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

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Abstract

Is the practice of pricing-to-market by exporters important to account for the large movements of relative prices across countries over time? To address this question we document new facts on aggregate and product-level real exchange rates using wholesale price data and information on the country of production for individual products sold in multiple locations in Canada and the United States over the period 2004-2006. Aggregate real exchange rates, constructed by averaging across goods the movements in Canada-U.S. relative prices, closely follow the appreciation of the Canadian dollar over this period. Relative prices across countries at the level of individual products are even more volatile, roughly four times as large as the Canada-U.S. nominal exchange rate at quarterly frequencies. For goods produced in one country and exported to other countries, these movements in relative prices reflect the practice of pricing-to-market by which producers vary over time the markup at which they sell their output across locations. Pricing-to-market is not mechanically accounted for by sticky prices in the buyer's currency, as prices change frequently and by large magnitudes. In light of these findings, we construct a simple model of international trade and pricing-to-market with flexible prices that can rationalize the large observed movements in aggregate and product-level real exchange rates for traded and nontraded goods. The international border plays a key role in generating pricing-to-market by segmenting competitors across countries.

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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 products to shed new light on the following questions: How important is pricing-to-market in accounting for the observed movements in international relative prices? Does pricing-to-market arise mechanically from nominal prices that remain sticky in each country in response to changes in nominal exchange rates? Is pricing-to-market more prevalent across countries than within countries? In order to rationalize our answers to these questions, we then build a model of international trade and pricing-to-market.

Our empirical work is based on scanner data for the period 2004-2006 from a major retailer that sells primarily nondurable 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. 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 by producers and wholesalers.

Our findings demonstrate that pricing-to-market plays an important role in accounting for movements in international relative prices. To substantiate this claim, we show that movements in *aggregate RERs*, constructed by averaging changes in relative prices across countries (expressed in a common currency) over a large set of products sold in both Canada and the U.S., closely track movements in Canada-U.S. relative unit labor costs (which are mainly accounted for changes in the Canada-US nominal exchange rate). For nontraded goods that are produced in each country and sold in both countries, these movements in aggregate RERs can simply reflect changes in relative costs across countries. However, the fact that this pattern holds as well for traded goods produced in a common location and sold in both countries implies that in response to the appreciation of Canada-U.S. labor costs, markups in Canada increase systematically relative to markups in the U.S.

Pricing-to-market does not stem, in a pure accounting sense, from large movements in nominal exchange rates and small movements in nominal prices in each country. Instead, nominal prices of individual products change frequently and by large magnitudes.[1] Moreover, changes in international relative prices at the level of individual products, *product-level RERs*, 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 evidence on pricing-to-market complements previous studies based on price indices from national statistical agencies or unit values at the level of goods categories or industries (see e.g. Goldberg and Knetter 1995, Atkeson and Burstein 2008, and references therein). One concern of inferring pricing-to-market using aggregate price data is that movements in international relative prices can result from differences in the product composition of the indices, and not from changes in relative price across locations for common goods. Here we address this concern by using relative price movements for matched individual products sold in multiple locations.

On this note, there is a recent and rapidly growing literature documenting the behavior of international relative prices using detailed product-level information. For example, Crucini et. al. (2005), Crucini and Shintani (2008), Broda and Weinstein (2007), and Gopinath et. al. (2008) measure the extent of differences in price levels across locations, as well as the volatility and persistence of relative price changes. Our empirical contribution to these papers is to measure the extent to which movements in relative prices of matched individual products across locations reflect pricing-to-market by producers and wholesalers. We can do so because of two unique features of our data. First, by observing wholesale prices we

[1] This observation is consistent with the evidence in Bils and Klenow (2004) based on U.S. consumer prices. For further work on the relation between price stickiness and international prices, see Gopinath and Rigobon (2008), Gopinath and Itskhoki (2009), and Kehoe and Midrigan (2008).

can more accurately measure movements in relative markups at the producer level than if we used retail prices, which contain a significant non-tradeable distribution component (see e.g. Burstein et. al. 2003). Second, by identifying the country of production of individual products sold in Canada and the U.S., we can infer changes in relative markups from observed movements in relative prices for goods that are produced in one country and exported to others. Hence, our data enable us to isolate movements in relative prices arising from pricing-to-market, from those due to movements in production or retail distribution costs (and not markups) across locations. Fitzgerald and Haller (2008), like us, provide evidence of pricing-to-market by individual exporters in response to changes in nominal exchange rates, using domestic and export prices of individual Irish producers. Goldberg and Hellerstein (2007), Hellerstein (2008), and Nakamura (2008) quantify the role of variable markups and local costs in accounting for incomplete pass-through of changes in costs and exchange rates into U.S. retail prices in the beer and coffee industries. Instead, we focus on the role of changes in relative markups across locations (i.e. differences in pass-through across locations) in accounting for movements in relative prices between regions in Canada and the U.S.

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 address these questions and others using a model of international trade and pricing-to-market.

Our model follows the recent work of Atkeson and Burstein (2007 and 2008), that builds on the pricing-to-market models with flexible prices pioneered by Dornbusch (1987) and Krugman (1987),[2] and upon the Ricardian models of international trade with heterogeneous producers and variable markups by Bernard et. al. (2004). We extend the model of Atkeson and Burstein (2007), in which producers compete in multiple countries à la Bertrand with limit pricing and are subject to international trade costs when selling abroad, along several dimensions. We highlight two key extensions. First, we introduce time-varying cost and demand shocks in order to account for idiosyncratic movements in product-level RERs 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 the movements in relative prices within and across countries.

[2]For other recent models of pricing-to-market, see for example Bergin and Feenstra (2001), Alessandria (2004), Corsetti and Dedola (2005), and Drozd and Nosal (2008).

We first provide a simple analytical characterization to illustrate the model's ability to generate pricing-to-market and match our key pricing observations. Pricing-to-market arises in our model because, with Bertrand competition and limit pricing, producers set prices that are determined not only by their own marginal cost, but also by the marginal cost of their latent competitor and by idiosyncratic demand shocks. Exporters facing a different local latent competitor in each country set prices that move, on average, one-to-one with changes in aggregate relative costs across countries. Moreover, producers also change relative prices across locations in response to idiosyncratic demand shocks (if these are not correlated across locations), and in response to idiosyncratic shocks to the latent competitor's cost (if the latent competitor differs across locations). Therefore, our model can produce persistent movements in aggregate RERs that track international aggregate relative costs, and underlying these movements in aggregate RERs it can generate large idiosyncratic movements in product-level RERs across locations, both for exported goods and for domestically-produced goods. These implications, as well as several others that we discuss below, are present in our data. We discuss alternative models that fail to account for our stylized facts along several dimensions. We also use our model to discuss what our empirical findings on prices imply for the significance of international trade costs (see Engel and Rogers 1996 and Gorodnichenko and Tesar 2008 for related work on inferring the role of international trade costs from price data).

Finally, we relax some of the assumptions that make the model analytically tractable, and numerically solve a parameterized version of the model that matches key observations on the volume of trade and movements of prices in Canada and the U.S. We show that our analytical results are largely unaffected, and that our model can give rise to a significant degree of pricing-to-market. In our baseline parameterization, the model generates an increase in Canada-U.S. markups for exported products that is roughly 70% as large as the increase in Canada-U.S. relative costs in the period $2004 - 2006$. The model can generate this large degree of pricing-to-market in response to a change in relative costs across countries even if prices are fully flexible and move by large magnitudes in response to idiosyncratic cost and demand shocks.

Our paper is organized as follows. Section 2 describes our data. Section 3 reports our main findings on international price movements. Section 4 presents our model. Section 5 examines the pricing implications of an analytically tractable version of the model. Section 6 presents the quantitative results of a parameterized version of the model. Section 7 concludes.

2. Data Description

Our analysis is based on scanner data from a large food and drug retail chain that operates hundreds of stores in Canadian provinces and U.S. states.[3] 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 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 93 product categories, including beverages, cleaning products, personal care, and processed food.

For each store we have information on quantities sold, sales revenue, and the retailer's cost of purchasing the goods from the vendors, net of discounts and inclusive of shipping costs. Using this data, we construct retail and wholesale prices, as described in Appendix 1. In order to measure the extent of pricing-to-market at the producer level, we focus our analysis primarily on wholesale prices, which are the closest measure of producer prices in our data. Local distribution services are substantially less sizeable at the wholesale level than at the retail level. Based on information from the U.S. Wholesale and Retail Census, the average 1998-2006 gross margin as a percentage of sales for groceries and related products is 16% at the wholesale level and 48% combining the wholesale and retail levels.[4] In Section 3.4, we briefly report our central empirical findings based on retail prices.

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. If pricing-to-market is more prevalent across different retailers, then our results understate the extent of pricing-to-market in the data.[5]

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

[4] This information is available at www.census.gov/econ/www/retmenu.html

[5] See Nakamura (2008) for a discussion of retail pricing within and across retail chains.

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. Based on information from the retailer and on our own calculations, we identify 17 pricing regions in Canada and 73 pricing regions in the U.S. Given the similarity of retail and wholesale prices across stores within pricing regions, we choose to focus on these as our geographic unit. Considering all individual stores within each pricing region would substantially increase the size of our dataset without essentially adding new information.

We thus construct a weekly wholesale price for each pricing region as the median wholesale price across stores within the pricing region. For most products in our data, there is considerable variation in wholesale prices across pricing regions. This is because vendors charge different prices for the same product in different regions.

Our baseline statistics are computed for the five 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 (more on this below). We also report our statistics based on the pricing regions in the Center-West geographic area. This includes all 17 pricing regions in Canada, and 51 pricing regions in the U.S. located in California, Oregon, Washington, Idaho, Montana, and Wyoming, chosen to match roughly the geographic coverage in Canada.

Aggregation across time Our statistics are based on prices at quarterly frequencies. These are constructed as average weekly prices within the quarter.[6] In doing so, we are abstracting from sales and promotions that give rise to highly temporary price changes. In Section 3.4 we show that 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.

In computing our price statistics, we abstract from very short-lived products in our data, and only include those with at least four consecutive growth rates, and product categories with at least 50 growth rates per quarter.[7] Our results are largely unchanged to variations in this filtering criteria.

[6] We also constructed our price statistics using median and mode weekly prices within each quarter. These lead to even larger movements in product-level RERs (both within and across countries), and do not have a significant impact on the movements of aggregate RERs.

[7] The replacement bias studied in Nakamura and Steinsson (2009) is less likely to be of a concern in our data because prices change quite frequently.

2.2. Matching products

In order to measure movements in international relative prices, we need to match products in Canada and the U.S. We proceed in two steps. First, we match products that have identical UPC codes in both countries. This gives us $1,213$ identical product matches across countries.

Since our emphasis is on understanding price fluctuations over time, as opposed to differences in price levels at a point in time, we also consider a broader set of internationally matched products beyond these identical products. Our key assumption in this matching procedure is that 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. Under this assumption, changes in relative prices across locations for goods produced in a common location can be interpreted as movements in relative markups by individual producers (i.e., pricing-to-market).

Specifically, to broaden the set of matched products, we include items that have different UPC codes but share, in both countries, the same brand, manufacturer, and at least one additional characteristic in the product description. Our procedure does not require that matched products share a common size and exact product description. Given the degree of arbitrariness in our matching process, we classify our matches from "conservative" to "liberal" (more on this below). Our conservative 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 roughly $14,000$ product matches across countries.

Our baseline results use the union of the set of identical and the set of conservative product matches. To show that our main findings are not driven by non-identical matches, we also report results based on identical product matches (for statistics for which we have sufficient observations). In our sensitivity analysis, we also report our results based on liberal matches. Our findings are largely robust to these 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 was as follows. First, in the U.S., we used the country-of-origin label information that was available in the retailer's online store for sales in Northern California. Second, in Canada, given that the country-of-origin information was not available on-line, we hired two research assistants who physically visited the retailer store in Vancouver, British Columbia, and recorded the country-of-origin label information.[8] Third, our research assistants verified the label information by calling many of the individual manufacturers.[9] 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, it is possible that a product's country of production varies over time. Second, it is possible that a product's country of production varies across regions within the U.S. and Canada. With respect to the first caveat, we have informal evidence based on interviews with the retail managers that for most products there is small variation over time in the country of production. To address the second caveat, we define our baseline geographic area to include only the pricing regions in British Columbia and Northern California, where the information on country of production was obtained.

[8]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.

[9]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. As discussed in Section 5.4, these local distribution components would have to be extremely large to account entirely for the large movements in RERs observed in our data.

2.4. Descriptive statistics

Table 1 provides descriptive statistics for our matched products. We report the information for our identical and conservative matches separately, for the set of pricing regions in the Center-West, and for those in British Columbia and Northern California. Our 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 union of conservative and identical matches covers 52% of total expenditures in Canada and 36% in the U.S. (Row 14).[10]

Rows 2-7 and 15-20 summarize our country of production information for the set of products we cover. Rows 2-4 and 15-17 report expenditure shares by country of production, and rows 5-7 and 18-20 report the number of products by country of production. There is a significant degree of home bias in consumption. In particular, based on our set of identical and conservative matches, 90% of expenditures and 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 (or half of the number of products) are domestically produced, while imports from the U.S. and ROW account for 30% and 3% of expenditures, respectively.[11] 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 8-11 and 21-24 report the number of matched products, divided into our four country-of-production sets. We have roughly $1,000$ identical matches in the Center-West area, and 800 in British-Columbia and Northern California. Including conservative matches increases the number of matches to $11,000$ in Center-West and $9,000$ in British-Columbia and Northern California.[12]

Of these identical and conservative matched products, roughly half are produced in the U.S. for both U.S. and Canada sales (U.S. exports), and as many as 45% are domestically produced in each country. The share of matched products that are exported either by Canada

[10] 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.

[11] 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.

[12] Note that, while the total number of products in Rows 5-7 is equal to the total number of identical matched products in Rows 8-11, Panel A, it is lower than the total number of conservative matches in Rows 21-24, Panel B. This is because, as discussed above, in our conservative matching procedure some products are matched more than once.

or by ROW countries is less than 5%, and hence is significantly smaller than the number of those that are exported by the U.S. or domestically produced. Therefore, our statistics for Canadian and ROW exporters are more prone to small sample limitations.

3. Empirical findings on price movements

In this section we report our central empirical findings on aggregate- and product-level RER movements and on the extent of pricing-to-market. 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. Second, we show that these movements in relative prices are not the result of sticky nominal prices and volatile exchange rates. Instead, product-level RERs are very volatile, even for exported products, because price changes are frequent, large, and not very correlated across international locations. Third, 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. Finally, we show that the extent of pricing-to-market differs for U.S., Canadian, and ROW exports, and that exported goods in product categories with low international correlation of price changes also tend to be the ones that experience large aggregate RER movements in response to a change in relative unit labor costs. These two last findings provide some support for the model we develop in Section 4.

Definitions Our data contains time series information on prices of individual products sold in multiple regions in U.S. and Canada. We denote individual products by $n = 1, 2, ..,$ time periods by $t = 1, ..., T$, countries by $i = 1$ (U.S.) and $i = 2$ (Canada), and regions by $r = A, ..., R_i$.

The price (in U.S. dollars) of product n sold in country i, region r, in period t, is denoted by P_{nirt}. We refer to relative prices across regions for individual products as product-level RERs. The relative price of product n between region r in country i and region r' in country j is denoted by $Q_{nijrr't} = P_{nirt}/P_{njr't}$. The logarithmic percentage change in the price of an individual product between periods t and $t-1$ is denoted by $\Delta P_{nirt} = \log(P_{nirt}) - \log(P_{nirt-1})$. Similarly, the percentage change over time in the relative price between region r in country i and region r' in country j is denoted by:

$$\Delta Q_{nijrr't} = \log(Q_{nijrr't}) - \log(Q_{nijrr't-1}) = \Delta P_{nirt} - \Delta P_{njr't}.$$

For products that are produced in a common location and hence share a common percentage change in marginal cost, $\Delta Q_{nijrr't} \neq 0$ indicates that producers and wholesalers price-to-market by varying their markups across these two locations.

We also construct a measure of movements in aggregate RERs across countries by averaging the change in product-level RERs over a large set of individual products and pairs of regions across the two countries. Aggregate RERs average out the idiosyncratic changes in product-level RERs and hence capture the time-varying components that are common to many products. More specifically, the change in the Canada-U.S. aggregate RER between periods $t-1$ and t for products belonging to a set N and sold in both countries is defined as

$$\Delta Q_t = \sum_{n \in N} \sum_{r'=A}^{R_1} \sum_{r=A}^{R_2} \psi_{nrr't-1} \Delta Q_{n21rr't}, \tag{3.1}$$

where $\psi_{nrr't}$ denotes the average expenditure share of product n in region r in country 1 and region r' in country 2, in period t. These shares add up to one across all pairs of regions and products in the set N. Further details are provided in Appendix 1.[13]

3.1. Aggregate real exchange rates

Figure 1 depicts the cumulative movement of aggregate RERs, separately for each of the following country-of-production sets: all exported products, U.S. exports, Canada-ROW exports, and domestically-produced products. We do not consider separately Canada and ROW exports because the number of products is too low to smooth-out the idiosyncratic movements in prices. We focus on the pricing regions in British Columbia and Northern California, where our information on country-of-origin was obtained.

Over our sample period $2004 - 2006$, relative unit labor costs as constructed by the OECD 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. For domestically-produced products, the aggregate RER increased by roughly 10%. For all exported products, the aggregate RER rose roughly 13%. The magnitude of the movements in aggregate RERs is quite similar if we consider identical matches or our broader set of identical plus conservative

[13] 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).

product matches. The large aggregate RER movements for exported goods is evidence of pricing-to-market by which exporters systematically raise markups in Canada relative to the U.S. in response to an increase in Canada-U.S. costs.

