Understanding Movements in Aggregate and Product-Level Real Exchange Rates*

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Abstract

We provide new evidence on the importance of pricing-to-market in aggregate and product-level real exchange rate movements, using wholesale prices of consumer goods sold in multiple locations in Canada and the United States but produced in a common location. While movements in aggregate RERs for these goods closely track nominal exchange rates, product-level RERs across countries are four times as volatile as NERs, suggesting a limited role for sticky prices in accounting for pricing-to-market. We also show that product-level RER are twice as volatile across than within countries. We rationalize these facts using a model nesting widely-used models of pricing-to-market.

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1. Introduction

One of the central questions in international macroeconomics is why relative prices across countries, as measured by real exchange rates (RERs), are so volatile over time and more specifically why do they so closely track movements in nominal exchange rates across countries (e.g. Mussa 1986). This behavior is particularly puzzling for tradeable goods (e.g. Engel 1999). Researchers have long argued that these observations can partly be explained by the decision of individual firms to engage in pricing-to-market — that is, to systematically vary over time the markup at which they sell their output in different locations (e.g. Dornbusch 1987 and Krugman 1987).

In this paper we use detailed information on prices in Canada and the U.S. at the level of individual consumer products to document new facts on the extent of pricing-to-market in accounting for observed movements in relative prices across countries and within countries. We then use a model that nests a number of widely-used models of pricing-to-market in the literature to identify key ingredients that can account for these facts.

Our empirical work is based on scanner data for the period 2004-2006 from a major retailer that sells primarily nondurable consumer goods in multiple locations in Canada and the United States. For each product, we observe the retailer's purchase cost from the vendor, i.e. the wholesale price, in each location and over time. We also identify the country of production of individual products that are sold in Canada and the U.S. Under the assumption that goods produced in a common location and sold in multiple locations are subject to common percentage changes in the marginal cost, movements in relative prices across locations for these goods must arise from changes in relative markups charged by producers and wholesalers. With this information, we can thus assess the extent to which movements in relative prices of individual products across locations reflect the practice of pricing-to-market.

We first construct *aggregate RERs* by averaging changes in relative prices between Canada and the U.S. (both prices expressed in a common currency) over a large set of products sold in Canada and the U.S. Aggregate RERs in our data closely track movements in Canada-U.S. relative unit labor costs (which are mainly accounted for by changes in the Canada-U.S. nominal exchange rate), consistent with the observation of Mussa (1986). The fact that this pattern holds for nontraded goods that are produced in each country and sold in both countries could simply reflect changes in relative costs across countries. The fact that this pattern holds as well for the subset of matched individual traded goods produced in a common location and sold in both Canada and the U.S. provides direct evidence of pricing-to-market. In particular, our data suggests that for these goods markups in Canada increase systematically relative to markups in the U.S in response to the appreciation of Canada-U.S. labor costs.

Pricing-to-market in our data does not stem mechanically from large movements in nominal exchange rates and small movements in nominal prices in each country. To substantiate this claim, we proceed in two steps. First, we show that movements in aggregate RERs are roughly unchanged if we include or exclude observations associated with zero nominal price changes. Second, we show that nominal prices of individual products in our data change frequently and display a large idiosyncratic component.[1] Specifically, changes in international relative prices at the level of individual products, *product-level RER*s, are very large, roughly four times as volatile (at quarterly frequencies) as the Canada-U.S. nominal exchange rate, even for traded goods. Hence, while cross-country differences in markups on average track movements in nominal exchange rates and relative labor costs, the idiosyncratic product-specific component of pricing-to-market is significant. We also show that movements in product-level RERs between regions in the same country are substantial as well, but only roughly half as large as those between regions in different countries, and they average out when aggregated across many products. Hence, the idiosyncratic and aggregate components of pricing-to-market are more prevalent across countries than within countries.

Our empirical findings on pricing-to-market complement previous studies using data based on price indices from national statistical agencies or unit values at the level of goods categories or industries (see e.g. the survey in Goldberg and Knetter 1995).[2] One concern about inferring pricing-to-market at the level of individual goods using aggregate price data is that movements in international relative prices can result from differences across locations in the product and quality composition of the indices, and not from changes in relative price across locations for common goods. Here we address this concern by directly using relative price movements for matched individual products sold in multiple locations.

Our findings are also related to a recent and rapidly growing literature documenting the behavior of international relative prices using disaggregated price data.[3] Our empirical con-

[1] This observation is consistent with the large body of evidence on consumer prices reviewed in Klenow and Malin (2010).

[2] See also Atkeson and Burstein (2008), Drozd and Nosal (2012a) and references therein.

[3] For example, Crucini et. al. (2005) and Crucini and Telmer (2012) document a wide distribution of idiosyncractic deviations from the law of one price and idiosyncratic movements in product-level RERs for retail prices of narrowly defined product categories. Broda and Weinstein (2008) find similar patterns using ACNielsen's Homescan retail price database for products with identical UPC codes but sold by multiple retailers. Gopinath et. al. (2011) document a discontinuity in wholesale and retail prices across the Canada-

tribution to this literature is to measure the extent to which movements in relative prices of matched individual products across locations specifically reflect movements in markups (pricing-to-market) by producers and wholesalers. We can do so, in contrast to those other studies, because of two unique features of our data. First, by collecting information on the country of production of individual products sold in Canada and the U.S., we can identify goods that are actually traded — indeed, roughly half of our matched products are locally produced for domestic consumption in each country in spite of belonging to tradeable product categories. Second, by observing wholesale prices we can more accurately measure movements in relative markups at the producer and wholesale level than if we used retail prices, which contain a significantly higher non-traded distribution component. For traded goods produced in a common location, under the null that changes in marginal cost are independent of destination location, we can infer changes in relative markups across location from movements in relative prices. In contrast, for goods produced in different locations, movements in relative prices arise from movements in markups and from movements in production and distribution costs across locations.[4] Distinguishing between these two source of price changes is important from a normative perspective since changes in prices that reflect movements in costs are efficient while changes in prices that reflect movements in markups are inefficient.

In contemporaneous work to ours, Fitzgerald and Haller (2012) find that pricing-to-market by Irish producers is significant in response to movements in the Euro/Sterling exchange rate using domestic and export prices at the plant level from the PPI monthly survey.[5] In contrast, Berman, Martin, and Mayer (2012) find that the degree of pricing-to-market based on annual 8-digit unit values for French exporting firms is much smaller, but varies systematically across firms consistent with the models of pricing-to-market that we describe below. In addition to documenting a high degree of pricing-to-market using weekly and quarterly prices of matched individual products, we show that there is a large component of pricing-to-market that is uncorrelated with movements in the nominal exchange rate, and that pricing-to-market is more prevalent across than within countries.[6]

U.S. border for products with identical UPC codes using our same dataset.

[4] Amiti, Itskhoki, and Konings (2012) use unit values for Belgian firms to show that exchange-rate pass-through into costs has a significant role in accounting for pass-through into prices. We identify the component of pass-through stemming from variable markups by focusing on movements in relative prices across locations for identical traded goods.

[5] Prices used in Fitzgerald and Haller (2012) are significantly stickier than ours, which may reflect the survey nature of their data and differences in price stickiness between industrial goods and consumer goods.

[6] In related work, Goldberg and Hellerstein (2011), Hellerstein (2008), and Nakamura and Zerom (2010) use an estimated structural model to quantify the role of variable markups and local costs in incomplete

Our empirical findings raise the following questions: Why do relative markups systematically track movements in relative costs across countries, even if nominal prices of individual products change frequently and by large amounts? Why is pricing-to-market more prevalent across countries than within countries? What is the role of the international border in giving rise to pricing-to-market across countries? We present a simple partial equilibrium framework that allows us to provide some answers to these questions.

The framework encompasses a number of widely-used static models of international pricing with variable markups and flexible prices (for a recent review of these models, see Burstein and Gopinath 2012), which build on the pricing-to-market models pioneered by Dornbusch (1987) and Krugman (1987).[7] We extend these models in two ways. First, we introduce idiosyncratic time-varying cost and demand shocks in order to account for movements in product-level RERs (for traded goods) that are larger than movements in relative unit labor costs and aggregate RERs. Second, we introduce multiple regions within countries in order to account for movements in relative prices within and across countries. Within this class of models, we provide analytic expressions to isolate key forces that can rationalize our empirical findings. We also use our model to discuss what our findings on pricing-to-market for traded goods imply for the extent of segmentation of markets across and within countries. In doing this, we complement the insights of Engel and Rogers 1996, Gorodnichenko and Tesar 2009, and Gopinath et. al. 2011 that do not distinguish between goods produced in one location and sold in multiple locations and those that are not.

In our model, movements in product-level RERs for traded goods produced in a common location and sold in multiple regions result from a combination of (i) region segmentation, which induces differences across regions in a product's price sensitivity of its demand elasticity (which determines the markup elasticity), and (ii) less-than perfectly correlated demand shocks (or other shocks that move markups) across regions for individual products. Our model can account for our empirical fact that product-level RERs are more volatile across regions in different countries than within countries if either (i) regions are more segmented between countries than within countries, or (ii) demand shocks for individual products are less correlated between countries than within countries. Hence, one message from our model for empirical research is that the observed variation across regions in the volatility of product-

pass-through. De Loecker et. al. (2012) infers markups using producer prices and production function estimates. In contrast, we do not impose a theoretical structure to the data and instead use variation in relative wholesale prices for products produced in a common location and sold in multiple locations to quantify the extent of changes in relative markups across locations.

[7] See e.g. Drozd and Nosal (2012a,b) and Ravn, Schmitt-Grohe and Uribe (2007) for analysis of pricing-to-market in dynamic pricing models featuring adjustment costs and habit formation.

level RERs can be used to gauge the degree of segmentation within and between countries, *only* if the correlation of demand shocks across regions (or other shocks to markups) can be measured and "controlled" for.

In our model, the close comovement between relative unit labor costs and aggregate RERs for traded goods produced in a common location and sold in multiple regions results from a combination of (i) a demand featuring large markup elasticities to prices and (ii) movements in relative aggregate prices between regions that closely comove with relative unit labor costs, due to regional segmentation. Our model can account for our empirical fact that movements in aggregate RERs are smaller within countries than between countries if either (i) movements in unit labor costs are relatively smaller across regions within countries than between countries, or (ii) regions are less segmented within countries than between countries. Hence, one can use the observed variation across regions in movements of aggregate RER to gauge the degree of segmentation across regions within and between countries, only if one can identify and "control" for changes in relative costs across regions within countries that are comparable to changes in relative costs across countries (e.g. movements in nominal exchange rates).

Our paper is organized as follows. Section 2 describes our data. Section 3 reports our main findings on international price movements. Section 4 presents the framework to interpret our empirical facts. Section 5 concludes.

2. Data Description

Our analysis is based on scanner data from a major food and drug retail chain that operates hundreds of stores in Canadian provinces and U.S. states.[8] The Canadian stores are located in British Columbia, Alberta and Manitoba, and the U.S. stores are in multiple states covering a large area of the U.S. territory. We have weekly data over the period 2004-2006, covering roughly $60,000$ products defined by their universal product code (UPC).

The retailer classifies products as belonging to one of 200 categories. We exclude from our analysis "non-branded" products such as fruits and vegetables, deli sandwiches, deli salads, and sushi because for these products information on the identity and country-of-origin of the producer is harder to obtain. For the same reason, we abstract from retailer brands within each product category. We also leave out magazines because advertising revenues account for a substantial share of the publisher's total revenues. This leaves us with 71

[8]Data from this retailer have been used by Chetty et. al. (2008), Eichenbaum et. al. (2011), Einav et. al. (2008), and Gopinath et. al. (2011).

product categories satisfying the data requirements discussed below. These categories include beverages, cleaning products, personal care, and processed food. Since our findings do not vary systematically by product categories, we report aggregate statistics across all products with available data.

For each store we have weekly information on quantities sold, sales revenue (in local currency), and the retailer's total cost (in local currency) of purchasing the goods from the vendors, net of discounts and inclusive of shipping costs. Following Eichenbaum et. al. (2011), we divide revenues and costs by quantities sold to obtain a measure of weekly retail and wholesale prices, respectively. At any point in time, the wholesale price is viewed by the retailer as measuring the replacement cost of an item. As discussed in Eichenbaum et. al. (2011), the retailer uses this cost measure in its pricing decisions and in its calculations of variable profits per good.

In order to measure the extent of pricing-to-market, we focus our analysis primarily on wholesale prices (rather than retail prices). While wholesale prices are the closest measure of producer prices in our data, they are not free of local wholesale distribution costs. Hence, we cannot separately infer the extent of variable markups at the producer and wholesale level from distribution costs at the wholesale level. However, local distribution services are, on average, modest at the wholesale level, and substantially less sizeable than at the retail level. For example, based on information from the U.S. wholesale and retail census, for groceries and related products the average 1998-2006 gross distribution margin (as a percentage of wholesale sales) is only 16% at the wholesale level (the combined retail and wholesale margin as a percentage of retail sales is roughly 40%).[9] In Section 3.3, we briefly report our central empirical findings based on retail prices.[10]

2.1. Aggregation across space and time

Aggregation across space The retail chain groups different stores into relatively concentrated geographic areas within a province or a state that share a common pricing policy, which we denote as a *pricing region*. Based on information from the retailer and on our own calculations, the locations of the stores with products satisfying our data requirements can

[9] This information is available at www.census.gov/econ/www/retmenu.html , which was previously used in Burstein, Neves and Rebelo (2003).

