

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

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Abstract

We document new facts on international relative price movements using wholesale price data for common products sold in Canada and United States over the period 2004-2006, and information on the country of production for individual products. We find that international relative prices at the level of individual products are roughly three to four times as volatile as the Canada-US nominal exchange rate at quarterly frequencies. Aggregate real-exchange rates, constructed by averaging movements in international relative prices for individual goods, closely follow the appreciation of the Canadian dollar over this period. These patterns hold both for matched products that are locally produced in each country, as well as for goods that are produced in one country and traded to other countries. The large movements in international relative prices for traded goods are in conflict with the hypothesis of relative purchasing power parity, but instead point to the practice of pricing-to-market by exporters.

In light of these findings, we construct a model of international trade and pricing-to-market that can account for the observed movements in product- and aggregate real-exchange rates for both traded and non-traded products. The international border plays a key role in accounting for our pricing facts 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. This question is at the heart of the discussion on optimal exchange rate policy, and on the role of the border in creating frictions to the international trade of goods.

What are the implications on international relative price movements of simple models of price setting? Consider first the implications of models with perfect competition (or models with imperfect competition and constant markups) in which prices change one-to-one with movements in marginal costs. These models imply that the relative price of a traded good produced in a common location and sold in two countries should remain constant over time — namely the hypothesis of relative purchasing power parity (relative PPP). However, a large body of empirical work suggests that relative PPP does not provide an accurate representation for movements in relative prices of many goods (see, for example, the survey in Goldberg and Knetter 1995). Another implication of the competitive benchmark model is that, if all goods can be freely traded across countries, the consumer-price-based RERs should be constant over time.

In order to account for the large observed movements of RERs in the data, researchers have departed from the competitive costless-trade benchmark in two directions. First, by taking into consideration that many goods and services are not traded and that even traded goods include a substantial non-traded distribution component. Changes in relative prices across countries for non-traded goods can reflect movements in relative production or distribution costs across locations. Second, researchers have considered models of imperfect competition with variable markups, in which movements in international relative prices are the outcome of changes in relative markups. This is the practice of pricing-to-market by which exporters systematically vary the markup at which they sell their output in two different locations. Discriminating between these two alternative models of international price setting is important because they have very different normative implications. In the first model, changes in international relative prices are efficient given movements in costs, while in the second model movements in relative prices are typically not efficient.

In this paper, we use detailed product-level data on prices in Canada and US to document new facts on movements in international relative prices and measure the extent of pricing-to-market for individual products. We use these facts as a guide for the design of a model

of trade and international prices.

Our empirical work is based on scanner data from a major retailer that sells primarily nondurable goods in multiple locations in Canada and the US.¹ For each product and each location, we observe weekly wholesale prices paid by the retailer during the period 2004 through 2006. In order to abstract from highly temporary price changes, we aggregate weekly prices into quarterly prices. We also construct a set of common, or matched products, sold in both countries, for which we observe the country of production (separately for US and Canadian sales) at one point in time. Measuring the extent of pricing-to-market using product-level data for matched products has an advantage over using aggregate price indices constructed by national statistical agencies since these typically include products that are not common across countries. Therefore, movements in international relative prices based on aggregate price indices can result from differences in the product composition of these indices, as opposed to changes in relative price across countries for common goods. Other recent work on international relative prices using product-level information include Crucini and Telmer (2007), Broda and Weinstein (2008), Gopinath, Gourinchas, and Hsieh (2008), and Fitzgerald and Haller (2008).

Our main empirical findings can be summarized as follows. First, movements in aggregate RERs, constructed by averaging changes in relative prices across countries over a large set of matched products, closely track movement in the Canada-US relative unit labor costs. Hence, our price data is consistent with evidence in Mussa (1986) and Engel (1999) that movements in aggregate RERs and nominal exchange rates (which closely track movements in relative unit labor costs) are highly correlated.

Second, we show that the observed movements in international relative prices are not accounted for by large movements in nominal exchange rates and small movements in nominal prices. In fact, our data displays large and frequent movements in nominal prices (consistent with the evidence in Bils and Klenow 2004 and Klenow and Krystov 2008 for US consumer prices). Moreover, changes in international relative prices at the level of individual products are also very large, roughly four times as volatile, at quarterly frequencies, as the Canada-US nominal exchange rate (consistent with the evidence in Crucini and Telmer 2007 and Broda and Weinstein 2008).

Third, our data reveals substantial regional pricing-to-market for traded products that

¹Data from this retailer has been used in Chetty (2007), Eichenbaum, Jaimovich, Rebelo (2007), Einav and Nevo (2007), and Gopinath, Gourinchas, Hsieh (2008).

are produced in a single country and consumed in both countries. Pricing-to-market is more prevalent across regions in different countries than across regions within the same country. In particular, movements in product-level RERs are two to three times as volatile across countries than within countries. Our evidence on international pricing-to-market complements the findings of Fitzgerald and Haller (2008), who uses micro data on domestic and export prices set by Irish producers to show that, on average, relative prices systematically track changes in nominal exchange rates.