We also constructed intra-national aggregate RERs, averaging movements in product-level RERs across many products for pairs of regions within countries. The lower-right panel of Figure 1 displays the cumulative change in intra-national aggregate RERs within the Center-West geographic areas in Canada and the U.S., as defined in section 2.1. Note that intra-national aggregate RERs are roughly constant over time as idiosyncratic movements in product-level RERs wash-out. Region-specific shocks within countries seem to play a minor role in driving movements in aggregate RERs. In comparison, the large movements in international aggregate RERs suggest that 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.

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

In our data, however, individual prices in Canada and the U.S. move very frequently. Using our raw weekly wholesale data, the fraction of price adjustment across all products and weeks is 0.5, so that prices change on average every 2 weeks. Moreover, the fraction of observations across all of our matched products and weeks 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 N weeks is roughly 0.28^N. For $N = 13$ (i.e. a quarter) we obtain a number close to zero.

We also compute frequencies of price adjustment based on price series exclusive of sales or other highly temporary variation. Here we follow Eichenbaum et. al. (2008) and construct reference prices as the modal, or most common price across weeks within each quarter. The fraction of modal price adjustment across all products and quarters is 0.5 in Canada and U.S., so that modal prices change on average every 2 quarters. The fraction of matched products for which either the Canadian modal price or the U.S. modal price change in a quarter is still high at 0.75.

The fact that prices in our data change quite frequently suggest that sticky local currency prices have at most a limited role in accounting mechanically for the two-years, steady rise in Canada-U.S. aggregate RERs in Figure 1.

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 displayed in Figure 1, there are very large idiosyncratic movements in product-level RERs.

To fix ideas, Figure 2 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. The top panel displays the 11 quarterly growth rates of prices (all expressed in U.S. dollars), ΔP_{nirt}, in three regions: two regions in the U.S. (both in Northern California), and one region in Canada (in British Columbia). The bottom panel displays the percentage change in the relative price between the two U.S. regions, $\Delta Q_{n11rr't}$, and one region in the U.S. and one in Canada, $\Delta Q_{n12rr't}$. The lower panel 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.

Figure 3 presents histograms of the movements in international product-level RERs between British Columbia and Northern California like those displayed in Figure 2, but now across all pairs of regions and our entire set of identical and conservative matched products. The upper panel considers only products that are produced in a common country and exported to the other country. The lower panel considers matched products that are produced locally in each country and are not internationally traded. Observe that in both 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 N is defined as:

$$\text{Var}^{\text{inter}} = \sum_{n \in N} \sum_{r=A}^{R_1} \sum_{r'=A}^{R_2} \sum_{t=1}^{T-1} \frac{1}{\bar{n}} \left(\Delta Q_{n12rr't} - \overline{\Delta Q_{inter}} \right)^2 \ , \tag{3.2}$$

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 in Rows 3, 9 and 15 of Table 2 the standard deviation of international RERs, $\sqrt{\text{Var}^{\text{inter}}}$, instead of the variance, to facilitate the comparison of our results with standard measures of nominal and real exchange rate volatility. We report our statistics for the various country-of-production sets separately, for identical and conservative product matches.

Combining all of our country-of-production sets, the standard deviation of international product-level RERs is 13% for either our identical or identical plus conservative matches. To put this figure in 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%. Our finding that product-level RERs are highly volatile over time is consistent with the evidence in Broda and Weinstein (2007).

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 identical and conservative matches, the international standard deviation of product-level RERs is equal to 11% for U.S. exports, 14% for Canadian exports, 14% for ROW exports, and 13% for matched products that are domestically produced in each country. Product-level RERs are also very volatile if we only consider identical product matches.

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

$$\mathrm{Var}^{\mathrm{inter}} = \left(\mathrm{Var}_1^{\Delta P} + \mathrm{Var}_2^{\Delta P}\right)\left(1 - \frac{2\left(\mathrm{Var}_1^{\Delta P}\right)^{0.5}\left(\mathrm{Var}_2^{\Delta P}\right)^{0.5}}{\mathrm{Var}_1^{\Delta P} + \mathrm{Var}_2^{\Delta P}}\mathrm{Correl}^{\Delta P\mathrm{inter}}\right), \qquad (3.3)$$

where $\mathrm{Var}_i^{\Delta P}$ denotes the variance of price changes ΔP_{nirt} for products sold over the various pricing regions in country i, and $\mathrm{Correl}^{\mathrm{inter}}$ denotes the correlation of price changes between pairs of regions in country 1 and country 2. In our data, the variance of U.S. dollar denominated nominal price changes, $\mathrm{Var}_i^{\Delta P}$, is roughly equal in the U.S. and Canada. For 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 $2\mathrm{Var}_1^{\Delta P}\left(1 - \mathrm{Correl}^{\Delta P\mathrm{inter}}\right)$. If price changes are perfectly correlated across countries, then $\mathrm{Var}^{\mathrm{inter}} = 0$. If price changes are uncorrelated across countries, then $\mathrm{Var}^{\mathrm{inter}} = 2\mathrm{Var}_1^{\Delta P}$.

Rows 6, 12, and 18 of Table 2 report the value of $\mathrm{Correl}^{\Delta P\mathrm{inter}}$ for the various country-of-production sets, for identical and conservative 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, based on identical and conservative matches for all exported products, $\mathrm{Correl}^{\mathrm{inter}} = 0.09$.

The large observed idiosyncratic movements in RERs across countries (or, similarly, the low correlation of price changes) for products that are locally produced in each country could simply reflect movements in marginal costs across production locations. However, for products that are produced in one country and exported to others, this is evidence of pricing-to-market by which exporters vary their markups across locations. These movements in relative markups do not arise mechanically from sticky prices in local currency, but instead are the result of large differences in nominal price changes across countries.

3.3. Inter- and intra-national product-level real exchange rates

For our selected "Tea" product in Figure 2, 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 3 displays histograms of relative price movements across our entire set of identical and conservative 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 in country i analogously to $\text{Var}^{\text{inter}}$ in (3.2), as

$$\text{Var}_i^{\text{intra}} = \sum_{n \in N} \sum_{r=A}^{R_i} \sum_{r' \neq r}^{R_i} \sum_{t=1}^{T-1} \frac{1}{\bar{n}} \left(\Delta Q_{niirr't} - \overline{\Delta Q_{intra,i}} \right)^2 . \tag{3.4}$$

Rows 1 and 2 in Table 2 report the standard deviation of intra-national product-level RERs, $\sqrt{\text{Var}_i^{\text{intra}}}$, for our various country-of-production sets.

Product-level RERs are almost two times as volatile across countries than within countries. For example, based on identical and conservative matches, the standard deviation of product-level RERs for all exported products is 5% within Canada, 6% within the U.S., and 11% across countries. If we consider only identical product matches, intra-national product-level RERs are slightly more volatile, but still substantially less volatile than inter-national product-level RERs.[14]

These statistics are constructed based only on the pricing regions in British Columbia and Northern California. We can extend the geographic scope of our analysis by consider-

[14] Our finding that $Var_{US}^{\text{intra}} > Var_{Can}^{\text{intra}}$ echoes the findings in Gorodnichenko and Tesar (2008) who use more aggregated price data. Broda and Weinstein (2007) 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.

ing all pricing regions in our data. 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. 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 (suggesting that regions that are farther apart experience larger deviations from relative PPP), and the dummy coefficient is equal to 5.8% and statistically significant. Note that the value of this dummy coefficient is very similar to the difference in the standard deviation of 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.

To better understand why relative prices are more volatile across countries than within countries, we can express the ratio of inter- to intra-national RER variances defined in (3.2) and (3.4) as:

$$\frac{\text{Var}^{\text{inter}}}{\text{Var}_i^{\text{intra}}} = \left(\frac{\text{Var}_1^{\Delta P} + \text{Var}_2^{\Delta P}}{2\text{Var}_i^{\Delta P}}\right)\left(\frac{1 - \frac{2\left(\text{Var}_1^{\Delta P}\right)^{0.5}\left(\text{Var}_2^{\Delta P}\right)^{0.5}}{\text{Var}_1^{\Delta P}+\text{Var}_2^{\Delta P}}\text{Correl}^{\text{inter}}}{1 - \text{Correl}_i^{\text{intra}}}\right). \tag{3.5}$$

In obtaining expression (3.5), we used expression (3.3) and the analogous expression for $\text{Var}_i^{\text{intra}}$, $\text{Var}_i^{\text{intra}}=2\text{Var}_i^{\Delta P}\left(1 - \text{Correl}_i^{\Delta P\text{intra}}\right)$, where $\text{Correl}_i^{\text{intra}}$ denotes the correlation of price changes between the various pairs of regions in country i.

Given that in our data $\text{Var}_i^{\Delta P}$ 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. Rows $4-6$, $10-12$, and $16-18$ display the values of $\text{Correl}_i^{\text{intra}}$ 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 identical and conservative matches for all exported products, $\text{Correl}_{US}^{\text{intra}} = 0.73$, $\text{Correl}_{Can}^{\text{intra}} = 0.80$, and $\text{Correl}^{\text{inter}} = 0.09$.

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.

3.4. Robustness

Table 3 reports our statistics on product-level RERs if we change our baseline procedure along several dimensions. First, we vary our set of matched products by including 'liberal' matches, which loosen the conditions that define a matched product. Recall that our key assumption in this matching procedure, in order to assess the extent of pricing-to-market, is that 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. Liberal matches include pairs of goods that are produced by the same manufacturer but share fewer characteristics than under our benchmark matching procedure. For example, we match all pairs of Gatorade sport drinks even if they are of different flavors. This procedure increases the number of matched products at the expense of increasing the subjectiveness of our matching procedure. The results in Panel A reveal that our key statistics remain roughly unchanged. All remaining panels in Table 3 are based on our set of identical and conservative product matches.

Second, we vary the geographic scope in the construction of our statistics. Panel B is based on the pricing regions in the Center-West geographic area for our identical and conservative product matches (recall that in Panel C of Table 2, we considered this geographic area only for identical product matches). Panel C is based on a single pricing region in both British Columbia and Seattle, Washington which, given their geographic closeness, increases the likelihood that goods consumed in these districts with a common country-of-origin are actually produced in the same location (and hence, share a common change in marginal cost). Panel D is based on a single pricing region in British Columbia, Manitoba, Northern California, and Illinois, to ensure that our intra-national price findings are not driven by sampling prices from nearby pricing regions. Our findings that movements in product-level RERs are large, even for exported products, and roughly two times as volatile across countries than within countries are robust to these variations in geographic coverage.

Third, we construct our measure of product-level RERs net of movements in the category-wide RER. Panel E shows that 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.

Fourth, we construct our statistics based on weekly wholesale prices instead of average weekly prices within a quarter (see Panel F). Relative prices based on weekly data are even more volatile than when based on quarterly data. For example, for all exported products, the international standard deviation of product-level RERs is 0.19 using weekly data and 0.11 using quarterly data. Hence, pricing-to-market is more prevalent if we measure it using weekly prices. This is driven by sales and promotions (even at the wholesale level), which lead to temporary movements in prices. Given that our model abstracts from temporary sales and promotions, we choose to focus on quarterly prices in our baseline statistics.

Fifth, we construct our statistics based on retail prices instead of wholesale prices. As previously documented in Eichenbaum et. al. (2008), modal retail prices in this dataset change less frequently than wholesale prices. However, the fraction of matched products and quarters for which either the Canadian or U.S. modal price change is still quite high at 0.62 (recall that it was 0.75 using wholesale prices). Moreover, Panel G (identical matches) and Panel H (identical and conservative matches) in Table 3 reveal that 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, in those cases of our robustness analysis where we have enough data to compute aggregate RERs that smooth-out idiosyncratic product-level price movements, we find that the Canada-U.S. aggregate RER increases substantially in response to the appreciation of Canada-U.S. relative unit labor costs, even for traded goods, as in Figure 1 of our baseline configuration.

3.5. Additional findings

Comparison across country-of-production The results in Table 2 reveal differences in the measures of intra- and international product-level RER volatilities and price correlations for products belonging to our four different country-of-production sets. Directly comparing these measures, however, is not straightforward due to the fact that most of the categories in our data do not contain producers from all four possible production sets. For example, our product category "Dry Dog Food" only contains matches for products that are domestically produced in each country. This implies that when we compare our statistics across country-of-production sets, we are mixing differences between country-of-production and differences between product categories.

In order to address this concern, we construct our statistics based on categories that include products from both country-of-production sets we wish to compare. In particular, we only include those product categories for which products in each of the two country-of-production sets accounts for at least 5% of total expenditures. We compare the value of $\text{Correl}^{\Delta P^{\text{inter}}}$ between the following pairs of country-of-production sets: (*i*) U.S. exports and Canada-ROW exports, (*ii*) U.S. exports and domestically-produced goods, and (*iii*) all exports and domestically-produced goods. Given that this exercise requires a large number of product matches, we use the set of identical plus conservative product matches.

Our two findings are as follows. First, exported products display a higher international correlation of price movements relative to domestically-produced goods (10.7% higher, on average, over the 25 comparable product categories). Second, U.S. exports have a higher international correlation of price movements relative to Canada-ROW exports (6% on average over the 14 comparable product categories). This suggests that U.S. exporters engage in a higher degree of pricing-to-market than Canada and ROW exporters.[15] These results should be taken with caution, given the small number of categories that have a combination of products from different location-of-production sets.

Note that in Figure 1 there are differences in the magnitude of aggregate RER movements across our country-of-production sets. Again, these direct comparisons mix differences between country-of-production sets and differences between product categories. Unfortunately, we do not have sufficient data within each product category to accurately compare the magnitude of movements in aggregate RERs across these country-of-production sets.[16]

Relation between product-level and aggregate real exchange rate movements We now ask the question: do exported goods that display a high degree of idiosyncratic pricing-to-market also display a high degree of pricing-to-market in response to movements in relative unit labor costs? As we show later, our model has a clear prediction regarding this relationship.

To address this question, we investigate whether groups of exported products that exhibit a low international correlation of price changes also experience large aggregate RER movements in response to a change in the relative unit labor costs. We group individual products by their product categories as defined by the retailer. This approach has the advantage that products within a category share many similar characteristics.

We identify product categories with a minimum expenditure share and a minimum num-

[15] Our findings are consistent with those in Knetter (1990 and 1993). Those papers use information on export unit values to show that pricing-to-market by U.S. exporters is lower than pricing-to-market by exporters from other major industrialized countries. Relatedly, Gopinath and Rigobon (2008) show that a high fraction of U.S. exporters selling abroad and ROW exporters selling in the U.S. set their invoice in U.S. dollars.

[16] In particular, in order to smooth aggregate RER movements, we require a minimum of 100 growth rates per quarter/product category for multiple quarters, as outlined in the data appendix. This leaves us with very few product categories which have data for more than one country-of-production sets.

ber of observations accounted for by exported products (in order to minimize small sample uncertainty for product categories with very few observations) as described in Appendix 1. We include both identical and conservative matches to increase the number of observations. We end up with 21 product categories. For each product category j, we then calculate $\text{Correl}_j^{\Delta P^{\text{inter}}}$ and the average quarterly change in the category-wide RER (denoted by ΔQ_j) relative to the change in the relative unit labor cost for the quarters with available information.

We consider a regression of ΔQ_j on a constant and $\text{Correl}^{\Delta P^{\text{inter}}}$ across our 21 product categories. This yields a regression coefficient on $\text{Correl}^{\Delta P^{\text{inter}}}$ equal to -2.4 with a t-statistic of -2.6 (and hence significant at the 5% level). Our data therefore suggest that product categories with low (high) international correlation of price movements, also exhibit large (small) movements in aggregate RERs in response to a change in relative unit labor costs across countries. This finding should be taken with caution given the small number of product categories meeting the minimum data requirements.

4. Model

We now present a stylized model of international trade and multinational production that we use to isolate key forces that can rationalize our empirical findings on prices. We consider two extreme assumptions on pricing: perfect competition (or, more generally, pricing with constant markups) and Bertrand competition with limit pricing. We focus on the model's ability to generate pricing-to-market by producers (in particular, exporters) in response to both idiosyncratic shocks and aggregate movements in relative unit labor costs. We also examine what forces give rise to movements in relative prices across locations that are larger between countries than within countries.

4.1. Environment

Geography Three countries (indexed by i) produce and trade a continuum of goods subject to frictions in international goods markets. In our quantitative analysis, countries 1, 2, and 3 correspond to the U.S., Canada, and ROW, respectively. Countries 1 and 2 each contain two symmetric regions (indexed by $r = A$ and B).

Preferences Consumers in country i, region r, value a continuum of varieties (indexed by n) according to the CES aggregator:

$$y_{irt} = \left[\int_0^1 (y_{nirt})^{(\eta-1)/\eta} \, dn \right]^{\eta/(\eta-1)} , \eta \geq 1. \tag{4.1}$$

Utility maximization leads to standard CES demand functions with an elasticity of demand determined by η.

Each variety is potentially supplied by K distinct producers. The output of each potential producer is valued by the representative consumer according to:

$$y_{nirt} = \sum_{k=1}^{K} a_{knirt} y_{knirt} \; .$$

We refer to $a_{knirt} > 0$ as the idiosyncratic demand shock for product k, variety n, country i, region r, in period t. Different products within a variety are perfect substitutes (in the sense of having an elasticity of substitution equal to infinity), but have different valuations a_{knirt}. As we show below, the assumption of perfect substitutability across products, while extreme, gives an analytically tractable account of movements in product-level and aggregate RERs.[17]

With these preferences, consumers in country i, region r choose to purchase the product k with the highest demand/price ratio, a_{knirt}/P_{knirt}, and buy a quantity equal to $y_{knirt} = (a_{knirt})^{\eta-1} (P_{knirt}/P_{irt})^{-\eta} y_{irt}$. Here, P_{irt} denotes the price of the consumption composite, and P_{knirt} denotes the price of product k, variety n, country i, region r, in period t.