[10] Given that our data covers one single retail chain, we are not able to measure the extent of pricing-to-market by producers and wholesalers across different retail chains for common products (see e.g. Nakamura 2008 for a discussion of retail pricing within and across retail chains). If pricing-to-market by producers and wholesalers is more prevalent across different retailer chains than across different locations within a single retail chain, then our results understate the extent of pricing-to-market in the data.

be mapped into 14 pricing regions in Canada and 85 pricing regions in the U.S. We choose to focus on these as our geographic unit because, given the retailer's pricing policy, retail and wholesale prices are very similar across stores within pricing regions. That is, considering all individual stores within each pricing region would substantially increase the size of our dataset without essentially adding new information.

We construct a weekly wholesale price for each pricing region as the median wholesale price across stores within the pricing region. Our baseline statistics are computed for the 5 pricing regions in British Columbia in Canada, and 14 pricing regions in Northern California in the U.S. These regions are roughly comparable in geographic scope and cover the stores where the country of production was identified. In the sensitivity analysis, we report our statistics based on all pricing regions in our data and other variations in the geographic scope.

As we document below, there is some variation (both in levels and in changes) in wholesale prices of individual products across pricing regions. As we learnt from interviews with managers at the retailer, this is because vendors charge different prices for the same product in different regions. Part of this regional variation in prices may arise from differences in scale combined with non-linear pricing by vendors. Our goal, however, is to document the extent of movements in relative wholesale prices for exported goods across locations (i.e. pricing-to-market), without taking a stand on the form of contractual arrangements between the retailer and the vendors, which would require detailed information that is currently unavailable for the large number of products in our sample.[11]

Aggregation across time Our baseline statistics are based on prices at quarterly frequencies. For each product, these are constructed as unweighted averages of weekly prices within the quarter.[12] By averaging prices across weeks within quarters, we smooth out some of the highly temporary price changes that result from sales and promotions. As discussed in Section 3.3, relative prices across locations are more volatile at weekly frequencies than at quarterly frequencies. Therefore, our baseline statistics based on quarterly prices understate the extent of pricing-to-market in our data. We also calculate mode prices (the most common weekly price within each quarter) to perform sensitivity analysis on the role of sticky prices in accounting for movements in RERs.

[11] This information is not only unavailable to us, but also to the managers at the retailer that we interviewed.

[12] Constructing quarterly prices as quantity-weighted averages (rather than unweighted averages) of weekly prices within the quarter makes very little difference to our findings.

2.2. Matching products

In order to measure movements in relative prices between pairs of regions (within countries or across countries), we must first match products that are sold in both regions. For pairs of regions within the same country, we match products that have common UPC codes in both regions. For pairs of regions in different countries, we proceed in two steps.

First, we match products that have identical UPC codes in Canada and U.S. As reported in Table 1, this gives us 539 identical UPC product matches across countries (for which we have country of production information described below) in British Columbia and Northern California, and 987 across all pricing regions.

Second, since our emphasis is on understanding price changes over time, as opposed to differences in price levels at a point in time, we construct a broader set of internationally matched products beyond products with identical UPCs. To do so, we consider items within product categories that have different UPC codes but share, in both countries, the same brand, manufacturer, and at least one additional characteristic in the product description. This procedure does not require that matched products share a common size and exact product description. These broader matches include, for example, "Schweppes Raspberry Ginger Ale 2Lts" in Canada with "Schweppes Ginger Ale 24 Oz" in the U.S., "Purex Baby Soft" in Canada with "Purex Baby Soft Classic Detergent" in the U.S., "Crest toothpaste sensitivity protection" in Canada with "Crest sensitivity toothpaste whitening scope" in the U.S., and "Gatorade strawberry ice liquid sports drink" in Canada with "Gatorade sports drink fierce strawberry" in the U.S. Individual products can be matched more than once. For example, Coca-Cola 2lt in Canada is matched with Coca-Cola 12 Oz and Coca-Cola 24 Oz in the U.S. This process yields 7219 product matches across countries in British Columbia and Northern California, and 11872 across all pricing regions. As long as two products that are matched and produced in a common location share a common *percentage change* in marginal cost for sales in Canada and the U.S., changes in relative prices across locations can be interpreted as movements in relative markups by individual producers (i.e., pricing-to-market).

To show that our main findings on movements in RERs are not driven by matches with non-identical UPCs, we report separately results based on broad matches and results based only on identical product matches (for statistics for which we have sufficient observations). While differences in price levels across international regions are greater if we consider our broad set of matches (since these include e.g. products of different size), our findings on movements over time in relative prices are largely robust to these two alternative matching procedures.

2.3. Inferring country of production

Next, we identify the country of production for matched products sold in Canada and the U.S. For each of our matched products, our procedure is as follows. First, in the U.S., we use the country-of-origin label information that is available in the retailer's online store for sales in Northern California.[13] Second, in Canada, given that the country-of-origin information is not available on-line, two research assistants physically visited the retailer store in Vancouver, British Columbia, and recorded the country-of-origin label information.[14] Third, our research assistants verified the label information by calling many of the individual manufacturers. This procedure was carried out during the months of May-June 2008.

We group our matched products into four country-of-production sets. The first set consists of matched products that are produced in the U.S. for both U.S. and Canadian sales, such as Pantene shampoo, Ziploc bags, and Rold Gold Pretzels. The second set consists of matched products that are produced in Canada for both U.S. and Canadian sales, such as Sapporo beer, Atkins advantage bar, and Seagram whisky. The third set consists of matched products that are produced in the U.S. for U.S. sales and in Canada for Canadian sales, such as Coca-Cola, Haagen-Dazs ice-cream, Yoplait yoghurt, and Bounce softener. The fourth set consists of matched products that are produced in other countries for U.S. and Canadian sales, such as Myojo instant noodles (Japan), Absolut vodka (Sweden), and Delverde pasta (Italy).

There are two important caveats to our approach. First, a product's country of production may vary across regions within the U.S. and Canada. To address this concern, in our baseline results we only include the pricing regions in British Columbia and Northern California, where the information on country of production was obtained.

Second, a product's country of production may vary over time. To address this concern, between February 2010 and April 2010 (roughly two years after our first survey), we re-

[13] According to the U.S. Federal Trade Commission's rules, for a product to be labelled 'Made in USA', the product must be "all or virtually all" made in the U.S. In Canada we do not know of such a legal label requirement. If there was a bias in reporting goods as locally produced when they are not, then products that are labelled as foreign produced would be very likely to be so. Hence, given that our inference on pricing-to-market is based on goods that are produced in a common country, we believe that for these goods the country-of-origin information is quite accurate. Note also that foreign produced goods can potentially have a local packaging component. These local distribution components would have to be extremely large to account entirely for the large movements in RERs observed in our data.

[14] Given that our retail chain does not sell liquor products in Vancouver, we obtained their country-of-origin information from other stores. We use this information when examining price movements of liquor products in other Canadian cities.

sampled the country of origin in the U.S. Out of the 13718 products in the U.S. with available information on country of origin in 2008 (these products are not all matched with products in Canada), 13120 products (roughly 95%) did not change their country of origin between 2008 and 2010, 411 products (roughly 3%) had changed their country of origin, and 287 products (roughly 2%) had been discontinued. This information complements informal evidence based on interviews with managers of the retail chain suggesting that there is little variation over time in the country of production of continuing products.

2.4. Descriptive statistics on matched products

Table 1 provides descriptive statistics for the set of matched products that we use in our analysis. We report the information separately for identical and broader matches, for pricing regions in British Columbia and Northern California and for all regions. The set of identical matches covers roughly 5% of the retailer's total sales (evaluated at wholesale prices) over our set of product categories (Row 1), and the set of broader matches covers roughly 50% of total expenditures in Canada and 36% in the U.S. (Row 12).[15]

Rows 2-4 and 13-15 report expenditure shares by country of production. There is a significant degree of home bias in consumption. In particular, based on our broad set of matches, roughly 90% of expenditures on our set of matched products in the U.S. are domestically produced, while imports from Canada and the rest of the world (ROW) account for only 1% and 10% of expenditures, respectively. In Canada, roughly two-thirds of expenditures on our set of matched products are domestically produced, while imports from the U.S. and ROW account for 30% and 3% of expenditures, respectively.[16] The large size of the U.S. economy relative to Canada is reflected in the smaller share of U.S. imports from Canada in comparison to the share of Canadian imports from the U.S.

Rows 5-9 and 16-20 report the number of matched products, divided into our four country-of-production sets. Roughly half of the matched products are produced in the U.S. for both U.S. and Canada sales (U.S. exports). Roughly 30% of our set of broad matches are domestically produced in each country. The number of matched products that are exported either by Canada or by ROW is significantly smaller than the number of those that are

[15] We do not cover 100% of the expenditures for the following three reasons. First, we abstract from retailer brands. Second, many products cannot be matched across Canada and the US. Third, for some of the matched products we lack information on the country of production.

[16] Our data provide a good representation of bilateral trade shares for Canada and U.S. based on more aggregate data. In particular, the import shares reported in Table 1 are similar to OECD-based import shares for comparable industries including beverages, chemicals, food products, and tobacco over the period $1997 - 2002$.

exported by the U.S. or domestically produced. Therefore, our statistics for Canadian and ROW exports are more prone to small sample limitations.

Table 2 presents some basic statistics on the extent of price dispersion of wholesale prices of matched individual goods across locations. In particular, we calculate the average and median *absolute* logarithmic differences in quarterly price levels across pricing regions over all time periods. We present these statistics separately for our set of identical and broad product matches, and for all pricing regions and for pricing regions only in British Columbia and Northern California. Based on identical product matches, the average (median) absolute log price difference within countries is relatively small: 0.049 (0.02) between all pricing regions in the U.S., and 0.029 (0.011) between all pricing regions in Canada. These within-country price dispersion measures are very similar if we consider our broader set of product matches and if we consider only pricing regions in British Columbia and Northern California. The extent of price dispersion is much larger across countries. Based on the set of identical product matches, the average (median) absolute log price difference between all pricing regions in Canada and the U.S. is 0.23 (0.19). Price differences are larger if we consider our broad set of product categories (the average and median of absolute price differences are roughly twice as large). This is not surprising since, recall, broad product matches do not necessarily share a common size and exact product description. Below we show, however, that our statistics on movements in product-level RERs do not differ significantly if we focus on exact or broad product matches.

3. Aggregate- and product-level real exchange rates

In this section we construct and establish our central empirical findings on movements in aggregate- and product-level RERs. We first show that movements in Canada-U.S. aggregate RERs closely track relative unit labor costs. For exported products that are produced in a common country and sold in both countries, this is evidence of pricing-to-market by individual producers or wholesalers. Next, we show that these movements in relative prices are not the result of sticky nominal prices and volatile nominal exchange rates. Instead, product-level RERs are very volatile because price changes are frequent, large, and not very correlated across international locations. Next, we show that movements in relative prices are larger between countries than between pricing regions of the same country. We provide extensive robustness checks to these three findings.

Constructing product-level and aggregate RERs We denote individual products by $n \in \Omega$, time periods by $t = 1, ..., T$, and regions by $r = 1, ..., R$. Regions $r = 1, ..., R_1$ are located in Canada, regions $r = R_1 + 1, ..., R_2$ are located in U.S., and regions $r = R_2 + 1, ...R$ are located in the rest of the world (ROW). We typically indicate by r and r' the pricing regions where goods are sold, and we indicate by i and j the regions where goods are produced. We denote by $E_{rr't}$ the nominal exchange rate between regions r and r' in period t (units of currency r' per unit of currency r). For regions within the same country, $E_{rr't} = 1$.

The price in region r in period t for product n produced in region i is denoted by P_{nirt}. We denote by $Q_{nijrr't} = P_{nirt}E_{rr't}/P_{njr't}$ the price of product n in region r produced in region i relative to the price of product n in region r' produced in region j, both expressed in the same currency. We refer to the relative price of individual products across regions as product-level RERs. The log change in the product-level RER is given by:

$$\Delta q_{nijrr't} = \Delta p_{nirt} + \Delta e_{rr't} - \Delta p_{njr't},$$

where $x = \log(X)$, and $\Delta x_{nirt} = \log(x_{nirt}) - \log(x_{nirt-1})$. For products that are produced in a common location i and share a common percentage change in marginal cost, $\Delta q_{niirr't} \neq 0$ indicates that producers and wholesalers price-to-market by varying their markups across locations r and r', as we show in our model in Section 4. Throughout our analysis we trim our data by excluding observations for which quarterly changes in product-level RERs are larger than 100 log points, i.e. $|\Delta q_{nijrr't}| > 1$, which amount to less than 0.1% of the total number of observations.