In light of these findings, we then construct a model of international trade and pricing-to-market to rationalize our observed movements in international relative prices. Our model builds upon the pricing-to-market literature pioneered by Dornbusch (1987) and Krugman (1987),² and upon the recently developed quantitative models of international trade with heterogeneous producers and variable markups by Bernard, Eaton, Jensen, and Kortum (2004). Specifically, we extend the model of pricing-to-market with Bertrand competition and limit pricing of Atkeson and Burstein (2007), along the following dimensions. First, we introduce time-varying demand and cost shocks to generate idiosyncratic movements in product-level RERs. Second, we introduce the endogenous choice to serve foreign markets via exports (subject to international trade costs) or multinational production (subject to a loss in productivity) in order to account for the price movements of both traded and locally-produced matched products in our data. Third, we introduce multiple regions within countries to account for the movements in relative prices within and across countries. Finally, we allow for country asymmetries to account for the observed differences in pricing-to-market by US and non-US exporters.

We provide a simple analytical characterization to illustrate the model's ability to match our key pricing observations. The main force in the model is that, with Bertrand competition and limit pricing, prices are determined by idiosyncratic demand shocks and by the marginal cost of the latent competitor. Relative prices are more volatile across countries than within countries if either one of the two following conditions holds. First, idiosyncratic cost and demand shocks are less correlated across countries than within countries. Second, exporters are more likely to face the same latent competitor (with a common cost shock) within a country than across countries, which is largely determined by the size of international trade costs.

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

In the model, a lower likelihood that exporters compete with the same latent competitor in both countries, carries two additional implications. First, it increases the volatility of product-level RERs across countries because producers that face different latent competitors across countries set domestic and export prices that are uncorrelated. Second, as in Atkeson and Burstein (2007), a lower likelihood that exporters compete with the same latent competitor across countries implies that prices are more responsive to the local wage in the destination country, leading to larger movements in aggregate RERs in response to changes of relative costs across countries. Combining these two implications, the model predicts a negative relation between the international correlation of product-level price changes and the size of movements of aggregate RERs. This prediction is supported by observed differences in price movements across product categories in our data.

We show that our model, when parameterized to match key observations on the volume of trade and intra-national movements of prices in US and Canada can, to a large extent, quantitatively account for our observations on product-level and aggregate RERs.

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 in an analytically tractable version of the model. Section 6 presents the quantitative results of a parameterized version of our model. Section 7 concludes.

2. Data Description

Our analysis is based on scanner data from a large food and drug retailer that operates hundreds of stores in Canadian provinces and US states. The stores are located in British Columbia, Alberta and Manitoba, in Canada, and many US states covering a large area of the US 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 focus on 94 product categories, covering processed food, beverages, personal care, and cleaning products. We abstract from “non-branded” products such as vegetables and fruits, deli sandwiches, deli salads, and sushi, for which the country-of-origin is harder to identify. We also abstract from other product categories with very specific pricing practices, such as magazines.

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. Wholesale prices are the closest measure of producer prices in our data.

Our analysis primarily focuses on wholesale prices to abstract from local retail distribution services, and other retail pricing considerations such as multi-product pricing.³

2.1. Aggregation across space and time

We define our geographic unit as a pricing region. A pricing region is a relatively concentrated geographic area within a state with stores that share similar retail prices. Based on information from the retailer and our own calculations, we identify 24 pricing regions in Canada and 114 pricing regions in the US. We then 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 or wholesalers charge different prices for the same product in different regions.

Our baseline statistics are computed for the 5 pricing regions in British Columbia in Canada, and 14 pricing regions in Northern California in the US. These regions are roughly comparable in geographic scope and cover the stores where the country of production was identified (more on this below). In our sensitivity analysis, we consider other combinations of pricing regions.

In order to abstract from highly temporary price changes such as sales or promotions, which our model abstracts from, we aggregate weekly prices into quarterly prices.⁴ Quarterly prices are computed as average weekly prices within the quarter.

2.2. Matching products

In order to measure movements in international relative prices, we need to match products in the US and Canada. We first match products that have identical UPC codes. Given that our emphasis is on understanding price fluctuations over time, as opposed to differences in price levels at a point in time, we broaden our set of matched products beyond these identical products. Specifically, we match products that have different UPC codes but share the same

³Burstein, Neves, and Rebelo (2003) use US input-output data to measure distribution margins at the wholesale and retail levels. For non-durable goods in 1997, the total distribution margin is 46%, and the wholesale distribution margin is only 16%.

⁴Relatedly, Nakamura (2008) argues that idiosyncratic cost and demand shocks are more likely to drive price fluctuations at lower than weekly frequencies.

manufacturer, brand, and economically significant characteristic such as the product type. For example, we consider matches of products that only differ in their size. 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 US, “Purex Baby Soft” in Canada with “Purex Baby Soft Classic Detergent” in the US, “Crest toothpaste sensitivity protection” in Canada with “Crest sensitivity toothpaste whitening scope” in the US, and “Gatorade strawberry ice liquid sports drink” in Canada with “Gatorade sports drink fierce strawberry” in the US. This process yields roughly 14,000 product matches across countries. We perform sensitivity analysis to the degree of restrictiveness of our product matches, separately reporting our results for conservative and liberal matches. Overall, our findings are 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 US. In Canada, we recorded the label information for individual products sold in a specific store in the Vancouver area during the months of May-June 2008. In the US, we used the label information that is available in the retailer’s online store for sales in Northern California.⁵ For both countries, we complemented this information by calling some of the individual manufacturers. We abstract from retailer brands and non-branded products because we lack information on the identity of the manufacturer.

