement in the trade balance (as would be the case for producer currency pricing) is no longer effective. The deterioration in trade balance in country 1 arises because the shock generates an increase in overall consumption in country 1 while it remains unchanged in country 2, thus increasing imports in country 1 relative to exports. Employment rises in country 1 and remains approximately unchanged in country 2.

While the model can generate a persistent, hump-shaped response of the RER, it does not reproduce the rankings of ERPT and movements in tradeable RER (based on consumer, producer,

[49] For this figure, we assume $\kappa = 0.75$, $\rho_m = 0.5$, $\beta = 0.99$, $\sigma = 1$ and $\gamma = 0$. Given that with $\sigma = 1$ and $\gamma = 0$ the price dynamics are equal for tradeables and nontradeables, the share of nontradeables in consumption, the share of distribution costs, and the elasticity of substitution between tradeable and nontradeable goods do not affect these results.

and border prices) reviewed in Findings 2 and 3, or the relative movements of the terms of trade and PPI-based RER reviewed in Finding 5. This is because relative costs (and hence the relative price of domestically produced goods) remain constant across countries.

### 7.2 Wage rigidity

A textbook treatment of this extension can be found in Galí (2008). Each household is assumed to supply a differentiated variety of labor and there is monopolistic competition among the various types of labor. The aggregate labor composite is

$$L_{i,t} = \left[ \int_0^1 L_{i,t}(h)^{\frac{\eta-1}{\eta}} dh \right]^{\frac{\eta}{\eta-1}}$$

where $\eta$ is the elasticity of substitution across labor varieties. Firm's demand for each variety is then given by:

$$L_{i,t}(h) = \left( \frac{W_{i,t}(h)}{W_{i,t}} \right)^{-\eta} L_{i,t} \tag{34}$$

$$W_{i,t} = \left[ \int_0^1 W_{i,t}(h)^{1-\eta} dh \right]^{\frac{1}{1-\eta}}$$

The staggered wage setting problem of household $h$ is to maximize

$$\mathbb{E}_t \left\{ \sum_{l=0}^{\infty} (\beta \kappa_w)^l \, U(C_{i,t+l}(h), L_{i,t+l}(h)) \right\}$$

subject to labor demand (34) and its budget constraint. Following standard steps as in Galí (2008) we have the optimal reset wage for each household (given symmetry we drop $h$) given by

$$\bar{w}_{i,t} = (1 - \beta \kappa_w) \sum_{l=0}^{\infty} (\beta \kappa_w)^l \, \mathbb{E}_t \left\{ mrs_{i,t+l} + p^c_{i,t+l} \right\} + constant$$

where $mrs$ is the log of the marginal rate of substitution between consumption and labor supply. We solve for the dynamics of the wage following similar steps as in the derivation of (28).

Figure 5 depicts impulse responses for the case when wages are rigid and prices are flexible.[50] In response to a depreciation of the currency in country 1, the wage falls in country 1 relative to country 2, and so does the price of domestically produced goods. The terms of trade depreciates and the real trade balance improves in country 1. This follows because of the expenditure switching effect as consumers in both countries increase their relative demand for country 1 output. This effect outweighs the change in imports stemming from the rise in consumption in country 1 relative to country 2. Employment increases in both countries.

[50] For this figure, we assume $\kappa = 0$, $\kappa_w = 0.75$, $\rho_m = 0.5$, $\beta = 0.99$, $\sigma = 1$, $\gamma = 0$, price elasticity (elasticity between domestic and foreign goods) $\varepsilon = 1.5$, import share in tradeables (exlusive of distribution) $s^m = 0.25$, distribution share in tradeables $s^d = 0.5$, and expenditure share of tradeables in total consumption $s^{tr} = 0.5$.

The model reproduces the rankings of ERPT and movements in tradeable RER constructed (based on consumer prices, producer prices, and border prices) reviewed in Findings 2 and 3, as well as the relative movements of the terms of trade and PPI based RER reviewed in Finding 5. Clearly, matching all the findings described in the empirical section including infrequent price adjustment in the local currency requires a combination of both price and wage rigidity.

The literature has pointed out a number of important limitations of this model in terms of its implications on the relation between exchange rates and other macro variables. First, equation (31) implies a perfect correlation between RERs and relative consumption, while in the data it is much closer to zero (see e.g. Backus and Smith (1993)) [51]. Second, the model implies a relation between exchange rates and interest rates across countries that satisfies uncovered interest parity, which does not appear to hold in the data (see e.g. Fama (1984)). Third, and more generally, this model implies a counterfactually strong relation between exchange rates and macro variables at short and medium horizons, which is referred to as the "exchange rate disconnect" puzzle (see e.g. Baxter and Stockman (1989), Obstfeld and Rogoff (2000)). The model abstracts from non-monetary shocks, real, financial, expectation and information-based, etc. that may be important drivers of nominal exchange rates. For a broad survey of the literature on exchange rate determination and fundamentals we refer the reader to the chapter by Charles Engel in this handbook and also to the book by Evans (2011). Overall, the general equilibrium literature in open economy macro has yet to deliver theoretical models that generate predictions consistent with the empirical findings while matching the exchange rate disconnect phenomenon.

# 8 Conclusion

What does the literature teach us about the positive and normative issues raised in the introduction? On the question of deviations from relative PPP the takeaway is that for retail prices this has much less to do with inefficient relative price movements of the exact same good across locations. It has more to do with the fact that a large fraction of prices are of non-tradeable goods or only locally consumed tradeable goods. At the same time for developed countries for the subset of goods that are actually traded, there is evidence that firms do price to market by charging (inefficiently) different mark-ups, despite costs being the same. It is yet to be determined how large the aggregate welfare impact of these inefficient relative price movements is given the relatively small share of the pure traded goods component in total consumption.

As for the question of ERPT and expenditure switching, once again retail prices are not very sensitive to exchange rate movements. For border prices there is higher pass-through and the fact that it takes multiple rounds of price adjustment for ERPT to attain its long-run value suggests

[51] Corsetti and Leduc (2008) show that this correlation can be matched to the data in a model with incomplete markets and a very low elasticity of substitution between home and foreign goods

an important role for real rigidities in pricing. The magnitude of ERPT also depends on whether the country's currency is used in trade transactions. Since most developing countries trade in a currency that is not their own, ERPT in these countries tends to be higher than for developed countries like the U.S. for which 90% of its imports are priced in dollars.