Aggregate RERs are constructed by averaging changes in product-level RERs over a large set of matched individual products and pairs of regions. We are particularly interested in calculating aggregate RERs across goods produced in a common location and sold in multiple locations. The change in the Canada-U.S. aggregate RER between periods $t-1$ and t over a set of products produced in location $i \in I$ and sold in multiple regions in Canada and U.S. is defined as:

$$\Delta q_t = \sum_{i \in I} \sum_{n \in \Omega_i} s_{nt} \times \text{median}\left\{\Delta q_{niirr't},\right\}_{r=A,...,R_1\ ;\ r'=R_1+1,...,R}, \tag{3.1}$$

where Ω_i is the set of goods produced in location i and sold in multiple destinations. For the set of production locations I we use either all U.S. exported products or all exported products (Canada, U.S., and ROW). Expression (3.1) indicates that for each matched product, we calculate the median change in product-level RERs over pairs of regions in the two countries where the good is sold. The weights of each product, s_{nt}, are equal to expenditures in product n in period t relative to expenditures in all products sold in periods $t-1$ and t, where expenditures are summed over all time periods and all regions in Canada and U.S. By averaging-out the idiosyncratic changes in product-level RERs, aggregate RERs capture the time-varying components that are common to many products.[17] We also construct Canada-U.S. aggregate RER for goods produced domestically for sales in each country, and intranational aggregate RERs across regions within countries.

3.1. Aggregate real exchange rates

Figures 1 and 2 and Table 3 report cumulative movements of aggregate RERs between our sample period, $2004-2006$, for different set of matched products, as well as the cumulative increase in relative unit labor costs between Canada and the U.S. as constructed by the OECD. Over this time period, relative unit labor costs increased in Canada by roughly 15%, mainly accounted for by an appreciation of the Canadian dollar relative to the U.S. dollar of a similar magnitude.

Over this period, prices in Canada rose substantially relative to prices in the U.S., leading to the observed increase in Canada-U.S. aggregate RERs in the four panels in Figure 1. Based on the broad set of product matches and the pricing regions in British Columbia and North California, the aggregate RER rose by roughly 14.3% for all exported products (Panel A), 11.8% for only U.S. exported products (Panel B), and 12.2% for domestically produced goods (Panel B). The rise in Canada relative to U.S. prices is very similar if we consider all pricing regions instead of only British Columbia and North California (Panel C).

To illustrate that the large changes in aggregate RERs for exported products are not driven by our choice of broad product matches we proceed as follows. We first choose product categories that have sufficiently large observations of both broad and identical product matches. We identify five such product categories with U.S. exported products.[18] Panel D in Figure 1 and Table 3 display the cumulative change in the aggregate RER using identical product matches and broad product matches for these five product categories. Based on

[17] We use the median, rather than the mean change in product-level RERs across regions because the because the resulting movements in aggregate RERs constructed in that way are smoother. We do not consider separately aggregate RERs for Canada and ROW exports because the number of products exported by these countries is too low to smooth-out the idiosyncratic movements in product-level RERs. We also constructed aggregate RERs based on aggregate price indices defined as weighted-average changes in prices over a set of products and regions within a country, following the procedure of the U.S. Bureau of Labor Statistics. The resulting movements in aggregate RERs are very similar to those constructed using (3.1).

[18] To choose a category, we require a minimum of 10 identical product matches and 10 broad product matches over the 12 quarters of the data. There are only 5 categories that satisfy this constraint because the number of matched products with identical UPC codes is significantly smaller than the number of broad matched products (see Table 1) .

identical product matches, the Canada/U.S. aggregate RER rose by 13% over our sample period, while based on broad product matches the aggregate RER rose by 15.8%. Hence, aggregate RER based on broad product matches track quite closely aggregate RER based on identical UPC codes for comparable product categories.

We conclude from Figure 1 and Table 3 that, on average, wholesale prices for matched products rose systematically in Canada relative to the U.S. in response to the increase in Canada-U.S relative unit labor costs, even for exported products produced in one country and sold in both Canada and U.S.

Intra-national aggregate RERs We construct intra-national aggregate RERs, averaging movements in product-level RERs across matched products for all pairs of pricing regions within Canada and within the U.S. (using expression 3.1). Results are reported in Panels A and B in Figure 2 and in Table 3. Changes in intra-national aggregate RERs are significantly smaller than change in international aggregate RERs: for all products, the cumulative change is roughly 0 within Canada and within U.S. These statistics are very similar if we focus on exported or domestic goods. Intra-national aggregate RERs are roughly constant over time because idiosyncratic movements in product-level RERs wash-out, nominal exchange rates within countries are constant $E_{rr't} = 1$, and region-specific shocks within countries play a minor role in shaping movements in relative prices, on average, across regions. In comparison, the large observed changes in relative costs across countries (which in our data are mainly accounted for by changes in nominal exchange rates) are central in driving movements in aggregate RERs across countries.

Sticky prices and aggregate RERs If prices are sticky in the buyer's currency (local currency pricing), an appreciation of the Canadian dollar mechanically increases Canadian prices relative to U.S. prices measured in the same currency, as observed in Figures 1 and 2.

Individual wholesale prices in our data, however, move quite frequently. For our same retailer, Eichenbaum et. al. (2011) calculate the degree of price stickiness based on the raw weekly data across individual stores in the U.S. The probability of a weekly wholesale U.S. dollar price change across all product categories is 0.49 in the U.S., which implies that the expected duration of wholesale prices is 0.16 quarters. We complement this information by calculating the degree of price stickiness based on locations in Canada, which is very similar to that for the U.S. Moreover, the fraction of weekly observations across our matched products in which either the Canadian price or the U.S. price changes is even higher at 0.72

(and 0.73 for only exported products). This implies that, on average, the probability that Canadian and U.S. prices remain both unchanged (as required by the sticky local prices hypothesis above) over a period of 13 weeks (a quarter) is roughly 0.28^{13} which is close to zero.

We also measure price stickiness based on modal local-currency prices, the most common price across weeks within each quarter. Eichenbaum et. al. (2011) refer to these modal prices as reference prices, since they filter-out sales or other highly temporary variation in weekly prices. They report that reference prices are much stickier than weekly prices. For example, the probability of a change in the quarterly reference wholesale price across all product categories is 0.49 in the U.S., implying an expected duration of 2.2 quarters.[19]

We now gauge the role of price stickiness in shaping movements in aggregate RERs. We do not identify changes in nominal prices either from highly temporary changes in weekly nominal prices or from changes in average quarterly prices since it takes a single change in weekly prices within the quarter to change this average price. Instead, to be conservative, we identify changes in nominal prices from changes in the more sticky reference (modal) quarterly prices defined above. We re-calculate movements in aggregate RERs including changes in product-level RERs in which the modal price (in local currency) changes in either Canada or the U.S. That is, in equation (3.1), for each time period t we only include products n and pairs of location r, r' in which either the Canada or the U.S. modal price change between $t-1$ and t. Once we identify these observations in which modal nominal prices change, we calculate aggregate RERs using product-level RERs based on average quarterly prices to make them comparable to our baseline statistics.

Figure 2 and Table 3 report the results from these calculations. The cumulative change in the aggregate RER over our sample period is extremely similar if we include or exclude product-level RERs associated with sticky modal prices. For example, for all exported products, the aggregate RER increases by 14.3% including all price observations and 14.2% if we exclude observations with unchanged modal prices.

For robustness, to further assess the role of small price changes in shaping movements in aggregate RERs, we report changes in aggregate RER calculated using observations in which the sum of the absolute change of Canada and U.S. local-currency modal prices is

[19] Reference prices are even more sticky at the retail level. While the probability of a weekly retail price change is 0.43 (expected duration of 0.18 quarters), the probability of a change in the reference price is 0.27 (expected duration of 3.7 quarters). For comparable categories of goods, the frequency of price adjustment for wholesale prices in our data (reported in Eichenbaum et. al. 2011) is similar to that for U.S. import prices reported in Gopinath and Rigobon (2008).

larger than 1% or 2% (instead of using a threshold of 0%). The cumulative increase in the aggregate RERs is only 2% lower when we exclude product-level RERs associated with small modal price changes.

In sum, the presence of sticky local currency prices has at most a limited role in accounting mechanically for the two-years, steady rise in Canada-U.S. aggregate RERs. This is because, first, prices in our data change quite frequently, and second, relative prices associated to non-sticky local-currency prices track closely the movements in relative unit labor costs.[20]

3.2. International product-level real exchange rates

We now show that, underlying the smooth rise in Canada-U.S. aggregate RERs and the largely constant intra-national aggregate RERs reported in Figures 1 and 2 and in Table 3, there are very large idiosyncratic movements in product-level RERs.

To fix ideas, Panel A and B in Figure 3 depicts movements of prices and product-level RERs for one identically-matched product in our sample. The product belongs to the product category "Tea" and is produced in the U.S. for sales in both the U.S. and Canada. Panel A displays the 11 quarterly growth rates of prices (all expressed in U.S. dollars), ΔP_{nirt}, in three pricing regions: two regions in the U.S. (both in Northern California), and one region in Canada (in British Columbia). Panel B displays the percentage change in the relative price between the two U.S. regions and the relative price between one region in the U.S. and one in Canada. Panel B also displays quarterly changes in relative unit labor costs between Canada and the U.S. One can observe for this particular product that relative prices between Canada and the U.S. change by large magnitudes over time, more so than relative unit labor costs.

Panels C and D in Figure 3 presents histograms of the movements in international product-level RERs between British Columbia and Northern California like those displayed in Panel B, but now for all exported matched products across all pairs of regions. Panel C considers our broad set of matched products, while Panel D considers our set of identically matched products. Observe that in all panels, movements in product-level RERs are quite large.

To quantify this information, we construct a measure of volatility of international product-level RERs (i.e. between regions of different countries). The international variance of product-level RERs over a set of products produced in a common location $i \in I$ and sold in

[20]The replacement bias studied in Nakamura and Steinsson (2011) and Gagnon, Mandel and Vigfusson (2012) is less likely to be of a concern in our data than in the BLS data because prices in our data change quite frequently.

multiple regions is defined as

$$\mathrm{Var}^{\mathrm{inter}} = \sum_{i \in I} \sum_{n \in \Omega_i} \sum_{r=1}^{R_1} \sum_{r'=R_1+1}^{R} \sum_{t=2}^{T} \frac{1}{\bar{n}} \left(\Delta q_{niirr't} - \overline{\Delta q_{inter}} \right)^2 , \tag{3.2}$$

where $\overline{\Delta q_{inter}}$ denotes the average change in relative prices over these products, regions, and time periods, and $\bar{n}$ denotes the number of observations over which this statistic is evaluated. We report standard deviation of international RERs, $\sqrt{\mathrm{Var}^{\mathrm{inter}}}$, instead of the variance, to facilitate the comparison of our results with standard measures of nominal and real exchange rate volatility. For the set of production locations I we use either all exported products, U.S. exported products, Canada exported products, or ROW exported products. We also construct this statistic over products produced domestically and sold in each country. We report in Tables 4 and 5 our statistics for the various country-of-production sets, for identical and broad product matches, for British Columbia/ North California and for all pricing regions, and other sensitivity cases discussed below.

Product-level RERs across countries are very volatile not only for matched products that are domestically produced in each country, but also for matched products that are produced in one country and exported to other countries. In particular, based on our set of broad product matches in British Columbia and North California (Panel A of Table 4), the international standard deviation of product-level RERs is equal to 11.2% for all exported products, 10.9% for U.S. exports, 17.2% for Canadian exports, 13.1% for ROW exports, and 13.5% for matched products that are domestically produced in each country. Product-level RERs are also very volatile if we only consider identical product matches (e.g. 13.2% for all exported products in Panel B of Table 4), and if we consider all pricing regions (e.g. 13.1% for all exported broad matched products, see Panel B of Table 5). To put these figures into perspective, the standard deviation of quarterly changes in the Canada-U.S. relative unit labor costs, nominal exchange rate, and the CPI-based RER between 1998 and 2007 is roughly 3%.

The high volatility of product-level RERs is not mechanically driven by exchange rate movements and sticky local currency prices. To observe this, we calculate two statistics. First, we calculate changes in product-level RERs using local currency prices without converting international prices to a common currency. For all exported products, the standard deviation of international product-level RERs falls only from 11.2% to 10.8% (Panel C in Table 5). Second, we calculate changes in product-level RERs excluding those observations in which both the Canadian and the U.S. modal prices change (Rows 4 and 12 in Table 4). For all exported products, the standard deviation of international product-level RERs rises from 11.2% to 11.9%.[21] These two observations should not be very surprising given our previous results that individual wholesale prices in our data move quite frequently and by large magnitudes.

Product-level RER's are volatile because price changes are not very correlated between countries. To see this, we can express (3.2) as:

$$\mathrm{Var}^{\mathrm{inter}} = \left(\mathrm{Var}_{\mathrm{Can}}^{\Delta P} + \mathrm{Var}_{\mathrm{US}}^{\Delta P}\right)\left(1 - \frac{2\left(\mathrm{Var}_{\mathrm{Can}}^{\Delta P}\right)^{0.5}\left(\mathrm{Var}_{\mathrm{US}}^{\Delta P}\right)^{0.5}}{\mathrm{Var}_{\mathrm{Can}}^{\Delta P} + \mathrm{Var}_{\mathrm{US}}^{\Delta P}}\mathrm{Correl}^{\Delta P \mathrm{inter}}\right), \tag{3.3}$$

where $\mathrm{Var}_j^{\Delta P}$ denotes the variance of price changes ΔP_{nirt} over the various pricing regions in country j =Canada or U.S. and $\mathrm{Correl}^{\mathrm{inter}}$ denotes the correlation of price changes between pairs of regions in Canada and U.S. In our data, the variance of U.S. dollar denominated nominal price changes, is roughly equal in the U.S. and Canada, , $\mathrm{Var}_{\mathrm{Can}}^{\Delta P} \simeq \mathrm{Var}_{\mathrm{US}}^{\Delta P} = \mathrm{Var}^{\Delta P}$. For all exported products, for example, the standard deviation of price changes is 7.8% in Canada and 8.1% in the U.S. Hence, $\mathrm{Var}^{\mathrm{inter}}$ is roughly equal to $2\mathrm{Var}^{\Delta P}\left(1 - \mathrm{Correl}^{\Delta P \mathrm{inter}}\right)$. If price changes are perfectly correlated across countries, then $\mathrm{Var}^{\mathrm{inter}} = 0$. If price changes are uncorrelated across countries, then $\mathrm{Var}^{\mathrm{inter}} = 2\mathrm{Var}^{\Delta P}$.

