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ABSTRACT

We measure the proportion of real exchange rate movements accounted for by cross-country movements in relative reset prices (prices that changed since the previous period) using CPI microdata for five countries. Relative reset prices account for almost the totality of the real exchange rate movements. This is at odds with the predictions of most workhorse sticky price models used to generate volatile and persistent real exchange rates. In these models relative reset prices are sluggish because relative wages are either sluggish or mean revert quickly. We show that models where movements in relative wages are persistent and track the nominal exchange rate do replicate the empirical properties of both the real exchange rate and of relative reset prices.

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1 Introduction

Movements in real exchange rates –nominal exchange rates adjusted for relative inflation– are large, persistent, and closely track movements in nominal rates, while cross-country differences in inflation rates are small and stable. A classic explanation for these observations is that prices are sticky and thus respond sluggishly to shocks affecting the nominal exchange rate. Since Chari et al. (2002), an extensive literature has evaluated this explanation quantitatively using Sticky Price Open Economy (SPOE) models. Under some extensions, these models have been successful in replicating the properties of the real exchange rate observed in the data.

This paper evaluates this explanation using a new real exchange rate decomposition. In particular, we define the (log) real exchange rate between countries i and n as $rer_{in,t} \equiv p_{i,t} + e_{in,t} - p_{n,t}$, and decompose it into:

$$rer_{in,t} = \underbrace{\bar{p}_{i,t} + e_{in,t} - \bar{p}_{n,t}}_{\equiv \overline{rer}_{in,t}} + \underbrace{[p_{i,t} - \bar{p}_{i,t}] - [p_{n,t} - \bar{p}_{n,t}]}_{\equiv rer_{in,t} - \overline{rer}_{in,t}}. \tag{1}$$

Here $p_{\cdot,t}$ and $e_{in,t}$ are the aggregate price indexes and the nominal exchange rate, and $\bar{p}_{\cdot,t}$ are price indexes for the subsets of goods that adjusted prices between $t-1$ and t.[1] The first term in this decomposition is what we label as the *'reset exchange rate'*, $\overline{rer}_{in,t}$. It measures the cross-country relative price, in a common currency, of the subset of goods that adjusted between $t-1$ and t. The second term captures cross-country differences in reset prices relative to aggregate prices. The magnitude of these two terms informs whether sticky prices are an important factor dampening the adjustment of prices to shocks affecting the nominal exchange rate. If they are not, the distinction between reset and non-reset prices would be irrelevant, and the first term should account for most of the real exchange rate movements.[2]

We evaluate this central prediction of SPOE models using the microdata that underlies the construction of the CPIs in Austria, Chile, Finland, Mexico and the UK. These data contain monthly price quotes for uniquely defined products, sampled in specific outlets, which can be traced through time. The combined dataset contains over 43 million monthly price quotes for the 2006-2015 period. To our knowledge, this is the first study combining CPI microdata from multiple countries to study the behavior of real exchange rates. An advantage of these data is that they cover almost the entire basket of

[1] The real exchange rate in equation (1) is thus an index that measures cumulative changes in relative price levels across countries from a base year.

[2] Appendix E.3 discusses the alternative decomposition $rer_{in,t} = [\bar{p}_{i,t} - \bar{p}_{n,t}] + [rer_{in,t} + \bar{p}_{n,t} - \bar{p}_{i,t}]$.

consumption goods and services.[3] This is important for the study of price rigidities, as the frequency of price changes varies significantly across different types of consumption goods.[4] In addition, the data span a long time period, which is important for studying the persistence of the real exchange rate.

We show that real exchange rate movements in the data are driven almost exclusively by movements in the reset exchange rate. We compute changes in the real and the reset exchange rates at monthly, quarterly, semiannual and annual frequencies, and show that for all our country-pairs and frequencies, the real and the reset exchange rates move one for one with each other. This is despite the fact that reset prices are substantially more volatile than average prices. The reason for this comovement is that the correlation between relative reset inflation and changes in the nominal exchange rates is too small to offset movements in the nominal rate. We show that we obtain similar results from our decomposition when we focus on subsets of goods that are either tradable or non-tradable, though reset exchange rates are somewhat less volatile for tradable goods.

We then apply our decomposition to a wide class of models commonly used in the literature to study deviations from relative PPP. These models feature Calvo-style nominal rigidities based on local currency pricing. We first analyze models where cross-country relative wages expressed in a common currency are sluggish in equilibrium.[5] This is a common feature of models with complete markets and flexible wages, such as those in Chari et al. (2002), Bergin and Feenstra (2001), Benigno (2004), Bouakez (2005), Steinsson (2008), Carvalho and Nechio (2011), and Engel (2016). In this class of models, the stochastic processes of the real and reset exchange rates depend on parameters governing: (i) the frequency of price changes, (ii) the persistence of the nominal exchange rate, and (iii) the degree of real rigidities in price setting. While the models can generate large and persistent real exchange rates movements, only a fraction of these movements arises from movements in the reset exchange rate. Intuitively, reset prices largely depend on wages, so models with sluggish relative wages cannot generate large movements in reset exchange rates. We show that this central prediction holds in models with a large degree of real rigidities, and to extensions that incorporate multiple sectors as in Carvalho and Nechio (2011). We conclude that SPOE models with sluggish relative wages are inconsistent with the observed real exchange rate decomposition.

[3]Changes in final prices may not be a good reflection of changes in producer prices in the presence of variable retail markups. Gopinath et al. (2011) show that differences in retail markups are not important in generating real exchange rate movements.

[4]See Nakamura and Steinsson (2010) and Carvalho and Nechio (2011).

[5]Throughout the paper, we refer to relative wages expressed in a common currency simply as 'relative wages'. Relative wages are sluggish if nominal wages move to offset movements in the nominal exchange rate. In contrast, relative wages move with the nominal exchange rate when nominal wages are sluggish.

We then evaluate models where relative wages track the nominal exchange rate. We focus on two types of models that have this property. First, we introduce nominal wage rigidities into the complete-markets SPOE model. We show that even if relative wages move almost one to one with the nominal exchange rate due to the wage rigidities, the reset exchange rate does not. This is because the reset exchange rate depends on the discounted sum of current and future relative wages. Since relative wages in models with nominal wage rigidities mean revert quickly following a shock, the reset exchange rate behaves much like in models with flexible wages.

Finally, we evaluate a model where nominal wages are 'disconnected' from nominal exchange rates, so that movements in relative wages are persistent and track the nominal rate. Devereux and Engel (2002) showed that a SPOE model with incomplete markets, deviations from UIP, and small wealth effects from changes in nominal exchange rate can generate large exchange rate volatility that is disconnected from the rest of the economy. Jeanne and Rose (2002) and Gabaix and Maggiori (2015) provide micro-founded models where the UIP fails to hold. More recently, Itskhoki and Mukhin (2017) showed that incorporating UIP shocks along with mechanisms that mute the transmission of exchange rate movements to prices in a DSGE model can help resolve many of the puzzles associated with the exchange rate disconnect.[6] We show that such models are closer to replicating our empirical decomposition of the real exchange rate than models featuring complete markets. In these models, shocks affecting the nominal exchange rate do not directly affect nominal wages, and thus can generate movements in relative wages that are very persistent. In this case, the reset exchange rate does move with the nominal exchange rate and thus mirrors the real exchange rate.

In the models that we consider, the marginal cost of producing value added is given by the wage. In general, these two need not be equal if for example production uses physical capital, requires working capital, or if there are decreasing returns in production, among other factors. While incorporating all these ingredients into SPOE models is beyond the scope of this paper, our analysis suggests that relative marginal costs that are persistent and track the nominal exchange rate are needed to generate the observed movements in relative reset prices. In addition, our measure of reset exchange rates can be seen as a proxy for economy-wide relative marginal costs, which are hard to measure directly in the data.[7]

[6] These mechanisms are significant home bias, pricing to market, weak substitutability between home and foreign goods, and monetary policy that stabilizes inflation. In early work, Kollmann (2005) showed that the 'Mussa' puzzle can be rationalized in a model with incomplete markets and UIP shocks in a context of large home bias.

[7] See Gali et al. (2005) and the long literature that followed.

Our paper is related to a large literature that studies large and persistent deviations from relative PPP. Mussa (1986) argued that the observed volatility of the real exchange rate favored models with nominal shocks and price rigidities, a view echoed by Rogoff (1996). Engel (1999) showed that short run fluctuations in the real exchange rate are due to changes in the cross-country relative price of tradables, rather than to changes in the relative price of non-tradables. Betts and Devereux (2000) rationalized this finding in a general equilibrium model where firms price to market and prices are sticky in the buyers' currency. A more recent literature starting with Chari et al. (2002) quantitatively evaluates whether SPOE models can generate volatile and persistent real exchange rates.[8] Our main contribution to this literature is to evaluate the mechanisms in these models through a new decomposition of the real exchange rate applied to a new dataset of consumer prices across countries.[9] In doing so, we provide support to incomplete markets models driven by shocks that affect international asset demand, such as those developed by Jeanne and Rose (2002) and Gabaix and Maggiori (2015).

Our paper is also related to the empirical literature that uses microdata to study exchange rate pass-through and deviations from the law of one price across countries, isolating changes in relative prices that are not driven mechanically by nominal rigidities. Gopinath et al. (2010) study pass-through into US import prices, and show that even conditional on a price change, pass-through is only about 25 percent for firms pricing in US dollars. Burstein and Jaimovich (2012) find evidence on the importance of pricing-to-market using scanner data from a supermarket chain. They show that grocery prices change frequently,[10] so that their US-Canada real exchange rates measures are roughly unchanged if they exclude products with no nominal price changes from their price indexes. Boivin et al. (2012) use data from three online book sellers in Canada and the U.S. to show that violations of the law of one price arise even for reset prices.[11] Cavallo et al. (2014) study deviations of the law of one price for online prices of identical goods sold by four large global retailers. They show that deviations from the law of one price for countries outside currency unions arise at the time goods are introduced. Relative to these papers, our empirical results are based on a larger set of goods that by design

[8] See for example Bergin and Feenstra (2001), Benigno (2004), Bouakez (2005), Steinsson (2008), Carvalho and Nechio (2011) , and Engel (2016), among many others.

[9] In this sense, our paper complements Kehoe and Midrigan (2008), who show that real exchange rates are more persistent in stickier sectors, though the observed cross-sectoral differences in persistence are hard to reconcile quantitatively with the predictions of a multisector sticky price model.

[10] They report a weekly probability of price change of s 0.49.

[11] Gorodnichenko and Talavera (2017) argue that, relative to prices in regular stores, prices in online markets exhibit stronger pass-through and faster convergence in response to movements of the nominal exchange rate.

is representative of the universe of consumer prices, and our focus is on understanding deviations from relative PPP. Our empirical results show that changes in the aggregate real exchange rate are almost entirely driven by changes in reset exchange rate. We show that this observation informs about mechanisms at work in workhorse SPOE models.

Finally, our paper is also related to Bils et al. (2012) who compute an alternative measure of 'reset inflation'. Their measure mimics the methodology through which Zillow estimates prices for unsold houses, which involves imputing the reset price changes exhibited by price changers to all items, those changing and those not. Our reset price indexes measure cumulative log inflation from a base year for the subset of goods showing a change in price relative to the previous month. We measure reset inflation by computing changes in these price indexes. Kryvtsov and Carvalho (2016) compute yet another but related measure of reset inflation and suggest that it is an important driver of aggregate inflation. In models with Calvo pricing, all these measures of reset inflation coincide, capturing changes in the reset price in the Calvo model.[12] Relative to these papers, we show that relative reset inflation across countries does not offset movements in nominal exchange rates as most workhorse SPOE models of the real exchange rate would predict.

The rest of the paper is organized as follows. Section 2 presents a partial equilibrium SPOE model to derive intuition on the relationship between the real and the reset exchange rates. Section 3 presents the data and our empirical methodology. Section 4 presents our empirical results. Finally, Section 5 compares the data to quantitative SPOE models, and Section 6 concludes.

2 A simple SPOE model

Before presenting our data, we describe a partial equilibrium sticky price open economy model to build intuition on the relation between the real and the reset exchange rates.

Setup: Consider a one-period world economy consisting of two ex-ante symmetric countries indexed by i and n. The world economy can experience one of infinitely many shocks or states, s. In each country, there is a final good that is produced by aggregating a continuum of intermediate goods. Using lower case variables to denote logs, we write the price of the final good in country i as:

$$p_i(s) \equiv \mu p_{ii}(s) + [1-\mu]\, p_{ni}(s),$$

[12] We discuss the relation between these measures in Appendix E.2.

where $p_{ni}(s)$ is the average price across all the intermediate goods produced in country n and sold in country i, expressed in the currency of country i (i.e. the price of imports in country i). The parameter μ governs the share of domestic goods in the price index.

Intermediate goods are produced by a continuum of monopolistically competitive producers. We introduce price stickiness by assuming that only a fraction $1-\theta$ of these producers can observe the realization of the state before setting their prices. These producers set the following price denominated in the buyer's currency:

$$\bar{p}_{in}(s) = \bar{\rho} + w_i(s) + e_{in}(s),$$

where $\bar{\rho}$ is a markup, $w_i(s)$ is the marginal cost for firms in country i, which for now we assume is given by the wage, and $e_{in}(s)$ is the nominal exchange rate expressed in units of currency n per-unit of currency i.[13] The remaining producers must set prices in the buyer's currency before observing the realization of the state. The price set by these producers is

$$p^e = \bar{\rho} + w^e,$$

where w^e denotes the expected wage.[14]

Relative prices: We can now write the reset and the real exchange rates in this economy as functions of relative wages and the nominal exchange rate. The reset exchange rate is defined as:

$$\overline{rer}_{in}(s) \equiv \bar{p}_i(s) + e_{in}(s) - \bar{p}_n(s),$$

with $\bar{p}_i(s) \equiv \mu \bar{p}_{ii}(s) + [1-\mu]\,\bar{p}_{ni}(s)$. Substituting we obtain,

$$\overline{rer}_{in}(s) = [2\mu - 1]\, rer^w_{in}(s), \tag{2}$$

where $rer^w_{in}(s) \equiv w_i(s) + e_{in}(s) - w_n(s)$ denotes relative wages expressed in a common currency. Finally, noting that the average price set by producers from country i selling in country n is $p_{in}(s) = [1-\theta]\,\bar{p}_{in}(s) + \theta p^e$, we can write the real exchange rate as:

$$rer_{in}(s) = \theta e_{in}(s) + [1-\theta]\,[2\mu - 1]\, rer^w_{in}(s), \tag{3}$$

[13] We relax the assumptions of constant markups and on the cost function in Section 5.

[14] We omit country subscripts since countries are symmetric before the state is realized (and, for the same reason, set the expected log-exchange rate equal to zero).

where the equality follows from the definitions of rer_{in}, p_i, $\bar{p}_i$ and from equation (2).

Discussion: Equation (3) shows the determinants of the real exchange rate. Since some prices are set before the realization of the state, the real exchange rate mechanically tracks the nominal exchange rate. This is the primary mechanism driving real exchange rates in the SPOE models with sluggish relative wages described in the introduction. On the other hand, prices that are set after the realization of the state track nominal wages. Hence, the real exchange rate also moves with the nominal exchange rate if relative wages move with the nominal exchange rate.[15] If the fraction of firms that observe the state is small, (large θ), the effect of relative wages on the real exchange rate is small.

Equation (2) shows the determinants of the reset exchange rate. Compared to the real exchange rate, the reset exchange rate is more sensitive to movements in relative wages. In particular, if relative wages are constant, $rer^{w}_{in} = 0$, then the reset exchange rate is constant. In the next section we'll show that in the data rer_{in} and $\overline{rer}_{in}$ move one to one with each other. This implies that models that generate real exchange rate movements through price stickiness with little movements in relative wages will fail to match the empirical decomposition between real and reset exchange rates. In Section 5, we show that this intuition prevails even in quantitative DSGE models featuring a large degree of real rigidities.

3 Data

This section describes the CPI microdata from Austria, Chile, Finland, Mexico and the United Kingdom. It then describes how the datasets are harmonized and used to compute the empirical counterparts of the real and reset exchange rates defined in the previous section.

3.1 Data sources and description

Our analysis combines the microdata that underly the construction of the Consumer Price Indexes in five countries: Austria, Chile, Finland, Mexico and the UK. We describe the sources of the data below.

Austria: The microdata used for the construction of the Austrian CPI was obtained from Statistics Austria. The dataset spans the 2006-2015 period, and contains about 44,000 el-

[15] Section 5 describes different models where relative wages move with the nominal exchange.

ementary price quotes in the average month. In total, there are roughly six million price quotes covering about 95 percent of Austrian non-shelter consumption expenditures in the dataset. The remaining expenditures correspond to the shelter portion of the Austrian CPI, for which Statistics Austria only reports price indexes. Each elementary price quote corresponds to a unique product sampled in a specific outlet, and contains information on the date, the outlet, and the units in which prices are quoted. For confidentiality reasons the raw dataset has been anonymized with respect to product brands and outlet identifiers. The majority of the price quotes are sampled from individual outlets across 20 major Austrian cities. For about 40 percent of the product categories, price quotes are collected centrally.

Chile: We obtain the microdata used to compute the Chilean CPI from the National Institute of Statistics (INE). This dataset only spans the 2010-2015 period, and contains over 90,000 price quotes per month. There are over 7.1 million elementary price quotes over the period, representing 80 percent of the CPI basket in Chile. Each elementary price quote corresponds to a specific product sampled in a specific outlet, and contains information on the date, the outlet, the units in which prices are quoted, and the method used for the data collection. The price quotes are sampled across the regional capitals and major cites across 15 Chilean regions. As in the other datasets, the data has been anonymized with respect to product brands and outlet identifiers.