We consider four country-of-production sets of matched products. The first set consists of matched products that are produced in the US for both US 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 US 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 US for US 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 US and Canadian sales, such as

⁵Note that the country-of-production reported in the product’s label refers to the country where the final stage of production takes place. Intermediate stages and input production can be carried out in other countries. For our purposes, the key is that the marginal cost of the final good produced in a common location is equal across the various regions where the good is sold.

Myojo instant noodles (Japan), Absolut Vodka (Sweden), and Barilla tortellini (Italy).

There are two important caveats in our approach. First, it is possible that the country of production of a product varies over time. Second, it is possible that the country of production of a product varies across regions within the US 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 only include the pricing regions in British Columbia and North California, where the information on country of production was obtained.

2.4. Descriptive statistics

Table 1, Columns 1 and 2, provide descriptive statistics of our matched products in British Columbia (Canada) and North California (US).

Row 1 shows that our matching procedure covers a significant share of the retailer's total sales on our set of product categories. Namely, we cover 36% of total expenditures in the US, and 51% in Canada.⁶

Rows 2-7 summarize our country of production information for the set of products we cover. Rows 2-4 report expenditure shares by country of production, and rows 5-7 report the number of products by country of production. In the US, 87% of expenditures in our set of products (and 87% of the total number of products) are domestically produced. Imports from Canada and the rest of the world (ROW) account for 1% and 11% of expenditures, respectively. In Canada, roughly two thirds of expenditures in our set of products are domestically produced (or 42% of the number of products). Imports from the US account for a sizeable expenditure share of 30%, and imports from ROW account for an expenditure share of 3%.⁷

Rows 8-11 report the number of matched products, divided into our four production sets. Note that the total number of matched products exceeds the number of unique products in our data, because some products can be matched more than once. For example, Coca Cola

⁶We do not cover 100% of the expenditures for the following three reasons. First, we abstract from retailer brands. Second, many products cannot be matched in the US and Canada. Third, for some of the matched products we lack information on the country of production.

⁷Our data provides a good representation of bilateral trade shares for Canada and US 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 chemicals, food products, beverages, and tobacco over the period 1997-2002.

2lt in Canada is matched with Coca Cola 12 Oz and Coca-Cola 24 Oz in the US. Our matching process yields roughly 9,000 products in British Columbia - Northern California.

Of these matches, 50% are produced in the US for US and Canada sales, 1.4% are produced in Canada for US and Canada sales, 2.6% are produced in a common third country for US and Canada sales, and the remaining 46% are domestically produced in each country. Note that the number of matches of products that are either exported by Canada or by other ROW countries is significantly smaller than the number of matches of products that are exported by the US or are domestically produced. Hence, our statistics for Canadian and ROW exporters are more prone to small sample limitations.

3. Findings on Price Movements

3.1. Notation

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

The price (in US dollars) of product n sold in country i , region r , in period t , is denoted by P_{nirt} . Relative prices across regions for individual products are referred to 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:

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

We focus on percentage price changes of relative prices, as opposed to dollar changes in price levels, because movements in relative prices immediately indicate deviations from relative PPP.

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. By averaging changes in relative prices across many products and regions, we average-out the idiosyncratic, product-level movements in RERs and capture the time-varying components that are common to many products.

More specifically, the change in the aggregate RER between periods $t - 1$ and t for products belonging to a set N and sold in both countries is defined as:

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

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 products in the set N and pairs of regions. Further details are provided in Appendix 1. Our findings are virtually unchanged if we instead assign an equal weight to each product-level RER.⁸

3.2. Quantifying real-exchange rate fluctuations

We are interested in quantifying the extent of fluctuations of product-level and aggregate RERs. We consider measures of volatility for intra-national (i.e. between regions of the same country) and international (i.e. between regions of different countries) product-level RERs. In particular, the intra-national variance of product-level RERs in country i over a set of products N is defined as:

$$\text{Var}_i^{\text{intra}} = \sum_{n \in N} \sum_{r=A}^{R_i} \sum_{r' \neq r}^{R_i} \sum_{t=1}^{T-1} \frac{1}{\bar{n}} \left(\Delta Q_{niirr't} - \overline{\Delta Q_{intra,i}} \right)^2, \quad (3.2)$$

where $\overline{\Delta Q_{intra,i}}$ 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.

Analogously, the international variance of product-level RERs is defined as:

$$\text{Var}^{\text{inter}} = \sum_{n \in N} \sum_{r=A}^{R_1} \sum_{r'=A}^{R_2} \sum_{t=1}^{T-1} \frac{1}{\bar{n}} \left(\Delta Q_{n12rr't} - \overline{\Delta Q_{inter}} \right)^2, \quad (3.3)$$

⁸We also constructed measures of 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 by the US Bureau of Labor Statistics. The resulting movements in aggregate RERs are very similar to those constructed using (3.1).