Tables 4 and 5 report the value of $\mathrm{Correl}^{\Delta P \mathrm{inter}}$ for the various country-of-production sets, for the set of broad and identical product matches. We can see across all rows and columns that $\mathrm{Correl}^{\Delta P \mathrm{inter}}$ is very low, even for exported products. For example, for all exported broad matched products (Row 8, Panel A in Table 4), $\mathrm{Correl}^{\mathrm{inter}} = 0.065$.

Inter- and intra-national product-level real exchange rates For our selected "Tea" product in Figure 3, one can observe that relative prices are more volatile between the pricing regions in British Columbia and Northern California than between the two pricing regions in Northern California. More generally, Figure 4 displays histograms of relative price movements across our entire set of broad matched products, between pairs of pricing regions in British Columbia and Northern California, as well as between pairs of pricing regions within British Columbia and within Northern California. Movements in product-level RERs are larger between countries than between pricing regions of the same country.

To quantify this pattern, we define the intra-national (i.e. between regions of the same country) variance of product-level RERs for goods produced in a common location in country i and sold in multiple locations in country j =Canada or U.S., analogously to $\mathrm{Var}^{\mathrm{inter}}$ in (3.2),

[21] If we exclude observations for which the sum of the absolute change of Canada and U.S. local-currency modal prices is less than 2% (Rows 5 and 13 in Table 4), the standard deviation of international product-level RERs further rises to 13.7%.

as:

$$\text{Var}_j^{\text{intra}} = \sum_{i\in I}\sum_{n\in\Omega_i}\sum_{r\in\tilde{R}}\sum_{r'\in\tilde{R}}\sum_{t=2}^{T}\frac{1}{\bar{n}}\left(\Delta q_{niirr't} - \overline{\Delta q_{intra}}\right)^2, \tag{3.4}$$

where $\tilde{R} = \{1, ..., R_1\}$ when j =Canada and $\tilde{R} = \{R_1 + 1, ..., R\}$ when j =US. Tables 4 and 5 report the standard deviation of intra-national product-level RERs, $\sqrt{\text{Var}_j^{\text{intra}}}$, for our various country-of-production sets and product matches.

Product-level RERs are almost two times as volatile across countries than within countries. For example, based on our broad set of product matches and pricing regions in British Columbia and Northern California (Rows 1 and 2, Panel A in Table 4), the standard deviation of product-level RERs for all exported products is 4.2% within Canada, 5.7% within the U.S., and 11.1% across countries. If we consider only identical product matches (Rows 9 and 10, Panel B in Table 4), intra-national product-level RERs are slightly more volatile (6.2% and 7.5%, respectively), but still substantially less volatile than inter-national product-level RERs.[22]

These statistics are constructed based only on the pricing regions in British Columbia and Northern California. If we include all pricing regions (Rows 1 and 2, Panels A and B in Table 5) intra-national product-level RERs are more volatile (6% in Canada and 8% in the U.S. for exported broad product matches) but still less volatile than international product-level RERs (13.1%). To control for variation in distance across regions, we follow the literature (e.g. Engel and Rogers 1996) and consider the following regression. The dependent variable is the standard deviation of product-level RERs across all pairs of pricing regions within and across countries for identical matches (there are 964, 179 upc/pair of regions for which we calculate this measure). The independent variables include a constant, the logarithm of distance between the pairs of regions, product-category dummies, and a dummy that equals one if the two regions lie in different countries. The distance coefficient is positive and significant (the coefficient equals 0.004 with a t-stat of 70), suggesting that regions that are farther apart experience larger deviations from relative PPP. More importantly, the dummy coefficient is equal to 5.4% and statistically significant (a t-stat of 357). Note that the value of this dummy coefficient is very similar to the difference in the standard deviation of

[22] Our finding that $Var_{US}^{\text{intra}} > Var_{Can}^{\text{intra}}$ echoes the findings in Gorodnichenko and Tesar (2009) who use more aggregated price data. Broda and Weinstein (2008) report a higher level of $\text{Var}_{Can}^{\text{intra}}$ and a smaller difference between $\text{Var}_{Can}^{\text{intra}}$ and $\text{Var}^{\text{inter}}$ than we do. Even though they use retail prices while we use wholesale prices, our results are largely unchanged with retail prices. Two other differences between their data and ours are: (i) prices in their data are averages across multiple retailers, which can lead to a higher $\text{Var}_{Can}^{\text{intra}}$ through changes in composition of retail sales over time, and (ii) U.S. prices in their data are averages of prices across multiple regions, which can reduce $\text{Var}^{\text{inter}}$ by eliminating the region specific component of U.S. price changes.

inter- and intra-national product- level RERs based only on data from British Columbia and Northern California. This confirms our previous findings that pricing-to-market is roughly twice as prevalent across countries than within countries.

Relative prices are more volatile across countries than within countries because price changes are more correlated across regions within countries than across pricing regions between countries. To see this, we can express the ratio of inter- to intra-national RER variances defined in (3.2) and (3.4) as:

$$\frac{\text{Var}^{\text{inter}}}{\text{Var}_j^{\text{intra}}} = \left(\frac{\text{Var}_{\text{Can}}^{\Delta P} + \text{Var}_{\text{US}}^{\Delta P}}{2\text{Var}_j^{\Delta P}}\right)\left(\frac{1 - \frac{2\left(\text{Var}_{\text{Can}}^{\Delta P}\right)^{0.5}\left(\text{Var}_{\text{US}}^{\Delta P}\right)^{0.5}}{\text{Var}_{\text{Can}}^{\Delta P}+\text{Var}_{\text{US}}^{\Delta P}}\text{Correl}^{\text{inter}}}{1 - \text{Correl}_j^{\text{intra}}}\right). \tag{3.5}$$

In obtaining expression (3.5), we used the analogous expression (3.3) for $\text{Var}_j^{\text{intra}}$ given by $\text{Var}_j^{\text{intra}}=2\text{Var}_j^{\Delta P}\left(1 - \text{Correl}_j^{\Delta P\text{intra}}\right)$, where $\text{Correl}_j^{\text{intra}}$ denotes the correlation of price changes between the various pairs of regions in country j. Given that in our data $\text{Var}_j^{\Delta P}$ is roughly equal in the U.S. and Canada, differences in inter- and intra-national RER volatilities are mainly accounted for by differences in the correlation of price changes within and across countries.

Tables 4 and 5 report the values of $\text{Correl}_j^{\text{intra}}$ and $\text{Correl}^{\text{inter}}$ for our various sets of products. Note that in all cases, prices are more correlated within Canada than within the U.S., and prices are more correlated within countries than across countries. For example, based on the broad set of product matches for all exported products (Rows 1 and 2, Panel A in Table 4), $\text{Correl}_{\text{Can}}^{\text{intra}} = 0.85$, $\text{Correl}_{\text{US}}^{\text{intra}} = 0.76$, and $\text{Correl}^{\text{inter}} = 0.06$.

Hence, understanding why pricing-to-market is more prevalent across countries than within countries amounts to understanding why producers set prices that are less correlated across countries than within countries.

3.3. Additional robustness checks

Table 5 reports our statistics on product-level RERs if we change our baseline procedure along other dimensions. First, we construct our measure of product-level RERs net of movements in the category-wide RER (Panel D). Our findings on product-level RERs are roughly unchanged relative to our baseline results, highlighting the large extent of pricing-to-market that is idiosyncratic to individual products. Our findings on product-level RERs are also roughly unchanged if we construct movements in product-level RERs net of movements in nominal wages in each country, as in Engel and Rogers (1996), or if we define product-level RERs as ratios of nominal prices without converting them into a common currency.

Second, we construct our statistics based on weekly wholesale prices instead of average weekly prices within a quarter (Panels E and F). Relative prices based on weekly data are even more volatile than when based on quarterly data. For all exported broad (identical) product matches, the international standard deviation of product-level RERs is 26% (33%) using weekly data and 13% (11%) using quarterly data. Hence, pricing-to-market is more prevalent if we measure it using weekly prices. This is basically driven by the presence of sales and promotions (even at the wholesale level), which lead to temporary movements in prices.

Third, we construct our statistics based on retail prices instead of wholesale prices (Panels G and H). As discussed above, retail prices change less frequently than wholesale prices. However, movements in product-level RERs based on retail prices are also very large and three to four times as volatile as relative unit labor costs.

Finally, we consider two additional variations in the geographic scope of our statistics (due to space limitations, these are available upon request). First, we calculate international RERs based on single pricing regions in British Columbia and Seattle, Washington. Given the geographic closeness of these two districts, it is very likely that goods consumed in these pricing regions with a common country-of-origin are actually produced in the same location (and hence, share a common change in marginal cost). Second, we calculate our statistics based on single pricing regions in British Columbia and Manitoba in Canada, and Northern California and Illinois in the U.S. By using prices from single pricing regions in these larger geographical areas of Canada and U.S., we make sure that our intra-national price findings are not driven by sampling prices from nearby pricing regions in each country. Our findings are largely unchanged to these variations in geographic coverage.

4. Model

In what follows we present a simple framework that allows us to isolate key forces to rationalize our empirical findings on prices. Since price stickiness has a limited role in accounting for movements in quarterly RERs in our data, we focus on models in which changes in markups stem from desired movements in markups and not from sticky prices in the currency of the buyer. The model encompasses a number of widely-used static models of international pricing with variable markups including Kimball non-CES aggregator (Kimball 1995, Klenow and Willis 2006, Gopinath and Itskhoki 2010 and 2011), distribution costs (Corsetti and Dedola 2008), and nested-CES with a finite number of products per sector (Atkeson and

Burstein 2007 and 2008).[23] We use this model to understand the mechanisms that can rationalize our main empirical findings on RERs for traded goods produced in a common location and sold in multiple destinations: (*i*) product-level RERs are very volatile across regions in different countries, (*ii*) they are more volatile across regions in different countries than within countries, (*iii*) aggregate RERs comove closely with relative unit labor costs, and (*iv*) they move much more across regions in different countries than within countries.

Our model is partial equilibrium in that we take as given movements in wages and exchange rates. This is without loss of generality for the model's pricing implications given a fixed set of goods. We do not address in this paper the general equilibrium question of what shocks lead to these large and persistent changes in relative labor costs across countries.

Notation All nominal prices are expressed in the currency of the region where the good is sold. The logarithm of the producer price at time t of product n produced in region i and sold in region r is denoted by p_{nirt}.[24] This price can expressed as the sum of log marginal cost (mc_{nirt}) and log gross markup (μ_{nirt}):

$$p_{nirt} = \mu_{nirt} + mc_{nirt}.$$

The log change of the price, Δp_{nirt}, is given by:

$$\Delta p_{nirt} = \Delta mc_{nirt} + \Delta \mu_{nirt}. \tag{4.1}$$

The log change in the price of product n in region r (produced in region i) relative to the price in region r' (produced in region j) is:

$$\Delta q_{nijrr't} = \left(\Delta mc_{nirt} + \Delta e_{rr't} - \Delta mc_{njr't}\right) + \left(\Delta \mu_{nirt} - \Delta \mu_{njr't}\right). \tag{4.2}$$

Movements in product-level RERs are accounted for by changes in relative markups between regions and by changes in relative marginal costs of supplying each region. If good n is produced in the same location i for sales in regions r and r', assuming that the change in

[23]In the class of models we consider, the markup depends on a firm's price relative to the aggregate price. Arkolakis, Costinot, Donaldson, and Rodriguez-Clare (2012) and references therein consider a class of static pricing models in which markups depend on the difference between a firm's price and a "choke price" at which quantity is zero. The show under some assumptions that changes in the choke price are equal to a trade-weighted average of wage changes, very similar to changes in the aggregate price in our framework. Hence, this two class of models have similar implications for pricing-to-market.

[24]While we focus on producer prices, incorporating into the model a local wholesale distribution cost is straightforward. Since wholesale gross margins represent a modest share of wholesale sales (on average 16% for U.S. groceries and related products, as discussed above), this force can only account for a small fraction of the overall change in aggregate RERs in response to a change in relative unit labor costs.

marginal cost of supplying both regions is equal (so the first term in (4.2) is zero), then the change in the product-level RER is given by the change in relative markups between regions:

$$\Delta q_{niirr't} = \Delta \mu_{nirt} - \Delta \mu_{nir't}.$$

For goods that are not produced in the same location, changes in product-level RERs reflect changes in relative markups and marginal costs across locations.