Idiosyncratic demands shocks are distributed independently across products and time, but are potentially correlated across regions within the same country.[18] In particular, demand shocks for a product in a country are distributed according to:

$$\begin{pmatrix} \log \; a_{kniAt} \\ \log \; a_{kniBt} \end{pmatrix} \sim N \left(0, \begin{pmatrix} \sigma_a^2 & \rho_a \sigma_a^2 \\ \rho_a \sigma_a^2 & \sigma_a^2 \end{pmatrix} \right),$$

where σ_a denotes the standard deviation, and ρ_a the intra-national correlation of demand shocks. We assume that demand shocks are uncorrelated across countries for simplicity. In Appendix 3 we show that our main qualitative results are unchanged if we relax this assumption.

[17] Atkeson and Burstein (2008) study a version of this model in which products within each variety are imperfect substitutes. While this assumption makes the model less analytically tractable, its qualitative implications for pricing are not substantially different than those under the assumption of perfect substitubility.

[18] We abstract from variety-wide demand shocks because, as we show below, in our model they have no implications on prices.

Technologies Each variety has K_i potential producers from country $i \in \{1, 2, 3\}$, giving a total of $K = K_1 + K_2 + K_3$ potential producers of each variety in the world. These potential producers of each variety have technologies to produce the same good with different marginal costs. Specifically, each potential producer has a constant returns production technology of the form $y = l/z$, where l is labor and z is the inverse of a productivity realization that is idiosyncratic to that producer.

Firms from countries 1 and 2 can serve the other country either by domestically producing and exporting, or by engaging in MP and producing abroad.[19] Exports are subject to iceberg costs $D \geq 1$.[20] Productivity for MP is $1/z'$, where $z'/z \geq 1$ is the producer-specific efficiency loss associated with MP. Firms from country 3 can serve countries 1 and 2 only by domestically producing and exporting (subject to an iceberg cost $D^* \geq 1$ that can be different from D). International trade is costless when $D = D^* = 1$. For simplicity, we abstract from frictions in intra-national goods markets by assuming that producers face equal costs of supplying the two regions within each country. In Appendix 3, we show that our qualitative results are unchanged if we relax this assumption. We assume that it is technologically infeasible for any third party to ship goods across regions or countries to arbitrage price differentials. In other words, as suggested by our data, firms can segment markets and charge different prices in each location.[21]

We denote by c_{knirt} the marginal cost of supplying a unit of product k, variety n, to country i, region r, in period t, conditional on the optimal choice by the producer on exporting or engaging in MP. Marginal cost is determined by the product of the inverse of the producer's idiosyncratic productivity (either z or z'), the wage rate (denoted by W_i in country i, expressed in terms of a common numeraire), and international trade costs if the good is exported. Specifically, for a country 1 producer with idiosyncratic productivity $1/z$ and $1/z'$ for domestic and foreign production, respectively, the marginal cost of supplying to each country is:

$$\text{Marginal cost for country 1 producers} = \begin{cases} W_1 z \text{ , domestic sales in country 1} \\ DW_1 z \text{ , exports to country 2} \\ W_2 z' \text{ , foreign prod. and foreign sales to country 2} \end{cases}$$

[19] Neiman (2008) studies a related model of international pricing and compares the implications on exchange rate pass-through of multinational production and outsourcing.

[20] In our model, international trade costs have identical implications for trade volumes and prices as home-bias for national goods built into preferences.

[21] One can show that, under our pricing assumptions, if demand shocks are sufficiently small (i.e. a low value of σ_a), then deviations from the law of one price across countries are limited by the size of trade costs D. In this case, no third party has an incentive, in equilibrium, to ship goods to arbitrage these price differentials across countries.

If $z' > z$, a producer faces a non-trivial choice of supplying to country 2: it can export its product subject to iceberg costs, or produce abroad subject to a productivity loss. We assume that producers that are indifferent between exporting or engaging in MP, choose to export. Marginal cost for country 2 producers is defined analogously. Marginal cost for country 3 producers exporting to countries 1 or 2 is $D^* W_3 z$.

We now describe our assumptions on the realization of productivity and wages, that determine the distribution of marginal costs across producers and countries over time.

Productivity We denote by z_{knt} the inverse of productivity for a firm that domestically produces product k, variety n, in period t. We assume that z_{knt} is the product of a permanent component, $\bar{z}_{kn}$, and a temporary component, $\tilde{z}_{knt}$, so that $z_{knt} = \bar{z}_{kn}\tilde{z}_{knt}$. Analogously, for foreign production, $z'_{knt} = \bar{z}'_{kn}\tilde{z}'_{knt}$.

In order to gain analytical tractability, we make the following distributional assumptions. First, following Ramondo and Rodriguez-Clare (2008), the permanent component of productivity is determined from the draw of two independent random variables, $\bar{u} \sim \exp(1)$ and $\bar{u}' \sim \exp(\lambda)$. We then define $\bar{z} = (\min\{\bar{u}, \bar{u}'\})^{\theta}$ and $\bar{z}' = (\bar{u}')^{\theta}$. A higher value of λ lowers the average draw of $\bar{u}'$, and hence increases the competitiveness of foreign production relative to domestic production. In particular, the probability that $\bar{u}' \geq \bar{u}$, so that producers face a higher productivity of supplying the foreign market via exports, is equal to $1/(1+\lambda)$, which is decreasing in λ.

Second, the temporary components of productivity, $\tilde{z}_{knt}$ and $\tilde{z}'_{knt}$, are drawn independently every period from a lognormal distribution. In particular, the logarithm of $\tilde{z}_{knt}$ and $\tilde{z}'_{knt}$ are normally distributed with mean 0 and standard deviation σ_z.

Wages Our approach is partial equilibrium in that we take as given the movements in the cost of labor, W_i. This is without loss of generality for the model's pricing implications because in our model, price changes are independent of the source of the shock that leads to a given change in relative labor costs. In particular, we assume that the logarithm of the wage in each country is drawn every period from a normal distribution that is independent over time and countries, with standard deviation σ_w. These movements in unit labor costs can also be thought of as stemming from changes in aggregate productivity, or from changes in nominal exchange rates in the presence of sticky wages. 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.

4.2. Pricing

Recall that consumers in each region purchase the product with the highest demand/price ratio, a_{knirt}/P_{knirt}. We consider two alternative assumptions on the type of competition that determines prices: perfect competition (or, more generally, pricing with constant markups) and Bertrand competition.

Perfect competition The active producer within each region is that with the highest demand/cost ratio a_{knirt}/c_{knirt}. We denote the demand shock and marginal cost of the highest demand/cost producer by a_{nirt}^{1st} and c_{nirt}^{1st}, respectively. With perfect competition, price equals marginal cost, so the price of the active product of variety n in country i, region r, is:

$$P_{nirt} = c_{nirt}^{1st}. \tag{4.2}$$

Bertrand competition Each variety is supplied by the producer with the highest a_{knirt}/P_{knirt}, as under perfect competition. However, the price charged equals:

$$P_{nirt} = \min\left\{ \frac{\eta}{\eta - 1} c_{nirt}^{1st} \ , \ \frac{a_{nirt}^{1st}}{a_{nirt}^{2nd}} c_{nirt}^{2nd} \right\}. \tag{4.3}$$

Here, a_{nirt}^{2nd} and c_{nirt}^{2nd} indicate the demand shock and marginal cost of the "latent competitor", which is the producer with the second highest demand/cost ratio of supplying that variety to the specific country and region. The optimal price is the minimum between (i) the monopoly price and, (ii) the maximum price at which consumers choose the active product when the latent competitor sets its price equal to marginal cost.

4.3. Mapping of data to model

While our model is admittedly extremely stylized, we view the mapping to our price data as follows. Recall that our retailer classifies individual products into different categories (e.g. "Peanut butter and spreads" and "Pretzels"). In our model, each product category is associated to a CES aggregator like (4.1), and can differ in the values of parameters K, D, D^*, η, etc. Each of the individual products within a product category corresponds in our model to a variety n. Under our simplifying assumption that goods within each variety have an infinite elasticity of substitution, there is only one active product within each variety.

Even though products in our dataset are sold to consumers through a retailer, our model abstracts from retail considerations. Extending our model to incorporate a retail sector with retail markups and/or distribution margins that are constant over time in percentage terms would not alter its implications on pricing at the wholesale level. This assumption of constant retail markups receives some support by the findings in Eichenbaum et. al. (2008), who show that in their data, the retailer does not significantly vary its markups over wholesale prices over time at quarterly frequencies.

In our model, we do not distinguish between producer prices and wholesale prices (as in Goldberg and Hellerstein 2007 and Nakamura 2008). Extending our model to include constant wholesale margins would not change its pricing predictions. Moreover, in Section 5 we argue that time-varying region- and product-specific wholesale margins would have to be extremely volatile to account for the large relative wholesale price movements in our data.

We focus on the pricing implications of our model for matched products that are sold by the same producer in multiple geographic locations across time periods, as in our data analysis in Sections 2 and 3. For each of our four country-of-production sets, we use price data generated from the model to construct the same statistics we constructed using the actual data. Given that the statistics are based on price changes, for each pair of consecutive peridos we only use the set of products that are active and belong to the same country-of-production in both periods.

5. Model: Analytic results

This section is organized as follows. In Propositions 1 and 2 we characterize the movements in product-level and aggregate RERs under perfect competition (Proposition 1) and Bertrand competition (Proposition 2). Proofs to these Propositions are presented in Appendix 2. We then discuss the ability of our model, as well as alternative models, to qualitatively account for our empirical observations in Section 3.

We characterize the movements in prices under perfect competition in the following proposition:

Proposition 1 (Perfect competition): *Consider our model economy with perfect competition. For all set of matched products, the variance of price changes is* $\mathrm{Var}^{\Delta P} = 2\left(\sigma_z^2 + \sigma_w^2\right)$*; the correlation of price changes and the variance of relative price changes between regions in the same country are* $Correl^{\Delta P \mathrm{intra}} = 1$ *and* $Var^{\mathrm{intra}} = 0$*, respectively. For matched exported products (those in sets* N_{x1}*,* N_{x2}*, and* N_{x3}*), the correlation of price changes and the variance of relative price changes between regions in different countries are* $Correl^{\Delta P \mathrm{inter}} = 1$ *and* $Var^{\mathrm{inter}} = 0$*, respectively. For matched domestically-produced products (those in set* N_d*), the correlation of price changes and the variance of relative price changes between regions in different countries are* $Correl^{\Delta P \mathrm{inter}} = 0$ *and* $Var^{\mathrm{inter}} = 2\,Var^{\Delta P}$*, respectively. The change* *in the aggregate RER in response to a movement in relative wages is* $\Delta Q_t = 0$ *for exported products, and* $\Delta Q_t = \Delta W_{2t} - \Delta W_{1t}$ *for matched domestically-produced products.*

Under perfect competition exporters do not engage in pricing-to-market either in response to idiosyncratic shocks or aggregate changes in labor costs. Instead, they set prices that are perfectly correlated across locations, so relative prices are constant over time. This is because changes in prices equal changes in marginal costs, and changes in marginal cost are the same irrespective of where the good is sold. In contrast, producers that domestically produce in each country face country-specific marginal cost shocks and hence set prices that fluctuate across locations. Note that since our price statistics only include products that remain active and in the same country-of-production set over two consecutive time periods, they are not affected by switching in the identity of active producers in the face of large shocks.

Under Bertrand competition, changes over time in the identity of latent competitors do affect price movements for continuing products (see equation 4.3). In this section we solve for our price statistics abstracting from switching over time in the identity of latent competitors. In particular, we assume that cost, demand, and wage shocks are arbitrarilly small. In this limit of our model, the identity of active and latent producers is determined only by the permanent component of productivity, $\bar{z}_{kn}$, $\bar{z}'_{kn}$, and the level of international trade costs D (Lemma 1 in Appendix 2 provides analytic expressions for the set of matched products, exporters, and latent competitors from each country). We also assume that the elasticity of demand η is sufficiently close to one so that the monopoly price is high and the monopoly price in (4.3) never binds. In Section 6 we relax these assumptions and numerically calculate these statistics.

We summarize our results in the following proposition:

Proposition 2 (Bertrand competition): *Consider the limit of our model economy with Bertrand competition as* σ_z*,* σ_a*, and* σ_w *approach zero but remain positive, and* η *is arbitrarilly close to one. The variance of price changes for all set of matched products is given by:*

$$\text{Var}^{\Delta P} = 2\left(2\sigma_a^2 + \sigma_z^2 + \sigma_w^2\right) \tag{5.1}$$

The correlation of price changes between regions in the same country for all set of matched products is

$$\text{Correl}^{\Delta P \text{intra}} = \frac{2\rho_a\sigma_a^2 + \sigma_z^2 + \sigma_w^2}{2\sigma_a^2 + \sigma_z^2 + \sigma_w^2}. \tag{5.2}$$

The correlation of price changes between regions in different countries for matched products *in the set N_{xi} is*

$$\text{Correl}_i^{\Delta P\text{inter}} = \frac{\sigma_z^2 + \sigma_w^2}{2\sigma_a^2 + \sigma_z^2 + \sigma_w^2} r_i. \tag{5.3}$$

The variance of relative price changes between regions in the same country for all set of matched products is

$$\text{Var}^{\text{intra}} = 8\sigma_a^2 (1 - \rho_a) \text{ and} \tag{5.4}$$

The variance of relative price changes between regions in different countries in the set N_{xi} is

$$\text{Var}_i^{\text{inter}} = 4\left[2\sigma_a^2 + \left(\sigma_z^2 + \sigma_w^2\right)(1 - r_i)\right] \tag{5.5}$$

The change in the aggregate RER in response to a movement in relative wages for matched products in the set N_{xi} is

$$\Delta Q_{it} = (1 - r_i)\,\Delta\left(W_{2t}/W_{1t}\right) + \frac{1}{m_{i,-i}}\left[\left(s_{i1}^3 - s_i^3\right)\Delta W_{1t} + \left(s_i^3 - s_{i2}^3\right)\Delta W_{2t} + \left(s_{i2}^3 - s_{i1}^3\right)\Delta W_{3t}\right]. \tag{5.6}$$

Here, m_{ij} *denotes the mass of exporters from country i to country j, s_{ij}^l denotes the mass of exporters from country i facing a latent competitor from country l when selling in country j, s_i^l denotes the mass of exporters from country i facing the same latent competitor from country l when selling in countries 1 and 2,* and $r_i = \frac{1}{m_{ij}} \sum_{l=1}^{3} s_i^l$ *denotes the fraction of exporters from country i facing the same latent competitor when selling in countries 1 and 2.*

Consider the correlation of price changes between regions in different countries for exported products, displayed in equation (5.3). To understand this expression, suppose first that price changes are driven only by cost shocks ($\sigma_a = 0$). Exporters facing the same latent competitor in both countries set prices that are perfectly correlated across countries (i.e. they do not engage in pricing-to-market) because the latent competitor is hit by the same cost shock in both countries. In contrast, exporters facing a different latent competitor in each country set prices that are uncorrelated across countries (i.e. they do engage in pricing-to-market) because the cost shocks to each latent competitor are uncorrelated. Hence, in this case $\text{Correl}_i^{\Delta P\text{inter}} = 0 * (1 - r_i) + 1 * r_i$.

Suppose instead that price movements are driven solely by demand shocks ($\sigma_z^2 = \sigma_w^2 = 0$). Given that these shocks are uncorrelated across countries, changes in prices by exporters are uncorrelated across countries (i.e. $\text{Correl}_i^{\Delta P\text{inter}} = 0$). With both cost and demand shocks, the correlation of price changes (given by expression 5.3) is a weighted average between r_i and 0, with a weight over r_i determined by the contribution of cost shocks in the variance of price changes, $\left(\sigma_z^2 + \sigma_w^2\right) / \left(2\sigma_a^2 + \sigma_z^2 + \sigma_w^2\right)$.

In calculating the correlation of price changes for matched products between regions within the same country, we need to take into account that all producers face the same latent competitor in both regions and that demand shocks are correlated across regions. Hence the correlation of price changes between regions in response to costs and demand shocks is 1 and ρ_a, respectively. A weighted average of these two correlations, using the same weights as above, implies expression (5.2). Note that pricing-to-market across regions in the same country is more prevalent if demand shocks are not highly correlated across regions (i.e. low ρ_a).

Combining (5.4) and (5.5), we obtain an expression that summarizes the extent to which pricing-to-market is more prevalent across countries than within countries:

$$\frac{\text{Var}_i^{\text{inter}}}{\text{Var}^{\text{intra}}} = \frac{1 + \frac{\left(\sigma_z^2 + \sigma_w^2\right)}{2\sigma_a^2}\left(1 - r_i\right)}{1 - \rho_a} \tag{5.7}$$

A high inter- to intra-national ratio of RER variances for exports can result from (i) a low fraction of exporters facing the same latent competitor in both countries, (ii) a high contribution of cost shocks in overall price fluctuations, and (iii) a high correlation of demand shocks within countries.