Finland: The microdata used to compute the CPI in Finland is collected by Statistics Finland. The dataset spans the 2006-2015 period, and contains over 50,000 price quotes per month. There are over 6 million elementary price quotes in total representing 66 percent of the non-shelter CPI basket in Finland. Items related to housing and telephone calls are available in index form only and are excluded from our analysis. The remaining elementary price quote corresponds to a specific product sampled in a specific outlet, and contains information on the date, the outlet, the units in which prices are quoted, and the method used for the data collection. The majority of the price quotes are sampled from individual outlets across six major Finnish regions. The data has been anonymized with respect to product brands and outlet identifiers.

Mexico: The microdata used to compute the Mexican CPI are collected by the National Institute of Statistics and Geography (INEGI). Since January 1994, these data are published monthly in the Diario Oficial de la Federacion (DOF), the official bulletin of the Mexican government. Each elementary price quote in the DOF represents a unique product-outlet combination that can be traced through time. As with our other datasets, for each elementary product we observe its monthly price, the city in which it is sold and the units in which prices are quoted. The data for the 2006-2015 period are sampled from 46 Mexican cities and contain about 85,000 monthly price quotes, representing about 84 percent of consumption expenditures in the average month. The remaining expenditures correspond to shelter and car insurance, which we exclude from our analysis since for these items the INEGI only reports aggregated price indexes. For the same reasons, we also exclude computers for the 2011-2016 sub-period. The DOF also publishes a list of products that are added to the CPI basket due to product substitutions or changes in the set of outlets sampled by the INEGI. Earlier versions of this dataset has been used previously by Ahlin and Shintani (2007), Gagnon (2009) and Cravino and Levchenko (2017).

United Kingdom: The microdata used to compute the CPI in the UK are collected by the United Kingdom's Office for National Statistics (ONS). The product-level price quotes and item-level price indexes used for the construction of the CPI were made publicly available in September of 2012. This data has been previously used by Kryvtsov and Vincent (2014) and Blanco (2017). We use the portion of these data that spans the 2006-2015 period, containing almost 14 million price quotes. For most item categories, the ONS collects price quotes of individual products by sampling outlets around 150 locations in the UK. Each elementary price quote collected through this method represents a unique product, sampled in a particular outlet. Prices for the remaining CPI items are collected centrally by the ONS with no field work. Such items include shelter, university tuition fees, rail fares, and other services. Unfortunately, the ONS only provides item-level price indexes for these items.[16] Since observing individual price trajectories is central for the study of reset prices, we exclude these items from our analysis. We do include educational and other services, which are reported in index form but only change once per year.

For a small subset of items and regions, the ONS does not report outlet identifiers to comply with confidentiality guidelines. In such cases, there could be multiple price quotes with the same product-outlet identifier in a given month in the dataset. In most of these cases, there is no variation in prices that share an identifier in a given month.[17] For the few cases in which we do observe different prices with the same identifier, we use information provided by the ONS on cumulative inflation at the unique good level and the

[16]For some of these items, such as housing rent, price indexes are obtained from alternative surveys, such as the household survey. For most items, including rail fares and tuition fees, price indexes are computed by aggregating price-quotes that are centrally collected the ONS. Unfortunately, the ONS does not disseminate these quotes.

[17] See Blanco (2017) for a detailed description.

algorithm described in Appendix A.2 to recover: i) a unique price-trajectory associated to a product-outlet pair, and ii) a weight for each price trajectory reflecting the frequency of each price under a particular identifier.

3.2 Harmonization and cleaning

As described above, statistical agencies in our sample of countries share similar methodologies for collecting consumer prices. The datasets do differ in terms of the number and the composition of the products sampled. In addition, in each country we had to exclude different product categories in cases where only aggregated price indexes were available (the most important category, which we exclude in all five datasets, is shelter). Table 1 and Appendix Tables A1 and A2 summarize these differences in our final sample. The datasets also differ in other aspects, such as the treatments of temporary sales, product substitutions, and updates to the basket of goods sampled, which we describe below.

Table 1: Summary Statistics, CPI Microdata

	Austria	Chile	Finland	Mexico	UK
Number of price quotes					
Total	5,200,658	7,104,572	6,075,259	10,180,732	13,845,685
Average month	43,339	98,675	50,627	84,839	115,381
Number of item categories	779	352	487	298	697
% of non-shelter CPI	95	80	66	85	74

Note: This table summarizes our final sample of the microdata used for the construction of the CPI in Austria, Chile, Finland, Mexico and the UK. Each price quote corresponds to a specific product-outlet combination. 'Item categories' are the most dissagregated categories for which the statistical agencies construct price indexes and provide CPI weights.

Temporary sales: Temporary sales are flagged in the UK, Austria, Finland and Chile, but not in the Mexican data. To maintain consistency across datasets, we create our own indicator for temporary sales by defining them as a price change that is reverted after one or two months. In our baseline calculations, we do not consider temporary sales as price changes (that is, we replace sale prices with regular prices).

Planned changes to the CPI basket: Statistical agencies periodically update the basket of goods that comprise the CPI to reflect changes in expenditure patterns or the introduction of new products. In the UK, updates to the CPI basket are introduced every February. In Austria, the CPI basket was updated every January since January 2011. In Finland the basket was updated in January 2011. Because some new products are introduced to the CPI basket with each update, the number of price changes that we can compute in the month of an update is slightly smaller than in the typically month. Appendix Table A3 summarizes the share of new products that are introduced after each update. In the UK, in the average update month 13 percent of the price quotes correspond to new products (relative to 3 percent of new products in the average month). In Austria, in the average update month only 3 percent of the price quotes correspond to new products. In practice, the only important update to the Austrian basket is on January 2011, where about 12 percent of the products are new. In our main calculations, we treat update months in these countries as regular months (the caveat is that we cannot compute price changes for the new products introduced in the update, so the effective sample in these months is slightly smaller).

In Mexico, the CPI basket was updated in January 2011, and in Chile the basket was updated in 2014. In these two cases, all the product-store identifiers were changed between December and January of the update year. This means that we cannot compute inflation between these months with our microdata. In our baseline results, we set the aggregate and the reset inflation in these two months equal to zero.

Forced substitutions and outliers: In a given month, price inspectors may not be able to sample some elementary-products in the basket due to unanticipated reasons. Such reasons include changes in product characteristics, products that get discontinued, and in rare cases outlets that shut down. In such cases, statistical agencies typically sample another product which they consider to be a close substitute to the original product. Forced substitutions are flagged in all five datasets. Most of these substitutions are flagged as 'comparable', indicating that the new product is sufficiently close to the one being substituted. Statistical agencies include changes in prices arising from these substitutions in the CPI. Some substitutions are flagged as 'non-comparable', and changes in prices arising from these type of substitutions are excluded from the CPI. To keep our results comparable to the official inflation numbers, we treat non-comparable substitutions as new products. Finally, to account for rare month-to-month price movements that may arise from coding errors in the datasets we exclude observations with the largest percentile of log-price changes in absolute value, following Alvarez et al. (2016) and Kryvtsov and

Carvalho (2016).

Weighting and aggregation: The statistical agencies in the UK, Austria, Finland, Mexico and Chile divide products into Item categories, similarly to how the BLS divides products into 'Entry Level Items' (ELIs) for the construction of the US CPI. These are the most dissagregated categories for which the agencies construct price indexes and provide CPI weights. From now on we refer to these detailed categories as simply as 'Items'. The categorization of products into Items varies across the countries in our sample. For instance, Mexico is the only country that assigns an Item for 'Tortillas', while Austria is the only country that assigns an item for 'Hazelnut Cuts'. In contrast, all countries assign an Item to 'Beer'. All Items can be grouped into broader categories following the international standards in the 'Classification of Individual Consumption According to Purpose' (COICOP). In the example above, 'Tortillas' and 'Hazelnut Cuts' are both part of the COICOP -class category 'Bread and cereals', which in turn is part of the broader COICOP -group category 'Food'. The number of items groups in each country is listed in Table 1. In what follows, we use the country-specific Item weights to aggregate the price quotes from the microdata into measures of inflation at the class-level of the COICOP classification. We then compute real exchange rates and relative prices for each class-level of the COICOP classification and aggregate up using a Fisher formula as described below.

3.3 Computing real and reset exchange rates

We now describe how we use the microdata to compute real and reset exchange rates. To be consistent with the theory in Section 2, we compute inflation between two consecutive months as the change in the average log price for the set of goods that continue in the sample for the two months. We do so following the procedures used to compute aggregate inflation in the UK.

First, we normalize the price trajectories in our data to construct elementary-product level price indexes. In particular, for each product ω, we construct a price index defined as:

$$p^{\iota}_{n,t}(\omega) \equiv \begin{cases} log\left[P^{\iota}_{n,t}(\omega) / P^{\iota}_{n,t_0}(\omega)\right] & if\ t_0 = \text{Jan 2006} \\ log\left[P^{\iota}_{n,t}(\omega) / P^{\iota}_{n,t_0}(\omega)\right] + p^{\iota}_{n,t_0} & if\ t_0 \neq \text{Jan 2006} \end{cases}. \tag{4}$$

Here t_0 is the first month in which product ω appears in our data. $P^{\iota}_{n,t}(\omega)$ and $P^{\iota}_{n,t_0}(\omega)$ are the raw prices in country n of product ω belonging to Item category ι, at dates t and t_0. p^{ι}_{n,t_0} is the price index for item category ι, normalized to take a value of zero on January

2006. Equation (4) defines log price indexes that measure cumulative inflation between month t and January 2006, the first month in our sample. For a product that is introduced to the CPI basket in the middle of the sample, the log price index is normalized so that it takes the value of the Item-level index in the month that the product is introduced (so that it captures the official cumulative inflation for the item category between t_0 and January 2006). In what follows, we take averages of these measures of cumulative inflation across different set of products.[18]

We construct Item-level price indexes as simple averages of the product-level price indexes in each Item category. That is, for each Item category ι we compute a price index given by:

$$p^{\iota}_{n,t} = \frac{1}{\left|\Omega^{\iota}_{n,t}\right|} \sum_{\omega \in \Omega^{\iota}_{n,t}} p^{\iota}_{n,t}(\omega), \tag{5}$$

where $\Omega^{\iota}_{n,t}$ and $\left|\Omega^{\iota}_{n,t}\right|$ are the set and the number of products in item category ι that are in the sample at dates t and $t-1$. Similarly, we compute a reset price index for each category as:

$$\bar{p}^{\iota}_{n,t} = \frac{1}{\left|\bar{\Omega}^{\iota}_{n,t}\right|} \sum_{\omega \in \bar{\Omega}^{\iota}_{n,t}} p^{\iota}_{n,t}(\omega), \tag{6}$$

where $\bar{\Omega}^{\iota}_{n,t}$ and $\left|\bar{\Omega}^{\iota}_{n,t}\right|$ are the set and the number of products in item ι for which $p^{\iota}_{n,t}(\omega) \neq p^{\iota}_{n,t-1}(\omega)$.

The Item-level price indexes defined in equations (5) and (6) are hard to compare directly across countries, since each country has its own classification for the Item categories. To compute real exchange rates, we thus aggregate the Item level prices (5) and (6) at the class-level of the COICOP classification, and compute 'COICOP-class' level indexes,

$$p^{j}_{n,t} = \sum_{\iota \in j} \frac{s^{\iota}_{n,t}}{s^{j}_{n,t}} p^{j}_{n,t}; \quad \bar{p}^{j}_{n,t} = \sum_{\iota \in j} \frac{s^{\iota}_{n,t}}{s^{j}_{n,t}} \bar{p}^{\iota}_{n,t}. \tag{7}$$

Here $p^{j}_{n,t}$ and $\bar{p}^{j}_{n,t}$ are price indexes for COICOP-class category j, and $s^{\iota}_{n,t}$ and $s^{j}_{n,t} \equiv \sum_{\iota \in j} s^{\iota}_{n,t}$ are the official weights of item category ι and COICOP-class category j in country $n's$ CPI. Since the definition of the COICOP-class categories are harmonized internation-

[18] Kryvtsov and Carvalho (2016) use an alternative normalization for their measure of reset inflation. In particular, instead of normalizing by the initial prices of the elementary product, they normalize all prices relative to an item-strata level mean.

ally, $p^j_{n,t}$ and $\bar{p}^j_{n,t}$ are comparable across countries.

To compute real exchange rates we always use the UK as the base country, and obtain bilateral nominal exchange rates between the Euro area-UK, Mexico-UK and Chile-UK from the OECD. We construct a log-index for the bilateral nominal exchange rate as

$$e_{iUK,t} \equiv log\left[E_{iUK,t}/E_{iUK,\text{Jan06}}\right],$$

where $E_{iUK,t}$ is the bilateral nominal exchange rate, expressed in terms of pounds per domestic currency. We then compute real exchange rates for each COICOP-class category for which the microdata is available in the two countries as

$$rer^j_{in,t} \equiv p^j_{i,t} + e_{in,t} - p^j_{n,t},$$

and

$$\overline{rer}^j_{in,t} \equiv \bar{p}^j_{i,t} + e_{in,t} - \bar{p}^j_{n,t}.$$

Finally, we aggregate across all COICOP-level categories to compute the economy-wide real and reset exchange rates:

$$rer_{in,t} = \sum_j s^j_{in,t} rer^j_{in,t}; \quad \overline{rer}_{in,t} = \sum_j s^j_{in,t} \overline{rer}^j_{in,t}, \tag{8}$$

where $s^j_{in,t} \equiv \frac{s^j_{i,t}+s^j_{n,t}}{\sum_j s^j_{i,t}+s^j_{n,t}}$ is the average of country i and country $n's$ weight in COICOP category j, scaled so that the weights add up to 1.[19] Note that by construction, these indexes are zero in January 2006, and reflect cumulative changes relative to January 2006 at other dates.

Comparison with official statistics Before conducting our empirical analysis, we evaluate the representativeness of our data by comparing it with official inflation statistics. With this in mind, we compute aggregate price indexes for each country in our sample using our microdata, according to $p_{n,t} = \sum_\iota \tilde{s}^\iota_{n,t} p^\iota_{n,t}$, where $\tilde{s}^\iota_{n,t} \equiv s^\iota_{n,t} / \sum_\iota s^\iota_{n,t}$ are country specific item-level weights that are based on the official weights and are rescaled to add up to 1 (see footnote 19). Note that, in contrast with our measures presented above, these formulas use weights that are country-specific (instead of country-pair-specific), and are

[19] The scaling is necessary since the items in our sample represent a fraction of total CPI expenditures (see Table 1).

used only in this section with the purpose of evaluating the quality of our data. We compute aggregate inflation from the microdata by taking changes in these price indexes. The resulting inflation may differ from that reported by official sources because (i) our data does not cover 100% of CPI expenditures (see Table 1), and (ii) the formulas we use to compute inflation differ from those used by national statistical offices.

Appendix Figure A1 compares aggregate inflation computed from the microdata to the official inflation series in each of the countries in our sample. The figure shows that our microdata mimics the official inflation extremely well in all countries. We conclude that despite differences in methodologies and coverage, the inflation and real exchange rate measures we compute from the microdata are representative of the measures computed from official data.

Changes in aggregate and reset prices Appendix Table A2 reports the average frequency of price changes in each COICOP 2 sector for each of the countries in our sample. On average, in a given month, the fraction of prices that change is 16 percent in the UK, 17 percent in Austria, and 23 percent in Finland. This is in line with the average frequency of 0.21 reported by Nakamura and Steinsson (2010) for the United States.[20] Prices in Mexico and Chile adjust more frequently, in line with the evidence in Gagnon (2009).

We conclude this section by comparing our measures of inflation for aggregate and reset prices. To do so, we first compute aggregate reset prices in each country according to $\bar{p}_{n,t} = \sum_{\iota} \bar{s}^{\iota}_{n,t} \bar{p}^{\iota}_{n,t}$. Figure A2 plots monthly changes in aggregate and reset and price indexes, summary statistics are presented in Table 2. As expected, reset inflation is substantially more volatile than aggregate inflation. The ratio of the standard deviation of reset inflation to the standard deviation of aggregate inflation is 5 for UK, 4.5 for Austria, and 3.2 for Finland. In Mexico and Chile this ratio is 'only' about 2.5. This is not surprising since, as summarized in Table A2, prices adjust more frequently in Mexico and Chile than in Austria, Finland and the UK.

[20]The median frequency of price changes is lower than this, both in our countries and in the US. Our quantitative models are all calibrated to match the weighted average duration of price spells.

Table 2: Empirical properties of aggregate inflation and reset inflation

	Austria	Chile	Finland	Mexico	UK
Relative st. dev.	4.57	2.42	3.29	2.50	5.03
Correlation	0.44	0.56	0.54	0.59	0.71

Note: 'Relative st. dev.' is the ratio of the standard deviation of monthly reset inflation to the standard deviation of monthly inflation, given by $\sigma_{\Delta \bar{p}_i} / \sigma_{\Delta p_i}$. 'Correlation' is the coefficient of correlation between monthly aggregate inflation and reset monthly inflation.

4 Empirical results

This section conducts an empirical decomposition of the real exchange rates according to equation (1). Figure 1 plots cumulative changes in real exchange rates, reset exchange rates, and in the difference between these two for each country relative to the UK. The figure shows that real exchange rate movements are driven almost exclusively by movements in the reset exchange rate in each of the country-pairs in our sample. In particular, movements in the reset exchange rate are as large and are strongly correlated to those in real exchange rates. In contrast, the difference between these two is much less volatile and almost uncorrelated to the real exchange rate. In fact, the cumulative change in this difference is centered around zero, while sharp movements in the real exchange rate are persistent.