Marginal Costs To study the determination of markup movements across regions, we impose some additional structure on markups and marginal costs. The log of marginal cost is equal to the sum of the bilateral trade cost between the production location i and the destination r, $\tau_{ir} \geq 0$ (with $\tau_{ii} = 0$), the wage in location i in period t expressed in region r's currency $(w_{it} + e_{irt})$, and a product-specific idiosyncratic cost component, z_{nit}:

$$mc_{nirt} = \tau_{ir} + w_{it} + e_{irt} + z_{nit}.$$

In order to calculate expressions for the variance of product-level RERs, we assume that z_{nit} is independently, normally distributed across products and regions, with $z_{nit} \sim N\left(\bar{z}_{nit}, \sigma_z^2/2\right)$. Abstracting from movements over time in bilateral trade costs, the log change in marginal cost in period t is:

$$\Delta mc_{nirt} = \Delta w_{it} + \Delta e_{irt} + \Delta z_{nit}, \tag{4.3}$$

where Δz_{nit} is normally distributed with mean zero and variance σ_z^2. Changes in average relative costs across regions are driven by changes in relative wages expressed in the same currency, $\Delta w_{it} + \Delta e_{irt} - \Delta w_{rt}$.

Markups We assume that the mark-up of product n in region r is a function of its price relative to the aggregate price in region r, $p_{nirt} - p_{rt}$, and an exogenous shock to the markup, a_{nirt}, that we refer to as *demand shifter*. That is, $\mu_{nirt} = \mu(p_{nirt} - p_{rt}, a_{nirt})$. In the appendix we describe three widely-used models of international pricing that produce this reduced-form relationship between markups, relative prices, and exogenous demand shifters, where the exact specification of $\mu\left(.,.\right)$ and p_{rt} depends on model details.

The aggregate price p_{rt} is, up to a first-order approximation, an expenditure-weighted average of log prices (adjusted for demand shifters a_{nirt}) over all varieties sold in the region. We assume that a_{nirt} is distributed independently across products and time, but is potentially correlated across regions. In particular, a_{nirt} is normally distributed with mean $\bar{a}_{nir}$ and variance-covariance matrix Λ given by $\sigma_a^2 \rho_{a,rr'}/2$, with $\rho_{a,rr} = 1$. Hence Δa_{nirt} is normally distributed with mean 0 and variance-covariance matrix $\sigma_a^2 \rho_{a,rr'}$.[25]

We now solve for changes in RERs, up to a first-order approximation, around a *non-stochastic equilibrium.* In a *non-stochastic equilibrium*, regions are ex-ante symmetric ($e_{rr'} = 0$ and $w_i = w_r$ for all countries and regions) and $\sigma_z^2 = \sigma_a^2 = 0$ so that each product's marginal cost and demand shifter is at its average, i.e. $mc_{nir} = \tau_{ir} + \bar{z}_{ni}$ and $a_{nir} = \bar{a}_{nir}$.

Up to a first-order approximation, the log-change in markup is:

$$\Delta\mu_{nirt} = \Gamma_{p,nir} \left(\Delta p_{rt} - \Delta p_{nirt}\right) + \Gamma_{a,nir} \Delta a_{nirt}. \tag{4.4}$$

where $\Gamma_{p,nir} \equiv -\frac{\partial \mu(.,.)}{\partial (p_{nir} - p_n)}$ is the elasticity of the mark-up with respect to the relative price evaluated at prices in the non-stochastic equilibrium, and $\Gamma_{a,nir} \equiv \frac{\partial \mu_{nir}(.,.)}{\partial a_{nir}}$ is the elasticity of the mark-up with respect to the demand shifter evaluated in the non-stochastic equilibrium. We make the following assumptions on $\Gamma_{p,nir}$ and $\Gamma_{a,nir}$, which are satisfied under some parameter restrictions in the three models described in the appendix.

Assumption on markups: (*i*) Markups are weakly decreasing in the relative price $p_{nir} - p_r$, $\Gamma_{p,nir} \geq 0$; (*ii*) markups are weakly increasing in the demand shifter $\Gamma_{a,nir} \geq 0$; (*iii*) the price elasticity of markups, $\Gamma_{p,nir}$, is weakly decreasing in the relative price $p_{nir} - p_r$ and weakly increasing in the demand shifter a_{nir}.

These assumptions imply that, everything else the same, a firm tends to set higher prices (relative to the aggregate price p_r), lower markups, and be subject to a lower markup elasticity in locations in which marginal costs are high relative to its competitors. Similarly, a firm tends to set lower prices, lower markups, and face a lower markup elasticity in locations in which the demand shifter is relatively low. This implies that a firm producing in region i selling in regions i and r facing trade costs $\tau_{ir} > 0$ and/or a lower demand shifter in region r will tend to set lower markups and be subject to a lower markup elasticity in region r than in region i.

Changes in prices and real exchange rates Combining (4.1), (4.3), and (4.4), the log change in price (in the destination currency) is:

$$\Delta p_{nirt} = \frac{1}{1 + \Gamma_{p,nir}} \left(\Delta z_{nit} + \Delta w_{it} + \Delta e_{irt}\right) + \frac{\Gamma_{a,nir}}{1 + \Gamma_{p,nir}} \Delta a_{nirt} + \frac{\Gamma_{p,nir}}{1 + \Gamma_{p,nir}} \Delta p_{rt}. \tag{4.5}$$

[25] We have assumed that firms can charge a different price by destination, and that it is technologically infeasible for any third party to ship goods across regions or countries to arbitrage price differentials. It can be shown for the models presented in the appendix that price differences between two regions do not exceed the bilateral trade cost if differences in a_{nirt} are not too large. Under this assumption, any agent facing the same trade cost as firms do not have incentives to buy goods from another location.

The first term represents the change in price in response to a change in cost (including the idiosyncratic and aggregate components). Pass-through is lower the higher is the markup elasticity $\Gamma_{p,nir}$. The second term represents the change in price in response to an idiosyncratic change in the demand shifter. Pass-through is lower the higher is the markup elasticity $\Gamma_{p,nir}$ and pass-through is higher the higher is $\Gamma_{a,nir}$. The third term represents the change in price in response to a change in the aggregate price level in the region where the good is sold. Pass-through is higher, the higher is the markup elasticity $\Gamma_{p,nir}$.

Using (4.5), the change in product-level RER for good n produced in region i and sold in regions r,r' is:

$$\begin{aligned}\Delta q_{niirr't} &= \left(\frac{\Gamma_{p,nir'}}{1+\Gamma_{p,nir'}} - \frac{\Gamma_{p,nir}}{1+\Gamma_{p,nir}}\right)(\Delta z_{nit} + \Delta w_{it}) + \frac{\Gamma_{a,nir}}{1+\Gamma_{p,nir}}\Delta a_{nirt} - \frac{\Gamma_{a,nir'}}{1+\Gamma_{p,nir'}}\Delta a_{nir't} \\ &+ \frac{\Gamma_{p,nir}}{1+\Gamma_{p,nir}}\Delta p_{rt} + \frac{\Gamma_{p,nir'}}{1+\Gamma_{p,nir'}}\left(\Delta e_{rr't} - \Delta p_{r't}\right), \end{aligned} \tag{4.6}$$

Product-level RERs move with changes in producer costs $(\Delta z_{nit} + \Delta w_{it})$ if the markup elasticity differs across the two regions. Product-level RERs move with changes in demand shifters (Δa_{nirt} and $\Delta a_{nir't}$) if these are not perfectly correlated between regions or if markup elasticities differs across regions. Product-level RERs move with changes in aggregate prices in the region where the good is sold if changes in aggregate prices differ between regions $(\Delta p_{rt} + \Delta e_{rr't} - \Delta p_{r't} \neq 0)$ or if markup elasticities differ between regions.

We are interested in examining the forces shaping the statistics that we report in the empirical section. We use (4.6) to derive expressions for the variance of product-level RERs and movements in aggregate RERs for goods produced in a common location. In deriving these expressions, we assume that there is a large number of products in the economy.

Product-level RERs: We first provide an expression for the variance of product-level RERs abstracting from aggregate movements in wages and exchange rates (or, similarly, assuming that idiosyncratic shocks are much larger than aggregate shocks).

Suppose that wages and exchange rates are constant across all regions: $\Delta w_{it} = \Delta e_{irt} = 0$ for all i and r. Up to a first-order approximation, the variance of product-level RERs for goods produced in a common location i and sold in regions r and r' is:

$$\text{Var}(\Delta q_{niirr't}) = \Psi^z_{irr'}\sigma^2_z + \Psi^a_{irr'}\sigma^2_a, \tag{4.7}$$

where

$$\Psi^z_{irr'} = \int_{n\in\Omega_{irr}} \frac{1}{|\Omega_{irr}|}\left(\frac{\Gamma_{p,nir'}}{1+\Gamma_{p,nir'}} - \frac{\Gamma_{p,nir}}{1+\Gamma_{p,nir}}\right)^2 dn$$

and

$$\Psi^a_{irr'} = \int\limits_{n\in\Omega_{irr}} \frac{1}{|\Omega_{irr}|}\left[\left(\frac{\Gamma_{a,nir}}{1+\Gamma_{p,nir}}\right)^2+\left(\frac{\Gamma_{a,nir'}}{1+\Gamma_{p,nir'}}\right)^2-2\rho_{a,rr'}\left(\frac{\Gamma_{a,nir}}{1+\Gamma_{p,nir}}\right)\left(\frac{\Gamma_{a,nir'}}{1+\Gamma_{p,nir'}}\right)\right]dn,$$

where Ω_{irr} denotes the set of products produced in a common location i and sold in regions r and r', and $|\Omega_{irr}|$ denotes the measure of this set.

Expression (4.7) indicates that product-level RERs are more volatile the larger is the difference in markup elasticities between regions (which raises $\Psi^z_{irr'}$ and $\Psi^a_{irr'}$), and the less correlated between regions are shocks to demand $\rho_{a,rr'}$.

Aggregate RERs: We now provide an expression for the change in the aggregate RER, calculated as an expenditure-weighted average of product-level RERs over a large set of goods produced in a common location i.

The change in the aggregate RER between regions r and r' for goods produced in a common location i is:

$$\begin{aligned}\Delta q_{irr't} &= \int\limits_{n\in\Omega_{irr}}\left(\frac{s_{nir}+s_{nir'}}{2\,|\Omega_{irr}|}\right)\Delta q_{niirr't}dn \\ &= (\Phi_{ir'}-\Phi_{ir})\,\Delta w_{it}+\Phi_{ir}\Delta p_{rt}+\Phi_{ir'}\left(\Delta e_{rr't}-\Delta p_{r't}\right)\end{aligned} \tag{4.8}$$

where

$$\Delta p_{rt} = \frac{\sum_i\left(\Delta w_{it}+\Delta e_{irt}\right)\int_{\Omega^c_r}\frac{s_{nir}}{1+\Gamma_{p,nir}}dn}{\sum_i\int_{\Omega^c_r}\frac{s_{nir}}{1+\Gamma_{p,nir}}dn}, \tag{4.9}$$

$$\Phi_{ir} = \int\limits_{n\in\Omega_i}\left(\frac{s_{nir}+s_{nir'}}{2\,|\Omega_{irr}|}\right)\frac{\Gamma_{p,nir}}{1+\Gamma_{p,nir}}dn,$$

s_{nir} denotes the expenditure share of product n in region r in the non-stochastic equilibrium, and Ω^c_r denotes the set of products consumed in region r (including goods from all source locations).

Expression (4.8) indicates that movements in aggregate RERs are determined by the difference in markup elasticities between regions and by the extent of changes in relative aggregate prices between regions.[26] Expression (4.9) indicates that the change in the aggregate price in region r is a weighted average of changes in aggregate wages in each country

[26] Note that aggregate RERs in our empirical analysis, defined in expression (3.1), are slightly different than aggregate RERs in expression (4.8). First, instead of using one production location i, they are calculated across a set of production locations I (e.g. all U.S. exported products). Second, instead of using product-level RERs between two regions r and r', they are calculated using for each good the median change in product-level RERs across all pairs of regions. In our model, with a continuum of products and if all regions within a country are ex-ante symmetric, the two measures in expressions (3.1) and (4.8) coincide.

measured in a common currency, where the weights are determined by expenditure shares and markup elasticities. At fixed markup elasticities, movements in aggregate prices across regions in response to changes in relative wages are larger when regions spend a higher share on domestically produced goods (s_{nii} increases relative to s_{nir}).

To better understand these expressions, we first focus on three simple cases.

(i) Constant markups: Suppose that markups are constant: $\Gamma_{p,nir} = \Gamma_{a,nir} = 0$. In this case, product-level and aggregate RERs are constant: $\Delta q_{niirr't} = \text{Var}(\Delta q_{niirr't}) = \Delta q_{irr't} = 0$.