The statistics $\text{Var}_i^{\text{intra}}$ and $\text{Var}^{\text{inter}}$ can be expressed as:

$$\begin{aligned}\text{Var}_i^{\text{intra}} &= 2\text{Var}_i^{\Delta P} (1 - \text{Correl}_i^{\Delta P \text{intra}}) , \text{ and} \\ \text{Var}^{\text{inter}} &= (\text{Var}_1^{\Delta P} + \text{Var}_2^{\Delta P}) \left(1 - \frac{2(\text{Var}_1^{\Delta P})^{0.5} (\text{Var}_2^{\Delta P})^{0.5}}{\text{Var}_1^{\Delta P} + \text{Var}_2^{\Delta P}} \text{Correl}^{\Delta P \text{inter}} \right) .\end{aligned}\tag{3.4}$$

Here, $\text{Var}_i^{\Delta P}$ denotes the variance of price changes (i.e. ΔP_{nirt}) for products $n \in N$ sold over the various regions in country i . $\text{Correl}_i^{\text{intra}}$ denotes the correlation of price changes between the various pairs of regions in country i . $\text{Correl}^{\text{inter}}$ denotes the correlation of price changes between pairs of region in country 1 and country 2.

Using (3.4), the ratio of international to intra-national RER variances is:

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

Note that the term $2(\text{Var}_1^{\Delta P})^{0.5} (\text{Var}_2^{\Delta P})^{0.5} / (\text{Var}_1^{\Delta P} + \text{Var}_2^{\Delta P})$ is very close to one for small differences in $\text{Var}_i^{\Delta P}$ across countries (as we report below, this is the case in our actual calculations). Then, international product-level RERs are more volatile than intra-national RERs in country i either because (i) prices changes are more volatile in country $-i$ relative to country i , i.e. $\text{Var}_{-i}^{\Delta P} > \text{Var}_i^{\Delta P}$, or (ii) price changes are more correlated within than across countries, i.e. $\text{Correl}_i^{\text{intra}} > \text{Correl}^{\text{inter}}$. Note also that the ratio of international to intra-national variances can differ with the choice of base country if $\text{Var}_i^{\Delta P}$ and/or $\text{Correl}_i^{\text{intra}}$ differ across countries.

Finally, to measure the magnitude of aggregate RER movements, given the relatively short time span of our data (12 quarters), we only report cumulative changes, $\sum_{t=1}^T \Delta Q_t$.

3.3. Findings: Product-level real exchange rates

To fix ideas, Figure 1 depicts movements of prices and product-level RERs for one particular matched product in our sample. The product belongs to the product category ‘‘Processed fruit juices’’ and is produced in the US for sales in both the US and Canada. The top panel displays the 11 quarterly growth rate of prices (all expressed in US dollars), ΔP_{nirt} , in three regions: two regions in the US (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 US regions, $\Delta Q_{n1rr't}$, and one region in the US and one in

Canada, ΔQ_{n12rrt} . The lower panel also displays quarterly changes in relative unit labor costs between Canada and the US, as constructed by the OECD. One can observe in this example that relative prices are very volatile (more than relative unit labor costs), and that relative prices are more volatile across countries than within countries.

Figure 2 presents a series of histograms of the movements in product-level RERs across our entire set of matched products, separately for pairs of pricing regions within Northern California, within British Columbia, and across Northern California and British Columbia. The upper panel considers only matched products that are produced in one country and exported to other countries. The lower panel considers only matched products that are locally produced in each country. Observe that in both panels, movements in product-level RERs are quite large, and larger across countries than across pricing regions of the same country. The large observed movements in international relative prices for locally produced products could simply reflect movements in marginal costs across production locations. Instead, the large movements in international relative prices across countries for exported products point to the practice of pricing-to-market.

We summarize in Table 2 the information contained in Figure 2. We report standard deviations of intra- and international RERs, $\sqrt{\text{Var}_i^{\text{intra}}}$ and $\sqrt{\text{Var}^{\text{inter}}}$ (we use standard deviations rather than variances to facilitate the comparison of our numbers with standard measures of nominal and real-exchange rate volatility), as well as intra- and international correlations of price changes, $\text{Correl}_i^{\text{intra}}$ and $\text{Correl}^{\text{inter}}$. We separately report our statistics for the various country-of-production sets.

Combining all matched products, the international standard deviation of product-level RERs is 12% (Row 3). To put this figure in perspective, the standard deviation of quarterly changes in the Canada-US relative unit labor costs, nominal exchange rate, and the CPI-based RER between 1998 and 2007 is roughly 3%.