Figure 2 compares movements in the real exchange rates (x-axis) to changes in the reset exchange rates (y-axis), for changes computed at monthly, quarterly, semiannual and annual frequencies. We pool all countries-pairs into each figure, so that each point in a figure represents a country pair in a given month/quarter/semester/year.[21] To facilitate the comparison across country pairs, we normalize all changes by twice standard deviation of the real exchange rate.[22] The figure shows that the changes in the real and the reset exchange rate always line up around the 45 degree line,[23] showing that the changes in these two variables go one to one with each other, independently of the frequency at which these changes are computed.

[21] For this figure we include all possible country pairs in our sample. We do not plot individual figures for each country pair to conserve space, thought the decomposition looks similar for each country-pair.

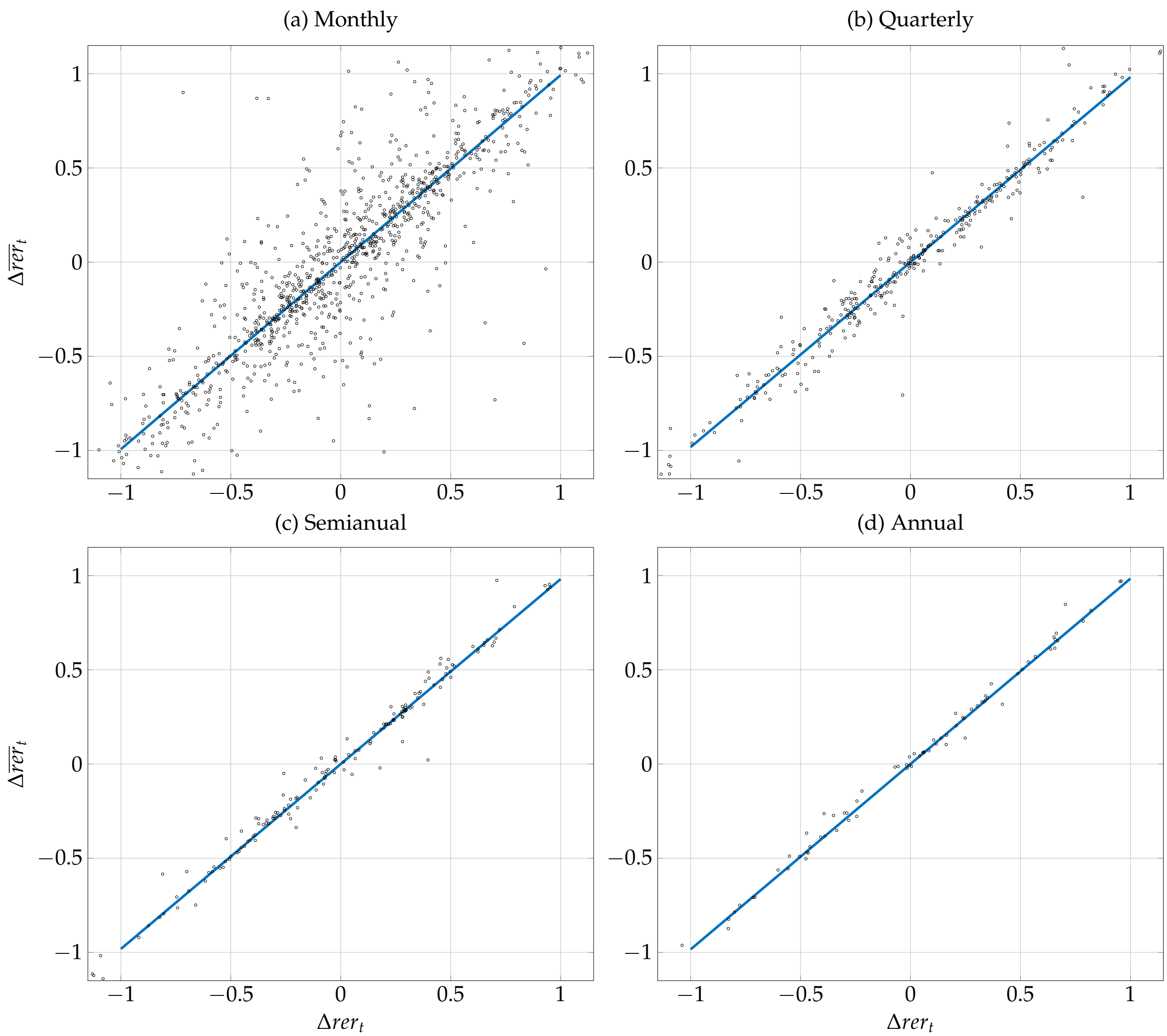
[22] This normalization is for presentation purposes only, so that most circles lie in the [-1,1] interval.

[23] The blue line plotted in the figure is a fitted line, almost indistinguishable from the 45 degree line.

Figure 1: Empirical decomposition of the real exchange rate

Note: ‘Real’ and ‘Reset’ refer to the real and the reset exchange rates reset, defined in equation (8). The figure plots cumulative changes relative to January 2006 for Austria-UK, Mexico-UK and Finland-UK, and cumulative changes since January 2010 for Chile UK.

Figure 2: Changes in real vs. reset exchange rates



Note: The figure plots changes in real exchange rates (x-axis) and changes in reset exchange rates (y-axis) computed at monthly, quarterly, semiannual and annual frequencies. Changes in real and reset exchange rate are both normalized by two times the standard deviation of the change in the bilateral real exchange rate. Each circle represent a change for a country pair. A fitted line is depicted in solid blue.

Understanding reset exchange rate movements We now evaluate the sources of co-movement between the reset and real exchange rates. As documented by Mussa (1986), real exchange rates track nominal exchange rates because movements in relative inflation rates are small. Table 3 shows that in our data, relative inflation rates are indeed far less volatile than nominal exchange rates. The standard deviation of relative price changes is between 0.09 and 0.21 of the standard deviation of nominal exchange rate changes when computed at a monthly frequency, and 0.1-0.26 when computed at a yearly frequency.

In contrast Table 3 shows that the volatility of relative reset inflation is sizable, even relative to the observed changes in the nominal exchange rate. For the Austria-UK pair, the standard deviation of the monthly relative reset inflation is 0.66 times the standard deviation of the monthly nominal exchange rate changes, and for the Finland-UK pair this number is 0.79. This is three times the standard deviation of relative aggregate inflation. Even at a yearly frequency, the standard deviation of relative reset inflation is 50 percent larger than that of aggregate relative inflation. Why does the reset exchange rate comove with the nominal rate? The answer can be gleaned from the second panel of Table 3, which shows that changes in relative reset prices are uncorrelated to nominal exchange rate changes at the monthly frequency. That is, while relative reset prices move more than relative prices, the correlation between relative reset price changes and nominal exchange rates is still too small to offset movements in the nominal rate.

Table 3: Relative inflation and relative reset inflation

Relative	Austria-UK		Chile-UK		Finland-UK		Mexico-UK	
to $\Delta e \downarrow$	$\pi_i - \pi_n$	$\bar{\pi}_i - \bar{\pi}_n$	$\pi_i - \pi_n$	$\bar{\pi}_i - \bar{\pi}_n$	$\pi_i - \pi_n$	$\bar{\pi}_i - \bar{\pi}_n$	$\pi_i - \pi_n$	$\bar{\pi}_i - \bar{\pi}_n$
Std. Dev.								
Monthly	0.17	0.66	0.16	0.67	0.21	0.79	0.09	0.37
Quarterly	0.17	0.22	0.19	0.31	0.21	0.31	0.10	0.16
Yearly	0.10	0.14	0.26	0.32	0.14	0.18	0.16	0.20
Correlation								
Monthly	0.13	0.12	-0.13	-0.12	0.08	0.10	0.16	-0.08
Quarterly	-0.02	-0.14	-0.34	-0.38	0.18	0.04	0.26	0.11
Yearly	-0.61	-0.59	-0.56	-0.61	0.02	-0.14	0.32	0.17

Note: 'Std. dev.' is the ratio of the standard deviation of relative inflation and relative reset inflation to the change in the nominal exchange rate. 'Correlation' is the coefficient of correlation between relative inflation (or relative reset inflation) and the change in the nominal exchange rate. Relative inflation rates are computed as $\pi_i - \pi_n \equiv \Delta rer_{in,t} - \Delta e_{in,t}$ and $\bar{\pi}_i - \bar{\pi}_n \equiv \Delta \overline{rer}_{in,t} - \Delta e_{in,t}$, where $rer_{in,t}$ and $\overline{rer}_{in,t}$ are defined in equation (8).

Differences across tradeable and non-tradeable goods We conclude this section by evaluating whether our decomposition looks different for alternative subsets of goods. We focus here in the distinction between tradeable and non-tradeable goods. To do so, we classify each class-level COICOP category into tradable and non-tradable following the classification in Berka et al., (forthcoming). We then separately aggregate the tradeable and non-tradeable categories when computing the aggregate exchange rates defined in equation (8).

Appendix Figure A3 reports the changes in the reset vs. the real exchange rates at different frequencies, computed separately for tradeable and non-tradeable goods. The figures shows that relation between the real the reset exchange is somewhat less volatile for tradable than for tradable goods. However, both for tradables and non-tradables the relative standard deviation of the reset vs. the real exchange rate changes is always close to one. Thus, the partition between tradable and non-tradables does not alter our conclusions from the previous sections. For both types of goods, real exchange rates are almost entirely driven by reset exchange rates.

5 Quantitative SPOE models

This section describes various SPOE models that the literature has used to study the joint dynamics of the nominal and the real exchange rates. It then evaluates their implications for the real exchange rate decomposition in equation (1). The models that we evaluate share a pricing block that describes how firms facing nominal rigidities set prices given demand and costs. The general equilibrium structure differs across models. We start by analyzing a class of models where relative wages are sluggish or revert quickly in equilibrium.[24] We then analyze a model where shocks driving the nominal exchange rate do not directly affect nominal wages, so that relative wages in a common currency move with the nominal exchange rate.

5.1 SPOE models: pricing block

We start by describing the pricing block of the models considered in this section. The pricing block describes how producers facing nominal rigidities set prices given demand and costs, and will allow us to write real and reset exchange rates as functions of relative wages and the nominal exchange rate. We allow for two sources of real rigidities that

[24] Many of the models in the literature fit into this category, including, Bergin and Feenstra (2001), Benigno (2004), Bouakez (2005), Steinsson (2008), Carvalho and Nechio (2011) and Engel (2016).

the literature has used to generate persistent real exchange rates. We will study a world economy consisting of two countries, i and n, each inhabited by a producer of final goods and a continuum of monopolistic intermediate producers indexed by $\omega \in [0, 2]$.

Final goods producers: The final good in country i, $Y_{i,t}$, is produced with according to:

$$Y_{i,t} = [\mu Y_{ii,t} + [1-\mu] Y_{ni,t}]^{\frac{\xi}{\xi-1}}, \tag{9}$$

$$1 = \int \Psi \left(\frac{Y_{ni,t}(\omega)}{Y_{ni,t}} \right) d\omega. \tag{10}$$

Here $Y_{ni,t}(\omega)$ denotes the quantity of intermediate good ω produced in country n and consumed in country i, μ is the share of domestic goods in absorption in the symmetric steady state, and ξ is the elasticity of substitution between domestic and foreign goods. $\Psi(x)$ is a Kimball (1995) aggregator. In what follows, we adopt the specification of Klenow and Willis (2007) for $\Psi(x)$ that yields $\Psi'^{-1}(x) = [1-\phi x]^{\frac{\gamma}{\phi}}$. Under this specification, the elasticity of demand for good ω depends its price relative to the price of its competitors, that is $\varepsilon \equiv -\frac{\partial log \Psi'^{-1}(x)}{\partial log x} = \frac{\gamma}{1-\phi log(x)}$. This is constant and equal to γ as $\phi \to 0$, and increasing in x if $\phi > 0$. Thus, the parameter ϕ controls the degree of strategic complementarities in price setting.

Intermediate good producers: Intermediate producers behave as monopolistic competitors and set prices as in Calvo (1983). Importantly, producers set prices in the currency of the country where they sell. The probability that a producer can change its price in any period is given by $1-\theta_p$. The production function for intermediate goods is

$$Y_{ni,t}(\omega) = \bar{a} N_{ni,t}(\omega)^{1-\bar{\alpha}} X_{ni,t}(\omega)^{\bar{\alpha}}, \tag{11}$$

with

$$N_{ni,t}(\omega) = \left[\int_0^1 n_{ni,t}(\omega, h)^{\frac{\eta-1}{\eta}} dh \right]^{\frac{\eta}{\eta-1}}, \tag{12}$$

and $\bar{a} \equiv \bar{\alpha}^{\bar{\alpha}} [1-\bar{\alpha}]^{1-\bar{\alpha}}$. Here $N_{ni,t}(\omega)$ is a labor bundle, and $X_{ni,t}(\omega)$ and $n_{ni,t}(\omega, h)$ are the quantities of intermediate inputs and of labor of type h used to produce good ω in country n to serve market i. $\bar{\alpha}$ is the share of intermediate inputs in production, which is another source of real rigidities in the model: the cost faced by producers depend on all other prices in the economy.

The profit maximizing price for an intermediate producer that gets to adjust prices satisfies:

$$\bar{P}_{in,t} = \arg\max \left\{ \mathbb{E}_t \sum_{k=0}^{\infty} \frac{\Theta_{i,t+k}}{\Theta_{i,t}} \theta_p^j \left[\frac{\bar{P}_{in,t}}{E_{in,t+k}} - W_{i,t+k}^{1-\bar{\alpha}} P_{i,t+k}^{\bar{\alpha}} \right] Y_{in,t+j} \left(\bar{P}_{ni,t} \right) \right\}. \tag{13}$$

Here $\frac{\Theta_{i,t+k}}{\Theta_{i,t}}$ is country i's nominal discount factor between dates t and $t+k$, $E_{in,t+k}$ is the nominal exchange rate, expressed in units of currency n per-unit of currency i, $W_{i,t}$ and $P_{i,t}$ are the prices of the labor bundle and of the final good in country i, and $Y_{in,t}\left(\bar{P}_{ni,t}\right)$ is the demand function associated with the aggregator (10).

Real and reset exchange rates in partial equilibrium: We now characterize the joint process of the real and the reset exchange rates as functions of relative wages and the nominal exchange. We continue with our notation from the previous section and use lower case to denote the log of a variable, and denote relative wages in a common currency by $rer^w_{in,t} \equiv w_{i,t} + e_{in,t} - w_{n,t}$.

Appendix B shows that under Calvo prices, the laws of motion for the real and reset exchange rates satisfy:

$$rer_{in,t} = \left[1 - \theta_p\right] \overline{rer}_{in,t} + \theta_p \left[rer_{i,t-1} + \Delta e_{in,t}\right], \tag{14}$$

and

$$\overline{rer}_{in,t} = \left[1 - \beta\theta_p\right] \left[\iota rer^w_{in,t} + \alpha rer_{in,t}\right] + \beta\theta_p \mathbb{E}_t \left[\overline{rer}_{in,t+1} - \Delta e_{in,t+1}\right] \tag{15}$$

where $\alpha \equiv \frac{\phi + \bar{\alpha}[\gamma-1][2\mu-1]}{\gamma-1+\phi}$, $\iota \equiv \frac{[1-\bar{\alpha}][\gamma-1][2\mu-1]}{\gamma-1+\phi}$, and β^{-1} is the steady state real interest rate.

Equation (14) states that the real exchange in period t is a weighted average of the real exchange rate for reset prices, $\overline{rer}_{in,t}$, and the real exchange rate in the previous period adjusted by the change in the nominal exchange rate, $rer_{i,t-1} + \Delta e_{in,t}$. The weights are determined by the fraction of producers that reset prices, θ_p. Equation (15) states that the reset exchange rate depends on the discounted present value of current and future relative wages and aggregate prices, captured by $\iota rer^w_{in,t} + \alpha rer_{in,t}$. Note that, given $rer^w_{in,t}$ and $\Delta e_{in,t}$, the dynamics of the real and reset exchange rate will depend on the discount factor, β, the degree of nominal rigidities, θ_p, and parameters governing the degree of real rigidities in the model, $\bar{\alpha}$ and ϕ. In what follows, we describe how $rer^w_{in,t}$ and $\Delta e_{in,t}$ are determined in equilibrium in various workhorse models used in the literature.

5.2 Models where relative wages are sluggish or mean revert quickly

This section considers a class of models in which relative wages are sluggish or mean revert quickly. We study an economy that, in addition to the producers described above, is inhabited by a continuum of households indexed by $h \in [0,1]$, a government, and a monetary authority.

Households: Each household in country i has preferences given by

$$U_i = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\varphi_{i,t} log C_{i,t} - N_{i,t}(h) \right], \tag{16}$$

where $C_{i,t}$ and $N_{i,t}$ denote consumption and labor, $\varphi_{i,t}$ is a taste shock to the utility of consumption à la Stockman and Tesar (1995).[25]

Households supply differentiated labor services, have monopoly power over their wage, and face Calvo-type constraints on their ability to adjust wages, as in Kollmann (2001). The probability that a household can change its wage in a given period is given by $1 - \theta_w$. The date 0 inter-temporal budget constraint is:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \Theta_{i,t} \left[P_{i,t} C_{i,t} - W_{i,t}(h) N_{i,t}(h) - \Upsilon_{i,t} - T_{i,t} \right] = 0. \tag{17}$$

Here $P_{i,t}$, $W_{i,t}(h)$, $\Upsilon_{i,t}$, and $T_{i,t}$ respectively denote the price of consumption, nominal wages, firm's profits, and government transfers, all denominated in the currency of country i. $\Theta_{i,t}$ is the date $t = 0$ local-currency price of an arrow security that pays one unit of the local currency in at time t. By definition, the nominal exchange rate satisfies: $E_{in,t} = E_{in,0} \frac{\Theta_{i,t}}{\Theta_{n,t}}$.