(ii) No trade costs or home bias in preferences: Suppose that regions r and r' satisfy the following three conditions: (i) trade costs between between these two regions are zero, $\tau_{rr'} = 0$, (ii) trade costs between these two regions and third regions r'' are equal for both regions, $\tau_{rr''} = \tau_{r'r''}$, and (iii) for each product the *mean* demand shifter is the same in both regions, $\bar{a}_{nir} = \bar{a}_{nir'}$. Under these assumptions, for any products the marginal marginal cost to supply both regions is equal, $mc_{nirt} = mc_{nir't}$, and with $\bar{a}_{nir} = \bar{a}_{nir'}$ so is the markup level, markup elasticity, and expenditure share $s_{nir} = s_{nir'}$ in a non-stochastic equilibrium. Using (4.9), changes in aggregate prices are equal in both regions, $\Delta p_{rt} + \Delta e_{rr't} - \Delta p_{r't} = 0$. Therefore, using (4.6):

$$\Delta q_{niirr't} = \frac{\Gamma_{a,nir}}{1 + \Gamma_{p,nir}} \left(\Delta a_{nirt} - \Delta a_{nir't} \right),$$

so movements in product-level RERs arise only due to different realizations of the demand shifter a_{nirt}. The variance of product-level RERs is:

$$\text{Var}(\Delta q_{niirr't}) = 2\sigma_a^2 \left(1 - \rho_{a,rr'}\right) \int_{n \in \Omega_{irr}} \frac{1}{|\Omega_{irr}|} \left(\frac{\Gamma_{a,nir}}{1 + \Gamma_{p,nir}} \right)^2 dn,$$

$\text{Var}(\Delta q_{niirr't})$ is zero if demand shifters are perfectly correlated between regions ($\rho_{a,rr'} = 1$) and non-zero otherwise. Idiosyncratic demand shifters are on average equal to zero in each region so they do not impact aggregate RERs, which remain constant over time: $\Delta q_{irr't} = 0$

(iii) Foreign firms selling in two symmetric regions: Consider firms from region i (in e.g. France) selling in two regions $r, r' \neq i$ (e.g. in Canada and/or the U.S.) that are ex-ante symmetric from the perspective of country i producers: $\tau_{ir} = \tau_{ir'} \geq 0$ for all $i \neq r, r'$ and $\bar{a}_{nir} = \bar{a}_{nir'}$. Under these assumptions, for every product from country i sold in regions r and r', $mc_{nirt} = mc_{nir't}$. Given symmetry, the level and the elasticity of the markup for country i products is equal in regions r and r'. Movements in product-level RERs result from different realizations of demand shifters when $\rho_{a,rr'} < 1$ as in the previous case, but also due to movements in relative aggregate prices between regions r and r' (which in general are no longer zero when there is home bias in preferences or trade costs are positive between these two regions):

$$\Delta q_{niirr't} = \frac{\Gamma_{a,nir}}{1+\Gamma_{p,nir}} \left(\Delta a_{nirt} - \Delta a_{nir't}\right) + \frac{\Gamma_{p,nir}}{1+\Gamma_{p,nir}} \left(\Delta p_{rt} + \Delta e_{rr't} - \Delta p_{r't}\right),$$

The expression for the variance of product-level RERs (abstracting from aggregate shocks) is the same as in case (ii). Changes in aggregate RERs are given by:

$$\Delta q_{irr't} = \Phi_{ir} \left(\Delta p_{rt} + \Delta e_{rr't} - \Delta p_{r't}\right)$$

The higher is the markup elasticity $\Gamma_{p,nir}$ (and hence Φ_{ir}) the closer is the comovement between aggregate RERs and relative movements in aggregate prices between regions.

Summary of three simple cases Absent variable markups or if trade costs are zero and there is no home bias in preferences, aggregate RERs are constant. Region segmentation in the form of positive trade costs and/or home bias in preferences induces movements in aggregate prices across regions in response to changes in relative costs across regions, resulting in movements of markups that track these changes in aggregate prices. On the other hand, even if trade costs are zero and there is no home bias in preferences, idiosyncratic movements in product-level RERs can result from demand shocks that are imperfectly correlated between regions.

More generally, movements in RERs depend on the precise details of how markup elasticities vary across locations and across products. Region segmentation between the home production location and the selling location (due to home bias in preferences or trade costs) induces differences in markup elasticities across locations. Under our assumptions, on average markups are more sensitive to relative prices at home than abroad: $\Gamma_{p,nii} > \Gamma_{p,nir}$. This contributes to larger movements in product-level RERs, as can be seen in expression (4.6). Moreover, region segmentation implies that regions spend a higher share on domestically produced goods which, at fixed markup elasticities, leads to larger movements in aggregate prices across locations in response to changes in relative costs across locations, contributing to larger movements in aggregate RERs.[27]

[27] While movements in aggregate prices across locations, $(\Delta p_{rt} + \Delta e_{rr't} - \Delta p_{r't})$, are constant when regions are perfectly integrated, and move one-to-one with movements in relative costs when regions are fully segmented, these movements are not monotonic on trade costs or home bias in preferences. As trade costs or home bias in preferences rise, regions increase their expenditure share on domestically produced goods, which at fixed markup elasticities contributes to a rise in aggregate relative prices in region r in response to an increase in relative costs. On the other hand, the sensitivity of markups to relative prices rises for domestic producers in each region, which reduces the rise in aggregate relative prices in region r.

Interpreting empirical facts We now interpret our empirical findings through the lens of our model. The fact that for traded goods product-level RERs across regions are volatile can stem from a combination of (i) region segmentation which induces differences in markup elasticities across regions, and (ii) less-than perfectly correlated demand shocks (or other shocks to markups) across regions. The fact that product-level RERs are more volatile across regions in different countries than within countries can result from a combination of (i) more regional segmentation between countries than within countries, and (ii) lower correlation of demand shocks between countries than within countries. Hence, one can use the observed variation across regions in the volatility of product-level RERs to gauge the degree of segmentation (trade costs and home bias in preferences) across regions within and between countries, only if one can measure and "control" for the correlation of demand shocks (or other shocks to markups) across regions.

The fact that aggregate RERs across regions between countries comove closely with relative unit labor costs stems from a combination of (i) large markup elasticities and (ii) movements in aggregate prices between regions that closely comove with relative unit labor costs, due to the regional segmentation. The fact that movements in aggregate RERs across regions within countries are much smaller than movements in aggregate RERs between countries stems from a combination of (i) smaller movements in unit labor costs across regions within countries than between countries and (ii) less regional segmentation across regions within countries, both of which induce small movements in aggregate prices across regions within countries. Hence, one can use the observed variation across regions in movements of aggregate RER to gauge the degree of segmentation across regions within and between countries, only if one can identify and "control" for changes in relative costs across regions within countries that are comparable to changes in relative costs across countries (mostly driven by changes in nominal exchange rates).

5. Conclusions

In this paper, we provide new observations on aggregate and product-level RERs using non-durable goods price data from a Canada-U.S. retailer. A unique feature of the data is that it allows us to distinguish between goods that are produced in one country and exported to others, and goods that are produced locally in each country. While the data is limited to one particular retailer and a narrow set of product categories, it provides detailed price information at the level of matched individual products and locations in two countries. Our data reveals large deviations from relative purchasing power parity for traded goods and substantial regional pricing-to-market, particularly across countries. There is a significant component of pricing-to-market that is idiosyncratic to the product and not correlated to the exchange rate. To help rationalize our observations, we use a simple multi-region model of pricing-to-market that allows for both idiosyncratic and aggregate shocks. Based on this model, we discuss how movements in RERs for goods produced in a common location and sold in multiple locations can be used to infer the extent of region segmentation between countries and within countries.

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Table 1: Descriptive Statistics

Panel A: Identical Matches

		British Columbia	North California	Canada	US
1	Expenditure share of matched products in total expenditures	0.04	0.06	0.04	0.05
	Expenditure share of products produced in:				
2	U.S.	0.68	0.74	0.67	0.76
3	Canada	0.16	0.04	0.27	0.04
4	ROW (Same Country)	0.16	0.22	0.06	0.20
	Number of matched products by country-of-production set				
5	Total	539	539	987	987
6	US exports (produced in US for sales in Canada and US)	369	369	557	557
7	Canada exports (produced in Canada for sales in Canada and US)	8	8	44	44
8	ROW Exports (produced in ROW for sales in Canada and US)	125	125	331	331
9	Domestically produced (in Canada for Canada sales and in US for US sales)	37	37	55	55
10	Number of product categories	43	43	48	48
11	Number of pricing regions	5	14	14	85

Panel B: Broad Matches

		British Columbia	North California	Canada	US
12	Expenditure share of matched products in total expenditures	0.51	0.36	0.52	0.40
	Expenditure share of products produced in:				
13	U.S.	0.30	0.87	0.32	0.92
14	Canada	0.67	0.01	0.67	0.02
15	ROW (Same Country)	0.03	0.11	0.01	0.06
	Number of matched products by country-of-production set				
16	U.S. exports (produced in U.S. for sales in Canada and US)	7219	7219	11872	11872
17	U.S. exports (produced in U.S. for sales in Canada and US)	4613	4613	6424	6424
18	Canada exports (produced in Canada for sales in Canada and U.S.)	128	128	363	363
19	ROW exports (produced in ROW for sales in Canada and U.S.)	269	269	802	802
20	Domestically produced (in Canada for Canada sales and in U.S. for U.S. sales)	2209	2209	4283	4283
21	Number of product categories	69	69	71	71
22	Number of pricing regions	5	14	14	85

Table 2: Dispersion in Product-Level RER Levels

	Panel A: Identical Matches				Panel B: Broad Matches			
	British Columbia	North California	Canada	US	British Columbia	North California	Canada	US
Intra-national price dispersion								
1 Average absolute log price difference	0.023	0.034	0.029	0.049	0.015	0.026	0.023	0.047
2 Median absolute log price difference	0.007	0.012	0.011	0.020	0.004	0.010	0.010	0.018
International price dispersion								
3 Average absolute log price difference	0.235		0.228		0.445		0.449	
4 Median absolute log price difference	0.189		0.188		0.301		0.302	

Table 3: Movements in Aggregate Real-Exchange Rates

Cumulative 100*log change: Q1 2004 - Q4 2006

	Panel A: Broad Matches			Panel B: Broad Matches			Panel C: Identical & Broad Matches Five Common Categories	
	British Columbia and North California			All Pricing Regions			British Columbia and North California	
	All Exports	US Exports	Domestic	All Exports	US Exports	Domestic	US Exports Identical	US Exports Broad
Intranational								
1 Canada	-0.04	-1.15	-0.17	0.27	0.32	-2.35	-0.66	-0.50
2 US	-0.595	-0.07	1.47	1.07	0.87	-0.29	0.39	-0.42
International: Canada - US								
3 All	14.27	11.76	12.25	13.68	12.47	13.17	13.54	15.85
4 Only changes in modal price > 0	14.24	11.62	13.14	13.50	12.87	12.02	12.95	15.12
5 Only changes in modal price > 0.01	12.47	11.62	12.36	13.51	12.97	8.72		
6 Only changes in modal price > 0.02	12.19	9.74	12.1	13.2	12.53	6.31		

Cumulative increase in 100*log Canada/US relative unit labor costs = 15.1 , Source OECD

Table 4: Movements in Product-Level Real-Exchange Rates

Panel A: Broad Matches, North California and British Columbia

		All Exports	US Exports	Can Exports	ROW Exports	Domestic
1	**Std^{intra} Can**	0.042	0.041	0.032	0.063	0.039
2	**Std^{intra} US**	0.057	0.056	0.102	0.076	0.071
3	**Std^{inter}**	0.112	0.109	0.172	0.131	0.135
4	**Std^{inter} $\|dp\|>0$**	0.119	0.116	0.180	0.149	0.142
5	**Std^{inter} $\|dp\|>0.02$**	0.137	0.134	0.189	0.161	0.162
6	**$Correl^{intra}$ Can**	0.848	0.850	0.944	0.804	0.882
7	**$Correl^{intra}$ US**	0.762	0.765	0.726	0.740	0.782
8	**$Correl^{inter}$**	0.065	0.064	0.033	0.122	0.031

Panel B: Identical Matches, North California and British Columbia

		All Exports	US Exports	Can Exports	ROW Exports	Domestic
9	**Std^{intra} Can**	0.062	0.057	0.027	0.072	0.043
10	**Std^{intra} US**	0.075	0.072	0.055	0.091	0.051
11	**Std^{inter}**	0.132	0.132	0.076	0.137	0.105
12	**Std^{inter} $\|dp\|>0$**	0.143	0.143	0.078	0.147	0.110
13	**Std^{inter} $\|dp\|>0.02$**	0.155	0.156	0.071	0.155	0.148
14	**$Correl^{intra}$ Can**	0.802	0.809	0.906	0.800	0.850
15	**$Correl^{intra}$ US**	0.710	0.723	0.460	0.664	0.478
16	**$Correl^{inter}$**	0.097	0.069	0.168	0.165	-0.205

Table 5: Movements in Product Level RERs: Robustness

		A: All pricing regions, identical matches					*B: All pricing regions, broad matches*				
		All exp	US exp.	Can. exp.	ROW exp.	Domestic	All exp	US exp.	Can. exp.	ROW exp.	Domestic
1	**Std^{intra} Can**	0.07	0.06	0.04	0.10	0.05	0.06	0.06	0.04	0.07	0.06
2	**Std^{intra} US**	0.09	0.08	0.07	0.10	0.07	0.08	0.08	0.10	0.09	0.08
3	**Std^{inter}**	0.14	0.14	0.08	0.16	0.09	0.13	0.13	0.17	0.14	0.14
4	**Correl^{intra} Can**	0.75	0.79	0.82	0.69	0.73	0.81	0.81	0.89	0.77	0.81
5	**Correl^{intra} US**	0.63	0.66	0.27	0.60	0.38	0.69	0.68	0.74	0.62	0.66
6	**Correl^{inter}**	0.10	0.06	0.13	0.12	-0.08	0.07	0.05	0.04	0.11	0.08