Given local currency price stability for retail prices the ability of flexible exchange rates to generate large expenditure switching at the consumer level is limited for small to moderate exchange rate movements. It is possibly higher for intermediate inputs at the producer level or for large devaluations that coincide with large contractions in economic activity. To provide a more definite conclusion on the extent of expenditure switching it is important to address the relationships between prices and quantities in the data.[52]

As for the debate on fixed versus floating exchange rates, the fact that firms mimic the short-run flexible price benchmark by choosing their border pricing currency optimally may reduce the welfare gap between floating exchange rates and pegs.

# 9 Appendix

**Industry and General equilibrium with nominal rigidities**

In this appendix we provide additional details on the aggregate industry model of section 6 and on the general equilibrium model of section 7. We present log-linear approximations (around the non-stochastic steady state) of the equations that determine the model dynamics. We first consider the one sector model of section 6 under the general equilibrium assumptions of section 7. Next, we consider a two-sector (tradeables and non-tradeables) version of this model that we relate to the empirical findings. Throughout this appendix we assume that countries are symmetric so that in the initial steady-state, the elasticity, the markup, and the markup elasticity are equal across countries and producers selling in each country: $\varepsilon_{in} = \varepsilon$, $\mu_{in} = \mu$, and $\Gamma_{in} = \Gamma$.

**One sector model**

We first embed the one sector model of section 6 in general equilibrium. For a given path of wages and exchange rates, the dynamics of the reset price for producers from each country is given, up to a first-order approximation, by expression (16), which can be re-written as

$$\overline{p}_{in,t} = (1-\beta\kappa)\frac{(w_{i,t}+e_{in,t}+\Gamma p_{n,t}+const_{in})}{1+\Gamma}+\beta\kappa\mathbb{E}_t\overline{p}_{in,t+1}. \quad (35)$$

Aggregate source-country specific prices (or import price indices $ipi_{in,t}$) follow the law-of-motion

$$p_{in,t} = \kappa p_{in,t-1} + (1-\kappa)\overline{p}_{in,t} \quad (36)$$

[52]Cravino (2012) uses detailed Chilean exports to measure the response of prices and quantities to exchange rate movements for goods priced in different currencies and sold in a given destination. Even though exchange rate movements induce large changes in relative prices between goods priced in different currencies, expenditure switching is on average quite limited.

The aggregate producer price with two-symmetric countries $n$ is

$$p_{n,t} = s_m p_{in,t} + (1 - s_m) p_{nn,t} + constant_n. \tag{37}$$

Expression (28) is obtained as follows. Combining (35) and (37), we have

$$\overline{p}_{n,t} = \frac{(1-\beta\kappa)}{1+\Gamma}\left(\hat{p}_{n,t} + \Gamma p_{n,t}\right) + \beta\kappa \mathbb{E}_t \overline{p}_{n,t+1}, \tag{38}$$

where

$$\hat{p}_{n,t} = s^m e_{in,t} + (1 - s^m)\, w_{n,t} + s^m w_{i,t} + constant \text{ , for } i \neq n.$$

Using equation (36),

$$\begin{aligned}
p_{n,t} - p_{n,t-1} &= (1-\kappa)\left(\bar{p}_{n,t} - p_{n,t-1}\right) \\
&= (1-\kappa)\left(\frac{(1-\beta\kappa)}{1+\Gamma}\left(\hat{p}_{n,t} + \Gamma p_{n,t}\right) + \beta\kappa\left(\mathbb{E}_t \overline{p}_{n,t+1} - p_{n,t}\right) + \beta\kappa p_{n,t} - p_{n,t-1}\right) \\
&= (1-\kappa)\left(\frac{(1-\beta\kappa)}{1+\Gamma}\left(\hat{p}_{n,t} + \Gamma p_{n,t}\right) + \beta\kappa\left(\frac{\mathbb{E}_t p_{n,t+1} - \kappa p_{n,t}}{1-\kappa} - p_{n,t}\right) + \beta\kappa p_{n,t} - p_{n,t-1}\right) \\
&= (1-\kappa)\left(\frac{(1-\beta\kappa)}{1+\Gamma}\left(\hat{p}_{n,t} - p_{n,t}\right) + p_{n,t} - p_{n,t-1}\right) + \beta\kappa\left(\mathbb{E}_t p_{n,t+1} - p_{n,t}\right)
\end{aligned}$$

and combining terms we obtain expression (28):

$$\Delta p_{n,t} - \beta \mathbb{E}_t \Delta p_{n,t+1} = \frac{(1-\kappa)(1-\beta\kappa)}{\kappa(1+\Gamma)}\left(\hat{p}_{n,t} - p_{n,t}\right). \tag{39}$$

Consumption of any good (domestic or foreign) requires distribution costs in terms of the final good. At this point we only assume that consumption and distribution costs are combined through some constant returns to scale technology. Under these assumptions, the price and quantity of final consumption are proportional to the price and quantity of production of the final good,

$$\begin{aligned}
c_{n,t} &= q_{n,t} + constant \\
p^c_{n,t} &= p_{n,t} + constant
\end{aligned} \tag{40}$$

Aggregate consumption, given money supply and the aggregate price level, is determined from the cash in advance constraint (33). Given aggregate prices and consumption, aggregate quantities of country $i$ goods sold in country $n$ are given, to a first-order approximation, by

$$q_{in,t} = -\varepsilon\left(p_{in,t} - p_{n,t}\right) + q_{n,t}. \tag{41}$$

Labor-market clearing requires that labor used for domestic production and for exporting must equal total labor $l_{n,t}$. The condition for labor market clearing in country $n$ can be expressed, up to a first-order approximation (ignoring higher-order productivity losses from price dispersion), as

$$l_{n,t} = (1 - s^m)\, q_{nn,t} + s^m q_{ni,t} + constant. \tag{42}$$

To close the model, wages in each country must be consistent with labor supply (30) and the nominal exchange rate with the risk sharing condition (31).[53]

This finishes the description of the equations that are required to solve for all endogenous variables in the model. Equations (35) and (36) conform a second-order difference equation that must be solved using standard methods.

Note that in this one-sector general equilibrium model we have not specified the details that give rise to variable markups. Given other parameters (including the elasticity $\varepsilon$), variable markups only matter through the markup elasticity $\Gamma$ in equation (35).