To help understand the movements in relative prices resulting from an aggregate change in relative labor costs across countries, as displayed in expression (5.6), suppose that international trade costs from countries 1 and 2 to the rest of the world, D^*, are very high. Then, it is very unlikely that producers selling in countries 1 and 2 face a country 3 latent competitor ($s_{ij}^3 \simeq 0$), and the change in the aggregate RER for country i exporters is simplified to:

$$\Delta Q_{it} = \left(1 - r_i\right) \Delta \left(W_{2t}/W_{1t}\right) \tag{5.8}$$

This expression indicates that aggregate RERs are more responsive to movements in relative wages (i.e. there is more pricing-to-market) the lower the fraction of producers facing the same latent competitor in both countries (i.e.: low r_i). This is because a low r_i indicates that exporters are likely to face local latent competitors in each country, so that prices are more responsive to the local wage in the destination country. In the extreme, with costless international trade ($D = 1$), we have $r_i = 1$ (see Lemma 2 in Appendix 2) and $\Delta Q_{it} = 0$ because firms face the same latent competitor in both countries with a common wage change.

Consider now the general case with a lower D^* so that some exporters from countries 1 and 2 face latent competitors from country 3 ($s_{ij}^3 \simeq 0$). Suppose that the wages in countries 2 and 3 increase by the same magnitude (i.e. $\Delta W_{3t} = \Delta W_{2t}$). Then, the change in the aggregate RER is:

$$\Delta Q_{it} = \left(1 - r_i + \frac{s_i^3 - s_{i1}^3}{m_{i,-i}}\right) \Delta \left(W_{2t}/W_{1t}\right) \tag{5.9}$$

One can show that $\left(s_i^3 - s_{i1}^3\right)/m_{i,-i} \leq 0$, so movements in the aggregate RER are smaller than in (5.8). To understand this, note that $\left(s_{i1}^3 - s_i^3\right)$ indicates the mass of country i exporters facing a latent competitor from country 3 in country 1 and a local latent competitor in country 2. Even though these exporters face different latent competitors in each country, their relative wage remains unchanged. Therefore, in response to the change in W_2/W_1, these exporters do not change the relative price at which they sell their output in the two countries. Our quantitative analysis, however, suggests that this term is relatively small.

In Appendix 3, we extend the results of Proposition 2 in a version of our model in which demand shocks for each product are correlated across countries, producers are subject to different productivity shocks in each region within a country, and goods can be traded within countries subject to an intra-national trade cost. Relative prices are more volatile across countries than within countries the lower is the fraction of producers facing the same latent competitor across countries than within countries, and the less correlated are demand shocks across countries than within countries.

Discussion In Propositions 1 and 2, we derived the implications of our model for price movements under two alternative assumptions: perfect competition (or, more generally, constant markups), and Bertrand competition. We now assess the ability of the models, as well as alternative models, to account qualitatively for our empirical observations in Section 3. We also discuss the role of international trade costs in shaping our price statistics.

Our data reveals that product-level price movements for matched products are highly correlated across regions within countries, and roughly uncorrelated across regions in different countries (the counterpart of this observation is that product-level RERs move over time, more so across countries than within countries). These patterns hold both for matched products that are exported and for matched products that are domestically produced in each country. The constant markup model with time-variation in costs is consistent with the data in predicting that product-level RERs should fluctuate across countries for matched products that are domestically produced in each country. However, this model does not account for the movements of product-level RERs across countries for traded products. This observation points instead to models of pricing-to-market in which exporters systematically vary their markups in Canada relative to the U.S., as is the case in our model with Bertrand competition. Additionally, with Bertrand competition, if idiosyncratic cost and demand shocks are more correlated within than across countries, and if producers are less likely to compete with the same latent competitor across countries than within countries, movements in product-level RERs are larger across countries than within countries.[22]

Our data also display large swings in Canada-U.S. aggregate RERs that closely track movements in aggregate relative costs across countries, both for matched products that are actually traded, as well as for matched products that are domestically produced in each country. The constant markup model is consistent with this feature of the data for domestically-produced products, but not for traded products. With Bertrand competition, if exporters compete with local latent producers in each country, prices are responsive to the local wage in each country. Hence, when Canada-U.S. relative labor costs increase, exporters price-to-market by raising their markups and prices in Canada relative to the U.S.

The Bertrand model also predicts a negative relation between the international correlation of price changes, $\text{Correl}_i^{\Delta P\text{inter}}$, and the magnitude of movements in aggregate RERs, ΔQ_i. Ceteris-paribus, the smaller the fraction r_i of exporters facing the same latent competitor in both countries, the lower is $\text{Correl}_i^{\Delta P\text{inter}}$ and the higher is ΔQ_i. This negative relationship is supported by our data in Section 3 when we compare $\text{Correl}^{\Delta P\text{inter}}$ and ΔQ across various product categories.[23]

We now discuss the role of the international border, parameterized by D, in shaping our pricing results. In our model, higher international trade costs reduce not only the volume of international trade, but also the fraction of exporters from country i facing the same latent competitor in both countries r_i (see Lemma 2 in Appendix 2). Therefore, everything else being equal, a higher level of D lowers the international correlation of price changes for exported products, increases the ratio of inter/intra-national volatility of product-level RERs, and increases the movements in aggregate RERs for traded products in response to a

[22] Our model with $D > 1$, both under perfect and Bertrand competition, is also consistent with the findings in Gopinath et. al. (2008) in predicting that international dispersion in price levels is higher than intra-national dispersion in price levels. Our model can be extended to allow for constant region/variety-specific cost differences that equally affect all K potential suppliers within that variety in that region. We can show that the magnitude of these cost differences can be chosen to match any level of inter-to-intra dispersion in price levels, without changing any of our model's implications on price movements.

[23] An alternative way of gauging the central mechanism of the model is to obtain direct measures of the extent to which exporters face local competitors in each country, and to relate these to observed movements in RERs. Constructing these measures requires taking a stand on the relevant scope of competition for each product, including other product categories within the retailer, other retailers, and local producers outside of the retail industry. For example, the relevant set of competitors for Myojo instant noodles includes other Asian noodles, other types of pasta, general food (all of these within and across retailers), as well as Asian or other general restaurants and food suppliers in the geographic region. Our procedure of comparing movements in product-level and aggregate RERs to assess our model's implications has the advantage that it circumvents this difficult measurement problem.

change in relative costs across countries. Note that observing a high ratio $\text{Var}^{\text{inter}}/\text{Var}^{\text{intra}}$ is not sufficient to conclude that international trade costs play a significant role in pricing (see, e.g. Engel and Rogers 1996), because it can also result from cost and demand shocks that are more correlated within countries than across countries.[24,25] On the other hand, movements in aggregate RERs across countries wash-out idiosyncratic cost and demand shocks, and are thus more informative on the role of international trade costs on pricing.[26]

Our analysis also suggests that data on product-level and aggregate RER fluctuations for domestically-produced matched products are not informative enough to gauge the extent of pricing-to-market and international trade costs. This is because, in order to account for these data, we cannot discriminate between our model with variable markups and a model with constant markups in which producers engaged in MP are hit by different cost shocks in both countries. In such a model, conditional on the producers' choice of serving the foreign market via exports or MP, trade costs have no bearing on the size of price changes.

While our model provides a simple account of pricing-to-market when competitors are segmented across locations, other assumptions on demand and market structure might also give rise to movements in markups across locations like the ones observed in the data. Here we discuss the ability of three alternative models of international pricing to account for our empirical observations. First, consider a model in which international market segmentation plays a minor role in pricing, and pricing-to-market is driven by region-specific demand shocks. This model can account for the observed patterns of intra- and international correlations of price changes if these shocks are more correlated within countries than across countries. However, it does not generate movements of aggregate RERs for traded goods that closely track movements in international relative labor costs, and it does not have sharp predictions on the relationship between the extent of idiosyncratic and aggregate pricing-to-

[24] This last implication is closely related to Gorodnichenko and Tesar (2008). They show that differences in intra-and-international RER movements can result from differences in intra-national RER movements across countries. We extend this result and show that, even with symmetric countries, international RER movements can exceed intra-national RER movements if product-level shocks are more correlated within than across countries.

[25] Our model abstract from other forces that can make pricing-to-market more prevalent across countries than within countries. For example, wholesalers might engage in more price discrimination across retail branches belonging to a common retail chain and located in two different countries than across retail branches located in the same country.

[26] Can one assess the importance of international trade costs relative to intra-national trade costs using our price data? In principle one could do so by comparing movements in aggregate RERs within countries and across countries in response to changes in production costs. However, as suggested by the small movements in intra-national RERs displayed in Figure 1, it is hard to identify in the data large changes in relative costs across regions within countries that are comparable in size to changes in relative costs across countries driven by changes in exchange rates.

market for exported products (as measured by $\text{Correl}^{\Delta P_{\text{inter}}}$ and ΔQ). Second, consider a model in which pricing-to-market is driven by sticky prices in local currency. This model can generate large movements in aggregate RERs in response to changes in unit labor costs driven by nominal exchange rate movements. However, nominal prices in our data change quite frequently and by large magnitudes. Third, consider a model with constant markups in which movements in wholesale prices across locations are driven by shocks to wholesale distribution costs that are region- and product-specific. Since wholesale gross margins represent a modest share of wholesale sales (16% for U.S. groceries and related products, as discussed above), then this model can only account for a small fraction of the overall change in aggregate RERs in response to a change in relative unit labor costs, and requires extremely large changes in distribution margins across regions to account for the large volatility of product-level RERs observed in our data.[27]

6. Model: Quantitative results

In establishing our analytical results under Bertrand competition, we have assumed that shocks to cost, demand, and wages are small. However, in our data, changes in prices over time are quite large. In this section we relax this assumption, but to do so we must solve the model numerically. We thus consider a parameterized version of the model that matches key observations on the volume of trade and the magnitude of price changes in Canada and the U.S. We assess the model's ability to generate substantial pricing-to-market and hence account quantitatively for the large movements in product-level and aggregate RERs for traded goods.

Model parameterization Based on our analysis in Section 5, the parameters of our model can be divided broadly into two groups. First, the number of potential producers per variety from each country (K_1, K_2, and K_3), the dispersion across producers in the permanent component of productivity (θ), international trade costs between countries 1 and 2 (D) and between these two countries and country 3 (D^*), and the average productivity loss in MP (λ), determine the shares of international trade and MP in each country, through the expressions presented in Lemma 1 of Appendix 2. The parameter θ affects these shares

[27] Note that an increase in international trade costs (due to, for example, an increase in the price of fuel) in a model with constant markups would lead to an increase in the price of exports relative to domestic sales. While such a change in trade costs can lead to an increase in Canadian prices relative to U.S. prices for U.S. exporters, it will generate a reduction in Canadian prices relative to U.S. prices for Canadian exporters, which is the opposite of what we observe in our data.

only through D^{θ} and $(D^{*})^{\theta}$, and K_3 affects those shares only through $K_3/(D^{*})^{\theta}$. These parameters also determine the measures of latent competitors in each country. Second, the elasticity of substitution across varieties (η), the volatility of temporary productivity and demand shocks (σ_z and σ_a), the intra-national correlation of demand shocks across regions within a country (ρ_a), and the movement of wages in each country, determine how prices change over time.

We choose parameter values to target some key features of expenditure shares and prices of the typical product category in our data. In particular, we set K_2, $K_3/(D^{*})^{\theta}$, $(D)^{\theta}$, and λ to match the following four observations: (i) the U.S. expenditure share of imports from Canada is 2%, (ii) the Canadian expenditure share of imports from the U.S. is 25%, (iii) the average expenditure share in the U.S. and Canada of imports from the rest of the world is 10%, and (iv) the ratio of Canadian expenditures in matched traded products relative to expenditures in matched products that are domestically produced in each country is 1. Observations (i)-(iii) correspond roughly to the average import shares in gross output between 1997 and 2002 in beverages, chemical products, food products, and tobacco reported by Source OECD. These values are quite close to the import shares for our sample of products (identical and conservative matches) displayed in Table 1. Observation (iv) roughly corresponds to the median ratio of expenditure in traded and domestically-produced matched products across the product categories in the data which contain both of these type of products. We set $K_1 = 28$, which implies that the calibrated value of K_2 is equal to 4. We experimented with higher and lower values of K_1. Conditional on matching our targets, our results remain roughly unchanged. We set $\theta = 0.3$, which is at the high range of values considered in Eaton and Kortum (2002).

We assume that one period in our model corresponds to a quarter. We set σ_z and σ_a to match the magnitude of product-level price movements and intra-national correlation of price changes for U.S. exporters across all product categories in our baseline statistics. In particular, we target $\text{Var}^{\Delta P} = 0.08^2$ and $\text{Correl}^{\Delta P \text{intra}} = 0.75$, which are roughly equal to the corresponding average values in Canada and the U.S. In our baseline parameterization, we assume that demand shocks are uncorrelated across regions ($\rho_a = 0$). We also set $\eta = 1.01$, as we did in deriving our analytical results. In spite of the low value of η, the model implies an average markup of 30% because many producers charge the limit price determined by demand and marginal cost of the latent competitor. Table 4 summarizes the parameter values and targets of our baseline parameterization.

We generate artificial data from our model for 12 quarters. Initial wages are normalized to one (and trade shares are calibrated at these wage levels). We assume that W_1 remains constant, and that wages in Canada and ROW (expressed in a common numeraire) increase proportionally to the appreciation of the Canada-U.S. relative unit labor cost in the period $2004 - 2006$.

Pricing implications: Baseline parameterization Column 1 in Table 5 reports our pricing findings when demand shocks are uncorrelated across regions ($\rho_a = 0$). Recall that the only statistics targeted in our calibration procedure are the size of price changes, $\text{Var}^{\Delta P}$, and the intra-national correlation of price changes, $\text{Correl}^{\Delta P \text{intra}}$, for U.S. exporters. The main quantitative findings are as follows.

First, the model generates substantial product-specific pricing-to-market in response to idiosyncratic cost and demand shocks. The correlation of price changes between Canada and U.S. for U.S. exporters is $\text{Correl}^{\Delta P \text{inter}} = 0.26$, which is significantly below the benchmark value of one in the absence of pricing-to-market. The counterpart of this low correlation of price changes is a high volatility of relative price changes across countries, $\sqrt{Var^{\text{inter}}} = 0.1$. Relative prices are more volatile across countries than within countries (i.e. the ratio of inter-to-intra-national standard deviation of product-level RERs is 1.7) due to the presence of international trade costs that reduce the extent to which producers face the same latent competitor in different countries.

Note that the extent of pricing-to-market generated by the model for U.S. exporters is slightly less than in the data. In particular, the correlation of price changes across countries for U.S. exporters is 0.1 in our data and 0.26 in our baseline parameterization. In order to account for the lower level of $\text{Correl}^{\Delta P \text{inter}}$ in the data while still matching our target trade volumes and price statistics, we can raise the correlation of demand shocks within countries, ρ_a, and increase the size of demand shocks relative to cost shocks, as suggested by our analytic expressions (5.1), (5.2), and (5.3). The results of this alternative parameterization are reported in column 2, Table 5. Note that raising ρ_a also increases the ratio of inter-to-intra-national standard deviations of product-level RERs from 1.7 to 1.9. This illustrates our finding that this ratio is determined not only by the extent to which trade costs segment competitors across countries, but also by the extent to which demand shocks are more correlated within than across countries.

Second, the model generates substantial product-specific pricing-to-market by Canadian and ROW exporters, as reflected by their low international correlation of price changes across countries. Note that $\text{Correl}^{\Delta P \text{inter}}$ is higher for U.S. exporters than for Canadian and ROW exporters, as in our data. This is because, in our model, U.S. exporters engage in less pricing-to-market than do exporters from Canada and ROW. This is, in turn, due to the relatively high number of U.S. potential producers ($K_1 > K_2$ and $K_1 > K_3$), which implies that U.S. producers are more likely to export and, conditional on exporting, are more likely to compete with the same U.S. latent producer in both countries. In contrast, if we had assumed $K_1 = K_2 = K_3$ and $D = D^*$, the model would imply that $\text{Correl}^{\Delta P_{\text{inter}}}$ is equal for all matched exported products. Note that the model also generates a low correlation of price changes across locations for domestically-produced matched products, as in our data.

Third, the model generates substantial pricing-to-market in response to aggregate movements in labor costs across countries. Figure 4 displays the cumulative change in relative labor costs W_2/W_1, and the cumulative change in Canada-U.S. aggregate RERs, ΔQ, for each country-of-production set. Panel B in Table 5 reports the ratio of cumulative change in aggregate RERs and relative unit labor costs in the last quarter of our simulation. This ratio ranges between 0.64 and 0.78 across our country-of-production sets. Recall that in models with constant markups, this ratio would be equal to zero for exported products.

For U.S. exporters, the ratio of RER movements to relative wage movements is 0.64. The rise in Canada-U.S. relative prices reflects the fact that exporters facing local latent competitors in each country set prices that are responsive to the local wage in the destination country, and less so to the wage in the production country. Even though pricing-to-market in our model is substantial, the increase in the Canada-U.S. aggregate RERs for U.S. exported products is smaller than the one observed in the data (0.85). Extending the model to include a moderate share of local distribution costs at the wholesale level would result in a larger rise in aggregate RERs closer to the level observed in our data.

Note also that Canadian and ROW exporters in our model display larger movements in aggregate RERs than do U.S. exported products. This is because there is a relatively large number of U.S. producers (i.e. $K_1 > K_2$ and $K_1 > K_3$), that are likely to face U.S. latent competitors in both countries. The model also generates large movements in aggregate RERs for domestically-produced goods, as in the data.

Pricing implications: Sensitivity analysis We now examine the sensitivity of our results to alternative targets and parameter values. The findings are presented in columns 3-7 of Table 5.

Column 3 reports the results when time-varying shocks are very small. In particular, we target $\text{Var}^{\Delta P} \simeq 0$ and $\Delta W_2 = \Delta W_3 \simeq 0$ in our calibration. This is the assumption we made in Section 4 to calculate our statistics analytically. For example, using expression (5.3), $\text{Correl}^{\Delta P\text{inter}} = 0.21$ for U.S. exporters is the product of $r_1 = 0.28$ (i.e. the fraction of U.S. exporters facing the same latent competitor in both countries), and $(\sigma_z^2 + \sigma_w^2) / (2\sigma_a^2 + \sigma_z^2 + \sigma_w^2) = 0.75$ (i.e., the importance of cost shocks in price movements). On the other hand, for Canadian exporters we have $r_2 = 0.185$, leading to $\text{Correl}^{\Delta P\text{inter}} = 0.14$.