Monetary and fiscal policy: As Carvalho and Nechio (2011) we leave the monetary policy implicit, and assume that aggregate nominal expenditures in each country are exogenous and given by $Z_{i,t} \equiv P_{i,t} C_{i,t}$.[26] Additionally, government expenditures G_t are exogenous. The government balances its budget every period, $G_{i,t} = T_{i,t}$.

[25] As it will become clear later, the assumption of quasi-linear preferences permits us to solve for all relative prices in this model in closed form. We show that our quantitative results do not depend on this assumption on Section 5.2.3.

[26] We make this assumption for tractability following Kehoe and Midrigan (2008) and Carvalho and Nechio (2011). Section 5.2.3 evaluates the case in which the monetary authority follows a Taylor rule.

Equilibrium: An equilibrium for this economy is a set of allocations for the households $\{C_{i,t}, W_{i,t}(h)\}_{\forall i,h,t}$, final good producers $\{Y_{i,t}, Y_{in,t}, \{Y_{in}(\omega)\}_{\omega}\}_{\forall n,t}$, and price policy functions for intermediate producers $\{\bar{P}_{in,t}\}_{\forall i,n,t}$, such that given prices: (i) households maximize (16) subject to (17); (ii) final good producers minimize cost according to equations (9) and (10); (iii) intermediate producers maximize profits according to equation (13); and (iv) labor and goods markets clear.

Nominal exchange rates and relative wages: The model described above allows for preference shocks, φ_t, real shocks, G_t, and nominal shocks, Z_t. We note however that from the complete market assumption and the process for nominal expenditures, the nominal exchange rate is given by

$$E_{in,t} = \frac{\varphi_{i,t} P_{n,t} C_{n,t}}{\varphi_{n,t} P_{i,t} C_{i,t}} = \frac{\varphi_{i,t} Z_{n,t}}{\varphi_{n,t} Z_{i,t}}.$$

For the analytical results that follow, we will focus on the case where $log\left[\frac{Z_{i,t}}{Z_{i,t-1}}\right]$ and $log\left[\frac{\varphi_{i,t}}{\varphi_{i,t-1}}\right]$ each follows an AR(1) process with persistence ρ and i.i.d. innovations,[27] so that the nominal exchange rate satisfies $\mathbb{E}_t\left[\Delta e_{in,t+1}\right] = \rho \Delta e_{in,t}$.[28] The complete market assumption and the labor-leisure condition also imply that if wages are flexible, $\theta_w = 0$, relative wages are constant across countries, $rer^w_{in,t} = 0$. In this case, movements in nominal wages completely offset movements in the nominal exchange rate. If instead wages are sticky, relative wages depend of previous relative wages and changes in the nominal exchange rate

$$rer^w_{in,t} = \left[1-\theta_w\right]\overline{rer}^w_{in,t} + \theta_w\left[rer^w_{i,t-1} + \Delta e_{in,t}\right], \tag{18}$$

where $\overline{rer}^w_{in,t} = \beta\theta_w \mathbb{E}_t\left[\overline{rer}^w_{in,t+1} - \Delta e_{in,t+1}\right]$. Appendix B completely characterizes the stochastic process of the real and the reset exchange rates in this model.

5.2.1 Sluggish relative wages ($\theta_w = 0$)

We can now study the behavior of the real and the reset exchange rates in models where wages are flexible. A large literature has studied the persistence of the real exchange rate in these models, showing that it increases with: (i) the degree of nominal price rigidities,

[27] Alternatively, we can shut down one of these shocks so that the nominal exchange rates are either driven exclusively by nominal or preference shocks.

[28] We relax this assumption for our quantitative results in Section 5.2.3.

θ_p (Chari et al. 2002), (ii) the persistence of the exogenous shocks, ρ, (Benigno 2004, Carvalho and Nechio 2011 and Engel, 2016), and (iii) the degree of real rigidities, α, (Bergin and Feenstra 2001, Bouakez 2005). In what follows, we proceed in steps and evaluate alternative parameterizations that isolate how each of these mechanisms affects the contribution of the reset exchange rate to real exchange rate movements.[29] To this end, we will measure the persistence of the real exchange rate by its autocorrelation, which we denote by $\mathcal{P}\left[rer_{in}\right]$. We will also study the cumulative impulse response of the real exchange rate at period $t+k$ to shocks in period t,[30] and evaluate the fraction of this impulse response that is accounted for by the reset exchange rate. We denote this fraction by $\chi_k \equiv \mathbb{E}_t\left[\overline{rer}_{in,t+k}\right]/\mathbb{E}_t\left[rer_{in,t+k}\right]$. Appendix B derives the following proposition:

Proposition 1. (Relative prices properties) *In the following special parameterizations, $\mathcal{P}\left[rer_{in}\right]$ and χ_k are given by:*

- *Case 1- Only price rigidities: if $\rho = \alpha = 0$, then $\mathcal{P}\left[rer_{in}\right] = \theta_p$ and $\chi_k = 0$.*
- *Case 2- Persistent shocks: if $\rho > 0$ and $\alpha = 0$, then $\mathcal{P}\left[rer_{in}\right] = \frac{\theta_p+\rho}{1+\theta\rho}$ and $\chi_k = \frac{\theta_p\beta\rho}{1-\theta\beta\rho}\frac{\theta_p^{k+1}-\rho^{k+1}}{\theta_p-\rho}$.*
- *Case 3- Real rigidities: if $\rho = 0$ and $\alpha > 0$, then $\mathcal{P}\left[rer_{in}\right] = \theta_p\Omega(\alpha)$ and $\chi_k = \frac{1-1/\Omega(\alpha)}{1-\theta_p}$, where $\Omega(\alpha)$ is increasing and satisfies $\Omega(0) = 1$ and $\Omega(1) = 1/\theta_p$.*

Proposition 1 evaluates our decomposition under three special cases described below.

Case 1- Only price rigidities: In this case depicted in the solid blue lines in Figure 3, the autocorrelation of the real exchange rate is given by θ_p, and the reset exchange rate is constant, $\overline{rer}_{in,t} = 0$, so $\chi_k = 0$. Intuitively, the persistence of the real exchange rate arises only from the infrequent price adjustment, but the relative prices for the firms that do adjust (i.e. the reset exchange rate) are constant. If we set $\theta_p = 0.85$ to match the average frequency of price changes in the UK microdata, the model cannot generate enough persistence in the real exchange rate, as noted by Chari et al. (2002).

Carvalho and Nechio (2011) show that multi-sector models yield more persistent aggregate real exchange rates than a one-sector model calibrated to match the average frequency of price changes. Online Appendix C shows numerically that the multi-sector model yields very similar results to a one-sector model in which θ_p is chosen to match the

[29] After evaluating the role of each parameter in isolation in this section, and after adding sticky wages in the next section, we will evaluate to a full quantitative model that combines all the mechanisms presented here. We take our parameter values from the literature, and evaluates the robustness of our results to alternative parameterizations in Appendix E.

[30] Formally, starting from a symmetric steady state in period $t-1$, we evaluate how different parameters affect $\mathcal{CIR}_{t+k}\left[rer_{in,t}\right] \equiv \mathbb{E}_t\left[rer_{in,t+k}\right]/\Delta e_{in,t}$.

average duration of prices, which in our data corresponds to setting $\theta_p = 0.93$.[31] We use this value of θ_p in all our calibrations.[32] While this increases the persistence of the real exchange rate, the reset exchange rate is still constant in this calibration, $\chi_k = 0$.

Case 2- persistent shocks: Increasing the persistence of the shocks makes the IRF of the real exchange rate hump-shaped and more persistent, but also makes the reset exchange rate negatively correlated to the real exchange rate. This is illustrated in the red x-doted lines in Figure 3 for $\rho = 0.2$.[33] Intuitively, since producers that reset prices may be unable to change prices again in the future, they respond more than one to one to a persistent shock. This implies that increasing the real exchange rate persistence by increasing ρ moves the reset exchange rate in the opposite direction than in the data.

Case 3- real rigidities: This case is depicted in the green doted lines in Figure 3. Since $\Omega(\alpha)$ is increasing, real rigidities simultaneously increase the persistence of the real exchange rate and the contribution of the reset exchange rate to the real exchange rate. Intuitively, now reset prices track aggregate prices due to the real rigidities, so that reset exchange rates move with the real exchange rate. We explore quantitatively if real rigidities alone can replicate our empirical decomposition by calibrating $\bar{\alpha}$ and ϕ following the literature.[34] In this case, $\chi_k \simeq 0.44$, well below what is observed in the data.

We conclude that SPOE models with sluggish relative wages can generate persistent real exchange rates, but are hard to reconcile with the reset exchange rate data. The following section evaluates whether the behavior of the reset exchange rate can be approximated in models with sticky wages.

5.2.2 Sticky wages

We now evaluate the model presented above when wages are sticky. Appendix B generalizes Proposition 1 to the case of $\theta_w > 0$. To isolate how wage stickiness affects real and reset exchange rates, we first consider a case with no real rigidities $\alpha = 0$ and i.i.d

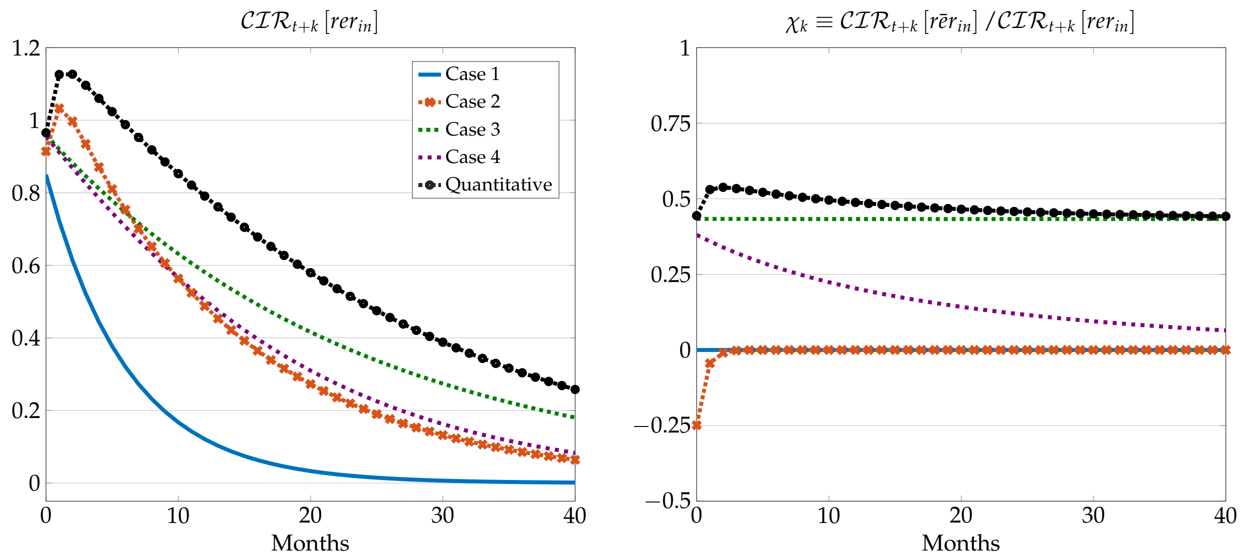
[31] Blanco and Bailey (Forthcoming) and Alvarez et al. (2016) show that, if shocks are i.i.d and there are no real rigidities, the effects of monetary shocks in a single-sector vs. a multi-sector closed economy are the same if the two models are calibrated to match the same average duration of price spells.

[32] We also take $\beta = 0.96^{1/12}$ and $\mu = 0.94$ from Chari et al. (2002).

[33] We use $\rho = 0.2$ to match the monthly autocorrelation of the growth rate of the UK-Austria nominal exchange rate for the 2006-2015 period.

[34] In particular, we set $\bar{\alpha} = 0.5$ to match the share of intermediate inputs in production, $\frac{\phi}{\gamma-1} = \frac{2}{3}$ to match the elasticity of markups following Amiti et al. (2016) . Appendix E shows that our conclusions hold in a quantitative model with an extreme calibration of $\frac{\phi}{\gamma-1} = 4$.

Figure 3: Impulse responses



Note: The left panel plots the impulse response of the real exchange rate and right panel plots the χ_k in equation defined in the main text.

shocks, $\rho = 0$. Figure 3 depicts this case for $\theta_w = 0.90$ under 'Case 4'.[35] Introducing wage rigidities increases the persistence of the real exchange rate. The figure shows that in this case χ_k is still below 0.5 at every horizon. Thus, although relative wages track the nominal exchange rate in this model (see eq. 18), the reset exchange rate accounts for only a fraction of the real exchange rate.

Discussion: Equation (18) shows that if θ_w is large, relative wages mimic movements in the nominal exchange rate. From our discussion of the static model in Section (2), one would expect that this model could replicate the empirical real exchange rate decomposition. However, in the dynamic model the reset exchange rate depends on current *and future* relative wages (see equation 14). Because relative wages mean revert, the reset exchange rate at period t does not track Δe_t, even if $rer^w_{in,t}$ does.

To emphasize this point, consider the cumulative impulse responses when $\alpha = 0$ and $\rho = 0$. In this case

$$\mathbb{E}_t\left[rer^w_{in,t+k}\right] = \theta_w^{k+1}\Delta e_{in,t},$$

[35]We take this value from Del Negro et al. (2007).

and by equation (14):

$$\overline{rer}_{in,t} = \frac{1-\beta\theta_p}{1-\beta\theta_p\theta_w}\left[2\mu-1\right]\theta_w \Delta e_{in,t}. \tag{19}$$

Note that in the limiting case of $\beta \to 1$ and $\theta_p \to 1$, the reset exchange rate is constant, $\overline{rer}_{in,t} \to 0$, even for large values of θ_w. That is, if producers discount future periods at a low enough rate, $\overline{rer}_{in,t}$ behaves like in the flexible wage model, insofar as relative reset wages mean revert. In contrast, in the limiting case of completely rigid wages, $\theta_w \to 1$, if $\theta_p < 1$, $\overline{rer}_{in,t} \to [2\mu-1]\,\Delta e_{in,t}$. In this case, relative wages do not mean revert, so the reset exchange rate does track the nominal exchange rate.[36]

The discussion above highlights that reset exchange rates don't track the nominal exchange rate if wages mean revert quickly relative to the discount rate (i.e. whether θ_w is large relative to $\beta\theta_p$). In our calibration, β is close to 1 and there are large wage and price rigidities. If $\theta_p \simeq \theta_w$ we obtain $\overline{rer}_{in,t} \simeq \frac{[2\mu-1]\theta}{1+\theta}\Delta e_{in,t}$. Thus, if θ and μ are close to 1, then on impact the elasticity of the reset exchange rate to a change in the nominal exchange rate is close to 1/2, and so is $\overline{rer}_{in,t}/rer_{in,t}$ by equation (14). This is what is reflected in Figure 3.

5.2.3 Quantitative results

We conclude this section by considering different quantitive versions of the model presented above. The parameters used for each of these models are reported in Table 4, though we evaluate the robustness to our results to alternative parameterizations in Appendix E. Here, we first evaluate a model that combines all the mechanisms that were studied separately under Cases 1-4. The impulse responses of this calibration are plotted in the circled-black lines in Figure 3 to facilitate comparisons with our previous results. Combining the different ingredients studied in the literature, the model generates persistent real exchange rates, with a half life that is close to 30 months, in line with the data.[37] However, the fraction of the impulse response of the real exchange rate accounted by the reset exchange rate χ_k is only around 0.5.[38] Business-cycle statistics of this model are listed in the second column of Table 5, under the column labeled 'Benchmark'. While the

[36]This is also the case if agents completely discount the future, $\beta \to 0$, as that model works much like the static model presented in Section 2.

[37]See i.e. Rogoff (1996) and Burstein and Gopinath (2015).

[38]Note that while both real rigidities and wage stickiness each individually generate a χ_k of around almost 0.5, incorporating both simultaneously only produces a marginally higher χ_k. The reason is that, when real rigidities are large, reset prices depend more on competitors prices and less on wages, which mitigates the effects of the nominal wage rigidities.

Table 4: Parameterization

Parameter	Description	Value	Target/source
β	Discount factor	$0.96^{1/12}$	Chari et al. (2002)
μ	Home bias parameter	0.94	Chari et al. (2002)
ξ	Elast. subst. imported vs. domestic goods	1.5	Chari et al. (2002)
$\frac{\phi}{\gamma-1}$	Markup elasticity	0.66	Amiti et al. (2016)
$\bar{\alpha}$	Share of intermediates in production	0.5	VA/Output. WIOD
ρ	Persistence of nominal exchange rate	0.20	Persistence of nominal exchange rate
$1-\theta_p$	Frequency of price changes	0.07	Average price duration across items, UK
$1-\theta_w$	Frequency of wage changes	0.10	Del Negro et al. (2007)

Note: Appendix E evaluates the robustness of our quantitative results to alternative parameterizations.

model is close to matching the autocorrelation of the real exchange rate and its correlation with the nominal exchange rate, it does not produce enough movements in the reset exchange rate. The slope of the relation between $\overline{rer}_{in}$ and rer_{in} is about half of that in the data plotted data in Figure 2.