**Proof of Proposition 8:** The proof here follows Carvalho and Nechio (2011) closely. When $\sigma = 1$ and $\gamma = 0$ it follows from equations (30)-(33) that $w_{i,t}+e_{in,t} = w_{n,t}$ and $w_{i,t} = m_{i,t}$ in both countries. The assumption that money growth follows an AR(1) process implies $\mathbb{E}_t \Delta m_{i,t+\ell} = \rho_e^{\ell} \Delta m_{i,t}$. Using these results, equation (16) can be written as

$$\bar{p}_{in,t} = \bar{p}_{nn,t} = \bar{p}_{n,t} = m_{n,t} + \frac{\rho_m \beta \kappa}{1-\rho_m \beta \kappa}(m_{n,t} - m_{n,t-1}).$$

The aggregate price index in country $n$ is

$$\begin{aligned} p_{n,t} &= \kappa p_{n,t-1} + (1-\kappa)\bar{p}_{n,t} \\ &= \kappa p_{n,t-1} + (1-\kappa)\left( m_{n,t} + \frac{\rho_m \beta \kappa}{1-\rho_m \beta \kappa}(m_{n,t} - m_{n,t-1}) \right). \end{aligned}$$

The real exchange rate can be expressed, using the equivalence between producer and consumer prices in equation (40), as

$$\begin{aligned} rer_{in,t} &= p^c_{i,t} + e_{in,t} - p^c_{n,t} \\ &= \kappa \cdot rer_{in,t-1} + \left( \kappa - (1-\kappa)\frac{\rho_m \beta \kappa}{1-\rho_m \beta \kappa} \right) \Delta e_{in,t} \end{aligned}$$

Given that $e_{in,t} = m_{n,t} - m_{i,t}$, we have $\Delta e_{in,t} = \rho_m \Delta e_{in,t-1} + u_{in,t}$ where $u_{in,t} \equiv \sigma_{\epsilon_m}(\epsilon_{n,t} - \epsilon_{i,t})$. Using the lag operator notation $\Delta e_{in,t} = \frac{u_{in,t}}{1-\rho_m L}$ and $rer_{in,t} - \kappa rer_{in,t-1} = (1-\kappa L) rer_{in,t}$ and substituting into the previous equation we arrive at the main expression in the proposition.

### Two sector model

We introduce a non-tradeable final good because, as discussed under empirical finding 2, movements in the price of traded goods (at border prices) relative to nontraded goods account for a non-trivial share of overal RER movements. Final consumption in country $n$ is a Cobb-Douglass composite of consumption of the tradeable and non-tradeable final good,

$$c_{n,t} = s^{tr} c^{tr}_{n,t} + \left(1 - s^{tr}\right) c^{ntr}_{n,t} \ ,$$

[53] Assuming financial autarky (trade balance equal to zero) instead of complete asset markets, expression (31) is substituted by $e_{in,t} + p_{in,t} + q_{in,t} = p_{ni,t} + q_{ni,t}$.

The final good price is a composite of the retail tradeable price index and the non-tradeable price index:

$$p_{n,t}^{c} = s^{tr} p_{n,t}^{r} + \left(1 - s^{tr}\right) p_{n,t}^{ntr} + constant.$$

We assume that each unit of final tradeable consumption requires a fixed number of units of distribution costs in the form of the final non-traded good. The retail tradeable price index is, up to a first order approximation

$$p_{n,t}^{r} = \left(1 - s^{d}\right) p_{n,t}^{tr} + s^{d} p_{n,t}^{ntr} + constant.$$

Given prices and consumption, tradeable and non-tradeable consumption are given by

$$\begin{aligned} c_{n,t}^{ntr} &= p_{n,t}^{c} + c_{n,t} - p_{n,t}^{ntr} + constant \\ c_{n,t}^{tr} &= p_{n,t}^{c} + c_{n,t} - p_{n,t}^{r} + constant \end{aligned}$$

With two sectors, we have a reset price and an aggregate price for each sector. That is, equations (35), (36), (37) apply separately for tradeables and nontradeables, where $s^{m} = 0$ for non-tradeables. Note that, in equation (35) the term $\Gamma p_{n,t}$ indicates that markups depend on a firm's price relative to the aggregate price index in its sector. This formulation depends on the particular specification of variable markups. It is consistent with non-CES demand such as the Kimball aggregator described in section 4.1. On the other hand, in the model of variable markups with distribution costs in section 4.3, the price index multiplying $\Gamma$ in expression (35) would be $p_{n,t}^{ntr}$ if distribution costs use non-tradeable goods. Hence, in using equation (35) with the term $\Gamma p_{n,t}$, we are assuming that variable markups result from a non-CES aggregator as in section 4.1, and that distribution costs do not affect markups because they apply to the final tradeable good.

Labor-market clearing requires that labor used for domestic production of tradeable goods, exports, and production of nontradeable goods (including nontradeable consumption and distribution costs which are proportional to tradeable consumption) must equal total labor $l_{n,t}$. This condition can be expressed as:

$$l_{n,t} = s^{tr}(1 - s^{d})\left[(1 - s^{m})\, q_{nn,t} + s^{m} q_{ni,t}\right] + s^{tr} s^{d} c_{n,t}^{tr} + \left(1 - s^{tr}\right) c_{n,t}^{ntr} + constant,$$

where $q_{in,t}$ denotes the aggregate quantity of country $i$ tradeable goods sold in country $n$, given by

$$q_{in} = -\varepsilon\left(p_{in,t}^{tr} - p_{n,t}^{tr}\right) + c_{n}^{tr} + constant.$$

Other market clearing conditions that determine wages and exchange rates are the same as in the one-sector model.

Recall that if $\sigma = 1$ and $\gamma = 0$ (as in proposition 9), relative wages between countries are constant. In this case it is straightforward to show that in response to a monetary shock as the one considered in section 7, the aggregate price of tradeable and non-tradeable goods change by the same amount. This explains the price patterns in Figure 4: the rise in prices is equal for tradeable prices at the border $p^{tr}_{in,t}$, tradeable prices at the consumer level $p^{r}_{in,t}$, as well as the overall consumer price $p^{c}_{n,t}$.