		C: Prices in local currency Broad, BC and NC					*D: Prices Demeaned by Category-wide price* Broad, BC and NC				
		All exp	US exp.	Can. exp.	ROW exp.	Domestic	All exp	US exp.	Can. exp.	ROW exp.	Domestic
7	**Std^{intra} Can**	0.04	0.04	0.03	0.06	0.04	0.06	0.05	0.09	0.07	0.06
8	**Std^{intra} US**	0.06	0.06	0.10	0.08	0.07	0.04	0.04	0.03	0.05	0.04
9	**Std^{inter}**	0.108	0.11	0.17	0.13	0.13	0.11	0.11	0.21	0.13	0.13
10	**Correl^{intra} Can**	0.85	0.85	0.93	0.79	0.88	0.76	0.76	0.71	0.74	0.79
11	**Correl^{intra} US**	0.76	0.76	0.73	0.74	0.78	0.86	0.86	0.95	0.84	0.90
12	**Correl^{inter}**	0.08	0.08	0.04	0.12	0.04	0.09	0.09	0.00	0.13	0.06

		E: Weekly prices, BC and NC, identical matches					*F: Weekly Prices, BC and NC, broad matches*				
		All exp	US exp.	Can. exp.	ROW exp.	Domestic	All exp	US exp.	Can. exp.	ROW exp.	Domestic
13	**Std^{intra} Can**	0.12	0.12	0.12	0.12	0.12	0.10	0.10	0.08	0.08	0.11
14	**Std^{intra} US**	0.18	0.18	0.18	0.18	0.18	0.12	0.11	0.14	0.17	0.12
15	**Std^{inter}**	0.26	0.26	0.26	0.26	0.26	0.33	0.34	0.30	0.28	0.43
16	**Correl^{intra} Can**	0.90	0.90	0.90	0.90	0.90	0.95	0.95	0.95	0.91	0.93
17	**Correl^{intra} US**	0.60	0.60	0.60	0.60	0.60	0.82	0.83	0.76	0.62	0.83
18	**Correl^{inter}**	-0.03	-0.03	-0.03	-0.03	-0.03	0.01	0.02	-0.04	0.00	0.00

		G: Retail Prices, Identical Matches, NC and BC					*H: Retail Prices, Broad Matches, NC and BC*				
		All exp	US exp.	Can. exp.	ROW exp.	Domestic	All exp	US exp.	Can. exp.	ROW exp.	Domestic
19	**Std^{intra} Can**	0.08	0.08	0.05	0.09	0.05	0.07	0.07	0.08	0.07	0.10
20	**Std^{intra} US**	0.05	0.05	0.03	0.05	0.04	0.05	0.05	0.04	0.05	0.04
21	**Std^{inter}**	0.12	0.12	0.07	0.13	0.09	0.14	0.14	0.17	0.13	0.14
22	**Correl^{intra} Can**	0.73	0.73	0.59	0.71	0.77	0.75	0.75	0.89	0.77	0.75
23	**Correl^{intra} US**	0.80	0.81	0.70	0.76	0.82	0.83	0.83	0.81	0.05	0.87
24	**Correl^{inter}**	0.07	0.07	0.15	0.06	-0.04	0.03	0.03	0.18	0.01	0.13

NC: Northern California, BC: British Columbia

Figure 1: Canada-US Aggregate Real Exchange Rates

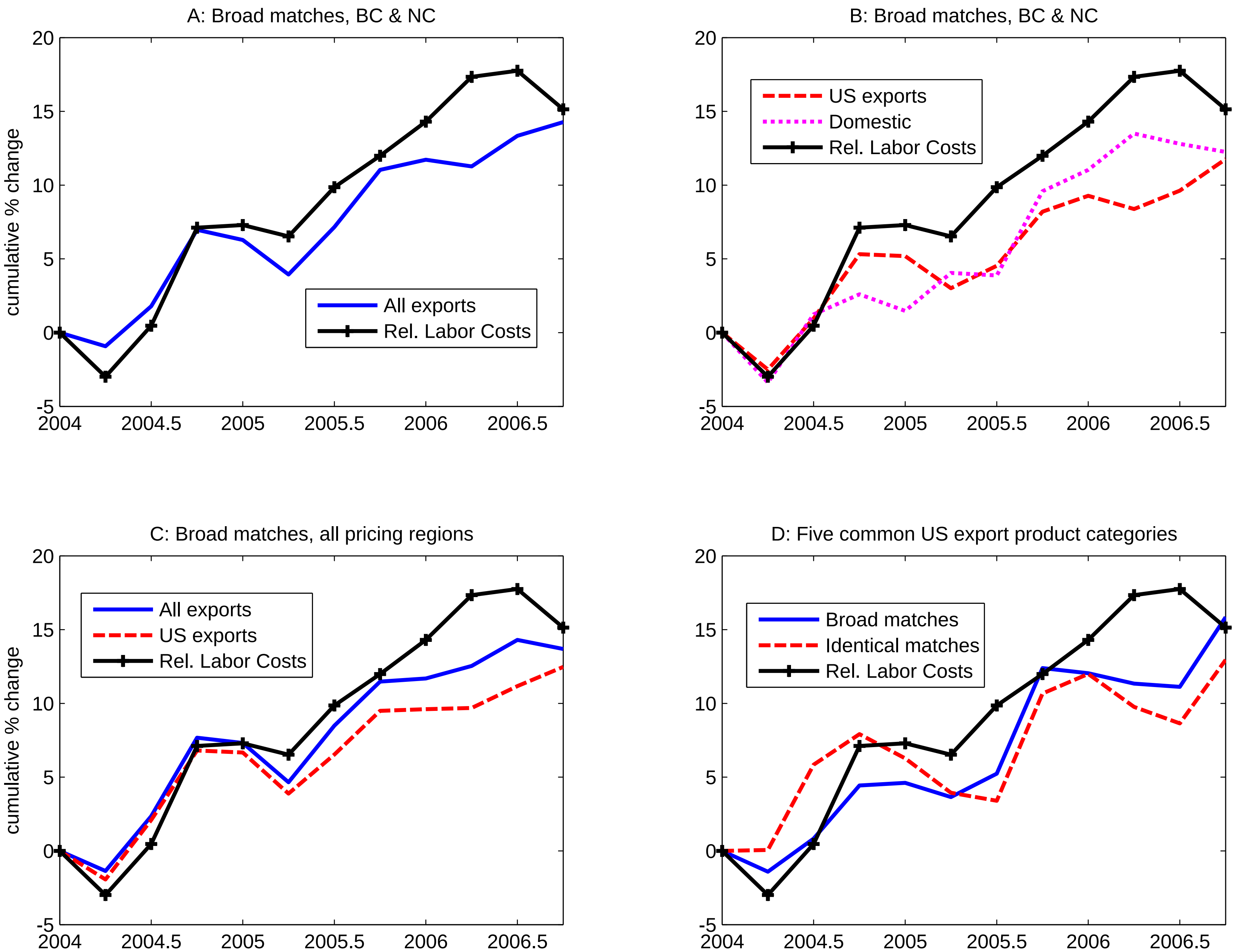


Figure 2: Canada-US Aggregate Real Exchange Rates

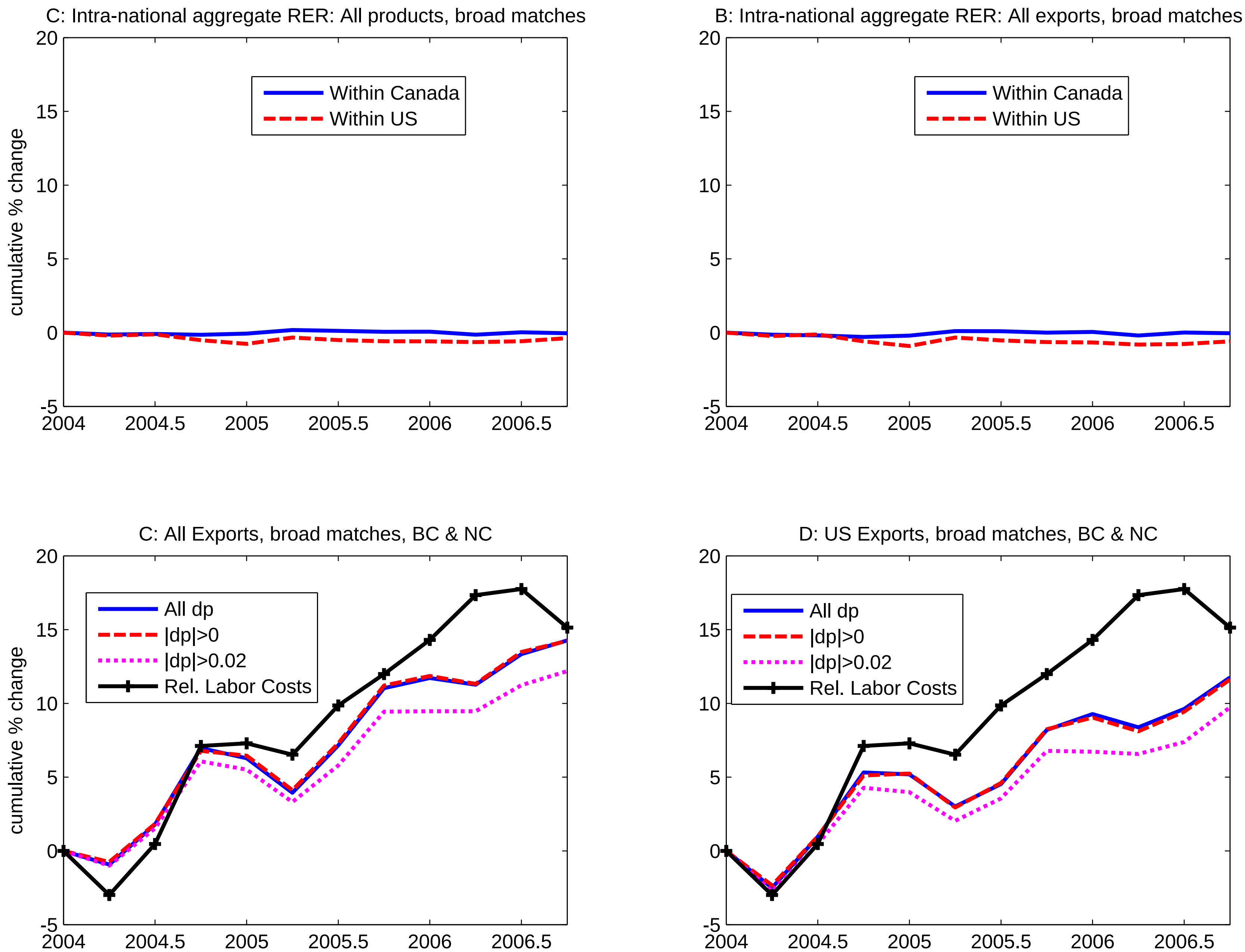
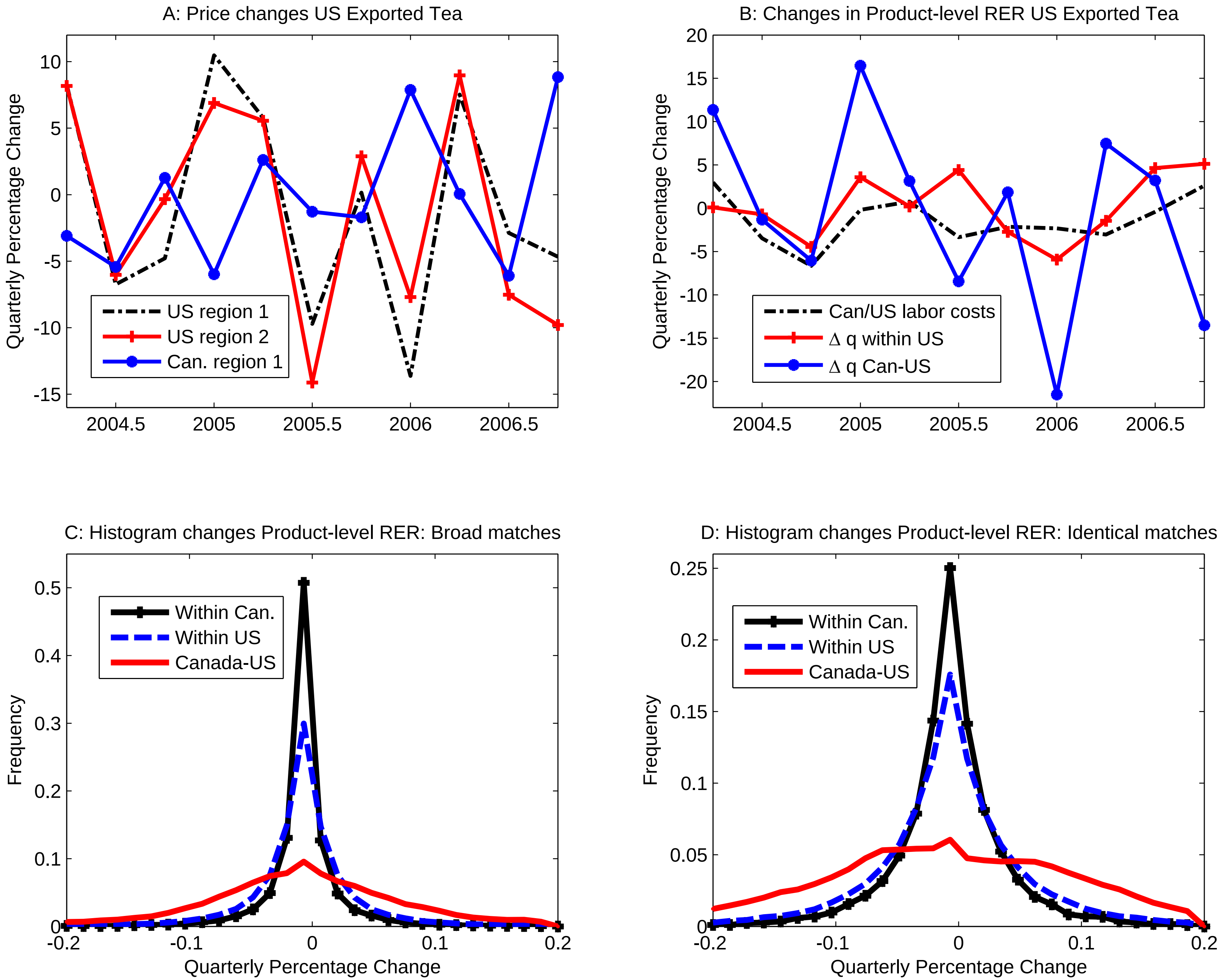


Figure 3: Product-Level Real Exchange Rates



Appendix

In this appendix we briefly describe three widely used demand models that produce the assumed relation between relative prices, demand shifters, and markups represented by $\mu(.,.)$ in Section 4. Since we focus on markups in a given region and at a point in time, for simplicity we abstract from location (i, r) and time (t) subscripts.