Next, we deviate from the restrictions needed for Proposition 1 by introducing more general preferences and by incorporating money in the utility function, as in Chari et al. (2002).[39] The third Column of Table 5 shows that the results from this model are close to those in the Benchmark case, though the relation between $\overline{rer}_{in}$ and rer_{in} is somewhat closer to the data. This implies that the additional restrictions imposed to derive Proposition 1 do not seem to be quantitatively important for the results of the models studied so far.

Finally, we allow for a more realistic monetary policy by assuming that the monetary authority follows a Taylor Rule as in Steinsson (2008), and focus on a model purely driven by real shocks. As noted by Steinsson (2008), this version of the model can generates hump-shaped dynamics in the real exchange rates, which greatly increase the real exchange rate persistence. In fact, the fourth column in Table 5 shows that this calibration produces an autocorrelation of the real exchange rate that is close to the data. However, the dynamics of the nominal exchange rate in this model generate a reset exchange rate that is much more volatile than in the data.

[39] Appendix C presents a full description of this model.

Table 5: Business cycle moments: models and data

Moments	Data	Benchmark	CKM2002	STE2008	Disconnect
Autocorrelations (levels)					
Real	0.971	0.959	0.943	0.987	0.998
Reset	0.939	0.964	0.937	0.980	0.998
Slope $\Delta \bar{rer}_{in,t}$ w.r.t. $\Delta rer_{in,t}$					
Monthly	0.993	0.466	0.637	1.468	0.804
Quarterly	0.982	0.534	0.632	1.664	0.920
Semiannual	0.981	0.535	0.628	1.777	0.958
Annual	0.984	0.523	0.620	1.868	0.980

Notes: The table presents business cycle moments of the data and the simulation series from the models. The time period in the data and in the model have the same lenght. All the moments in the model are the median over 5000 simulations.

5.3 A model with persistent movements in relative wages

We now evaluate an alternative model where nominal wages are 'disconnected' from the nominal exchange rate. In this model, relative wages track the nominal exchange rate not because nominal wages are rigid, but because they are not directly affected by the shocks driving the nominal rate. This is a common feature of incomplete market models in which the UIP fails to hold due to shocks to international asset demand, such as those proposed in Jeanne and Rose (2002) and Gabaix and Maggiori (2015), and quantified in Devereux and Engel (2002) and Kollmann (2005). More recently, Itskhoki and Mukhin (2017) show that incorporating this type of shocks into a dynamic general equilibrium model can help resolve many of the puzzles associated with the exchange rate disconnect. In this section, we evaluate whether a version of the model that incorporates these features can rationalize the observed exchange rate decomposition presented in Section 4.

We study this question in a version of the model above that closely follows the setup in Itskhoki and Mukhin (2017): financial markets are incomplete and there is a variable wedge on the return of country n bonds perceived by households from country i vs. country n. In particular, the sequential household budget constraint in country i is given by

$$\frac{B_{ii,t+1}}{R_{i,t}} + \frac{B_{ni,t+1}}{E_{in,t}e^{\psi_t}R_{n,t}} + P_{i,t}C_{i,t} = B_{ii,t} + \frac{B_{ni,t}}{E_{in,t}} + W_{i,t}N_{i,t} + \Upsilon_{i,t} + T_{i,t} + \Omega_{i,t}.$$

Here, $B_{ii,t+1}$ is a bond that pays one unit of the currency of country i in period $t+1$, and $1/R_{i,t}$ is the price of that bond. $B_{ni,t+1}$ is bond that pays one unit of the currency of country n, for which households in country i must pay a date t price in currency n of $1/\left[e^{\psi_t}R_{n,t}\right]$. As Itskhoki and Mukhin (2017), we make the simplifying assumption that country n households cannot purchase bonds issued in country i, and can purchase country n bonds at price $R_{n,t}$. They thus face the budget constraint:

$$\frac{B_{nn,t+1}}{R_{n,t}} + P_{n,t}C_{n,t} = B_{nn,t} + W_{n,t}N_{n,t} + Y_{n,t} + T_{n,t}.$$

Finally, e^{ψ_t} is a shock to international asset demand. This shock drives a wedge between the rate of return on bonds issued by country n that is perceived in the two countries. We assume that this wedge follows an AR(1) process, $\psi_t = \rho_\psi \psi_{t-1} + \epsilon_t$, and that the proceeds from this wedge are rebated to country i households, $\Omega_{i,t} \equiv \frac{B_{ni,t+1}}{E_{in,t}R_{n,t}}\left[\frac{1}{e^{\psi_t}} - 1\right]$. Market clearing in bonds implies $B_{ii,t+1} = B_{ni,t+1} + B_{nn,t+1} = 0$.

Appendix C presents the full model and its calibration, which is taken mostly from Itskhoki and Mukhin (2017). There we show that changes in the nominal exchange rate are given by:

$$\mathbb{E}_t\left[\Delta e_{in,t+1}\right] = i_{i,t} - i_{n,t} + \psi_t.$$

where $i_{\cdot,t}$ denotes the (net) nominal interest rate. Thus, by design the UIP does not hold in this model.

To understand why this model may be able to replicate the empirical decomposition of the real exchange rate, note that if there are no shocks in the model other than those to ψ_t, the labor-leisure condition associated with (16) together with our rule for aggregate nominal expenditures yields,

$$\bar{Z} = PC = \bar{W}.$$

If nominal expenditures are fixed, then nominal wages are fixed, which implies that $\Delta rer^w_t = \Delta e_t$. In contrast to the sticky wage model with $\theta^w < 1$, relative wages do not revert in this limiting version of the model with constant nominal demand. In this case, the properties of the reset exchange rate resemble the limiting case of the sticky wage model where $\theta^w = 1$, which as discussed above can replicate our empirical decomposition.

We conclude by presenting a quantitative version of this model with a more realistic monetary rule. In particular, we assume that the monetary authority follows a Taylor rule that targets inflation, as Itskhoki and Mukhin (2017). The fifth column in Table 5 summarizes the dynamic properties of the real and the reset exchange rate in this model. The model produces very persistent real exchange rates that are almost perfectly correlated to the nominal exchange rates. It also does a much better job in replicating the relation between rer_{in} and $\overline{rer}_{in}$.

Figure 4 compares movements in the real exchange rates (x-axis) to changes in the reset exchange rates (y-axis), in the data, the benchmark model, and in the incomplete markets model (labeled 'Disconnect'), for changes computed at monthly, quarterly, semiannual and annual frequencies. In each case, we normalize the growth rates of the real and the reset exchange rate by twice the standard deviation of the change in the real exchange rate. Note that in the Benchmark model, the slope of this relation is close to one-half for all frequencies, consistent with the impulse responses presented above, while in the data the slope is always close to one. In contrast, the model with incomplete markets generates a larger slope that is close to one at low frequencies.

6 Conclusion

Addressing the PPP puzzle is one of the central questions in international economics. This paper sheds light on the puzzle by showing that real exchange rates movements are primarily driven by movements in what we label as the 'reset exchange rate', i.e. relative reset prices across countries. This empirical finding is at odds with the predictions of Sticky Price Open Economy models where relative wages are sluggish or mean revert quickly. These models can generate volatile and persistent real exchange rates, but only through cross-country movements in the difference between reset and non-reset prices. Models where movements in relative wages are persistent and track the nominal exchange rate do replicate the empirical properties of both the real exchange rate and of relative reset prices.

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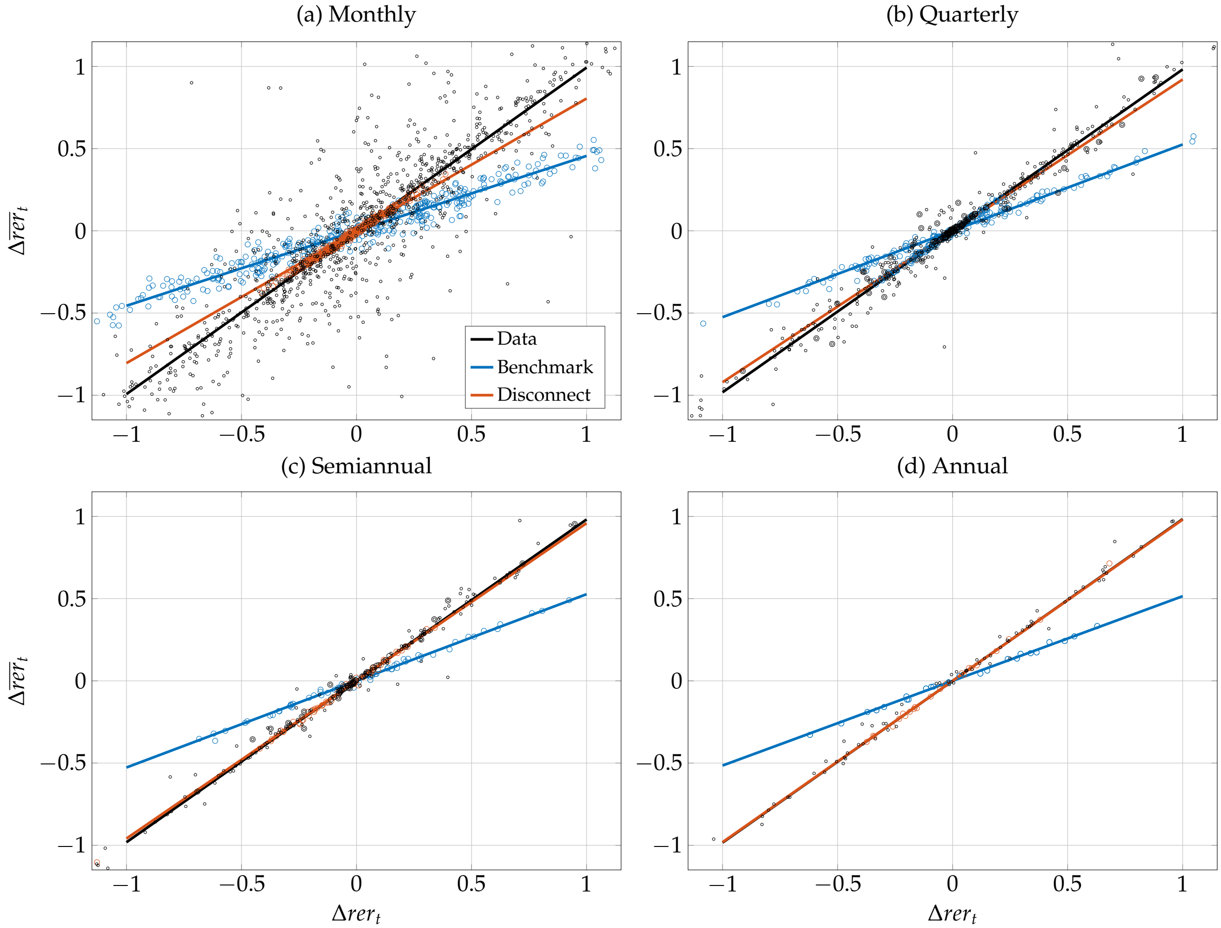
Figure 4: Changes in real vs. reset exchange rates: Models vs. Data



Note: The figure plots movements in real exchange rates (x-axis) and changes in reset exchange rates (y-axis), for changes computed at monthly, quarterly, semiannual and annual frequencies. Each circle represent a change for a country pair. 'Benchmark' refers to data simulated from our benchmark model. 'Disconnect' refers to data simulated from the incomplete markets model based on Itskhoki and Mukhin (2017).

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Table A1: CPI weights

	Austria		Chile		Finland		Mexico		UK	
	Microdata	Official	Microdata	Official	Microdata	Official	Microdata	Official	Microdata	Official
Food & non-alc. beverages	0.12	0.12	0.19	0.19	0.14	0.14	0.22	0.22	0.11	0.11
Alc. beverages & tobacco	0.03	0.03	0.02	0.02	0.02	0.05	0.02	0.02	0.04	0.04
Clothing & footwear	0.06	0.06	0.05	0.05	0.05	0.05	0.08	0.08	0.06	0.06
Housing & utilities	0.14	0.18	0.04	0.13	0.07	0.22	0.05	0.07	0.06	0.13
Furnishings	0.08	0.08	0.05	0.07	0.06	0.06	0.08	0.10	0.06	0.06
Health	0.05	0.05	0.06	0.06	0.04	0.05	0.05	0.05	0.02	0.02
Transport	0.14	0.14	0.17	0.18	0.08	0.14	0.11	0.11	0.06	0.15
Communication	0.02	0.02	0.03	0.05	0.02	0.02	0.02	0.02	0.01	0.03
Recreation & culture	0.12	0.12	0.07	0.07	0.08	0.12	0.05	0.05	0.09	0.15
Education	0.01	0.01	0.05	0.07	0.00	0.00	0.08	0.08	0.02	0.02
Restaurants & hotels	0.08	0.08	0.04	0.04	0.06	0.06	0.07	0.07	0.11	0.13
Miscellaneous	0.10	0.10	0.04	0.06	0.04	0.07	0.07	0.07	0.08	0.10
Aggregate	**0.96**	**1.00**	**0.81**	**1.00**	**0.65**	**0.99**	**0.91**	**0.95**	**0.74**	**1.00**

Note: 'Microdata' refers to the weights in our sample of the CPI data. 'Official' refers to the official CPI weights.

Table A2: Monthly frequency of regular price changes

	Austria	Chile	Finland	Mexico	UK
Food & non-alc. beverages	0.10	0.40	0.19	0.46	0.14
Alc. beverages & tobacco	0.08	0.27	0.13	0.27	0.23
Clothing & footwear	0.14	0.14	0.13	0.26	0.16
Housing & utilities	0.19	0.44	0.52	0.54	0.16
Furnishings	0.09	0.16	0.10	0.32	0.14
Health	0.26	0.13	0.16	0.19	0.10
Transport	0.31	0.47	0.38	0.23	0.19
Communication	0.12	0.27	0.38	0.15	0.35
Recreation & culture	0.24	0.17	0.17	0.25	0.17
Education	0.06	0.20	0.07	0.17	0.13
Restaurants & hotels	0.09	0.10	0.10	0.14	0.09
Miscellaneous	0.07	0.14	0.26	0.32	0.11
Aggregate	**0.17**	**0.30**	**0.23**	**0.31**	**0.15**

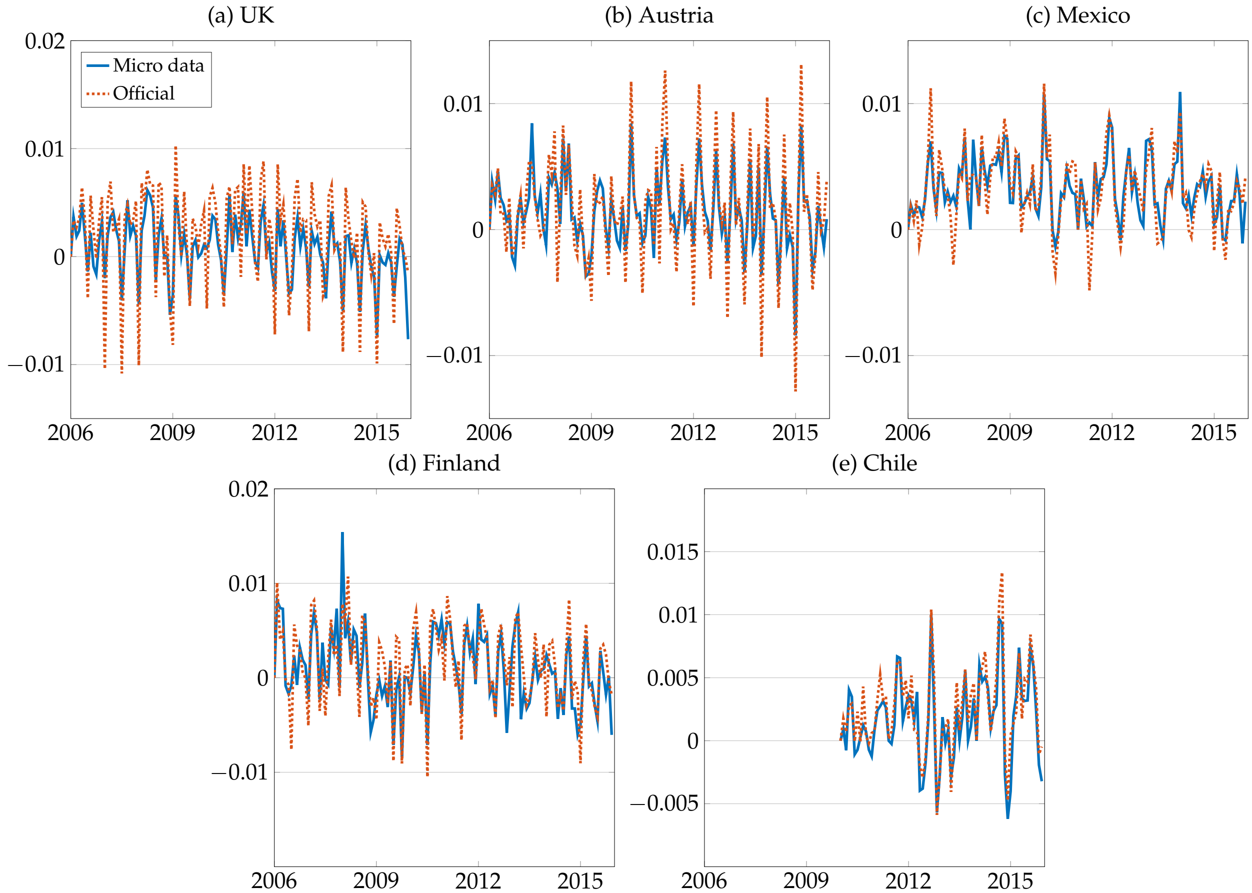
Note: 'Frequency' is the fraction of products that change price in a given month. All statistics are computed after excluding sales.