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| Real Vs. Nominal ER | U.S. | | Japan | | Italy | | U.K. | | France | | Germany | | Canada | | Switzerland | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | stdev | correl | stdev | correl | stdev | correl | stdev | correl | stdev | correl | stdev | correl | stdev | correl | stdev | correl |
| Differences | 0.92 | 0.97 | 1.03 | 0.99 | 0.90 | 0.82 | 1.04 | 0.95 | 0.87 | 0.91 | 0.94 | 0.90 | 1.00 | 0.97 | 0.95 | 0.95 |
| HP-filtered | 0.92 | 0.97 | 1.03 | 0.99 | 1.02 | 0.97 | 1.07 | 0.97 | 0.96 | 0.98 | 0.99 | 0.96 | 1.01 | 0.97 | 0.99 | 0.99 |

Table 1: Relation between nominal ER and CPI based RER (1975-2011)

| | U.S. | | Japan | | Italy | | U.K. | | France | | Germany | | Canada | | Switzerland | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Half-Life | Up-Life | Half-Life | Up-Life | Half-Life | Up-Life | Half-Life | Up-Life | Half-Life | Up-Life | Half-Life | Up-Life | Half-Life | Up-Life | Half-Life | Up-Life |
| **Median** | 6.0 | 2.4 | 3.7 | 1.6 | 5.60 | 2.0 | 2.90 | 1.3 | 3.20 | 1.0 | 3.7 | 2.1 | 8.7 | 3.4 | 1.6 | 0.9 |
| **Confidence** | 2.2 | 0.5 | 1.8 | 0.4 | 2.0 | 0.7 | 1.7 | 0.3 | 1.4 | 0.3 | 2.0 | 0.9 | 2.4 | 1.0 | 1.1 | 0.3 |
| **Interval (90 %)** | Inf | Inf | 24.9 | 6.5 | Inf | Inf | 10.5 | 3.0 | Inf | Inf | 13.4 | 5.2 | Inf | Inf | 2.6 | 1.3 |

Table 2: Persistence of RER deviations (1975-2011)

| | | U.S. | | Japan | | Italy | | U.K. | | France | | Germany | | Canada | | Switzerland | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Relative to Overall CPI-based RER | | **stdev** | **correl** | **stdev** | **correl** | **stdev** | **correl** | **stdev** | **correl** | **stdev** | **correl** | **stdev** | **correl** | **stdev** | **correl** | **stdev** | **correl** |
| Tradable CPI | Annual Diff. | 0.96 | 0.99 | 0.98 | 0.99 | 1.08 | 0.99 | 0.99 | 0.99 | 0.94 | 0.94 | 1.01 | 1.00 | 0.95 | 0.97 | 0.94 | 0.94 |
| | HP-filtered quart. | 1.01 | 0.99 | 0.98 | 1.00 | 0.98 | 0.94 | 0.99 | 0.98 | 0.93 | 0.95 | 0.98 | 0.98 | 0.95 | 0.97 | 0.94 | 0.93 |
| Manuf PPI | Annual Diff. | 0.93 | 0.97 | 0.95 | 0.99 | 0.91 | 0.98 | 0.88 | 0.97 | 1.05 | 0.89 | 1.09 | 0.96 | 0.77 | 0.91 | 1.01 | 0.97 |
| | HP-filtered quart. | 0.98 | 0.97 | 0.95 | 0.99 | 0.95 | 0.98 | 0.85 | 0.97 | 0.96 | 0.87 | 1.08 | 0.96 | 0.80 | 0.90 | 1.02 | 0.97 |
| Manuf IPI | Annual Diff. | 0.51 | 0.58 | 0.33 | 0.56 | 0.69 | 0.55 | 0.52 | 0.65 | 0.98 | 0.83 | 0.75 | 0.82 | 0.74 | 0.23 | 0.85 | 0.91 |
| | HP-filtered quart. | 0.48 | 0.51 | 0.33 | 0.49 | 0.71 | 0.55 | 0.47 | 0.60 | 0.93 | 0.85 | 0.76 | 0.82 | 0.83 | 0.29 | 0.85 | 0.91 |
| Contribution of Tradeable RER | | **lower** | **upper** | **lower** | **upper** | **lower** | **upper** | **lower** | **upper** | **lower** | **upper** | **lower** | **upper** | **lower** | **upper** | **lower** | **upper** |
| Tradable CPI | Annual Diff. | 0.92 | 0.97 | 0.97 | 0.99 | 0.98 | 1.16 | 0.98 | 0.99 | 0.89 | 0.89 | 0.99 | 1.01 | 0.91 | 0.94 | 0.88 | 0.89 |
| Manuf PPI | Annual Diff. | 0.86 | 0.94 | 0.91 | 0.98 | 0.82 | 0.95 | 0.77 | 0.94 | 0.78 | 1.11 | 0.90 | 1.19 | 0.60 | 0.81 | 0.93 | 1.02 |
| Manuf IPI | Annual Diff. | 0.26 | 0.33 | 0.11 | 0.26 | 0.28 | 0.48 | 0.27 | 0.40 | 0.67 | 0.95 | 0.57 | 0.67 | -0.21 | 0.55 | 0.72 | 0.82 |

Note:See appendix for series description, Coverage is as follows. US: CPIT and PPI (1975-2011), IPI (1985-2011) , Japan: CPIT, PPI, IPI (1975-2011), Italy: CPIT (1996-2011) , PPI (1981-2011), IPI (1975-2011), UK: CPIT (1988-2011), PPI and IPI (1975-2011), France: CPIT (1975-2011), PPI (1980-2011), IPI (1981-2011) , Germany: CPIT (1996-2011), PPI and IPI (1975-2011) , Canada: CPIT, PPI, and IPI (1975-2011) , Switzerland: CPIT and PPI (1975-2011), IPI (1990-2011)