Relative to our baseline with large shocks, this alternative parameterization generates slightly more pricing-to-market in response to idiosyncratic shocks (for U.S. exporters, $\text{Correl}^{\Delta P\text{inter}} = 0.21$ with small shocks and 0.26 with large shocks) and in response to aggregate movements in relative labor costs (the change in aggregate RERs for U.S. exporters is 0.71 with small shocks and 0.64 with large shocks). To understand these differences, recall that small time-varying shocks reduce the extent of switching of exporters and latent competitors over time. Switchers are more likely to compete with foreign producers (i.e., they switch because the cost or demand of the latent competitor changes). Had they not switched, they would likely have changed relative markups across countries in response to the competitor's change in cost or demand. Recall that our price statistics do not include products whose export status switches over time. Hence, the price statistics under our parameterization with large shocks excludes producers that would have chosen to vary relative markups in the face of small shocks. This explains why our parameterization with larger shocks results in less pricing-to-market than our parameterization with small shocks.

Column 4 reports our results if we reduce the competitiveness of MP by lowering λ from 0.35 to 0.15. This increases the ratio of expenditures in matched exports to matched domestically-produced goods from 1 to 2. Ceteris-paribus, a lower level of λ increases the volume of international trade and the fraction of exporters facing the same latent competitor in both countries, leading to smaller product-level and aggregate RERs. However, in order to match the shares of trade in the data, trade costs must be reduced, lowering the fraction of exporters facing the same latent competitor in both countries. These two offsetting effects imply that our results remain basically unchanged.

Columns 5 and 6 report our results if we consider higher and lower dispersions of permanent costs across products, parameterized by θ. The results, while remaining very similar, show that the accuracy of our analytical approximation deteriorates as we lower θ. To see this, note that the analytical results in column 3 are closer to those in column 6 than column 5. This is because a higher level of θ increases the role of permanent differences in costs for determining the identity of exporters and latent competitors, and reduces the extent of switching in response to time-varying shocks.

Finally, column 7 reports our findings when we increase the elasticity of substitution across varieties from $\eta = 1.01$ to $\eta = 2$. Relative to our baseline parameterization, there is less pricing-to-market in response to idiosyncratic shocks ($\text{Correl}^{\Delta P_{\text{inter}}}$ increases from 0.26 to 0.32 for U.S. exporters and remains roughly unchanged for Canadian exporters) and in response to aggregate changes in relative labor costs (aggregate movements in RERs fall from 0.64 to 0.53 for U.S. exporters and from 0.75 to 0.69 for Canadian exporters). To understand these differences, note that with a higher level of η, the optimal monopoly price becomes more binding in (4.3), and this reduces the extent of variable markups in pricing decisions. Note, however, that movements in product-level and aggregate RERs for exported products remain sizeable relative to models with constant markups.

7. 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, distinguishing 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. To help rationalize our observations, we construct a simple model of pricing-to-market and international trade. The international border plays an important role in our model by segmenting competitors across countries, leading to the practice of pricing-to-market by exporters in response to idiosyncratic shocks and changes in aggregate relative labor costs.

We have kept our model highly stylized in order to gain analytical tractability and identify key forces that account for movements in product-level and aggregate RERs. In doing so, we have abstracted from important industrial organization considerations such as richer demand systems, multi-product pricing, interactions between retailers and wholesalers, and long-term relationships between producers and retailers. Incorporating these elements into our analysis is an important task for future research. Goldberg and Hellerstein (2007), Hellerstein (2008), and Nakamura (2008) are examples of recent models of incomplete pass-through with richer demand systems. An important question is whether alternative models of demand and market structure can give rise to movements in relative markups across locations like the ones observed in the data.

In our model with variable markups, movements in international relative prices for traded goods are not efficient because they do not move one-to-one with relative costs. The extent of these relative price movements is determined by the magnitude of international border costs and changes in relative unit labor costs, which are themselves shaped by international trade policies and exchange rate policies. Our framework can be used to study the optimal design of these policies taking into account their effects on welfare from movements in international relative prices for traded goods.

References

[1] **Alessandria, George.** 2004. "International Deviations from the Law of one Price: The Role of Search Frictions and Market Share." International Economic Review, 45(4): 1263-1291.

[2] **Atkeson, Andrew and Ariel Burstein.** 2007. "Pricing-to-Market in a Ricardian Model of International Trade." American Economic Review, 97(2): 362-367.

[3] **Atkeson, Andrew and Ariel Burstein.** 2008. "Pricing-to-Market, Trade Costs, and International Relative Prices." American Economic Review, 98(5): 1998-2031.

[4] **Bergin, Paul, and Robert Feenstra.** 2001. "Pricing-to-market, Staggered Prices, and Real Exchange Rate Persistence." Journal of International Economics, 54(2):333-359.

[5] **Bernard, Andrew, Jonathan Eaton, J. Bradford Jensen, and Samuel Kortum.** 2003. "Plants and Productivity in International Trade." American Economic Review, 93(4): 1268-1290.

[6] **Broda, Christian, and David Weinstein.** 2007. "Understanding International Price Differences using Barcode Data." Mimeo. Univesity of Chicago.

[7] **Bils, Mark, and Pete Klenow.** 2004. "Some Evidence on the Importance of Sticky Prices." Journal of Political Economy, 112, 947-985.

[8] **Burstein, Ariel, Joao Neves, and Sergio Rebelo.** 2002. "Distribution Costs and Real Exchange Rate Dynamics During Exchange-Rate-Based Stabilizations." Journal of Monetary Economics, 50(6): 1189-1214.

[9] **Chetty, Raj, Adam Looney and Kory Kroft.** 2008. "Salience and Taxation: Theory and Evidence." forthcoming American Economic Review.

[10] **Corsetti, Giancarlo and Luca Dedola.** 2005. "Macroeconomics of International Price Discrimination." Journal of International Economics, 67(1): 129-155.

[11] **Crucini, Mario, Chris I. Telmer, and Marios Zachariadis.** 2005. "Understanding European Real Exchange Rates." American Economic Review, 95(3): 724-738.

[12] **Crucini, Mario and Mototsugu Shintani.** 2008. "Persistence in law of one price deviations: Evidence from micro-data." Journal of Monetary Economics, 55(3): 629-644.

[13] **Dornbusch, Rudiger.** 1987. "Exchange Rates and Prices." American Economic Review, 77(1): 93-106.

[14] **Drozd, Lukasz, and Jaromir Nosal.** 2008. "Understanding International Prices: Customers as Capital." Mimeo. University of Wisconsin.

[15] **Eaton, Jonathan and Samuel Kortum.** 2002. "Technology, Geography, and Trade." Econometrica. 70(5): 1741-1779.

[16] **Eiran, Liran, Ephraim Leibtag and Aviv Nevo.** 2008. "Not-so-classical Measurement Errors: A Validation Study of Homescan." Stanford University.

[17] **Eichenbaum, Martin, Nir Jaimovich and Sergio Rebelo.** 2008. "Reference Prices and Nominal Rigidities." Mimeo. Stanford University.

[18] **Engel, Charles.** 1999. "Accounting for U.S. Real Exchange Rate Changes." Journal of Political Economy, 107(3): 507-538.

[19] **Engel, Charles and John Rogers.** 1996. "How Wide Is the Border?" American Economic Review, 86(5): 1112-25.

[20] **Fitzgerald, Doireann and Stefanie Heller.** 2008. "Exchange Rates and Producer Prices: Evidence from Micro-Data." Mimeo. Stanford University.

[21] **Goldberg, Pinelopi K., and Michael Knetter.** 1997. "Goods Prices and Exchange Rates: What Have We Learned?" Journal of Economic Literature, 35(3): 1243-1272.

[22] **Goldberg, Pinelopi K., and Rebecca Hellerstein.** 2007. "A Framework for Identifying the Sources of Local Currency Price Stability with an Empirical Application." NBER Working paper 13183.

[23] **Gopinath, Gita, and Oleg Itskhoki.** 2008. "Frequency of Price Adjustment and Pass-through." *Quarterly Journal of Economics*, forthcoming.

[24] **Gopinath, Gita and Roberto Rigobon.** 2008. "Sticky Borders." *Quarterly Journal of Economics*, 123(2): 531-575.

[25] **Gopinath, Gita, Pierre-Olivier Gourinchas, and Chang-Tai Hsieh.** 2008. "Cross-Border Prices, Costs and Mark-ups." Mimeo. National Bureau of Economic Research

[26] **Gorodnichenko, Yuriy, and Linda Tesar.** 2008. "Border Effect or Country Effect? Seattle May not be so Far from Vancouver After All." Working Paper. University of Michigan.

[27] **Hellerstein, Rebecca.** 2008. "Who Bears the Cost of a Change in the Exchange Rate? Pass-Through Accounting for the Case of Beer." Journal of International Economics, 76(1): 14-32.

[28] **Kehoe, Patrick, and Virgiliu Midrigan.** 2008. "Sticky Prices and Real Exchange Rates in the Cross-Section." Mimeo. New York University.

[29] **Klenow, Pete, and Olexei Kryvtsov.** 2008. "State-Dependent or Time-Dependent Pricing: Does It Matter for Recent U.S. Inflation?" Quarterly Journal of Economics, 123: 863:904.

[30] **Knetter, Michael.** 1989. "Price Discrimination by U.S. and German Exporters." American Economic Review, 79(1): 198-210.

[31] **Knetter, Michael.** 1993. "International Comparisons of Price-to-Market Behavior." American Economic Review, 83(3): 473-86.

[32] **Krugman, Paul.** 1987. "Pricing to Market When the Exchange Rate Changes." in Real Financial Linkages Among Open Economies, eds. S. W. Arndt and J. Richardson, London: MIT Press.

[33] **Mussa, Michael.** 1986. "Nominal Exchange Rate Regimes and the Behavior of Real Exchange Rates." Carnegie-Rochester Series on Public Policy, 25: 117-214.

[34] **Nakamura, Emi.** 2008. "Pass-Through in Retail and Wholesale." American Economic Review, 98(2): 430-437.

[35] **Nakamura, Emi.** 2008. "Accounting for Incomplete Pass-through." Mimeo. Columbia University.

[36] **Nakamura, Emi, and Jón Steinsson. "**Lost in Transit: Product Replacement Bias and Pricing to Market." Mimeo. Columbia University.

[37] **Neiman, Brent.** 2008. "Intrafirm Trades and International Macro Dynamics." Mimeo. Harvard University.

[38] **Ramondo, Natalia, and Andres Rodriguez-Clare. 2008.** "The Gains from Openness: Trade, Multinational Production, and Diffusion." Mimeo. University of Texas, Austin.

Appendix 1: Data

Constructing time series of prices For each product, the retailer keeps records of the retail price and the replacement cost (wholesale price) in each store and week over the period 2004-2006. This replacement cost is net of discounts and inclusive of shipping costs. It is the most comprehensive measure of wholesale prices available to the retailer, and is used by the retailer in its pricing decisions. The data are presented to us in the following way. For each product/store/week, we observe the total revenues and total profits generated to the retailer from sales of that product (i.e., excluding other operational expenses by the retailer). Subtracting profits from total revenues, we obtain the retailer's total cost of acquiring the product from the vendor. Dividing total costs by total quantities, we recover the unit price at which the retailer can acquire the product i,e., the wholesale price. Our measure of retail prices is constructed as the ratio of total revenues to quantities.

Each store is assigned to one of the 73 pricing regions in the U.S., and one of the 17 pricing regions in Canada. For each product/region pair, we calculate the weekly price as the median weekly price across all stores in that pricing region for which we have data in that specific week, and we calculate quantity sold as the sum of quantities across all stores in the pricing region. Weekly data are aggregated to quarterly data by averaging the data over the weeks within the quarter. In our calculations, we only include products with at least four consecutive observations of price changes.

Calculating product-level statistics We first calculate the percentage change over time in the relative price between all pairs of pricing regions, for matched products belonging to a set $n \in N$. The set N corresponds to the product category and/or to the country of production of the good. We then group all the growth rates of all matched products into one of the three following sets according to the country of the pricing region: (i) both pricing regions in the U.S. (vector 1), (ii) both pricing regions in Canada (vector 2), and (iii) one pricing region in Canada and the other in the U.S. (vector 3). $\text{Var}_i^{\text{intra}}$ is equal to the variance of vector 1 for $i =$U.S. and vector 2 for $i =$Canada. $\text{Var}^{\text{inter}}$ is the variance of vector 3. To calculate the correlation of price changes, we proceed as above but construct each of the three vectors using the percentage change in the nominal U.S. dollar price, rather than the percentage change in relative price.

Calculating aggregate real exchange rates We first construct $\psi_{nrr't}$, the average expenditure share of product n in region r in country 1 and region r' in country 2, in period t, as follows:

$$\psi_{nrr't} = \frac{P_{n1rt}y_{n1rt} + P_{n2r't}y_{n2r't}}{\sum_n \left(P_{n1rt}y_{n1rt} + P_{n2r't}y_{n2r't}\right)} \ ,$$

where y_{nirt} is the quantity of product n sold in country i, region r, in period t. To construct the change in the aggregate RER over a set of products N, we first identify, for each pair of quarters t and $t+1$, the set of products $\tilde{N}_t \in N$ for which we observe the product-level RER growth rate between these two quarters. The change in the aggregate RER, ΔQ_t, is given by

$$\Delta Q_t = \sum_{n \in \tilde{N}_t} \sum_{r'=A}^{R_1} \sum_{r=A}^{R_2} \psi_{nrr't-1} \Delta Q_{n21rr't}.$$

We construct ΔQ_t separately for each of the product categories. In each quarter, we require a minimum of 100 growth rates. Quarter-category pairs without sufficient data are treated as missing. Aggregate RERs are constructed as a weighted average of RERs of the various product categories. In Section 5.3, we study movements of RERs at the product-category level. Here, we require that each product category has at least 5% expenditure share on exported products, and in order to smooth product-level RER movements at the category level we also require a minimum of $1,500$ growth rates per quarter, for at least 8 quarters.

Appendix 2: Lemmas 1, 2, and Proofs

Lemma 1: *Consider the limit of our model economy as σ_z, σ_a, and σ_w are positive but arbitrarily close to zero. Then, the following variables can be expressed as analytic functions of the model's parameters: (i) the mass of exporters from country i to country j, m_{ij}, (ii) the mass of exporters from country i facing a latent competitor from country l when selling in country j, s_{ij}^l, and (iii) the mass of exporters from country i facing the same latent competitor from country l when selling in countries 1 and 2, s_i^l. These variables depend only* *on the parameters K_1, K_2, K_3, D, D^*, θ, and λ. Furthermore, the identity of active and latent producers is the same in both regions within each country.*

Proof of Lemma 1: As σ_z, σ_a, and σ_w approach zero, $a_{knirt}/\left(z_{knt}W_{it}\right)$ and $a_{knirt}/\left(z'_{knt}W_{it}\right)$ converge in distribution to time-invariant random variables $1/\bar{z}_{kn}$ and $1/\bar{z}'_{kn}$ that are exponentially distributed. This result follows directly from Slutzky's lemma. With m_{ij}, s^1_{ij}, and s^l_i continuous functions of $a_{knirt}/\left(z_{knt}W_{it}\right)$ and $a_{knirt}/\left(z'_{knt}W_{it}\right)$, the limit of m_{ij}, s^1_{ij}, and s^l_i can be evaluated using the convenient properties of exponentially distributed random variables $\bar{z}_{kn}$ and $\bar{z}'_{kn}$, in terms of the parameters K_1, K_2, K_3, D, D^*, θ, and λ. In deriving these expressions, we also characterize the sets N_{x1t}, N_{x2t}, N_{x3t}, and N_{dt}. With our assumption that $\bar{z}_{kn}$ and $\bar{z}'_{kn}$ are common to both regions within each country, the identity of active and latent producers in our limit economy is the same in both regions within each country.