Table A3: Updates to the CPI basket

	Austria			UK		
	Fraction of new products	CPI weight of new items	Frequency	Fraction of new products	CPI weight of new items	Frequency
Months of basket update						
Average	0.03	0.01	0.26	0.13	0.03	0.17
Minimum	0.00	-	0.24	0.07	0.02	0.10
Maximum	0.12	0.05	0.29	0.22	0.10	0.25
Regular months						
Average	0.00	-	0.14	0.03	0.00	0.17
Minimum	-	-	0.09	-	-	0.10
Maximum	0.01	-	0.30	0.22	0.10	0.40

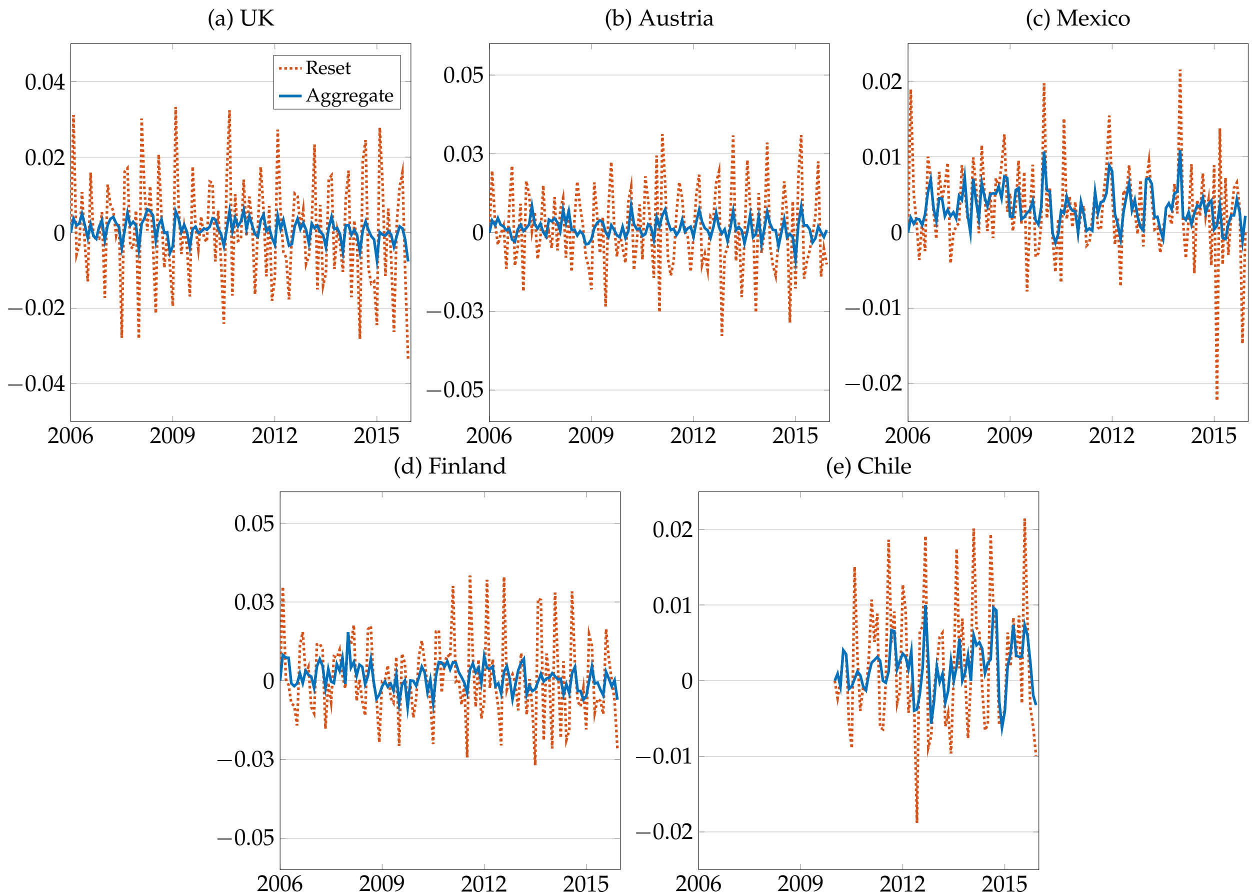
Note: 'Months of basket update' refers to every February for the UK, and every January starting in January 2011 for Austria. 'Regular months' refers to every other month. 'Fraction of new products' is the ratio of the number of new products over the total number of products. 'CPI weight new of new items' refers to the expenditure share of new item categories. 'Frequency' is the is the share of price changes relative to the number of price quotes in the month.

Figure A1: Inflation: Official sources vs. microdata



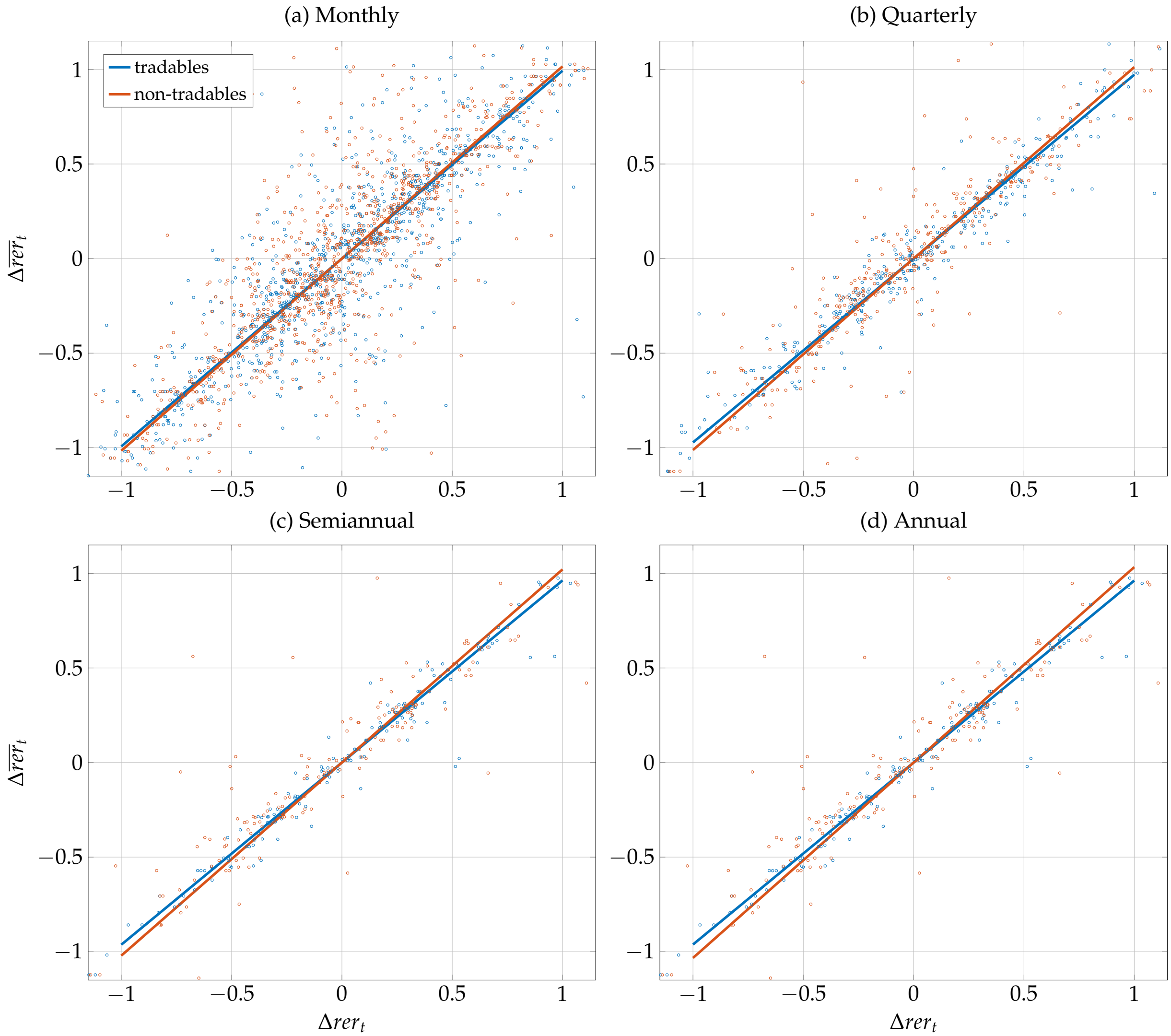
Note: The figures report monthly inflation computed from the microdata and monthly inflation obtained from official sources.

Figure A2: Empirical inflation and reset inflation (monthly)



Note: The figures report monthly aggregate and reset inflation defined in the main text.

Figure A3: Changes in real vs. reset exchange rates, Tradeables vs Non-Tradeables



Note: The figure plots changes in real exchange rates (x-axis) and changes in reset exchange rates (y-axis) computed at monthly, quarterly, semiannual and annual frequencies, for tradeable and non-tradeable exchange rates. Changes in real and reset exchange rate changes are both normalized by two times the standard deviation of the change in the aggregate bilateral real exchange rate. Each circle represent a change for a country pair.

Online Appendix - Not for Publication -

Price rigidities and the relative PPP

Andres Blanco and Javier Cravino

Appendix A Data

A.1 Algorithm used to define temporary sales

We now describe the algorithm used to filter sales. For that we need to identify dates t_s and t_e at which a sale starts and ends. With this in mind, we first define for every good ω the set $\mathcal{F}_{s,\omega}$ of all the dates where a sale starts, where a sale is defined as a period where, following a price change at date t, the cumulative price change between dates t and $t+k$ is close to zero:

$$\mathcal{F}_{s,\omega} = \{t_s : \quad |\Delta p_{i,t}(\omega) + \cdots + \Delta p_{i,t+k}(\omega) \leq \epsilon \quad , \quad \Delta p_{i,t}(\omega) \neq 0\}.$$

Similarly, we also define the set $\mathcal{L}_{e,\omega}$ of all the dates where a sale ends:

$$\mathcal{L}_{e,\omega} = \{t : \quad |\Delta p_{i,t-k}(\omega) + \cdots + \Delta p_{i,t}(\omega)| \leq \epsilon \quad , \quad \Delta p_{i,t}(\omega) \neq 0\}.$$

We identify as a sale all the price changes between (t_s, ω) and (t_e, ω), if $t_e - t_s \leq 2$.

A.2 Algorithm used in the UK data

For a small subset of items and regions, the United Kingdom's Office for National Statistics does not report outlet identifiers to comply with confidentiality guidelines. In such cases, there could be multiple price quotes with the same product-outlet identifier in a given month in the dataset. In most of these cases, there is no variation in prices that share an identifier in a given month. For the few cases in which we do observe different prices sharing an identifier in multiple dates, we must decide on how to link these prices across time period. We do so by using information on cumulative inflation for each good that is reported to us by the ONS.

Consider an non-unique identifier $\tilde{\omega}$ that includes multiple price quotes at both dates t_1 and t_2. Let $\mathscr{P}_{t_1}(\tilde{\omega})$ denote the set of price quotes reported in date t_1. We would like to link each of these prices quotes with another price quote belonging to the set $\mathscr{P}_{t_2}(\tilde{\omega})$. The mapping is non-trivial because the elements in $\mathscr{P}_{t_1}(\tilde{\omega})$ and $\mathscr{P}_{t_2}(\tilde{\omega})$ don't share a unique identifier that can be traced through time. We thus proceed in the following steps:

i. Take and element from $\mathscr{P}_{t_2}$ and use the data on cumulative inflation to back up the price that this element should have had in t_1. Label this 'backed-up' price x.

ii. Find the price in the set $\mathscr{P}_{t_1}$ that coincides with x.

iii. Repeat steps 1 and 2 for every element in $\mathscr{P}_{t_2}$.

We repeat this algorithm for all dates in which we observe the identifier $\tilde{\omega}$.

Appendix B Proofs and formulas

B.1 Derivation of equations (14) and (15)

We start by deriving the equations (14) and (15). To a first order, we can write the price indexes associated with (9) and (10) as:

$$p_{i,t} = \mu p_{ii,t} + [1-\mu]\, p_{ni,t}.$$

Under calvo pricing, the laws of motion for average prices are:

$$p_{ni,t} = \left[1-\theta_p\right] \bar{p}_{ni,t} + \theta_p p_{ni,t-1},$$

and optimal reset prices satisfy:

$$\bar{p}_{ni,t} = \left[1-\beta\theta_p\right] \tilde{p}_{ni,t} + \beta\theta_p \mathbb{E}_t \left[\bar{p}_{ni,t+1}\right].$$

Here, $\tilde{p}_{ni,t}$ is the 'optimal spot price', which satisfies

$$\tilde{p}_{ni,t} = \frac{\Gamma}{1+\Gamma} p_{ni,t} + \frac{1}{1+\Gamma}\left[mc_{n,t} - e_{in,t}\right], \tag{B.1}$$

where $\Gamma \equiv \frac{\phi}{\gamma-1}$ is the elasticity of markups implied by the aggregator in (10), and $mc_{n,t} = \bar{\alpha} w_{n,t} + [1-\bar{\alpha}]\, p_{n,t}$ are marginal costs for firms from country i. Combining these equations with the definition of the real exchange rate we obtain:

$$rer_{in,t} = \left[1-\theta_p\right] \overline{rer}_{in,t} + \theta_p \left[rer_{i,t-1} + \Delta e_{in,t}\right],$$

and

$$\overline{rer}_{in,t} = \left[1-\beta\theta_p\right] \widetilde{rer}_{in,t} + \beta\theta_p \mathbb{E}_t \left[\overline{rer}_{in,t+1} - \Delta e_{in,t}\right],$$

with $\widetilde{rer}_{in,t} \equiv \tilde{p}_{i,t} + e_{in,t} - \tilde{p}_{n,t}$. In combination with (B.1) we obtain:

$$\widetilde{rer}_{in,t} = \alpha rer_{in,t} + \iota rer^{w}_{in,t},$$

with $\alpha \equiv \frac{\Gamma+\bar{\alpha}[2\mu-1]}{1+\Gamma}$ and $\iota \equiv \frac{[1-\bar{\alpha}][2\mu-1]}{1+\Gamma}$, which coincides with the expressions in the text.

B.2 Derivation of equation (18)

In each country, the marginal utility of consumption satisfies:

$$\beta^t \frac{\partial u_j(C_{j,t}, X_{j,t})}{\partial C_{j,t}} = \lambda_i P_{i,t} \Theta_{i,t},$$

where λ_i is the Lagrange multiplier on country-i's budget constraint. Taking log-differences across countries and using the definition of the nominal exchange rate, assuming $E_{in,0} = 1$

we have that

$$rer_{in,t} = u^c_{i,t} - u^c_{n,t}.$$

The Calvo assumption for wage setting implies that the law of motion for wages is

$$w_{i,t} = [1-\theta_w]\,\bar{w}_{i,t} + \theta_w w_{i,t-1},$$

where reset wages satisfy

$$\bar{w}_{i,t} = [1-\beta\theta_w]\,\tilde{w}_{i,t} + \beta\theta_w \mathbb{E}_t\left[\bar{w}_{i,t+1}\right],$$

with

$$\tilde{w}_{i,t} = p_{i,t} - u^c_{i,t},$$

where $u^c_{i,t}$ is the utility of consumption. Relative wages are then:

$$rer^w_{in,t} = [1-\theta_w]\,\overline{rer}^w_{in,t} + \theta_w\left[rer^w_{i,t-1} + \Delta e_{in,t}\right],$$

and

$$\overline{rer}^w_{in,t} = \beta\theta_w \mathbb{E}_t\left[\overline{rer}^w_{in,t+1} - \Delta e_{in,t}\right].$$

B.3 Proof of Proposition 1

We now derive Proposition 1. We start by deriving a more general result that characterizes the laws of motion of the real and reset exchange rates under any combination of parameters. Proposition 1 is a special case of this results.