Table 3: Relation between tradeable RER and overall CPI based RER (1975 (or higher) - 2011)

| BIS Narrow NER | | U.S. | | Japan | | Italy | | U.K. | | France | | Germany | | Canada | | Switzerland | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **ERPT** | **SE** | **ERPT** | **SE** | **ERPT** | **SE** | **ERPT** | **SE** | **ERPT** | **SE** | **ERPT** | **SE** | **ERPT** | **SE** | **ERPT** | **SE** |
| **Import Price Index** | | | | | | | | | | | | | | | | | |
| Dynamic Lag | | | | | | | | | | | | | | | | | |
| Short run | Narrow NER | 0.20 | 0.05 | 0.75 | 0.06 | 0.51 | 0.06 | 0.38 | 0.02 | 0.40 | 0.09 | 0.41 | 0.05 | 0.74 | 0.05 | 0.13 | 0.03 |
| | Broad NER | 0.20 | 0.04 | | | | | | | | | | | | | | |
| Long Run | Narrow NER | 0.51 | 0.08 | 0.69 | 0.10 | 0.53 | 0.18 | 0.85 | 0.07 | 0.97 | 0.13 | 0.48 | 0.11 | 1.04 | 0.07 | 0.47 | 0.09 |
| | Broad NER | 0.27 | 0.11 | | | | | | | | | | | | | | |
| **Tradeable CPI** | | | | | | | | | | | | | | | | | |
| Dynamic Lag | | | | | | | | | | | | | | | | | |
| Short run | Narrow NER | 0.07 | 0.02 | -0.03 | 0.01 | -0.03 | 0.19 | 0.05 | 0.02 | 0.04 | 0.05 | -0.01 | 0.04 | 0.03 | 0.05 | 0.11 | 0.04 |
| | Broad NER | 0.09 | 0.03 | | | | | | | | | | | | | | |
| Long Run | Narrow NER | 0.17 | 0.04 | 0.11 | 0.03 | 0.01 | 0.11 | 0.14 | 0.07 | 0.36 | 0.11 | -0.01 | 0.05 | 0.29 | 0.13 | 0.20 | 0.11 |
| | Broad NER | 0.13 | 0.07 | | | | | | | | | | | | | | |

Note: Standard errors are calculated using the Newey-West (1987) HAC estimator with a bandwidth of 8. See appendix for series description, Coverage is: US (broad+narrow): CPIT (1975-2011), IPI (1985-2011), Japan: CPIT, IPI (1975-2011), Italy: CPIT (1996-2011), IPI (1975-2011), UK: CPIT (1988-2011), IPI (1975-2011), France: CPIT (1975-2011), IPI (1981-2011), Germany: CPIT (1996-2011), IPI (1975-2011), Canada: CPIT, IPI (1975-2011), Switz.: CPIT (1975-2011), IPI (1990-2011)

Table 4: Short-run and Long-run ERPT using aggregate indices

| | Cumulative percentage change since pre-devaluation month | | | | | |
|---|---|---|---|---|---|---|
| | **Argentina - Dec. 2001** | | **Brazil - Dec. 1998** | | **Korea - Sept. 1997** | |
| | 12 months | 24 months | 12 months | 24 months | 12 months | 24 months |
| US Dollar NER | 243.7 | 192.8 | 52.9 | 62.8 | 50.9 | 31.8 |
| Trade-weighted NER | 202.2 | 195.5 | 48.6 | 50.7 | 45.3 | 36.1 |
| Import prices (at the dock) | 204.4 | 169.9 | 53.9 | 64.1 | 24.0 | 21.8 |
| Consumer price index | 41.0 | 46.1 | 8.9 | 15.4 | 6.9 | 7.7 |
| Nontradable prices | 13.8 | 20.1 | 5.2 | 10.2 | 5.2 | 4.9 |
| Retail price of tradables | 67.4 | 71.3 | 12.0 | 18.3 | 8.6 | 10.7 |
| Import prices | 129.8 | | | | | |
| | **Mexico - Dec. 1994** | | **Thailand - June 1997** | | | |
| | 12 months | 24 months | 12 months | 24 months | | |
| US Dollar NER | 122.5 | 130.0 | 64.3 | 43.0 | | |
| Trade-weighted NER | 123.3 | 129.1 | 43.1 | 33.2 | | |
| Import prices (at the dock) | 131.6 | 138.5 | 49.8 | 22.6 | | |
| Consumer price index | 48.5 | 64.0 | 10.6 | 9.3 | | |
| Nontradable prices | 37.2 | 53.6 | | | | |
| Retail price of tradables | 57.8 | 105.6 | | | | |
| | **Finland - August 1992** | | **Italy - August 1992** | | **Sweden - Sept. 1992** | |
| | 12 months | 24 months | 12 months | 24 months | 12 months | 24 months |
| US Dollar NER | 46.6 | 29.2 | 45.6 | 43.5 | 49.5 | 40.5 |
| Trade-weighted NER | 19.7 | 11.4 | 23.5 | 30.2 | 32.2 | 30.3 |
| Import prices (at the dock) | 13.8 | 13.2 | 13.4 | 19.0 | 17.7 | 23.0 |
| Consumer price index | 2.1 | 4.0 | 4.5 | 8.5 | 4.2 | 6.9 |
| Nontradable prices | 1.1 | 3.0 | 4.4 | 8.1 | 4.4 | 7.6 |
| Retail price of tradables | 5.0 | 7.3 | 5.3 | 9.8 | 6.4 | 8.9 |
| | **UK - August 1992** | | **Iceland - Nov. 2007** | | | |
| | 12 months | 24 months | 12 months | 24 months | | |
| US Dollar NER | 30.0 | 25.7 | 122.6 | 103.6 | | |
| Trade-weighted NER | 12.0 | 14.4 | 94.4 | 100.3 | | |
| Import prices (at the dock) | 13.7 | 20.3 | | | | |
| Consumer price index | 1.7 | 4.2 | 17.2 | 27.3 | | |
| Nontradable prices | 4.9 | 8.3 | 11.5 | 20.3 | | |
| Retail price of tradables | 1.8 | 3.1 | 20.9 | 38.8 | | |
| Import prices | | | 27.0 | 49.0 | | |

For data description see Burstein, Eichenbaum, and Rebelo (2005), Iceland data source: Statistics Iceland

Table 5: Prices and Exchange Rates in Large Devaluations

| | MRPT | | LLPT | | MRPT | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Dollar | | Non-dollar | |
| | ERPT | SE | ERPT | SE | ERPT | SE | ERPT | SE |
| All | 0.20 | 0.01 | 0.28 | 0.04 | 0.16 | 0.01 | 0.80 | 0.04 |
| Japan | 0.24 | 0.02 | 0.32 | 0.03 | 0.17 | 0.02 | 0.84 | 0.06 |
| France | 0.24 | 0.05 | 0.36 | 0.11 | 0.18 | 0.06 | 0.81 | 0.10 |
| Germany | 0.41 | 0.04 | 0.51 | 0.08 | 0.22 | 0.04 | 0.84 | 0.08 |
| Canada | 0.27 | 0.07 | 0.51 | 0.09 | 0.25 | 0.07 | 0.60 | 0.45 |