Characterizing sets of matched products: The set of matched products that are supplied in countries 1 and 2 by the same producer located in country 1 (and hence is exported to country 2) is given by:

$$N_{x1} = \left\{ n \in N \text{ s.t. } D \min\left\{\bar{z}_{kn}\right\}_{k=1}^{K_1} \leq \min\left\{ \left\{\bar{z}'_{kn}\right\}_{k=1}^{K_1} \cup \left\{\bar{z}_{kn}\right\}_{k=K_1+1}^{K_1+K_2} \cup \left\{D^*\bar{z}_{kn}\right\}_{k=K_1+K_2+1}^{K} \right\} \right\}. \tag{7.1}$$

That is, in order for a variety n to belong to this set, the exporter with the minimum marginal cost of supplying country 2, $D \min\left\{\bar{z}_{kn}\right\}_{k=1}^{K_1}$ must have a lower marginal cost than (i) all potential multinationals from country 1, $\left\{\bar{z}'_{kn}\right\}_{k=1}^{K_1}$, (ii) all local producers from country 2, $\left\{\bar{z}_{kn}\right\}_{k=K_1+1}^{K_1+K_2}$, and (iii) all potential exporters from country 3, $\left\{D^*\bar{z}_{kn}\right\}_{k=K_1+K_2+1}^{K}$. Note that if conditions (ii) and (iii) are satisfied for a product, then this product will be also sold domestically. Therefore, any product that is exported from country 1 to country 2 is also active in country 1, and the set N_{x1}, coincides with the set of all exported products from country 1 to country 2. Hence, m_{12} is equal to the mass of the set N_{x1}. Similarly, the set of matched products that are supplied by the same producer located in country 2 is given by:

$$N_{x2} = \left\{ n \in N \text{ s.t. } D \min\left\{\bar{z}_{kn}\right\}_{k=K_1+1}^{K_1+K_2} \leq \min\left\{ \left\{\bar{z}_{kn}\right\}_{k=1}^{K_1} \cup \left\{\bar{z}'_{kn}\right\}_{k=K_1+1}^{K_1+K_2} \cup \left\{D^*\bar{z}_{kn}\right\}_{k=K_1+K_2+1}^{K} \right\} \right\}. \tag{7.2}$$

The set of matched products that are supplied in both countries 1 and 2 by country 3 producers, N_{x3}, is given by:

$$N_{x3} = \left\{ n \in N \text{ s.t. } D^* \min\left\{\bar{z}_{kn}\right\}_{k=K_1+K_2+1}^{K} \leq \min\left\{ \left\{\bar{z}_{kn}\right\}_{k=1}^{K_1} \cup \left\{\bar{z}_{kn}\right\}_{k=K_1+1}^{K_1+K_2} \right\} \right\}. \tag{7.3}$$

That is, in order for a product to be exported from country 3 to both countries, it has to be such that the producer from country 3 with the minimum marginal cost, $D^* \min\left\{\bar{z}_{kn}\right\}_{k=K_1+K_2+1}^{K}$ has a lower marginal cost than all potential local producers in country 1 and country 2, $\min\left\{ \left\{\bar{z}_{kn}\right\}_{k=1}^{K_1} \cup \left\{\bar{z}_{kn}\right\}_{k=K_1+1}^{K_1+K_2} \right\}$.

Finally, the set of matched products, N_{dt}, that are supplied by the same domestic producer in each region is composed of two sets, N_{d1} and N_{d2}. The first set, N_{d1}, is given by:

$$N_{d1} = \left\{ \begin{array}{c} n \in N \text{ s.t } \min\{\bar{z}_{kn}\}_{k=1}^{K_1} \leq \min\left\{\{D\bar{z}_{kn}, \bar{z}'_{kn}\}_{k=K_1+1}^{K_1+K_2} \cup D^*\{\bar{z}_{kn}\}_{k=K_1+K_2+1}^{K}\right\} \\ \& \ \min\{\bar{z}'_{kn}\}_{k=1}^{K_1} \leq \min\left\{D\min\{\bar{z}_{kn}\}_{k=1}^{K_1} \cup \{\bar{z}_{kn}\}_{k=K_1+1}^{K_1+K_2} \cup D^*\{\bar{z}_{kn}\}_{k=K_1+K_2+1}^{K}\right\} \\ \& \ \arg\min\{\bar{z}_{kn}\}_{k=1}^{K_1} = \arg\min\{\bar{z}'_{kn}\}_{k=1}^{K_1} \end{array} \right\} \tag{7.4}$$

There are two conditions that need to be satisfied in order for a variety to belong to the set N_{d1}. First, a producer from country 1 has to sell domestically. This happens if the producer with the lowest local marginal cost, $\min\{\bar{z}_{kn}\}_{k=1}^{K_1}$, has a lower marginal cost than (i) all producers from country 2 who either export from country 2 or produce in country 1, $\{D\bar{z}_{kn}, \bar{z}'_{kn}\}_{k=K_1+1}^{K_1+K_2}$, and (ii) all exporters from country 3, $D^*\{\bar{z}_{kn}\}_{k=K_1+K_2+1}^{K}$. Second, a producer from country 1 has to sell in the foreign market via MP. This occurs if it has a lower marginal cost than (i) all exporters from country 1 (including itself, since it chose to not to export but instead to engage in MP), $\{\bar{z}_{kn}\}_{k=1}^{K_1}$, (ii) all domestic producers from country 2, $\{\bar{z}'_{kn}\}_{k=K_1+1}^{K_1+K_2}$, and (iii) all exporters from country 3, $D^*\{\bar{z}_{kn}\}_{k=K_1+K_2+1}^{K}$. Finally, for consistency, the same producer from country 1 sells in both countries, $\arg\min\{\bar{z}_{kn}\}_{k=1}^{K_1} = \arg\min\{\bar{z}'_{kn}\}_{k=1}^{K_1}$. The set N_{d2} is defined in an analogous way for country 2 producers.

Characterizing measures of latent competitors: We now define the measures of exporters from country 1 facing the same latent competitor in both countries. These expressions are symmetric for country 2 exporters. The mass of country 1 exporters facing a latent competitor from country 1 when selling in country 2, s_{12}^1, is:

$$s_{12}^1 = Pr\left(D\min_2\{\bar{z}_{kn}\}_{k=1}^{K_1} \leq \min\left\{\{\bar{z}'_{kn}\}_{k=1}^{K_1} \cup \{\bar{z}_{kn}\}_{k=K_1+1}^{K_1+K_2} \cup D^*\{\bar{z}_{kn}\}_{k=K_1+K_2+1}^{K}\right\}\right).$$

These are the varieties for which the lowest and second-lowest cost exporting producers from country 1 have a lower cost than all other producers supplying country 2. Note that country 1 exporters facing a country 1 latent competitor in country 2, face the same latent competitor in country 1. There is no country 1 exporter that jointly faces a country 2 latent competitor in country 1 and a country 1 latent competitor in country 2. Therefore, $s_1^1 = s_{12}^1$. Similarly, the mass of country 1 exporters facing a latent competitor from country 2 when selling in country 1, s_{11}^2, is:

$$s_{11}^2 = Pr\left(\begin{array}{c} D\min\{\bar{z}_{kn}\}_{k=1}^{K_1} \leq \min\left\{\{\bar{z}'_{kn}\}_{k=1}^{K_1} \cup \{\bar{z}_{kn}\}_{k=K_1+1}^{K_1+K_2} \cup \{D^*\bar{z}_{kn}\}_{k=K_1+K_2+1}^{K}\right\} \\ \& \ D\min\{\bar{z}_{kn}\}_{k=K_1+1}^{K_1+K_2} \leq \min\left\{\min_2\{\bar{z}_{kn}\}_{k=1}^{K_1} \cup \{\bar{z}'_{kn}\}_{k=K_1+1}^{K_1+K_2} \cup \{D^*\bar{z}_{kn}\}_{k=K_1+K_2+1}^{K}\right\} \end{array} \right),$$

and $s_1^2 = s_{11}^2$.

The mass of country 1 exporters facing a latent competitor from country 3 when selling in country 1 is:

$$s_{11}^3 = \Pr\left(\begin{array}{c} D\min\{\bar{z}_{kn}\}_{k=1}^{K_1} \leq \min\left\{\{\bar{z}'_{kn}\}_{k=1}^{K_1} \cup \{\bar{z}_{kn}\}_{k=K_1+1}^{K_1+K_2} \cup \{D^*\bar{z}_{kn}\}_{k=K_1+K_2+1}^{K}\right\} \\ \& \ \min\{D^*\bar{z}_{kn}\}_{k=K_1+K_2+1}^{K} \leq \min\left\{\min_2\{\bar{z}_{kn}\}_{k=1}^{K_1} \cup D\{\bar{z}_{kn}\}_{k=K_1+1}^{K_1+K_2} \cup \{\bar{z}'_{kn}\}_{k=K_1+1}^{K_1+K_2}\right\} \end{array} \right).$$

Similarly, the mass of country 1 exporters facing a latent competitor from country 3 when selling in country 2 is:

$$s_{12}^3 = \Pr\left(\begin{array}{c} D\min\left\{\bar{z}_{kn}\right\}_{k=1}^{K_1} \leq \min\left\{\left\{\bar{z}'_{kn}\right\}_{k=1}^{K_1} \cup \left\{\bar{z}_{kn}\right\}_{k=K_1+1}^{K_1+K_2} \cup \left\{D^*\bar{z}_{kn}\right\}_{k=K_1+K_2+1}^{K}\right\} \\ \& \ \min\left\{D^*\bar{z}_{kn}\right\}_{k=K_1+K_2+1}^{K} \leq \min\left\{D\min_2\left\{\bar{z}_{kn}\right\}_{k=1}^{K_1} \cup \left\{\bar{z}'_{kn}\right\}_{k=1}^{K_1} \cup \left\{\bar{z}_{kn}\right\}_{k=K_1+1}^{K_1+K_2}\right\} \end{array}\right).$$

The mass of country 1 exporters facing the same latent competitor from country 3 when selling in countries 1 and 2 is:

$$s_1^3 = \Pr\left(\begin{array}{c} D\min\left\{\bar{z}_{kn}\right\}_{k=1}^{K_1} \leq \min\left\{\left\{\bar{z}'_{kn}\right\}_{k=1}^{K_1} \cup \left\{\bar{z}_{kn}\right\}_{k=K_1+1}^{K_1+K_2} \cup \left\{D^*\bar{z}_{kn}\right\}_{k=K_1+K_2+1}^{K}\right\} \\ \& \ \min\left\{D^*\bar{z}_{kn}\right\}_{k=K_1+K_2+1}^{K} \leq \min\left\{\min_2\left\{\bar{z}_{kn}\right\}_{k=1}^{K_1} \cup \left\{\bar{z}_{kn}\right\}_{k=K_1+1}^{K_1+K_2}\right\} \end{array}\right).$$

Note that $s_1^3 \leq s_{11}^3$ and $s_1^3 \leq s_{12}^3$. We provide analytic solutions for these expressions in the online appendix.

Lemma 2: *In the limit of our model economy as σ_z, σ_a, and σ_w approach zero, r_i is equal to 1 if $D = 1$, and r_i is weakly decreasing in D.*

Proof of Lemma 2: Recall from Lemma 1 that in this limit of our model, the identity of active and latent producers is determined only by the permanent components of marginal cost. This has the following implications. Exporters from country $i = 1, 2$ facing a latent competitor from their home country i when selling in country j, face the same latent competitor when selling domestically. This is because if two producers from country i are the lowest cost producers of supplying a good in country $j \neq i$, they must also be the lowest cost producers of supplying the home country. Therefore, $s_{12}^1 = s_1^1$ and $s_{21}^2 = s_2^2$. Similarly, exporters from country $i = 1, 2$ facing a foreign latent competitor from country $j = 2, 1$ in the domestic market, face the same foreign latent competitor when selling abroad in country $j = 2, 1$, respectively. Therefore, $s_{11}^2 = s_1^2$ and $s_{22}^1 = s_2^1$. Then, r_1 and r_2 can be expressed as:

$$r_i = \left(s_{i,-i}^i + s_{ii}^{-i} + s_i^3\right) / \left(s_{i,-i}^1 + s_{i,-i}^2 + s_{i,-i}^3\right),$$

where we used the fact that $m_{ij} = \sum_{l=1}^3 s_{ij}^l$.

With $D = 1$, producers have the same costs for domestic and export sales. Hence, the set of active producers and latent competitors is the same in both countries. This implies that $s_i^l = s_{ii}^l = s_{i,-i}^l$. Therefore, we have

$$r_i = \left(s_{i-i}^i + s_{ii}^{-i} + s_i^3\right) / \left(s_{i,-1}^1 + s_{i,-1}^2 + s_{i,-1}^3\right) = 1,$$

because $s_{ii}^{-i} = s_{i,-1}^{-1}$and $s_i^3 = s_{i,-1}^3$. Using our expressions for s_{ij}^l and s_i^l from Lemma 1 we show in the online appendix that s_{i-i}^i/m_{ij}, s_{ii}^{-i}/m_{ij}, s_i^3/m_{ij} are all weakly decreasing in D. Hence, r_i is also weakly decreasing in D. Q.E.D.

Proof of Proposition 1: Under perfect competition, prices of active products are set equal to the marginal cost of the lowest cost producer, so the percentage price change of active products is $\Delta P_{nirt} = \Delta c_{nirt}^{1st}$. The change in marginal cost is equal to the sum of the change in the wage and the temporary component of the active producer's idiosyncratic marginal cost, $\Delta c_{nirt}^{1st} = \Delta W_{nirt}^{1st} + \Delta z_{nirt}^{1st}$. With i.i.d. lognormal shocks, the asymptotic variance of ΔP_{nirt} is $2\left(\sigma_z^2+\sigma_w^2\right)$. Given that producers are subject to a common cost shock in supplying both regions in the same country, we have $correl\left(\Delta P_{niAt}, \Delta P_{niBt}\right)=1$. Exporters are subject to the same marginal cost shock for domestic and foreign sales, so the correlation of price changes across two regions in different countries is $correl\left(\Delta P_{n1At}, \Delta P_{n2At}\right)=1$. For matched products that are produced domestically in each country, shocks to the temporary component of the firm's idiosyncratic marginal cost and shocks to the wage are independently distributed across countries, so $correl\left(\Delta P_{n1At}, \Delta P_{n2At}\right)=0$. We then calculate the intra-national and international variance of product-level RERs as $Var\left(\Delta Q_{niiABt}\right) = 2\mathrm{Var}^{\Delta P}\left(1-\mathrm{Correl}^{\Delta P\mathrm{intra}}\right)$ and $Var\left(\Delta Q_{n12AAt}\right) = 2\mathrm{Var}^{\Delta P}\left(1-\mathrm{Correl}^{\Delta P\mathrm{inter}}\right)$, respectively.

Consider now movements in the aggregate RER between two periods of time, constructed as a weighted average of product-level RERs between two countries across a large set of products, as defined in (3.1). For simplicity, we compute this average only over products sold in region A in country 1 and region A in country 2. This is without loss of generality given our assumption that regions within countries are symmetric. For exported products, product-level RERs are constant over time, $\Delta Q_{n12AAt}=0$. Hence, aggregate RERs are also constant over time, $\Delta Q_t = 0$. For matched products that are produced domestically in each country, $\Delta Q_{n12AAt} = \Delta c_{n2At}^{1st} - \Delta c_{n1At}^{1st} = \left(\Delta W_{n2At}^{1st} + \Delta z_{n2At}^{1st}\right) - \left(\Delta W_{n1At}^{1st} + \Delta z_{n1At}^{1st}\right)$. Given that the mean of $\Delta z_{n2At}^{1st} - \Delta z_{n1At}^{1st}$ over a large number of products is equal to zero, the change in the aggregate RER is $\Delta Q_t = \Delta W_{2t} - \Delta W_{1t}$. Q.E.D.

Proof of Proposition 2: Under Bertrand competition, prices of active products are given by (4.3). With η is sufficiently close to one, the limit price $a_{nirt}^{1st}/\left(a_{nirt}^{2nd}\right)c_{nirt}^{2nd}$ is always binding. Hence, changes in prices of active products are given by:

$$\Delta P_{nirt} = \Delta a_{nirt}^{1st} - \Delta a_{nirt}^{2nd} + \Delta c_{nirt}^{2nd}. \tag{7.5}$$

With $i.i.d$ lognormal cost and demand shocks, the asymptotic variance of ΔP_{nirt} is (5.1).

Consider now the correlation of price changes across two regions in the same country:

$$correl\left(\Delta P_{niAt}, \Delta P_{niBt}\right) = cov\left(\Delta c_{niAt}^{2nd} + \Delta a_{niAt}^{1st} - \Delta a_{niAt}^{2nd}, \Delta c_{niBt}^{2nd} + \Delta a_{niBt}^{1st} - \Delta a_{niBt}^{2nd}\right)/\mathrm{Var}^{\Delta P}. \tag{7.6}$$

From Lemma 1, active producers face the same latent competitor in both regions within the same country, so $\Delta c_{niAt}^{2nd} = \Delta c_{niBt}^{2nd}$, and $cov\left(\Delta c_{niAt}^{2nd}, \Delta c_{niBt}^{2nd}\right) = 2\left(\sigma_z^2+\sigma_w^2\right)$. On the other hand, $cov\left(\Delta a_{niAt}^{1st} - \Delta a_{niAt}^{2nd}, \Delta a_{niBt}^{1st} - \Delta a_{niBt}^{2nd}\right) = 4\sigma_a^2\rho_a$. Plugging-in these results into (7.6), and using (5.1), we obtain (5.2).

Consider now the correlation of price changes across region A, country 1 and region A, country 2:

$$correl\left(\Delta P_{n1At}, \Delta P_{n2At}\right) = cov\left(\Delta c_{n1At}^{2nd} + \Delta a_{n1At}^{1st} - \Delta a_{n1At}^{2nd}, \Delta c_{n1At}^{2nd} + \Delta a_{n1At}^{1st} - \Delta a_{n1At}^{2nd}\right)/\mathrm{Var}^{\Delta P}. \tag{7.7}$$

With our assumption that demand shocks are uncorrelated across countries, we need only to focus on $cov\left(\Delta c_{n1At}^{2nd}, \Delta c_{n2At}^{2nd}\right)$. For producers facing the same latent competitor in both countries (a fraction r of all the matched products), $\Delta c_{n1At}^{2nd} = \Delta c_{n2At}^{2nd}$, so $cov\left(\Delta c_{n1At}^{2nd}, \Delta c_{n2At}^{2nd}\right) =$

$2\left(\sigma_z^2+\sigma_w^2\right)$. For producers facing a different latent competitor in each country (a fraction $1-r$ of all the matched products), $\Delta c_{n1At}^{2nd} \neq \Delta c_{n2At}^{2nd}$, and with *i.i.d.* lognormal shocks, $cov\left(\Delta c_{n1At}^{2nd}, \Delta c_{n2At}^{2nd}\right) = 0$. Plugging-in these results into (7.7), and using (5.1), we obtain (5.3). We can then calculate the variance of product-level RERs, Var^{intra} and Var^{inter} as in the proof of Proposition 1.