5.1. Non-CES demand

This setting was originally explored in Kimball (1995). A fixed continuum of intermediate goods of measure one, indexed by n, are combined in amounts C_n to produce a final good C (or utility) according to a constant returns to scale technology implicitly defined by:

$$\int_{\Omega} \Upsilon\left(\frac{C_n}{A_n C}\right) dn = 1,$$

The function Υ satisfies the constraints $\Upsilon(1) = 1$, $\Upsilon'(.) > 0$ and $\Upsilon''(.) < 0$. Under constant returns to scale (CES), $\Upsilon(.) = (.)^{\frac{\theta-1}{\theta}}$. Cost minimization (or utility maximization) gives rise to the following first-order-condition:

$$P_n = \Upsilon'\left(\frac{C_n}{A_n C}\right) \frac{\lambda}{A_n C},$$

where λ denotes the Lagrange multiplier. Expenditures over all varieties are given by:

$$PC = \int_{\Omega} P_n C_n dn = \lambda D,$$

where P is the price index, $P = \left[\int_{\Omega} P_n C_n dn\right] / C$, and $D \equiv \int_{\Omega} \Upsilon'\left(\frac{C_n}{A_n C}\right) \frac{C_n}{A_n C} dn$. Hence, the inverse demand function for variety n is:

$$\Upsilon'\left(\frac{C_n}{A_n C}\right) = \frac{D P_n}{A_n P},$$

which can we inverted to obtain:

$$C_n = A_n \psi\left(\frac{D P_n}{A_n P}\right) C,$$

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

$$c_n = a_n + \log\left(\psi\left(\exp\left(x_n\right)\right)\right) + c,$$

where $x_n = \log(D) - a_n + p_n - p$ and $a_n = \log(A_n)$. The demand elasticity is:

$$\varepsilon_n = -\frac{\psi'(.)}{\psi(.)} \frac{D P_n}{A_n P},$$

which can vary across firms depending on the shape of $\psi(.)$. It is straightforward to show that $dD = 0$ up to a first-order-approximation around an equilibrium in which ε_n is equal across all products. The log change in the aggregate price index (for a fixed aggregate consumption $C = 1$) is:[28]

$$\begin{aligned}\Delta p &= \int_{\Omega} \frac{P_n C_n}{P} \left(\Delta p_n + \Delta c_n\right) dn \\ &= \int_{\Omega} s_n \Delta p_n dn + \int_{\Omega} s_n \Delta c_n dn. \end{aligned} \tag{A1}$$

To calculate the second term in (A1), we differentiate the aggregator (subject to $C = 1$):

$$\int_{\Omega} \Upsilon' \frac{C_n}{A_n} \left(\Delta c_n - \Delta a_n\right) dn = 0.$$

Using the FOC from cost minimization and the fact that the expected value of Δa_n is equal to zero, we have that $\int_{\Omega} s_n \Delta c_n dn = 0$, so $\Delta p = \int_{\Omega} s_n \Delta p_n dn$.

To put more structure on the dependance of ε_n on the relative price, Klenow and Willis (2006) choose a specification Υ that results in a demand function:

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

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

$$\varepsilon_n = -\frac{\partial \log \psi\left(x\right)}{\partial x} = \frac{\theta}{1 - \eta x_n}$$

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

$$\mu_n = \log\left(\frac{\theta}{\theta - 1 + \eta x_n}\right)$$

and the elasticity of the markup with respect to the relative price and with respect to the demand shifter is:

$$\Gamma_{n,p} = \Gamma_{n,a} = \frac{\eta}{\theta - 1 + \eta x_n}.$$

Hence, when $\eta > 0$ markups are decreasing in the relative price and increasing in the demand shifter. Moreover, markups are more sentitive to relative prices $p_{in} - p_n$ (i.e. $\Gamma_{n,p}$ is higher) the lower is a firm's relative price and the higher is the demand shifter a_n.

[28] Depending on parameter values, there may be a choke price above which some products are not consumed even if fixed costs are zero (see e.g. Arkolakis et. al. 2012). Up to a first-order approximation, this margin has no impact on the aggregate price index since entering and exiting products have sales equal to zero.

5.2. Distribution costs

This setting was originally explored in Corsetti and Dedola (2005). Final consumption is given by

$$C = \left[\int_{\Omega} C_n^{\frac{\theta-1}{\theta}} dn \right]^{\frac{\theta}{\theta-1}}, \theta > 1.$$

In order to deliver an intermediate good to the final consumer, a retail (and wholesale) sector in the destination location bundles the domestically produced or imported good with distribution services. Assuming that the retail sector is competitive and combines the good and distribution services at fixed proportions, the retail price (in levels) of the intermediate good n, P_n^r, is given by:

$$P_n^r = P_n + \eta A_n P^d$$

where ηA_n denotes the distribution cost per good. We assume that production of one unit of distribution services uses one unit of the industry bundle, which implies $P^d = P$.[29]

Note that under this specification, movements in distribution costs, $\eta A_n P$, across regions gives rise to movements in product-level RERs at the wholesale and retail level even if producer markups are constant. Given that wholesale distribution margins for the products we consider are on average only 16% in the U.S., it is unlikely that this force by itself can rationalize our empirical findings on product and aggregate-RERs.

The presence of additive distribution costs, however, leads to variable markups at the producer level. The elasticity of demand faced by an intermediate good producer is

$$\varepsilon_n = \frac{\partial \log C_n}{\partial \log P_n} = \theta \left(1 - s_n^d\right)$$

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

$$\mu_n = \log \left[\frac{\theta \left(1 - s_n^d\right)}{\theta \left(1 - s_n^d\right) - 1} \right] = \log \left[\frac{\theta}{\theta - 1 - \eta \exp\left(a_n - (p_n - p)\right)} \right].$$

The elasticity of the markup with respect to the relative price $p_n - p$ is

$$\Gamma_{p,n} = \frac{1}{\frac{\theta-1}{\eta A_n \exp(-(p_n-p))} - 1} = \frac{1}{(\theta - 1)\frac{1-s_n^d}{s_n^d} - 1}, \tag{A2}$$

and the markup elasticity relative to a_n is $\Gamma_{a,n} = \Gamma_{p,n}$. Clearly $\Gamma_{p,n} = 0$ if $s_n^d = 0$ and $\Gamma_{p,n} > 0$ if $s_n^d > 0$.[30] Note also the the markup elasticity is increasing in s_n^d (and hence is decreasing

[29] An alternative assumption that gives similar results is that distribution services are produced using local labor instead of the industry bundle. In such case, the markup is a decreasing function of the price relative to the wage, $p_n - w$, instead of $p_n - p$. Markups in this case respond to changes in local wages and not directly to changes in the local aggregate price.

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

in relative price and increasing in a_n). Finally, under the assumption that distribution costs are produced using the final good, it is straightforward to show that changes in the final price index are given by $\Delta p = \int_\Omega s_n \Delta p_n dn$ as in the previous model.

5.3. Strategic complementarities in pricing with CES demand

This setting was originally studied in Dornbusch (1987) and more recently in Atkeson and Burstein (2008). Final sector output is modeled as a CES of the output of a continuum of sectors m with elasticity of substitution η and sector output is CES over a *finite* number of differentiated products with elasticity θ, where $1 \leq \eta \leq \theta$:

$$C = \left[\int C_m^{\frac{\eta-1}{\eta}} dn\right]^{\frac{\eta}{\eta-1}} \quad \text{and}$$

$$C_m = \left[\sum_\Omega A_n^{\frac{1}{\theta}} C_n^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}.$$

Firms own single products within each sector and compete in prices (Bertrand). Taking as given prices of other firms in its sector, the elasticity of demand for good i selling in country n in any given sector is:

$$\varepsilon_n = \eta s_n + \theta (1 - s_n),$$

where $s_n = \exp(a_n + (1-\theta)(p_n - p))$ represents the expenditure share of product i with taste parameter a_n in that sector and $p = \frac{1}{1-\theta}\log\left(\sum_i a_n + (1-\theta)(p_n - p)\right)$ is the log of the aggregate sector price. Note that, if $\eta < \theta$, ε_n is decreasing in the expenditure share of the firm in that sector. The optimal markup that results from choosing price to maximize profits taking prices of other firms in the sector as given is:

$$\mu_n = \log\left(\frac{\varepsilon_n}{\varepsilon_n - 1}\right) = \log\left(\frac{\eta s_n + \theta(1-s_n)}{\eta s_n + \theta(1-s_n) - 1}\right),$$

which is increasing in s_n (hence, decreasing in $p_n - p$ for a fixed a_n and increasing in a_{in} for a fixed $p_n - p$) if $\theta > \eta$. The elasticity of the markup with respect to relative price is:

$$\Gamma_{n,p} = (\theta - \eta)(\theta - 1)\frac{s_n}{[\eta s_n + \theta(1-s_n)][\eta s_n + \theta(1-s_n) - 1]}, \tag{A3}$$

and the markup elasiticty of the markup with respect to the demand shifter is $\Gamma_{n,a} = \Gamma_{n,p}/(\theta - 1)$, both of which are positive if $1 \leq \eta \leq \theta$. That is firms with lower relative price $p_n - p$, higher demand shifter a_n, and higher expenditure share s_n set higher markups. Markup elasticities $\Gamma_{n,p}$ and $\Gamma_{n,a}$ are higher the higher is a firm's market share s_n (e.g. the lower is its relative price $p_n - p$ and the higher is the demand shifter a_n). These results are qualitatively unchanged if firms compete in quantities (Cournot).[31] Moreover, the pricing

[31] Under Cournot competition, $\varepsilon_n = \left(\frac{s_n}{\eta} + \frac{1-s_n}{\theta}\right)^{-1}$ and $\Gamma_n = (\theta-1)\left(\frac{1}{\eta} - \frac{1}{\theta}\right)\mu_n s_n$, where s_n and p are given by the same expressions as under Bertrand competition, and $\mu_n = \varepsilon_n/(\varepsilon_n - 1)$. Once again, $\Gamma_{n,p}$ is decreasing in $p_n - p$ and increasing in s_n.

implications of this model are continuous in the elasticity of substitution between products within a sector, θ. Hence, with competition in prices and $\theta \longrightarrow \infty$ there is limit pricing (prices are equal to the minimum between the monopoly price and the cost of the latent competitor) as discussed in Atkeson and Burstein (2007).

Note that with a finite number of positive-mass firms per sector, any change in a product's price p_n has a non-zero effect on the sectoral price p. Taking this into account, the change in price of good n given by equation (4.5) becomes (abstracting from region and time indices):

$$\Delta p_n = \frac{\Delta z_n + \Delta w_n + \Delta e_n + \frac{(1-s_n)}{\theta-1}\Gamma_{p,n}\Delta a_n}{1+(1-s_n)\Gamma_{p,n}} + \frac{(1-s_n)\Gamma_{p,n}}{1+(1-s_n)\Gamma_{p,n}}\Delta p_{-n},$$

where Δe_n denotes the change in the exchange rate between the production and destination locations for product n, and Δp_{-n} is an expenditure-weighted average of price changes in the sector exclusive of product n (in models with a continuum of products, $s_n = 0$). Markups are constant if $s_n = 0$ or if $s_n = 1$. Hence, in this case movements in markups and in product-level RERs across firms are non-monotonic in relative marginal costs or in demand shifters as in the models with a continuum of firms. The markup elasticity is decreasing in relative price and increasing in the demand shifter only in the region in which $(1-s_n)\Gamma_{p,n}$ is increasing in s_n. This assumption is required for our discussion in the paper on how markup elasticities vary across location.

The change in aggregate price in a given sector is:

$$\Delta p = \frac{\sum \frac{s_n}{1+\Gamma_{p,n}}\left(\Delta z_n - \frac{\Delta a_n}{\theta-1} + \Delta w_n + \Delta e_n\right)}{\sum \frac{s_n}{1+\Gamma_{p,n}}}.$$

If the number of products in this sector is small, idiosyncratic shocks do not wash-out when calculating the change in the sector aggregate price. However, idiosyncratic shocks do cancel-out then calculating our statistics over a continuum of ex-ante symmetric sectors and we obtain the expressions for the change in the aggregate prices as in our previous models.