Table 6: ERPT into border prices using micro data (1994-2009): Medium-run PT (MRPT) and Life-long PT (LLPT)

| | | **U.S.** | | **Japan** | | **Italy** | | **U.K.** | | **France** | | **Germany** | | **Canada** | | **Switzerland** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Relative to manuf PPI-based RER | | **stdev** | **correl** | **stdev** | **correl** | **stdev** | **correl** | **stdev** | **correl** | **stdev** | **correl** | **stdev** | **correl** | **stdev** | **correl** | **stdev** | **correl** |
| IPI - EPI | Annual Differences | 0.40 | 0.53 | 0.51 | 0.65 | 0.58 | 0.47 | 0.36 | 0.56 | 0.87 | 0.19 | 0.60 | 0.74 | 0.55 | 0.61 | | |
| | HP-filtered quart. | 0.32 | 0.57 | 0.51 | 0.72 | 0.58 | 0.52 | 0.39 | 0.52 | 0.89 | 0.20 | 0.59 | 0.78 | 0.55 | 0.56 | | |
| EPI - PPI | Annual Differences | 0.32 | 0.44 | 0.48 | 0.82 | 0.50 | 0.66 | 0.55 | 0.61 | 1.09 | 0.17 | 0.16 | 0.00 | 0.89 | 0.69 | | |
| | HP-filtered quart. | 0.30 | 0.43 | 0.45 | 0.83 | 0.58 | 0.52 | 0.57 | 0.65 | 1.07 | 0.16 | 0.16 | -0.13 | 0.86 | 0.69 | | |
| foreign PPI + e - IPI | Annual Differences | 0.81 | 0.80 | 0.44 | 0.63 | 0.65 | 0.61 | 0.62 | 0.75 | 0.80 | 0.81 | 0.68 | 0.82 | 0.74 | 0.07 | 0.94 | 0.84 |
| | HP-filtered quart. | 0.73 | 0.73 | 0.43 | 0.61 | 0.64 | 0.62 | 0.57 | 0.74 | 0.83 | 0.77 | 0.67 | 0.84 | 0.72 | 0.14 | 0.92 | 0.86 |

Note: See appendix for series description. Coverage is as follows. US: 1985-2011 , Japan: 1975-2011, Italy: 1981-2011, UK: 1975-2011, France: 1981 - 2011, Germany: 1975-2011, Canada: 1975-2011, Switzerland: 1990-2011

Table 7: Terms of Trade and PPI based RER

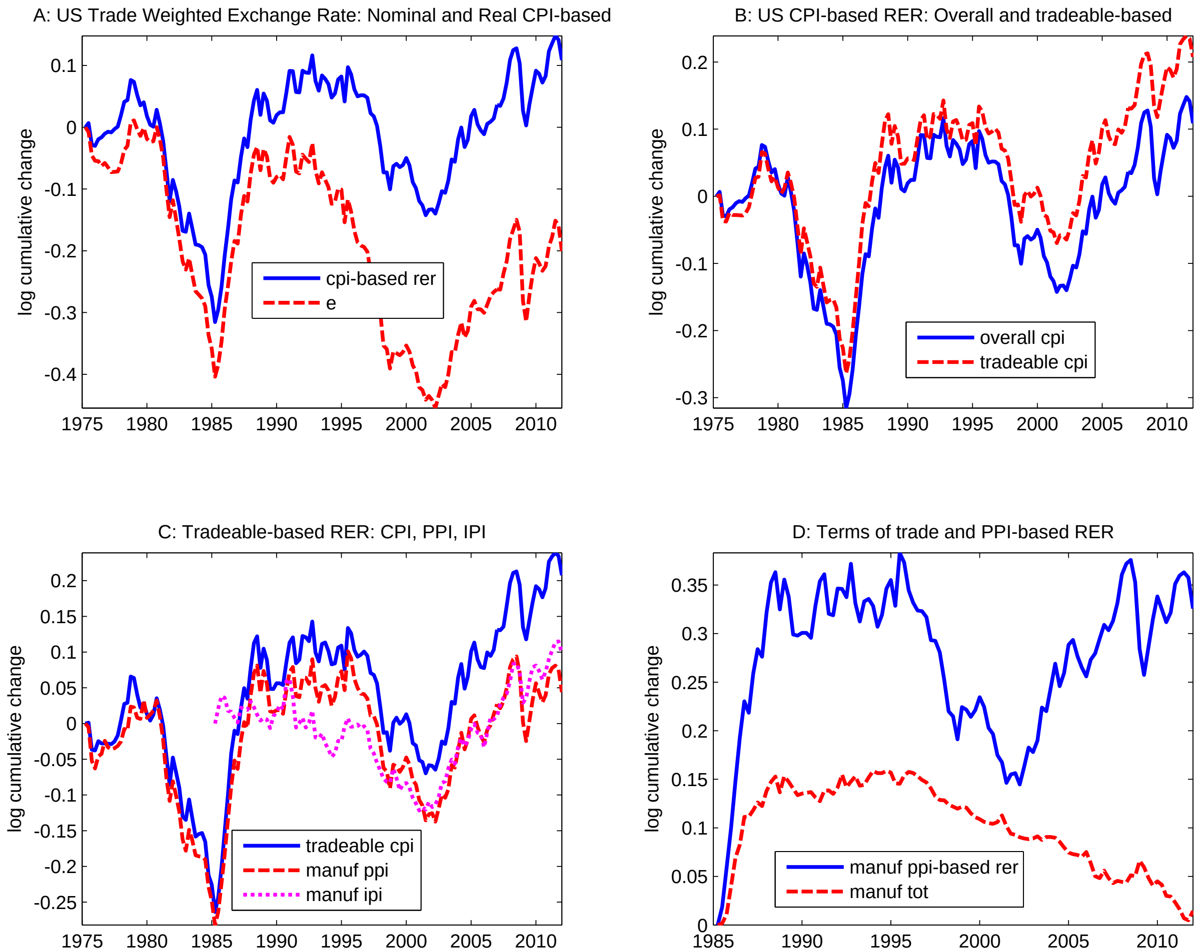


Figure 1: Relation between CPI based, PPI based and Terms of Trade based RER and NER