Consider now the change in the aggregate RERs across two periods. For matched exported products in the set N_{xi}, we have:

$$\begin{aligned}
\Delta Q_{it} &= \int_{N_{xi}} \psi_{n21AAt-1} \Delta Q_{n21AAt} \mathrm{d}n \qquad (7.8)\\
&= \int_{N_{xi}} \psi_{n21AAt-1} \left[\left(\Delta a_{n2At}^{1st} - \Delta a_{n2At}^{2nd} + \Delta c_{n2At}^{2nd}\right) - \left(\Delta a_{n1At}^{1st} - \Delta a_{n1At}^{2nd} + \Delta c_{n1At}^{2nd}\right)\right] \mathrm{d}n \\
&= \int_{N_{xi}} \psi_{n21AAt-1} \left(\Delta W_{n2At}^{2nd} - \Delta W_{n1At}^{2nd}\right) \mathrm{d}n \\
&= \frac{1}{m_{i,-i}} \left[\left(s_{i2}^1 - s_{i1}^1\right) \Delta W_{1t} + \left(s_{i2}^2 - s_{i1}^2\right) \Delta W_{2t} + \left(s_{i2}^3 - s_{i1}^3\right) \Delta W_{3t}\right] \ ,
\end{aligned}$$

where s_{ij}^l and $m_{i,-i}$ are defined in Lemma 1, and $\psi_{n21AAt-1}$ is the average share of product n in total expenditures in countries 1 and 2, region A, over the products in set N_{xi}. The second line in (7.8) is derived using (7.5). The third line is derived using the assumption that the mean of Δa and Δz over a large number of products is equal to zero, which implies that on average the change in the marginal cost of the latent competitor in country i, region r, is equal to the change in the wage of the latent competitor in this location, W_{n2At}^{2nd}. The fourth line in (7.8) uses notation introduced in Lemma 1 for the fraction of exporters from country i facing a latent competitor from country l when selling in country j, $s_{ij}^l/m_{i,i}$, and the result that with η sufficiently close to 1 the measure of products in any given set is equal to the expenditure share on these products. Finally, using $m_{ij} = \sum_{l=1}^3 s_{ij}^l$ and the definition of r_i, we obtain (5.6). Q.E.D.

Appendix 3: Model extensions

Our baseline model assumes that product-level demand shocks are uncorrelated across countries and that producers have equal marginal costs of supplying both regions within countries. Here we relax these assumptions and assume that (i) the cross-country correlation of product-level demand shocks is $\rho_a^{inter} \geq 0$, and that (ii) regions within countries have different realizations of production costs; each region is ex-ante symmetric but subject to a different idiosyncratic productivity shock and a common wage shock and producers can ship goods across regions subject to an intra-national trade cost. For simplicity, the cost of shipping goods internationally to each of the two regions in the foreign country is equal. We focus on the case of small time-varying shocks and Bertrand pricing (as in Proposition 2).

Under assumption (ii), producers can face a different local latent competitor in each region within a country. Note that producers will never face two different foreign latent competitors in two regions within a country because we assume that exporters face the same marginal cost of serving the two foreign regions. We denote by r_i^{intra} the fraction of producers in the set N_{xi} facing the same latent competitor in both regions within the same country, and by $\bar{r}_i^{intra}$ the fraction of producers facing two different latent competitors from the same country. In our baseline model, $r_i^{intra} = 1$ and $\bar{r}_i^{intra} = 0$. A higher intra-national trade cost lowers r_i^{intra} and raises $\bar{r}_i^{intra}$. Similarly, for products that are matched across countries, we denote by r_i^{inter} the fraction of producers facing the same latent competitor in both countries, and by $\bar{r}_i^{inter}$ the fraction of producers facing two different latent competitors from the same country. In our baseline model, $\bar{r}_i^{inter} = 0$. A higher intra-national trade cost lowers r_i^{inter} and raises $\bar{r}_i^{inter}$.

We use the same logic applied above to derive the correlation of price changes across regions within a country:

$$\text{Correl}_i^{\Delta Pj} = \frac{2\sigma_a^2\rho_a^j + \sigma_z^2 + \sigma_w^2}{2\sigma_a^2 + \sigma_z^2 + \sigma_w^2} r_i^j + \frac{\sigma_w^2}{2\sigma_a^2 + \sigma_z^2 + \sigma_w^2} \bar{r}_i^j \text{ , for } j = \text{intra or inter.}$$

Observe that, given that producers do not always face the same latent competitor in both regions within a country ($r_i^{intra} < 1$), the intra-national correlation of price movements is lower than in our baseline model.

The ratio of inter-to-intra-national variances of product-level RERs is:

$$\frac{\text{Var}_i^{\text{inter}}}{\text{Var}^{\text{intra}}} = \frac{1 - \rho_a^{inter} r_i^{inter} + \frac{\left(\sigma_z^2 + \sigma_w^2\right)}{2\sigma_a^2}\left(1 - r_i^{inter}\right) - \bar{r}_i^{inter} \frac{\sigma_w^2}{2\sigma_a^2}}{1 - \rho_a^{intra} r_i^{intra} + \frac{\left(\sigma_z^2 + \sigma_w^2\right)}{2\sigma_a^2}\left(1 - r_i^{intra}\right) - \bar{r}_i^{intra} \frac{\sigma_w^2}{2\sigma_a^2}}$$

A high inter/intra-national ratio of RER variances can result from (i) a higher likelihood that producers face the same latent competitor across regions within the same country than across regions in different countries ($r_i^{intra} > r_i^{inter}$), and (ii) a higher correlation of demand shocks within countries than across countries ($\rho_a^{inter} > \rho_a^{inter}$).

The expression that describes the change in aggregate RERs in response to a movement in relative unit labor costs is given by (5.6), where r_i is substituted by $r_i^{inter} - \bar{r}_i^{inter}$.

Figure 1: Canada-US Aggregate-Real Exchange Rates, British Columbia and Northern California

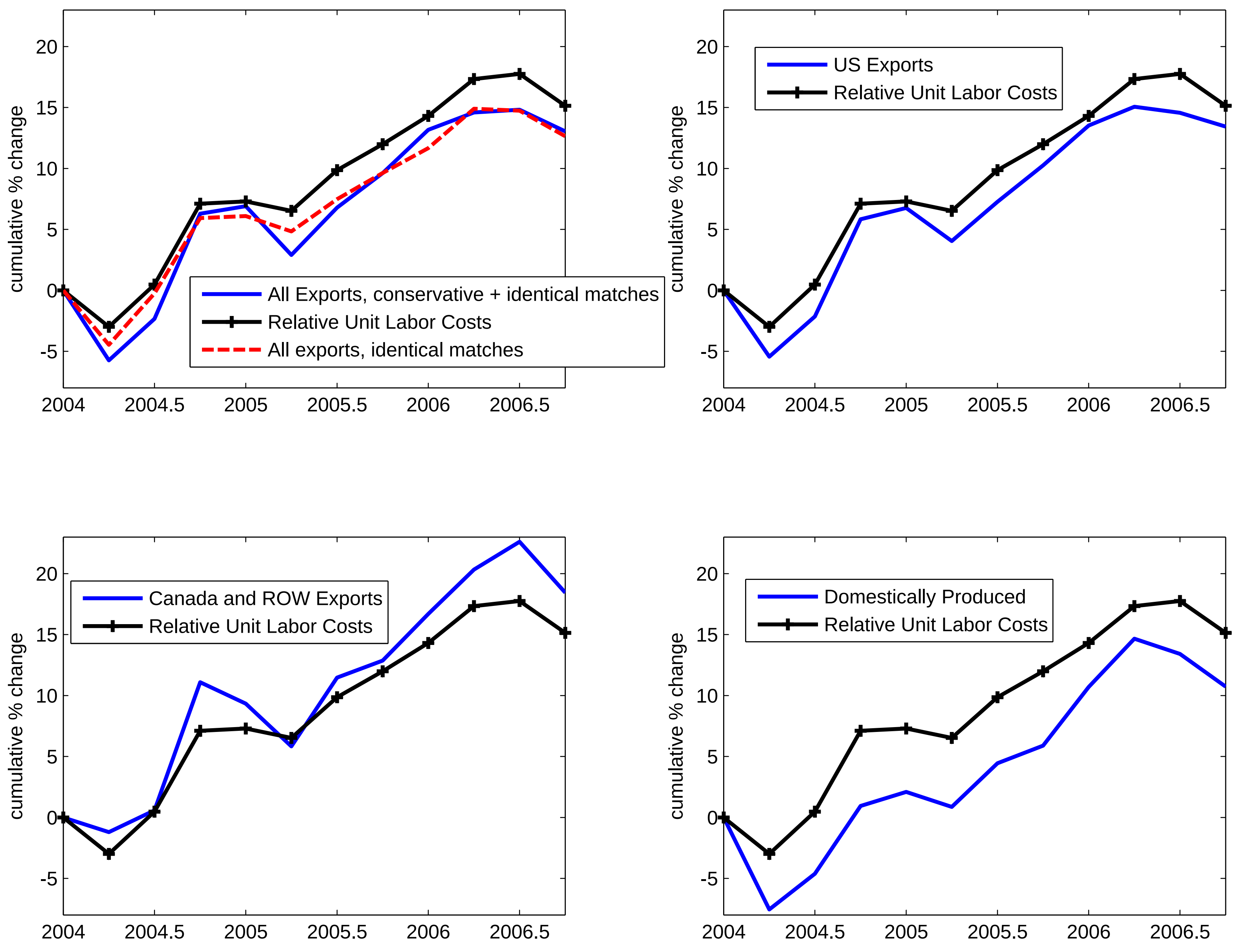


Figure 2: Price Movements for a US Exported Product in the "Tea" Category

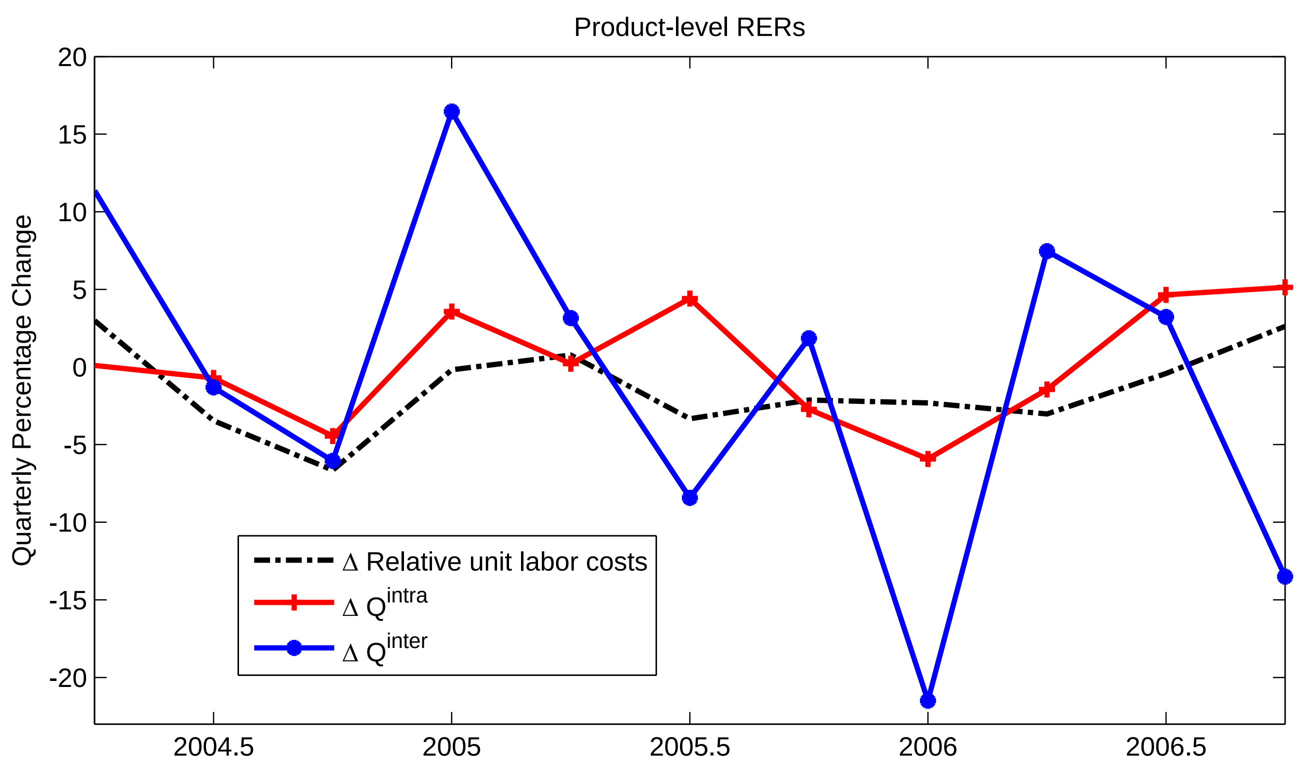
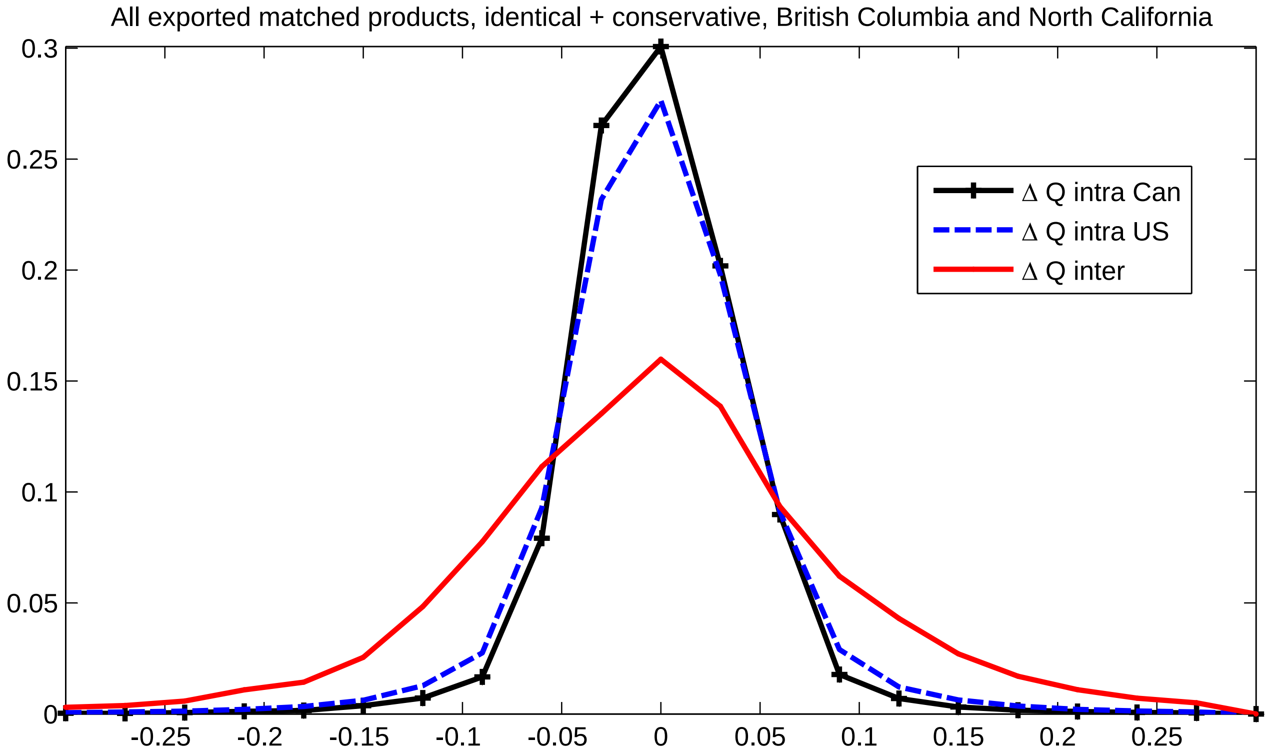