Stochastic processes for $rer_{in,t}$ and $\overline{rer}_{in,t}$ in general equilibrium Collecting the results derive above, we list the set of equilibrium conditions that from which we will derive Proposition 1:

$$\begin{aligned}
rer_{in,t} &= \left[1-\theta_p\right]\overline{rer}_{in,t} + \theta_p\left[rer_{i,t-1} + \Delta e_{in,t}\right], && \text{(B.2)}\\
rer^w_{in,t} &= \left[1-\theta_w\right]\overline{rer}^w_{in,t} + \theta_w\left[rer^w_{i,t-1} + \Delta e_{in,t}\right], && \text{(B.3)}\\
\overline{rer}_{in,t} &= \left[1-\beta\theta_p\right]\left[\iota rer^w_{in,t} + \alpha rer_{in,t}\right] + \beta\theta_p \mathbb{E}_t\left[\overline{rer}_{in,t+1} - \Delta e_{in,t+1}\right], && \text{(B.4)}\\
\overline{rer}^w_{in,t} &= \beta\theta_w \mathbb{E}_t\left[\overline{rer}^w_{in,t+1} - \Delta e_{in,t+1}\right], && \text{(B.5)}\\
\mathbb{E}_t\left[\Delta e_{in,t+1}\right] &= \rho\Delta e_{in,t}. && \text{(B.6)}
\end{aligned}$$

Combining equations B.3, B.5 and B.6 yields the following stochastic in difference equation:

$$rer^w_{in,t} = b^w_1 rer^w_{in,t-1} + b^w_2\Delta e_{in,t} + b^w_3\mathbb{E}_t[rer^w_{in,t+1}]$$

where $b_1^w \equiv \frac{1}{\Upsilon_w}$, $b_2^w \equiv \frac{1-\beta\rho}{\Upsilon_w}$, $b_3^w \equiv \frac{\beta}{\Upsilon_w}$ and $\Upsilon_w \equiv 1+\beta+\frac{[1-\theta_w][1-\beta\theta_w]}{\theta_w}$. We can solve this equation by guessing and verifying the answer. In particular, guessing that $rer^w_{in,t} = Crer^w_{in,t-1} + D\Delta e_{in,t}$, we have that

$$Crer^w_{in,t-1} + D\Delta e_{in,t} = b_1^w rer^w_{in,t-1} + b_2^w \Delta e_{in,t} + b_3^w C^2 rer^w_{in,t-1} + b_3^w \left[C+\rho\right] D\Delta e_{in,t}.$$

Which implies that

$$C = \frac{\Upsilon_w \pm \sqrt{\Upsilon_w^2 - 4\beta}}{2\beta}.$$

Using the Viete's rule it is easy to see that the two roots over C, (C_1, C_2) satisfy

$$C_1 + C_2 = \frac{\Upsilon_w}{\beta} \quad , \quad C_1 C_2 = \frac{1}{\beta};$$

Now we show that for all $\beta \in (0,1)$, the solution satisfies $0 < C_1 < 1 < C_2$. To see this property notice that using the previous two equations, $f(C) = C + \frac{1/\beta}{C} = 1 + \frac{1}{\beta} + H = \Delta$ where $H = \left[\theta_w^{-1} - 1\right]\left[\theta_w^{-1} - \beta\right]/\beta$. $f(C)$ has an unique minimum at $\beta^{-1/2}$. Since $f(C)$ is decreasing between $(0, \beta^{-1/2})$ and $f(1) \leq \Delta$, there exist a $C_1 < 1$ s.t. $f(C_1) = \Delta$. Since the the function is increasing after the minimum, there exist other root with $C_2 > \beta^{-1/2} > 1$. Thus if we discard the explosive root, we have

$$C = \frac{\Upsilon_w - \sqrt{\Upsilon_w^2 - 4\beta}}{2\beta}$$

and

$$D = \frac{2\left[1-\beta\rho\right]}{\Upsilon_w + \sqrt{\Upsilon_w^2 - 4\beta} - 2\beta\rho}.$$

Thus the solution for the real exchange rate is given by

$$rer^w_{in,t} = A_{1w} rer^w_{in,t-1} + A_{2w}\Delta e_{in,t}, \tag{B.7}$$

with $A_{1w} \equiv \frac{\Upsilon_w - \sqrt{\Upsilon_w^2-4\beta}}{2\beta}$ and $A_{2w} \equiv \frac{2[1-\beta\rho]}{\Upsilon_w + \sqrt{\Upsilon_w^2-4\beta}-2\beta\rho}$.

We proceed in a similar way to characterize the dynamics of the real exchange rate. Combining equations (B.2), (B.4) and (B.6) we obtain the following difference equation:

$$rer_{in,t} = b_0^p rer^w_{in,t} + b_1^p rer_{in,t-1} + b_2^p \Delta e_{in,t} + b_3^p \mathbb{E}_t[rer_{in,t+1}]$$

where $b_0^w \equiv \left[\theta_p^{-1} - 1\right]\left[\theta_p^{-1} - \beta\right]\iota_p/\Upsilon_p$, $b_1^p \equiv \frac{1}{\Upsilon_p}$, $b_2^p \equiv \frac{1-\beta\rho}{\Upsilon_p}$, $b_3^p \equiv \frac{\beta}{\Upsilon_p}$ and $\Upsilon_p \equiv 1+\beta+$

$\frac{[1-\theta_p][1-\beta\theta_p][1-\alpha]}{\theta_p}$. Doing a guess and verify as before, we obtain

$$rer_{in,t} = A_{0p} rer^{w}_{in,t} + A_{1p} rer_{in,t-1} + A_{2p} \Delta e_{in,t}, \tag{B.8}$$

with $A_{0p} \equiv \frac{[\theta_p^{-1}-1][\theta_p^{-1}-\beta]\iota_p}{\Upsilon_p-\beta[A_{1w}+A_{1p}]}$, $A_{1p}, \equiv \frac{\Upsilon_p-\sqrt{\Upsilon_p^2-4\beta}}{2\beta}$ and $A_{2p} \equiv \frac{2[1-\beta\rho(1-A_{0,p}A_{2w})]}{\Upsilon_p+\sqrt{\Upsilon_p^2-4\beta}-2\beta\rho}$. Finally, substituting (B.8) into (B.2) we obtain:

$$\overline{rer}_{in,t} = \frac{A_{0,p}}{1-\theta_p} rer^{w}_{in,t} + \frac{A_{1,p}-\theta_p}{1-\theta_p} rer_{in,t-1} + \frac{A_{2,p}-\theta_p}{1-\theta_p} \Delta e_{in,t}. \tag{B.9}$$

Equations (B.7), (B.8), and (B.9) completely characterize the stochastic processes for the relative wages, the real exchange rate, and the reset change rate.

Proposition 1. Iterating forward expression (B.7) for relative wages and using the definition of the cumulative impulse response we can write:

$$\begin{aligned}\mathcal{CIR}_{t+k}\left[rer^{w}_{in}\right] \equiv \frac{\mathbb{E}_t\left[rer^{w}_{in,t+k}\right]}{\Delta e_{in,t}} &= A_{2w}\sum_{i=0}^{k} A_{1w}^{i}\rho^{k-i} \\ &= A_{2w}\frac{A_{1w}^{k+1}-\rho^{k+1}}{A_{1w}-\rho}.\end{aligned}$$

Following the same steps using equation (B.8), for the real exchange rate we obtain

$$\begin{aligned}\mathcal{CIR}_{t+k}\left[rer_{in}\right] \equiv \frac{\mathbb{E}_t\left[rer_{in,t+k}\right]}{\Delta e_{in,t}} &= A_{0p}\sum_{i=l}^{k} A_{1p}^{k-l}\mathcal{CIR}_{t+l}\left[rer^{w}_{in}\right] + A_{2p}\sum_{i=0}^{k} A_{1p}^{i}\rho^{k-i} \\ &= A_{0p}\sum_{i=0}^{k} A_{1p}^{k-i}\mathcal{CIR}_{t+k}\left[rer^{w}_{in}\right] + A_{2p}\sum_{i=0}^{k} A_{1p}^{i}\rho^{k-i} \\ &= A_{2p}\frac{A_{1p}^{k+1}-\rho^{k+1}}{A_{1p}-\rho} + \frac{A_{0p}A_{2w}}{A_{1w}-\rho}\left[A_{1w}\frac{A_{1p}^{k+1}-A_{1w}^{k+1}}{A_{1p}-A_{1w}} - \rho\frac{A_{1p}^{k+1}-\rho^{k+1}}{A_{1p}-\rho}\right].\end{aligned}$$

Finally, using (B.9) we obtain:

$$\mathcal{CIR}_{t+k}\left[\overline{rer}_{in}\right] = \frac{A_{0,p}}{1-\theta_p}\mathcal{CIR}_{t+k}\left[rer^{w}_{in}\right] + \frac{A_{1,p}-\theta_p}{1-\theta_p}\mathcal{CIR}_{t+k}\left[rer_{in,t-1}\right] + \frac{A_{2,p}-\theta_p}{1-\theta_p}\rho^{k}$$

Case 1- Only price rigidities: In this case, $\theta^w = 0$, then $A_{1w} = A_{2w} = 0$, and $rer^{w}_{in,t} = 0$. In addition, if $\alpha = 0$, and $\rho = 0$ then $A_1^p - A_2^p = \theta$. Substituting in (B.8) and (B.9) we get, $rer_{in,t} = \theta\left[rer_{in,t-1} + \Delta e_{in,t}\right]$, and $\overline{rer}_{in,t} = 0$. Note that if $\rho = 0$, then $\mathbb{E}\left[\Delta e_{in,t+1}\right] = 0$ and the persistence of the real exchange rate is θ.

Case 2- Persistent shocks: In this case, $\theta^w = 0$, then $A_{1w} = A_{2w} = 0$, and $rer^w_{in,t} = 0$. In addition, if $\alpha_p = 0$, then $A^p_1 = \theta$ and $A^p_2 = \frac{-\theta\beta\rho}{1-\theta\beta\rho}$. The autocorrelation of the real exchange rate is $\mathbb{P} = \frac{\theta_p+\rho}{1+\rho\theta_p}$.

Case 3- Real rigidities: In this case, $\theta^w = 0$, then $A_{1w} = A_{2w} = 0$, and $rer^w_{in,t} = 0$. In addition, if $\rho_p = 0$, then $A^p_1 = A^p_2 > \theta_p$ and the autocorrelation of the real exchange rate is $\mathbb{P} = A^p_1$. Note that Υ_p is increasing in $1 - \bar{\alpha}$, so both the persistence and χ_j increase with α.

Appendix C Quantitative models

This section describes and analyzes the quantitative models from Section 5.

C.1 Setup

Chari et al. (2002) The Chari et al. (2002) model is analogous to the model in Section 5, except that household preferences are given by

$$U_n(h) = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma} \left[\kappa C_{n,t}(h)^{\frac{\xi-1}{\xi}} + [1-\kappa] \left[\frac{M_{n,t}(h)}{P_{n,t}} \right]^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi[1-\sigma]}{\xi-1}} - \frac{N_{n,t}(h)^{1+\varphi}}{1+\varphi} \right], \tag{C.1}$$

where C_n, N_n, and $\frac{M_n}{P_n}$ denote consumption, labor and real money balances in the n-country. Note that we are now introducing money explicitly in the utility function. We follow CKM and assume that the only shocks in the model are shocks to the money supply in each country $M_{i,t}$, which we assume follow an $AR(1)$ process in growth rates.

Taylor rule with real shocks This extension uses a Taylor rule to describe the monetary policy as in Steinsson (2008). In this model, we assume that preferences are given by (C.1), but replace the assumption that nominal demand in each country follows an AR(1) for a Taylor rule. In particular, we follow Steinsson (2008) and assume use the Taylor rule

$$1 + i_t = \left[\frac{\bar{\Pi}}{\beta}\right]^{1-\rho_i} [1 + i_{t-1}]^{\rho_i} \left[\left[\frac{\Pi_t}{\bar{\Pi}}\right]^{\phi_\pi} \left[\frac{C_t}{\bar{C}}\right]^{\phi_c} \right]^{1-\rho_i}.$$

The real shocks in this model are shocks to government expenditures, $G_t = Y_t \left[1 - \frac{exp[\bar{g}]}{exp[g_t]}\right]$, where $g_t = \rho_g g_{t-1} + \varepsilon_g$.

Incomplete markets and UIP shocks We now describe how to extend the model to allow for incomplete markets and deviations from UIP, as in Itskhoki and Mukhin (2017).

In particular, we maintain the structure of the model described in Section 5, but assume financial markets are incomplete. Household supply differentiated labor services and have monopoly power over their wage. They face Calvo-type constraints on their ability to adjust wages, the probability that a household can adjust its wage in a given period is given by $1-\theta^{w}$, but they can insure with state contingent securities $A_{n,t}(h)$ at time t. In country n the flow budget constraint is:

$$P_{n,t}C_{n,t}+\frac{B_{n,t+1}}{R_{n,t}}+\frac{B_{ni,t+1}}{E_{in,t}e^{\psi_{n,t}}R_{i,t}}+M_{n,t+1}=B_{n,t}+\frac{B_{ni,t}}{E_{in,t}}+M_{n,t}+A_{n,t}(h)+W_{n,t}(h)L_{n,t}(h)+T_{n,t}. \tag{C.2}$$

The flow budget constraint in country i is:

$$P_{i,t}C_{i,t}+\frac{B_{i,t+1}}{R_{i,t}}+M_{i,t+1}=B_{i,t}+M_{i,t}+A_{i,t}(h)+W_{i,t}(h)L_{i,t}(h)+T_{i,t}. \tag{C.3}$$

Following Itskhoki and Mukhin (2017), we assume that the monetary authority follows the Taylor rule given by

$$1+i_t=\left[\frac{\bar{\Pi}}{\beta}\right]^{1-\rho_i}[1+i_{t-1}]^{\rho_i}\left[\frac{\Pi_t}{\bar{\Pi}}\right]^{[1-\rho_i]\varphi_p}.$$

C.2 Calibrations

All the parameters are calibrated following the original papers, with the exception of those that come from the UK microdata. Table A5 list the calibrated parameters. The discount factor, β, the intertemporal and intratemporal elasticities of substitution, and the degree of home bias, σ, γ, ζ and μ are all taken from Chari et al. (2002). The persistence of the monetary shocks ρ is calibrated to match autocorrelation of the change in the Austria-UK bilateral exchange for the 2006-2015 period. The persistence of the government expenditure shocks used for the model with real shocks is taken from Steinsson (2008). Finally, for the model with incomplete markets we set a persistence of the shocks to $\rho_\phi=0.97$. The frequency of price changes, $1-\theta_p$, is chosen to match the average price duration observed in the UK microdata. We take the parameters in the Taylor rule from Steinsson (2008) and Itskhoki and Mukhin (2017), respectively.

Appendix D Numerical result claimed in Footnote 31

This section shows numerically two claims made in the main text. First, we show that under the conditions of Footnote 31, the impulse-response function of the one-sector model is quantitatively equivalently to the multi-sector model if both models are calibrated to match the same average duration of price changes. Second, we show that this result also holds in the full-quantitative model.

We start by extending the model to allow for multiple sectors that differ in the extent of price stickiness following Carvalho and Nechio (2011). With this in mind, we consider an economy where final goods producers aggregate the output of j different sectors

Table A5: Parameter values

Parameter	Description	Value	Target/source
		Benchmark model	
β	Discount factor	$0.96^{1/12}$	Chari et al. (2002)
μ	Home bias parameter	0.94	Chari et al. (2002)
ξ	Elast. subst. imported vs. domestic goods	1.5	Chari et al. (2002)
$\frac{\phi}{\gamma-1}$	Markup elasticity	0.66	Amiti et al. (2016)
$\bar{\alpha}$	Share of intermediates in production	0.5	VA/Output. WIOD
ρ	Persistence of nominal exchange rate	0.20	Persistence of nominal exchange rate
$1-\theta_p$	Frequency of price changes	0.07	Average price duration across items, UK
$1-\theta_w$	Frequency of wage changes	0.10	Del Negro et al. (2007)
		Additional parameters for Chari et al. (2002) model	
γ	Elasticity subst: varieties same country (prices)	10	Chari et al. (2002)
σ	Inter temporal elasticity of substitution	5	Chari et al. (2002)
κ	weight on consumption vs real balance	0.94	Chari et al. (2002)
ξ	Elasticity of subst.: consumption-real balances	0.34	Chari et al. (2002)
$\rho_{\Delta M}$	Persistence of monetary shocks	0.90	Chari et al. (2002)
φ	Elasticity of leisure	0.5	Chari et al. (2002)
		Additional parameters for Steinsson (2008) model	
ρ_i	Interest smoothing coefficient	0.95	Steinsson (2008)
ϕ_π	Inflation coefficient	2	Steinsson (2008)
ϕ_c	Consumption coefficient	0.5	Steinsson (2008)
ρ_g	Persistence of government expenditure shock	0.96	Steinsson (2008)
		Additional parameters for disconnect model	
ρ_i	Interest smoothing coefficient	0.95	Itskhoki and Mukhin (2017)
ϕ_π	Inflation coefficient	2.15	Itskhoki and Mukhin (2017)

according to

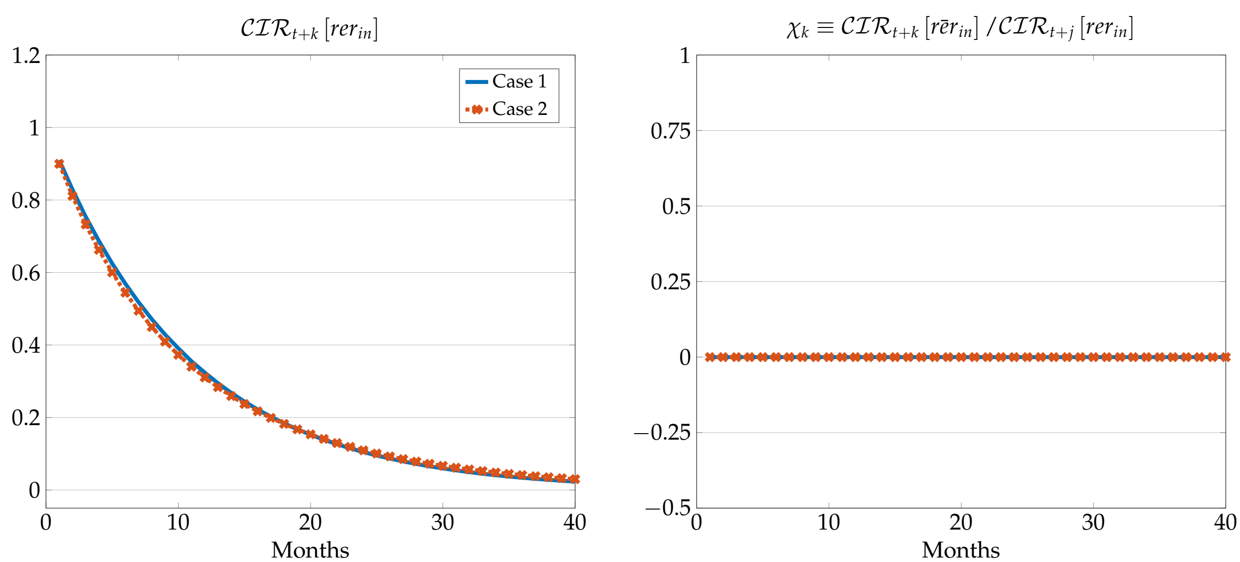
$$G_t = \left[\sum_{j=1}^{J} \omega_j^{\frac{1}{\eta}} Y_{j,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}.$$

Here, $Y_{j,t}$ is a bundle of goods from sector j, η is the elasticity of substitution across sectors, and the parameter ω_j controls the share of sector j in total the final good. Sectorial output is produced by aggregating a continuum of differentiated products, with the aggregator described presented in equation (9). As in the benchmark model, intermediate producers are monopolistic competitors and set prices as in Calvo (1983), and prices are sticky in the buyers' currency. Importantly, the probability that a producer can change its price in any period is sector specific, and given by $1 - \theta_j$. Finally, technologies in the foreign country are defined analogously.