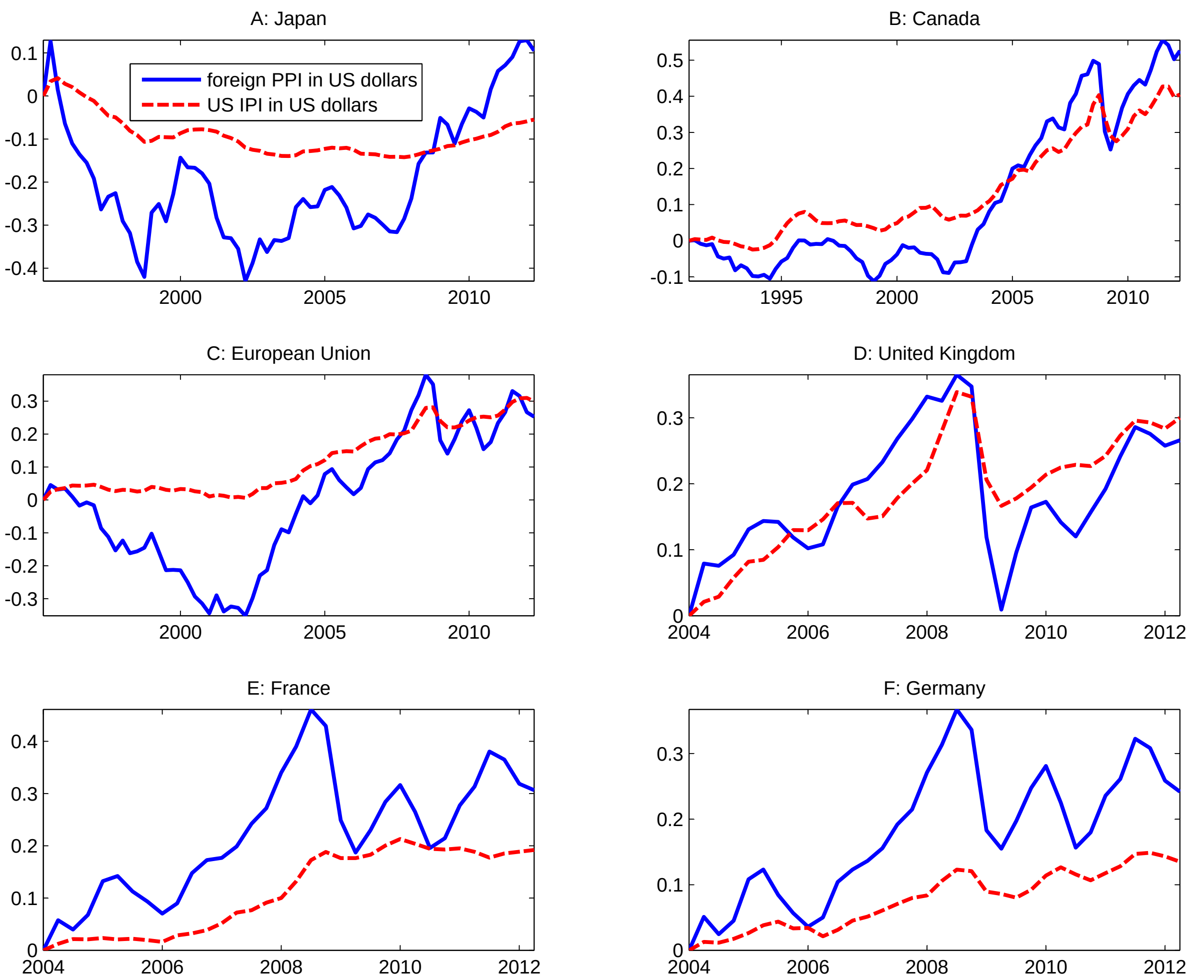


Figure 2: Foreign PPI versus IPI

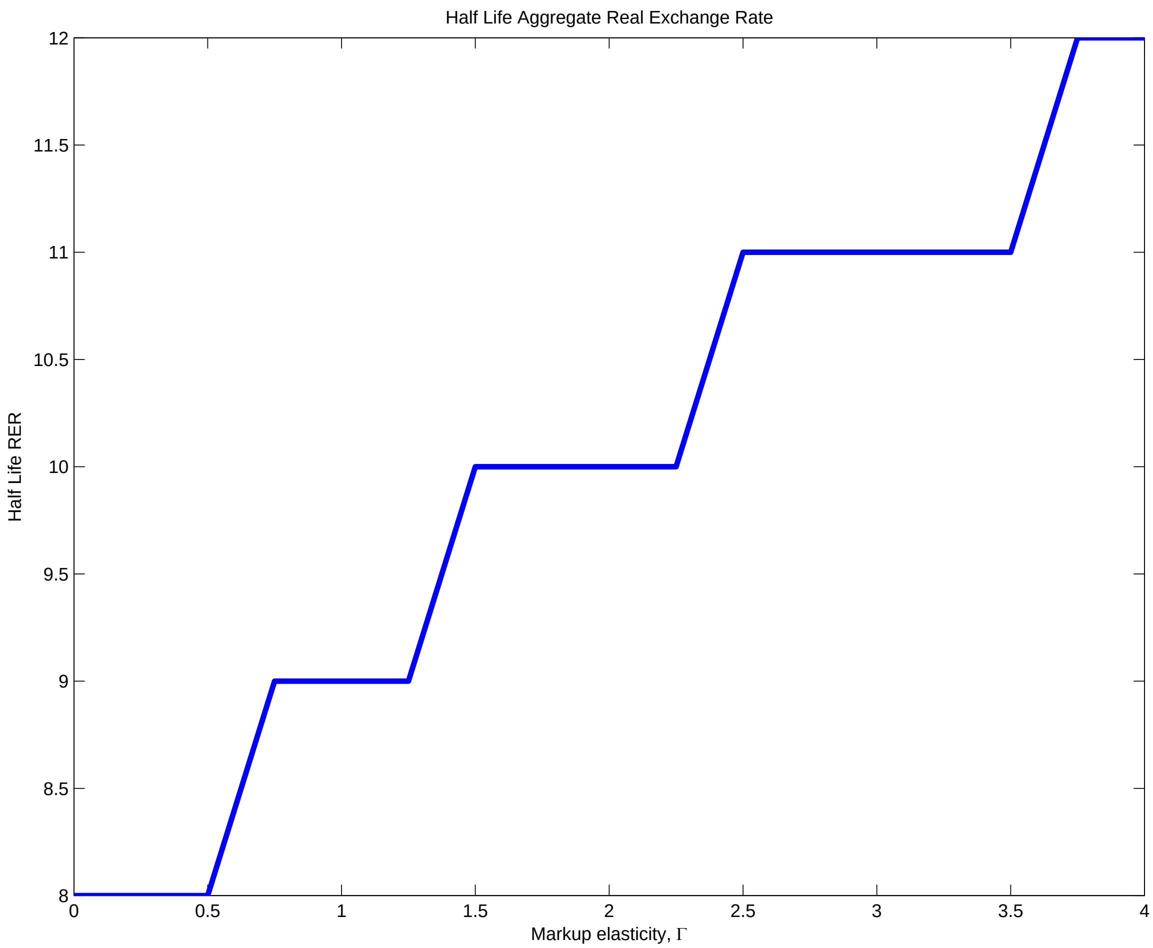


Figure 3: Half lives (in quarters) of the RER as a function of $\Gamma$

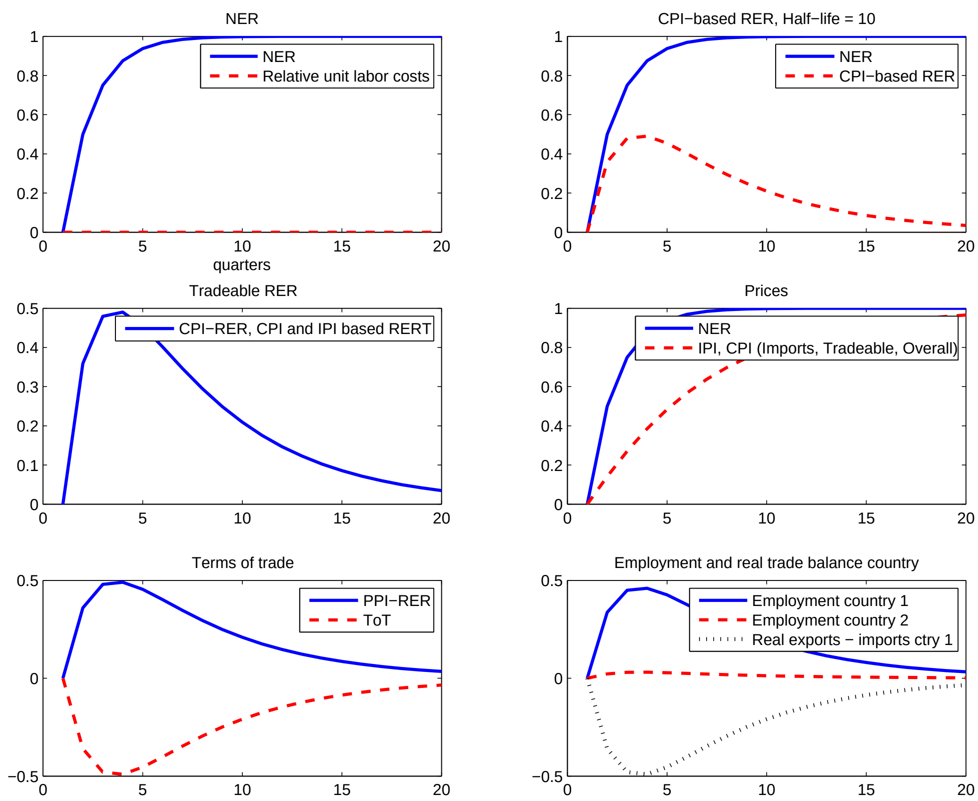