These large movements in product-level RERs do not stem, in a pure accounting sense, from infrequent nominal price changes and volatile nominal exchange rates. First, product-level RERs across countries are roughly 3 to 4 times as volatile as nominal exchange rates and RERs. In fact, our statistics are roughly unchanged if we compute product-level RERs as ratios of nominal prices without converting prices to a common currency. Second, individual prices in our data move quite frequently. To see this, we construct modal quarterly prices as in Eichenbaum, Jaimovich and Rebelo (2008). The mean frequency of modal price changes

is roughly 0.5 in Canada and US (or 2 quarters duration). More importantly, the fraction of matched products for which the modal price is unchanged in both countries in a typical quarters is only 0.25. The frequency of price adjustment is significantly lower if we consider all price changes in the data, and not only modal price changes.

Product-level RERs are very volatile for matched products that are domestically produced in each country, as well as for matched products that are produced in one country and exported to other countries. In particular, the international standard deviation of product-level RERs is equal to 11% for US exported products, 15% for Canadian exported products, 14% for exported products by other ROW countries, and 13% for matched products that are domestically produced in each country.

Table 2, Rows 1-3, shows that product-level RERs are 2 to 3 times as volatile across countries than within countries. For example, for all exported products the standard deviation of product-level RERs is 4.3% within Canada and 5.5% within the US.⁹

To understand the observed differences in intra- and international volatilities of product-level RERs, we can use expression (3.5). We first note that the variance of US-denominated nominal price changes, $\text{Var}_i^{\Delta P}$, is roughly equal in the US and Canada. For example, the standard deviation of price changes across all exported product matches is 7.8% in Canada and 8.4% in the US. Hence, differences in intra- and international RER volatilities are mainly accounted for by differences in the correlation of price changes within and across countries. Given that $\text{Var}^{\text{inter}} > \text{Var}_i^{\text{intra}}$, it must be that $\text{Correl}^{\text{inter}} < \text{Correl}_i^{\text{intra}}$. For example, Rows 4-6 show that for all exported products, $\text{Correl}_{US}^{\text{intra}} = 0.76$, $\text{Correl}_{Can}^{\text{intra}} = 0.85$, and $\text{Correl}^{\text{inter}} = 0.08$.

Hence, the key challenge to understand the observed differences in the volatilities of product-level RERs within and across countries is to understand why, even for exported products, price movements are less correlated across countries than within countries.

Comparison across locations of production

The results in Table 2 suggest that there are differences in the measures of intra- and inter product-level RER volatilities and price correlations for products belonging to our four different location of production sets. However, most of the categories in our data set 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

⁹Our finding that $\text{Var}_{US}^{\text{intra}} > \text{Var}_{Can}^{\text{intra}}$ echoes the findings in Gorodnichenko and Tesar (2008) who use more aggregated price data.

country. This implies that when we compare our statistics across country-of-production sets, we are mixing different categories and hence our inference can suffer from a composition bias.

In order to address this problem, we construct our statistics based on categories that include products from both country-of-production sets we wish to compare.¹⁰ We compare the value of $\text{Correl}^{\Delta P^{\text{inter}}}$ between the following pairs of country-of-production sets: (i) US exported products and Canada-ROW exported products, (ii) US exported products and products domestically produced in each country, and (iii) US-Canada-ROW exported products and products domestically produced in each country.

Our findings are as follows. First, exported products have a higher international correlation of price movements relative to domestically produced products (10.7% on average over the 25 comparable product categories). Second, US exported products have a higher international correlation of price movements relative to Canada-ROW exported products (6% on average over the 14 comparable product categories).¹¹ 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.

3.4. Findings: Aggregate real exchange rates

Figure 3 depicts the cumulative movement of aggregate RERs, constructed as weighted averages of changes in international product-level RERs across many products. We separately display the aggregate RER for the following country-of-production sets: all exported products, US exported products, Canada-ROW exported products, and domestically produced products. We do not separately consider Canada and ROW exported products due to lack of sufficient data (i.e.: we require a large number of products to smooth out the idiosyncratic movements in prices). We focus on the pricing regions in British Columbia and Northern California.

Over our sample period, relative unit labor costs increased in Canada by roughly 15%. Over this period, aggregate RERs also appreciated substantially for all our sets of products. For example, for US exported products, the aggregate RER rose by 12%, or 81%

¹⁰For example, when comparing the statistics between matched exported goods and matched products domestically produced, we only include those product categories for which these two location of production sets account for at least 5% of total expenditures.

¹¹Our 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 US exporters is lower than pricing-to-market by exporters from other major industrialized countries.

of the appreciation of the Canadian unit labor cost relative to the US. Note that aggregate RERs average-out the idiosyncratic changes in product-level RERs, and capture the common component of movements in international relative prices.

Observe that US exported products display larger movements in aggregate RERs than other exporters or domestically produced products. However, these comparisons are hard to interpret given that US exported products, other exported products, and domestically produced products are unevenly distributed across the different product categories. Unfortunately, we do not have sufficient data to accurately compare the magnitude of movements in aggregate RERs across these sets of producers.

3.5. Findings: Relation between product-level and aggregate real-exchange rate movements

We now 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 (as we show later, our model has a clear prediction regarding this relation). We group individual products by their product categories, as defined by the retailer. This has the advantage that products within a category share similar characteristics.

We first identify product categories with a minimum expenditure share and a minimum number of observations accounted for by exported products (in order to minimize small sample uncertainty for product categories with very few 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 relative to the change in the relative unit labor cost for the quarters with available information, denoted by ΔQ_j .