We calibrate the multi-sector model with $J = 12$, where each j represents a COICOP-2 and set θ_j to match the observed COICOP-2 frequencies price changes. We follow Carvalho and Nechio (2011) and set $\eta = 3$. For the one-sector model we set the frequency equal to $\theta = \left[\sum \omega_j \frac{1}{\theta_j} \right]^{-1}$.

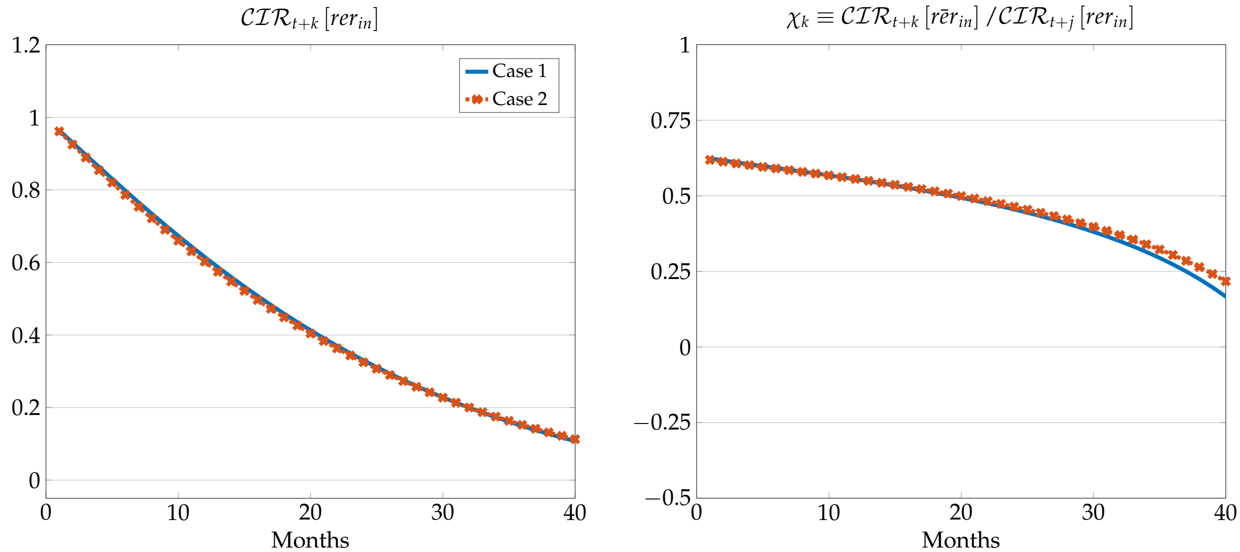
Figure A4 shows the impulse-response function for the one-sector model presented 5.2 in the main text and the multi-sector version of this model. As we can see, both models generate the same impulse-responses. Figure A5 shows the two models continue to deliver similar impulse responses under the more general assumptions of the full quantitative model presented in section C.

Figure A4: Aggregate vs multi-sector models with constant relative wages



Note: The left panel plots the impulse response of the real exchange rate and right panel plots the χ_k in equation defined in the main text.

Figure A5: Aggregate vs multi-sector models: quantitative



Note: The left panel plots the impulse response of the real exchange rate and right panel plots the χ_k in equation defined in the main text.

Appendix E Robustness

E.1 Alternative parameterizations

This section performs a series of robustness test with respect to the structural parameters used in subsection 5.2.3. We report the results of these alternative parameterization in Table A6. For each parameterization, we report the persistence of the real and the reset exchange rates, along with the slope of the relation $\Delta rer_{in} = \chi_k \Delta \overline{rer}_{in}$ computed at different frequencies. The first two rows in the table report repeat the results of the calibrations used in the main text for the 'Benchmark' and 'Disconnect' models. The remaining rows evaluate the sensitivity of these slopes to changes in parameter values.

As noted by Kose and Yi (2006), in a two country model the parameter $1-\mu$ controls both the aggregate and the bilateral trade shares. Calibrating $1-\mu$ to match bilateral shares would imply a very large degree of home bias.[40] With this in mind, we re-evaluate our exercise by setting $\mu = 0.97$. As shown in the Table, a larger μ increases the relation between reset and real exchange rates, although the model with complete markets still falls short of matching our empirical decomposition.

Next, we set $\theta_w = 0.95$, to increase the persistence of relative wages in the Benchmark model (see equation 19 in the main text). The results are reported in rows 5 and 6 of Table A6. Rows 7 and 8 show the effect of increasing the super-elasticity of demand ϕ in the Kimball (1995) aggregator so that the elasticity of markups is $\frac{\phi}{\gamma-1} = 4$. This calibration is meant to be extreme, we are increasing the degree of complementarities estimated by

[40]This is the strategy pursued by Kollmann (2005).

Amiti et al. (2016) by a factor of 6. The increase in the wage stickiness and in the real rigidities both increase the fraction of the real exchange rate accounted for by the reset exchange rate. However, even under these extreme calibrations, in the benchmark model is always well below one.

Finally, in the last two columns we increase the persistence of the structural shocks, which increase persistence of the nominal exchange rate. In the Benchmark model, this increment reduces the slope in the two models and in the Itskhoki and Mukhin (2017) has small quantitative effect.

Table A6: Robustness in Benchmark and IM2017 models

Moments	$P[rer]$	$P[r\bar{e}r]$	Slope $\Delta r\bar{e}r_{in,t}$ w.r.t. $\Delta rer_{in,t}$ Monthly	Quarterly	Semiannual	Annual
Benchmark Calibration						
(1) Benchmark	0.958	0.964	0.466	0.534	0.535	0.523
(2) IM2017	0.998	0.999	0.804	0.921	0.959	0.981
$\mu = 0.97$						
(3) Benchmark	0.959	0.963	0.497	0.559	0.559	0.545
(4) IM2017	0.999	0.999	0.908	0.974	0.988	0.995
$\theta_w = 0.95$						
(5) Benchmark	0.962	0.967	0.562	0.621	0.625	0.617
(6) IM2017	0.997	0.998	0.875	0.933	0.957	0.972
$\frac{\phi}{\gamma-1} = 4$						
(7) Benchmark	0.966	0.969	0.675	0.718	0.720	0.715
(8) IM2017	0.998	0.998	0.897	0.961	0.982	0.995
Persistence of Nominal Exchange Rate (shocks)						
(9) Benchmark ($\rho = 0.0$)	0.936	0.924	0.569	0.559	0.547	0.530
(10) IM2017 ($\rho_\phi = 0.95$)	0.997	0.998	0.904	0.962	0.979	0.989

Notes: The table presents business cycle moments of the simulated series from the Benchmark model and the Mukhin and Itskhoki (2017) model. The time period in the model is 10 years. All the moments in the model are the median over 5000 simulations. The benchmark calibration is the same as the main text.

Table A6: Constructing reset inflation: Example

	Period 0	Period 1	Period 2
Price of Good A	1	1.22	1.22
Inflation for Good A		0.2	0
Reset price BKM for Good A	1	1.22	1.22
Reset inflation BKM for Good A		0.2	0
Price of Good B	1	1	1.22
Inflation for Good B		0	0.2
Reset price BKM for Good B	1	1.22	1.22
Reset inflation BKM for Good B		0.2	0
Reset price index defined in (6), $\bar{p}_{i,t}$	1	1.22	1.22
Inflation, π_t		0.1	0.1
Reset inflation BKM, $\pi^*_{i,t}$		0.2	0
Reset inflation Blanco-Cravino, $\bar{p}_{i,t} - \bar{p}_{i,t-1}$		0.2	0

Note: This example was taken from Table 1 in Bils et al. (2012). 'Reset price BKM', 'Reset inflation BKM for Good A,B' and 'Reset inflation BKM' refers to the reset prices and reset inflation measures of Bils et al. (2012).

E.2 Alternative measures of reset inflation

We now describe how our measure of reset prices relates to the measure of reset inflation in Bils et al. (2012). In particular, Bils et al. (2012) define the log reset price level for good ω as

$$p^*_{i,t}(\omega) = \begin{cases} p_{i,t}(\omega) & \text{if } p_{i,t}(\omega) \neq p_{i,t-1}(\omega) \\ p^*_{i,t-1}(\omega) + \pi^*_{i,t} & \text{if} p_{i,t}(\omega) = p_{i,t-1}(\omega) \end{cases},$$

where starred variables denote reset values, and variables without stars are the (log of) the actual variables. Their estimate of reset inflation is

$$\pi^*_{i,t} = \frac{\sum_\omega s_t(\omega)\left[p_{i,t}(\omega) - p^*_{i,t-1}(\omega)\right]\mathbb{I}_{i,t}(\omega)}{\sum_\omega s_t(\omega)\, I_{i,t}},$$

where $\mathbb{I}_{i,t}(\omega)$ is an indicator that takes the value of one if $p_{i,t}(\omega) \neq p_{i,t-1}(\omega)$.

The example in Table A6, taken from Bils et al. (2012), shows how their measure of reset inflation works. The example has two goods, A and B. We start by describing how to compute inflation following Bils et al. (2012). In period 1, Good A's price increases by 0.2 log points, while good B's price does not change. This yields an aggregate inflation of 0.1 log points (assuming both goods have equal weights in the basket). Reset inflation, as computed by Bils et al. (2012), is 0.2 log points, though note that the change in Good A also changes the base reset price for good B to 1.22. When B's actual price increases to

1.22 log points in period 2, it does not add to reset inflation (since Good B's 'reset' price in period 1 was already set to 1.22, to account for the inflation in Good A). Reset inflation as computed by Bils et al. (2012) , $\pi^*_{i,t}$, thus equals 0.2 in period 1, and 0 in period 2.

The reset price index defined in (6) measures average cumulative inflation for the subset of goods that do change in a given period. In this example, this set of goods consists of good A in period 1 and of good B in period 2. The reset price index defined in (6) would then be $p_1^A = 1.22$ in period 1, and $p_2^B = 1.22$ in period 2. Thus, our measure of reset inflation would also equal 0.2 in period 1, and 0 in period 2.

We conclude this section by noting that both measures of reset inflation would coincide and capture changes in the reset price if the data was generated by the Calvo model. To see why this is the case for our measure, let t_0 define the base year. Changes in reset prices in the calvo model between dates $t = 1$ and $t = 2$ are given by $\bar{p}_2 - \bar{p}_1 = [\bar{p}_2 - \bar{p}_{t_0}] - [\bar{p}_1 - \bar{p}_{t_0}]$, which coincides with the changes in the reset price index defined in $\bar{p}_{i,t}$.

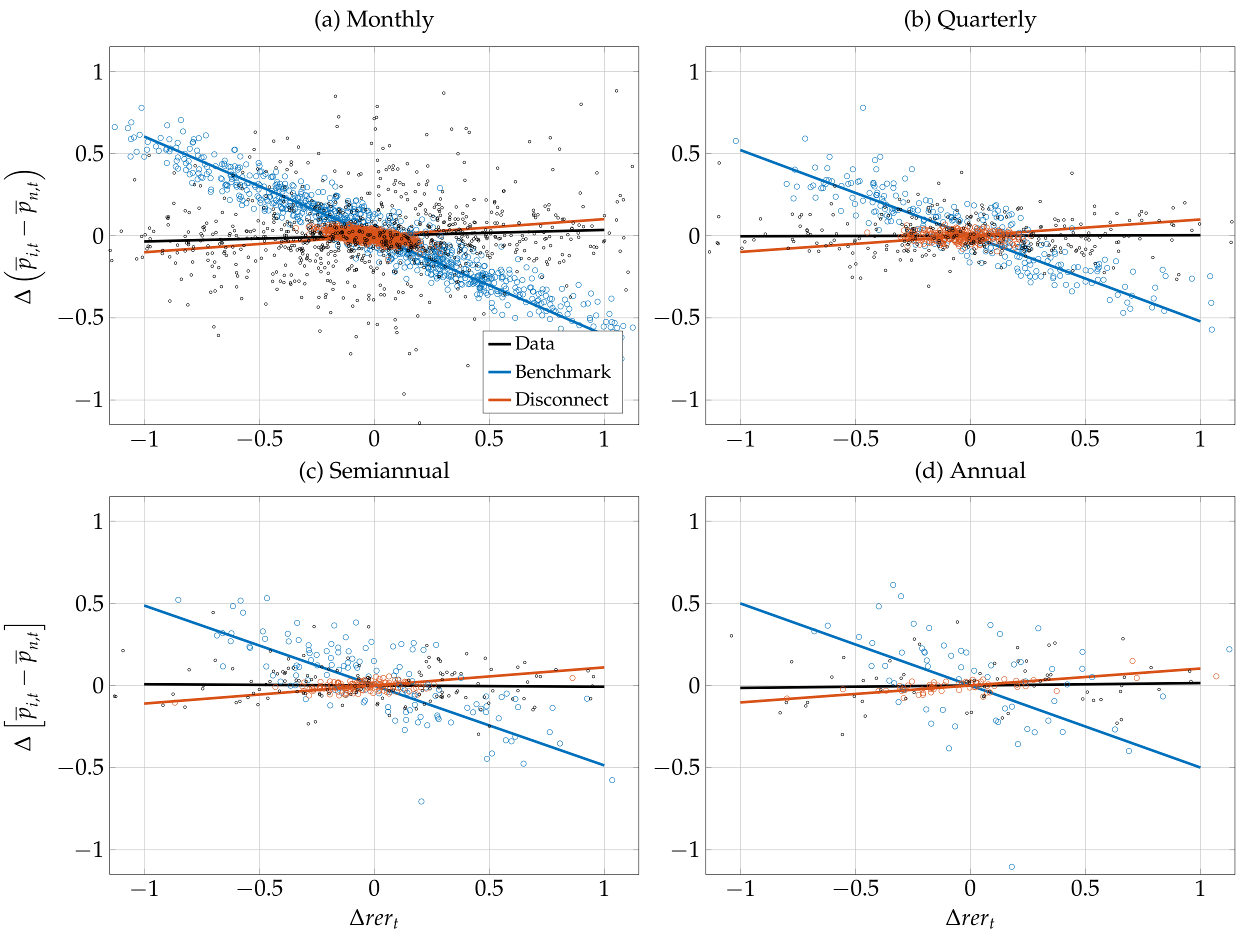
E.3 Alternative decompositions

This paper shows that relative reset prices account for all of the real exchange rate movements. As noted in the paper, this follows because changes in $\bar{p}_{i,t} - \bar{p}_{n,t}$ are uncorrelated to changes in the nominal exchange rate, so that both $rer_{in,t}$ and $\overline{rer}_{in,t}$ track $e_{in,t}$. We could also evaluate an alternative decomposition:

$$rer_{in,t} = \bar{p}_{i,t} - \bar{p}_{n,t} + \underbrace{[[p_{i,t} - \bar{p}_{i,t}] - [p_{n,t} - \bar{p}_{n,t}] + e_{in,t}]}_{\equiv\, rer_{in,t} - [\bar{p}_{i,t} - \bar{p}_{n,t}]}.$$

In this decomposition, we moved the nominal exchange rate into the second term. Appendix Figure A6 shows the relation between changes in $rer_{in,t}$ and changes $\bar{p}_{i,t} - \bar{p}_{n,t}$ both in the data and in the benchmark model. The figure shows that, as hinted in Table 3, changes $\bar{p}_{i,t} - \bar{p}_{n,t}$ are uncorrelated to changes in $rer_{in,t}$. In contrast, the benchmark model produces a strong negative correlation between changes in $\bar{p}_{i,t} - \bar{p}_{n,t}$ and changes in $rer_{in,t}$. Thus, our main conclusion, that the benchmark SPOE model is at odds with the data on reset prices clearly does not depend on how we group terms in the decomposition.

Figure A6: Changes in real vs. reset exchange rates: Models vs. Data



Note: The figure plots movements in real exchange rates (x-axis) and changes $\left[\overline{p}_{i,t} - \overline{p}_{n,t}\right]$ (y-axis), for changes computed at monthly, quarterly, semiannual and annual frequencies. Each circle represent a change for a country pair. 'Benchmark' refers to data simulated from our benchmark model. 'Disconnect' refers to data simulated from the incomplete markets model based on Itskhoki and Mukhin (2017).