Figure 4: Impulse Responses to money growth shock: Sticky local currency prices, flexible wages

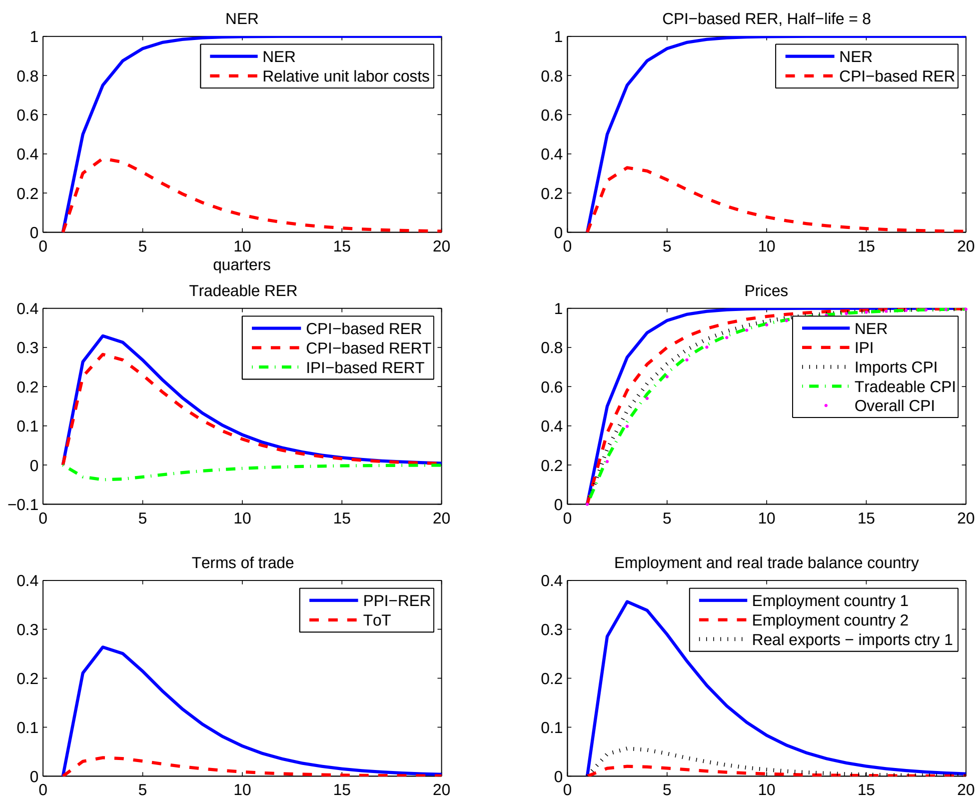


Figure 5: Impulse Responses to money growth shock: Sticky wages, flexible prices