Figure 4 displays a scatter plot of $\text{Correl}_j^{\Delta P^{\text{inter}}}$ and ΔQ_j across our 21 product categories with available information. We can observe a negative relation between these two statistics. Indeed, regressing ΔQ_j on a constant and $\text{Correl}_j^{\Delta P^{\text{inter}}}$ yields a regression coefficient equal to -2.4 with a t-statistic of -2.6 (and hence significant at the 5% significance level). Our data therefore suggests 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 few number of product categories with available information.

3.6. Sensitivity analysis on movements in product-level RERs

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 in two ways: (i) we only consider matched products with identical UPCs (Panel A), and (ii) we consider ‘liberal matches’ by loosening the conditions that define a matched product (Panel B). Specifically, liberal matches include pairs of goods that are produced by the same manufacturer but share less common characteristics than under our benchmark matching procedure. For example, we match all pairs of Gatorade sport drinks even if they do not share a common flavor. Focusing only on products with identical UPCs maximizes the objectiveness of our matching procedure, but substantially reduces the number of matches.¹² Conversely, focusing on liberal matches increase the number of matched products at the expense of increasing the subjectiveness of our procedure. Panels A and B show that our key findings are robust to the matching procedure.

Second, we vary the geographic coverage in the construction of our statistics. Panel C is based on the pricing regions in the *Center-West* geographic area. This includes all 24 pricing regions in Canada, and 51 pricing regions in the US located in California, Oregon, Washington, Idaho, Montana, and Wyoming, chosen to roughly match the geographic coverage in Canada. Table 1, Columns 3 and 4, provides descriptive statistics for our product coverage in this geographic area. Panel D is based on a single pricing region in British Columbia and Seattle to increase the likelihood that goods consumed in these districts with a common country of origin are produced in the same location. Panel E 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 finding that pricing-to-market is more prevalent across countries than within countries is robust to these variations in geographic coverage. Note, however, that consistent with previous work on the role of distance in determining the extent of deviations from relative PPP, regions in the US that are farther apart (e.g. Northern California and Illinois) display higher volatilities of relative price movements.

Third, we construct our measure of product-level RERs net of movements in the category-

¹²Given the small resulting number of matched products, we only report our statistics that combine all of our country-of-production sets.

wide RER. Panel F shows that our findings are roughly unchanged relative to our baseline results, which highlights the important role of individual product-level RER movements as opposed to category-wide price movements driven, for example, by seasonalities. Our findings are also robust to constructing movements in product-level RERs net of movements in nominal wages in each country (see Panel G), as in Engel and Rogers (1996).

We also find that, in those cases where we have enough data to compute aggregate RERs that smooth-out idiosyncratic product-level price movements, the movements of aggregate RERs in response to changes in relative unit labor costs resemble those under our baseline results.

Summary of data findings

Our findings can be summarized as follows. We find that both non-traded and traded goods exhibit large deviation from relative PPP: product-level RERs are four times as volatile as nominal exchange rates. Product-level RERs are two to three times as volatile across countries than within countries. These patterns are primarily accounted for by a relatively low correlation of price changes across countries. Our results also suggest that the international correlation of price changes is systematically higher for US exporters relative to other exporters. We also document large swings in aggregate RERs for traded and non-traded products that track quite closely the movement in Canada-US relative unit labor costs. Finally, our data suggests that exported goods in product categories with low international correlation of price changes also tend to be those that experience large aggregate RER movements in response to a change in relative unit labor costs.

4. Model

In this section we present a tractable model of international trade, multinational production, and intra- and international pricing that we use to rationalize our empirical findings.

4.1. 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 US, Canada, and an aggregate of the rest of the world (ROW), respectively. Countries 1 and 2 each contain two symmetric regions (indexed by $r = A$ and B).

4.2. Preferences

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

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

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

Each variety is potentially supplied by K producers. These are 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} . The assumption of perfect substitutability across products, while extreme, gives an analytically very tractable account of movements in product-level and aggregate RERs.¹³ 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 $y_{nirt} = (P_{knirt}/P_{irt})^{-\eta} y_{irt}$. 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 independently distributed across products and time, but are potentially correlated across regions within the same country.¹⁴ 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 Section 5 we show that our main qualitative results are unchanged if we relax this assumption.

¹³Atkeson and Burstein (2008) study a simple version of this model in which products within each variety are imperfect substitutes. The qualitative pricing patterns are similar to those obtained when products are perfect substitutes.

¹⁴We include idiosyncratic demand shocks, as opposed to variety-wide demand shocks because in our data movements in individual product-level RERs are very large relative to category-wide movements in RERs.

4.3. Technologies

Each variety has K_i potential producers, or firms, 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 country 1 and 2 can serve the other country by either producing domestically and exporting, or by engaging in multinational production (MP) and producing abroad.¹⁵ Exports are subject to iceberg costs $D \geq 1$.¹⁶ Productivity for multinational production is $1/z'$, where $z'/z \geq 1$ is the producer-specific efficiency loss associated to MP. Firms from country 3 can serve countries 1 and 2 only by producing domestically and exporting (subject to an iceberg cost $D^* \geq 1$ that can be different to D). International trade is costless when $D = D^* = 1$. For simplicity, we abstract from frictions in intra-national goods markets by assuming that producers have equal costs of supplying the two regions within each country. In Section 5 we show that our qualitative results are unchanged if we relax this assumption.