Figure 3: Histogram of Movements of Product-Level Real Exchange Rates



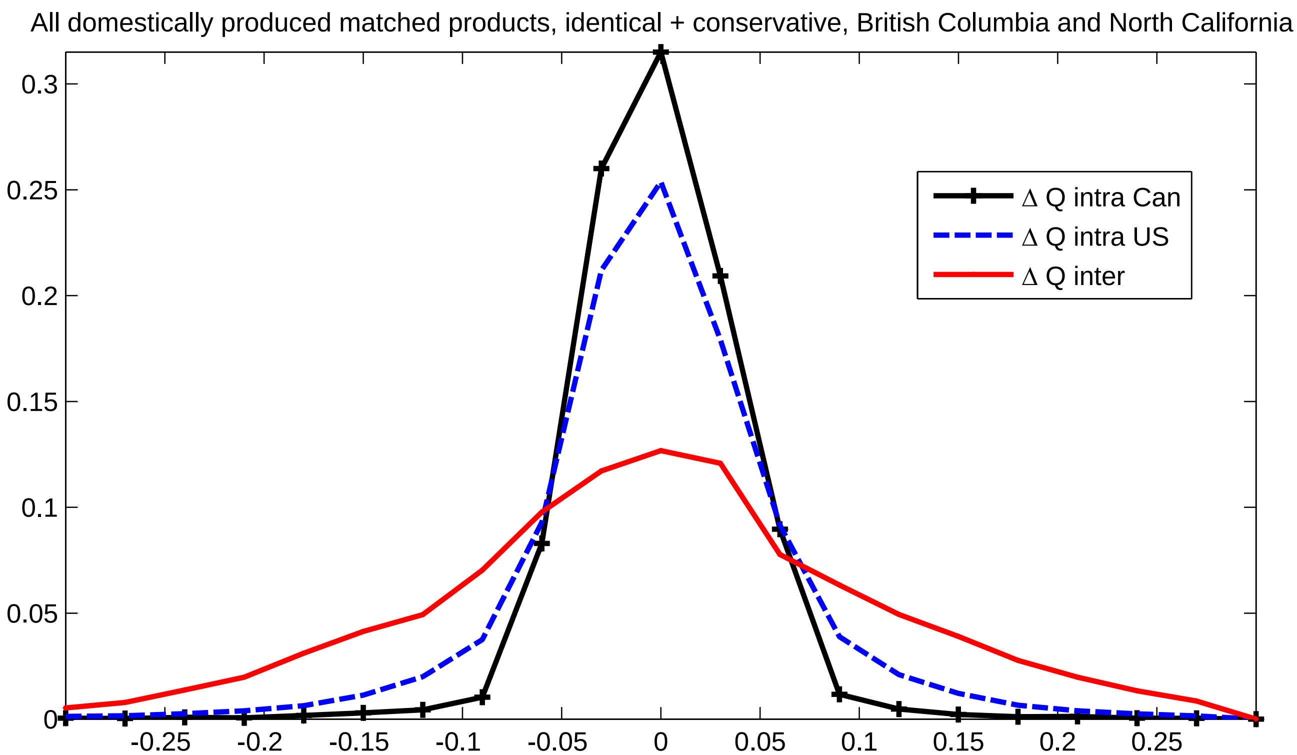


Figure 4: Model Aggregate Real Exchange Rates

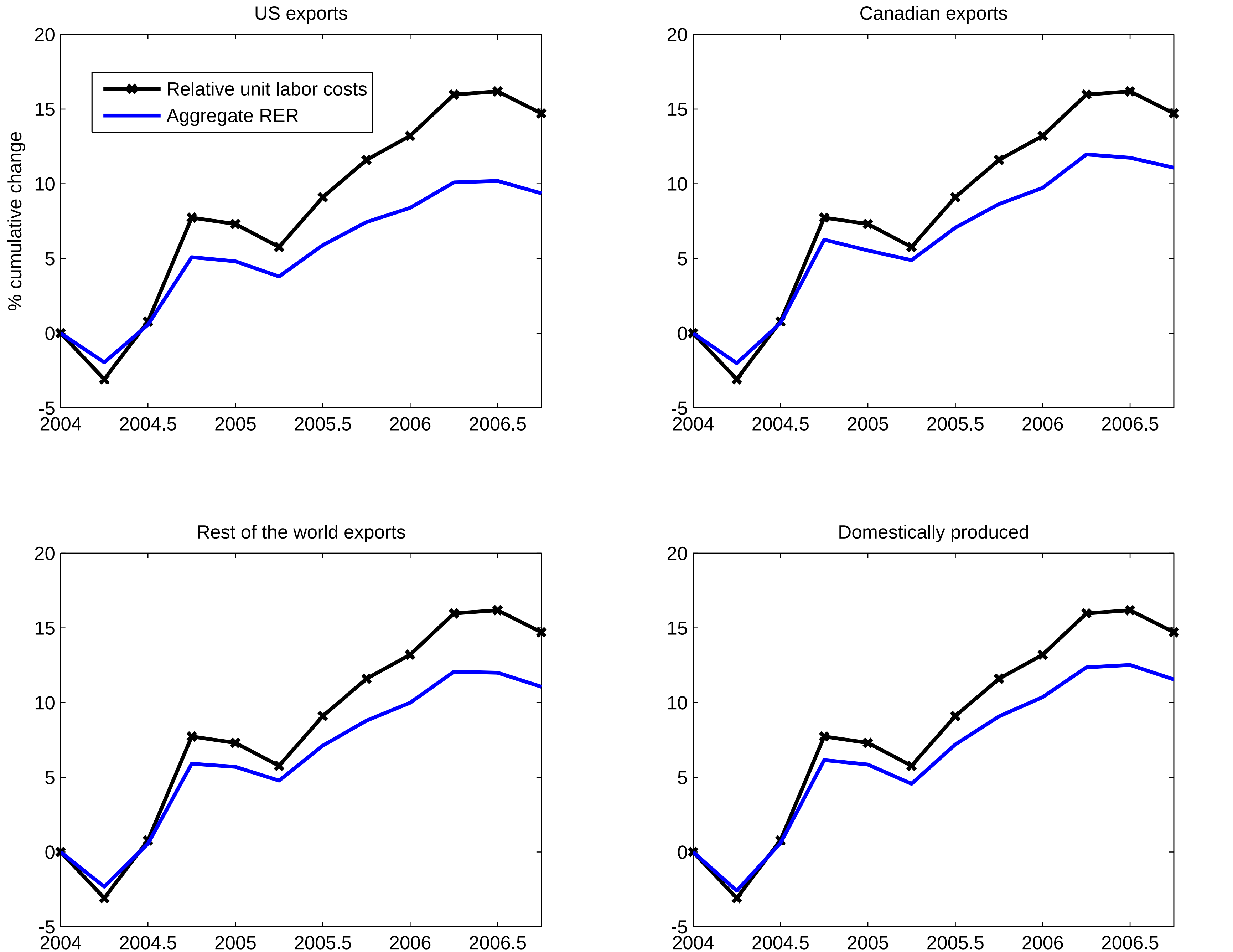


Table 1: Descriptive Statistics

Panel A: Identical Matches

		Center-West Canada	Center-West US	British Columbia	North California
1	**Expenditure share of matched products out of total expenditure**	0.04	0.05	0.04	0.06
	Expenditure share of products produced in:				
2	U.S.	0.60	0.76	0.63	0.73
3	Canada	0.24	0.03	0.21	0.05
4	ROW (Same Country)	0.16	0.21	0.16	0.22
	Number of products produced in:				
5	U.S.	573	628	444	543
6	Canada	128	39	105	23
7	ROW (Same Country)	332	302	179	234
	Number of matched products by country-of-production set				
8	US exports (produced in US for sales in Canada and US)	573	552	444	480
9	Canada exports (produced in Canada for sales in Canada and US)	44	39	25	23
10	ROW Exports (produced in ROW for sales in Canada and US)	332	302	179	234
11	Domestically produced (in Canada for Canada sales and in US for US sales)	84	76	80	63
12	**Number of product categories**	60	55	17	53
13	**Number of pricing regions:**	17	51	5	14

Panel B: Identical + Conservative Matches

		Center-West Canada	Center-West US	British Columbia	North California
14	**Expenditure share of matched products out of total expenditure**	0.52	0.36	0.51	0.36
	Expenditure share of products produced in:				
15	U.S.	0.29	0.89	0.30	0.87
16	Canada	0.68	0.02	0.67	0.01
17	ROW (Same Country)	0.03	0.09	0.03	0.11
	Number of products produced in:				
18	U.S.	1522	5278	1477	4185
19	Canada	1925	238	1727	161
20	ROW (Same Country)	418	636	303	470
	Number of matched products by country-of-production set				
21	U.S. exports (produced in U.S. for sales in Canada and US)	5496	5496	4504	4504
22	Canada exports (produced in Canada for sales in Canada and U.S.)	191	191	124	124
23	ROW exports (produced in ROW for sales in Canada and U.S.)	367	367	236	236
24	Domestically produced (in Canada for Canada sales and in U.S. for U.S. sales)	5385	5385	4187	4187
25	**Number of product categories**	93	93	93	93
26	**Number of pricing regions:**	17	51	5	14

Center-West includes all pricing regions in Canada (British Columbia, Alberta, and Manitoba), and 51 pricing regions in the U.S. located in California, Oregon, Idaho, Montana, and Wyomin

Table 2: Movements in Product-Level Real-Exchange Rates

Panel A: Identical + Conservative Matches, North California and British Columbia

		All	All Exports	US Exports	Can Exports	ROW Exports	Domestic
1	**Std^{intra} US**	0.06	0.06	0.06	0.08	0.08	0.07
2	**Std^{intra} Can**	0.05	0.05	0.05	0.04	0.07	0.05
3	**Std^{inter}**	0.13	0.11	0.10	0.14	0.14	0.13
4	**$Correl^{intra}$ US**	0.75	0.73	0.73	0.71	0.73	0.79
5	**$Correl^{intra}$ Can**	0.84	0.80	0.80	0.89	0.77	0.88
6	**$Correl^{inter}$**	0.07	0.09	0.10	0.05	0.09	0.07

Panel B: Identical Matches, North California and British Columbia

		All	All Exports	US Exports	Can Exports	ROW Exports	Domestic
7	**Std^{intra} US**	0.09	0.09	0.09	0.08	0.10	0.07
8	**Std^{intra} Can**	0.07	0.08	0.07	0.04	0.09	0.05
9	**Std^{inter}**	0.13	0.13	0.12	0.09	0.15	0.10
10	**$Correl^{intra}$ US**	0.52	0.53	0.56	0.36	0.47	0.45
11	**$Correl^{intra}$ Can**	0.72	0.72	0.72	0.78	0.71	0.79
12	**$Correl^{inter}$**	0.09	0.10	0.10	0.00	0.09	-0.03

Panel C: Identical Matches, Center-West Canada and Center-West US

		All	All Exports	US Exports	Can Exports	ROW Exports	Domestic
13	**Std^{intra} US**	0.07	0.07	0.07	0.06	0.09	0.06
14	**Std^{intra} Can**	0.07	0.07	0.06	0.03	0.09	0.05
15	**Std^{inter}**	0.13	0.13	0.12	0.08	0.15	0.10
16	**$Correl^{intra}$ US**	0.68	0.68	0.68	0.45	0.70	0.56
17	**$Correl^{intra}$ Can**	0.76	0.76	0.76	0.85	0.75	0.83
18	**$Correl^{inter}$**	0.11	0.12	0.13	0.00	0.10	-0.06

Table 3: Movements in Product-Level Real-Exchange Rates, Robustness

A: Liberal Matches

	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic
1 Std^{intra} US	0.06	0.06	0.05	0.10	0.07	0.07
2 Std^{intra} Can	0.04	0.04	0.03	0.02	0.08	0.04
3 Std^{inter}	0.13	0.11	0.11	0.17	0.14	0.15
4 $Correl^{intra}$ US	0.77	0.74	0.75	0.68	0.74	0.79
5 $Correl^{intra}$ Can	0.93	0.89	0.90	0.96	0.74	0.94
6 $Correl^{inter}$	0.07	0.05	0.06	-0.04	0.09	0.09

B: Center-West pricing regions

	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic
1 Std^{intra} US	0.06	0.06	0.06	0.09	0.09	0.07
2 Std^{intra} Can	0.04	0.04	0.04	0.05	0.07	0.04
3 Std^{inter}	0.12	0.11	0.11	0.15	0.14	0.13
4 $Correl^{intra}$ US	0.77	0.73	0.75	0.72	0.65	0.78
5 $Correl^{intra}$ Can	0.87	0.86	0.88	0.88	0.77	0.88
6 $Correl^{inter}$	0.07	0.06	0.05	0.08	0.08	0.07

C: One pricing region in Seattle and in British Columbia

	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic
7 Std^{intra} US						
8 Std^{intra} Can						
9 Std^{inter}	0.12	0.11	0.11	0.15	0.15	0.12
10 $Correl^{intra}$ US						
11 $Correl^{intra}$ Can						
12 $Correl^{inter}$	0.07	0.06	0.05	0.08	0.10	0.08

D: Four pricing regions: BC, Manitoba, NC, Illinois

	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic
7 Std^{intra} US	0.08	0.08	0.08	0.10	0.09	0.08
8 Std^{intra} Can	0.04	0.05	0.04	0.04	0.07	0.04
9 Std^{inter}	0.12	0.11	0.11	0.20	0.15	0.13
10 $Correl^{intra}$ US	0.61	0.59	0.57	0.84	0.62	0.62
11 $Correl^{intra}$ Can	0.87	0.82	0.82	0.92	0.78	0.91
12 $Correl^{inter}$	0.06	0.07	0.08	-0.03	0.06	0.05

E: Prices Demeaned by Category-wide price

	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic
13 Std^{intra} US	0.06	0.06	0.05	0.09	0.07	0.06
14 Std^{intra} Can	0.04	0.04	0.04	0.03	0.05	0.04
15 Std^{inter}	0.12	0.11	0.11	0.21	0.13	0.13
16 $Correl^{intra}$ US	0.78	0.76	0.76	0.71	0.74	0.79
17 $Correl^{intra}$ Can	0.88	0.86	0.86	0.95	0.84	0.90
18 $Correl^{inter}$	0.07	0.09	0.09	0.00	0.13	0.06

F: Weekly Prices

	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic
13 Std^{intra} US	0.07	0.07	0.07	0.09	0.07	0.07
14 Std^{intra} Can	0.05	0.04	0.05	0.06	0.07	0.05
15 Std^{inter}	0.19	0.19	0.23	0.19	0.21	0.20
16 $Correl^{intra}$ US	0.85	0.84	0.85	0.76	0.72	0.85
17 $Correl^{intra}$ Can	0.96	0.97	0.95	0.94	0.94	0.94
18 $Correl^{inter}$	0.06	0.09	0.03	0.03	0.06	0.04

G: Retail Prices, Identical Matches, NC and BC

	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic
19 Std^{intra} US	0.08	0.08	0.08	0.05	0.09	0.05
20 Std^{intra} Can	0.05	0.05	0.05	0.03	0.05	0.04
21 Std^{inter}	0.12	0.12	0.12	0.07	0.13	0.09
22 $Correl^{intra}$ US	0.73	0.73	0.73	0.59	0.71	0.77
23 $Correl^{intra}$ Can	0.80	0.80	0.81	0.70	0.76	0.82
24 $Correl^{inter}$	0.06	0.07	0.07	0.15	0.06	-0.04

H: Retail Prices, Identical + Conserv. Matches, NC and BC

	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic
19 Std^{intra} US	0.08	0.07	0.07	0.08	0.07	0.10
20 Std^{intra} Can	0.05	0.05	0.05	0.04	0.05	0.04
21 Std^{inter}	0.14	0.14	0.14	0.17	0.13	0.14
22 $Correl^{intra}$ US	0.75	0.75	0.75	0.89	0.77	0.75
23 $Correl^{intra}$ Can	0.85	0.83	0.83	0.81	0.05	0.87
24 $Correl^{inter}$	0.08	0.03	0.03	0.18	0.01	0.13

NC: Northern California, BC: British Columbia

Table 4 : Baseline Parameterization: Parameter Values and Targets

Panel A: Parameter values

	Parameters that determine trade patterns		
1	K_1	28	
2	K_2	4	
3	K_3	5	
4	D	1.58	
5	D*	1.15	
6	λ	0.35	
7	θ	0.3	

	Parameters that determine price movements	**Uncorrelated demand shocks**	**Correlated demand shocks**
8	σ_z	0.054	0.034
9	$\sigma_z^2/(\sigma_z^2+\sigma_a^2)$	0.780	0.333
10	ρ_a	0	0.64

Panel B: Targets

	Trade shares		**Source**
11	Exports Can to US , share of US expenditures, selected industries	2%	Source OECD
12	Exports US to Can , share of Can expenditures, selected industries	25%	Source OECD
13	Average Exports ROW to Can, ROW to US, share of US,Can expenditures, selected industries	10%	Source OECD
14	Expenditures in Nd / Expenditures in Nx1 and Nx2 , Canada	1%	Our data
	Prices		
15	Standard deviation price changes, US exporters, average US and Canada, Region 2	8%	Our data
16	Intra-national correlation of price changes, US exporters average US and Canada , Region 2	0.82	Our data
17	International correlation of price changes, US exporters average US reference and Canada reference , Region 2	0.08	Our data
18	Canada-US relative unit labor costs, overall apreciation 2004-2006	15%	OECD

Table 5: Quantitative Results, Baseline and Sensitivity Analysis

		1	2	3	4	5	6	7
		Baseline $\rho_a = 0$	Correlated demand shocks, $\rho_a > 0$	Small shocks	Lower MP $\lambda = 0.15$	$\theta = 0.45$	$\theta = 0.2$	$\eta = 2$
Panel A: Product-level price statistics								
	US Exports							
1	Correlation intranational prices	0.75	0.74	0.75	0.75	0.74	0.75	0.75
2	Correlation international prices	0.26	0.11	0.20	0.25	0.24	0.31	0.32
3	Variance inter / intra RER	1.72	1.87	1.90	1.74	1.73	1.67	1.68
	Canadian Exports							
4	Correlation intranational prices	0.73	0.73	0.75	0.74	0.73	0.74	0.70
5	Correlation international prices	0.19	0.08	0.14	0.18	0.16	0.22	0.20
6	Variance inter / intra RER	1.85	1.96	1.99	1.90	1.85	1.84	1.65
	ROW Exports							
7	Correlation intranational prices	0.74	0.74	0.76	0.74	0.74	0.75	0.72
8	Correlation international prices	0.17	0.08	0.12	0.14	0.15	0.21	0.22
9	Variance inter / intra RER	1.87	1.95	2.02	1.92	1.86	1.86	1.71
	Domestically produced							
10	Correlation intranational prices	0.74	0.74	0.76	0.74	0.74	0.75	0.71
11	Correlation international prices	0.18	0.07	0.14	0.14	0.15	0.22	0.11
12	Variance inter / intra RER	1.85	1.94	2.00	1.90	1.85	1.81	1.81
Panel B: Aggregate price statistics								
	Change in RER / Change in relative costs							
13	*US Exports*	0.64	0.63	0.71	0.64	0.66	0.60	0.53
14	*Canadian Exports*	0.75	0.73	0.81	0.76	0.77	0.71	0.69
15	*ROW Exports*	0.76	0.74	0.83	0.79	0.78	0.72	0.67
16	*Domestically produced*	0.78	0.79	0.81	0.83	0.80	0.75	0.87

In cases 2-7 we adjust the remaining parameters to match the other calibration targets.