We assume that it is technologically impossible 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.¹⁷

We denote by W_i the wage in country i , expressed in terms of a common numeraire. For a country 1 firm with idiosyncratic productivity $1/z$ and $1/z'$ for domestic and foreign production, respectively, the marginal cost of supplying each country is:

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

If $z' > z$, a firm faces a nontrivial choice of supplying country 2: it can export its product subject to iceberg costs, or produce abroad subject to a productivity loss. We assume that

¹⁵Neiman (2008) studies a related model of international pricing and compares the implications on exchange-rate pass-through of multinational production and outsourcing.

¹⁶In our model, international trade costs have identical implications on trade volumes and prices as home bias for national goods built into preferences.

¹⁷One 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.

producers that are indifferent between exporting or engaging in multinational production choose to export.

Similarly, for country 2 firms we have:

$$\text{Marginal cost for country 2 firms} = \begin{cases} W_2 z, & \text{domestic sales in country 2} \\ DW_2 z, & \text{exports to country 1} \\ W_1 z', & \text{foreign prod. and foreign sales to country 1} \end{cases}$$

Finally, the marginal cost for country 3 firms is:

$$\text{Marginal cost for country 3 firms} = D^* W_3 z, \text{ exports to country 1 or 2}$$

Idiosyncratic marginal cost

We denote the idiosyncratic marginal cost in period t for a firm that domestically produces product k , variety n , by z_{knt} . We assume that z_{knt} is the product of a permanent component, \bar{z}_{kn} , and a temporary component, \tilde{z}_{knt} :

$$z_{knt} = \bar{z}_{kn} \tilde{z}_{knt}.$$

Analogously, for foreign production:

$$z'_{knt} = \bar{z}'_{kn} \tilde{z}'_{knt}.$$

In order to gain analytical tractability, we make the following two distributional assumptions. First, following Ramondo and Rodriguez-Clare (2008), the permanent component of marginal cost is determined from the draw of two independent random variables:

$$\bar{u} \sim \exp(1) \text{ and } \bar{u}' \sim \exp(\lambda).$$

The parameter $\lambda \geq 0$ is the inverse of the mean of \bar{u}' . We then define:

$$\bar{z} = (\min\{\bar{u}, \bar{u}'\})^\theta, \text{ and } \bar{z}' = (\bar{u}')^\theta.$$

A higher value of λ reduces the competitiveness of foreign production relative to domestic production as the probability that $\bar{z}' > \bar{z}$ equals $1/(1 + \lambda)$.

Second, we assume that the temporary components of marginal cost, \tilde{z}_{knt} and \tilde{z}'_{knt} , are independently drawn 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 .

Aggregate costs

Our approach is partial equilibrium as we take as given movements in the cost of labor, W_i . In particular, we assume that the logarithm of the wage in each country is drawn every period from a normal variable that is independent over time and countries, with standard deviation σ_w .¹⁸ 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.

We denote by c_{knirt} the marginal cost of supplying product k , variety n , to country i , region r , in period t , conditional on the optimal choice on exporting or engaging in MP. It is the product of the idiosyncratic marginal cost, the wage, and international trade costs in the case the product is exported.

4.4. 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 and Bertrand competition.

Perfect Competition

Under perfect competition, the price of active producers is equal to their marginal cost. Therefore, within each region, the active producer 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. The price of variety n in country i , region r , is:

$$P_{nirt} = c_{nirt}^{1st}. \quad (4.1)$$

Bertrand Competition

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

$$P_{nirt} = \min \left\{ \frac{\eta}{\eta - 1} c_{nirt}^{1st}, \frac{a_{nirt}^{1st} c_{nirt}^{2nd}}{a_{nirt}^{2nd}} \right\}. \quad (4.2)$$

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.

¹⁸Given that our model assumes that prices are flexible and abstracts from other sources of endogenous dynamics, the assumption that wages are iid is without loss of generality.

4.5. Matched products

Guided by our data analysis in Section 2, 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. We divide matched products into four mutually exclusive country-of-production sets: (i) those that are supplied in all four regions by the same producer located in country 1 (and are exported to country 2) in period t , N_{x1t} , (ii) those that are supplied in all regions by the same producer located in country 2 (and are exported to country 1) in period t , N_{x2t} , (iii) those that are supplied in all regions by the same producer located in country 3 (and are exported to both countries 1 and 2) in period t , N_{x3t} , and (iv) those that are supplied by the same domestic producer in each region in period t , N_{dt} . The set of products N_{dt} includes producers from country 1 that serve country 2 via MP, and producers from country 2 that sell in country 1 via MP. Note that many varieties are not matched, but instead are produced by different producers in at least two regions.

For each set of matched products, we construct the following statistics based on price changes: the variance of price changes, $\text{Var}^{\Delta P}$, the correlation of price changes across regions within and across countries, Correl^{intra} and Correl^{inter} , and the change in aggregate RERs, ΔQ_t . With time variation in cost and demand shocks, the sets of matched products can vary over time. In constructing our price statistics, we only include price changes for products that belong to the same set of matched products in both time periods.

5. Analytic Results

In this section, we consider a version of the model with small time-variation of cost, demand, and wage shocks relative to permanent differences in productivity across products. This will imply that there is no switching in the identity of active producers and latent competitors over time, allowing us to derive simple expressions for our price statistics in terms of the underlying parameters. We proceed in two steps. First, we characterize the sets of matched products and the share of matched products that face the same latent competitor in both countries. We then use these sets to explicitly solve for our price statistics. We defer various details to Appendix 2.

5.1. Matched products and latent competitors

Consider the limit of our model economy as σ_z , σ_a , and σ_w go to zero. In this case, $a_{knirt}/(z_{knt}W_{tt})$ and $a_{knirt}/(z'_{knt}W_{it})$ converge in distribution to time-invariant random variables $1/\bar{z}_{kn}$ and $1/\bar{z}'_{kn}$ that are exponentially distributed.¹⁹ Then, a_{knirt}/c_{knt} remains roughly constant over time, and so does the identity of active producers and latent competitors. We characterize, for this limit of our economy, various sets that will be useful when evaluating our price statistics under Bertrand competition.

Measure of exporters

We denote the mass of exporters from country i to country j by m_{ij} . In the absence of cost and demand shocks, a product that is exported from country 1 to country 2 is also active in country 1. This is because, with international trade costs, producers have a higher cost of exports relative to domestic sales. Hence, if an exporter is productive enough to serve the foreign market, than it is certainly the most productive in its local market.²⁰ Therefore, the set of matched products that are exported from country 1 to country 2, N_{x1} , coincides with the set of all exported products from country 1 to country 2, and m_{12} is equal to the mass of the set N_{x1} . Using the same logic, the mass of exporters from country 2 to country 1, m_{21} , is equal to the mass of the set of matched products exported by country 2, N_{x2} .²¹

In Appendix 2 we provide simple expressions for m_{12} , m_{21} , m_{31} , m_{32} , and for the measure of the sets N_{x3} and N_{dt} , exploiting the convenient properties of exponentially distributed random variables. The measures of exported products coincide with the expenditure shares of exported products in the importing country (see Bernard, Eaton, Jensen, and Kortum 2003 for a proof of this statement that also applies in our model).

Latent competitors

We denote by s_{ij}^l the mass of exporters from country $i \in \{1, 2, 3\}$ facing a latent competitor from country $l \in \{1, 2, 3\}$ when selling in country $j \in \{1, 2\}$. The mass of exporters from country i to country j satisfies $m_{ij} = \sum_{l=1}^3 s_{ij}^l$.

¹⁹As σ_z , σ_a and σ_w limit to zero, $a_{knirt}/(\tilde{z}_{knt}W_{it})$ and $a_{knirt}/(\tilde{z}'_{knt}W_{it})$ both converge in probability to a probability mass at 1. Then, using Slutsky's lemma, $a_{knirt}/(z_{knt}W_{it})$ converges in distribution to $1/\bar{z}_{kn}$, and $a_{knt}/(z'_{kn}W_{it})$ converges in distribution to $1/\bar{z}'_{kn}$.

²⁰In the presence of large demand and cost shocks, this is not necessarily the case. An exporter can face a relatively low demand shock in one of the two regions at home, or a foreign competitor engaging in MP can face a low temporary cost shock when selling at home. In both cases, an exporter might not sell domestically.

²¹Note that goods exported by country 3 to country 1 are not necessarily exported to country 2 (and viceversa). Hence, the mass of the set of matched products that are exported from country 3 is weakly lower than m_{31} and m_{32} .

A fraction r_i of the exporters from country i face the same latent competitor when selling in countries 1 and 2. We denote by s_i^l the mass of exporters from country i facing the same latent competitor from country l when selling in countries 1 and 2, and $r_i = \frac{1}{m_{ij}} \sum_{l=1}^3 s_i^l$.

Note that exporters from country $i = 1, 2$ facing a latent competitor from their own country i when selling in country j , will face the same latent competitor when selling domestically. This is because, if the costs of the first and second lowest cost producers are the lowest abroad, they are also the lowest at home. 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, will face the same foreign latent competitor when selling abroad in country $j = 2, 1$. Therefore, $s_{11}^2 = s_1^2$ and $s_{22}^1 = s_2^1$. Then, r_1 and r_2 can be expressed as:

$$r_1 = (s_{12}^1 + s_{11}^2 + s_1^3) / m_{12} , \text{ and } r_2 = (s_{21}^2 + s_{22}^1 + s_2^3) / m_{21} \quad (5.1)$$

If $D = 1$, producers have the same cost for domestic and export sales. Hence, the set of latent competitors is the same in both countries. This implies that $s_i^l = s_{i1}^l = s_{i2}^l$, and $s_i^3 = s_{i1}^3 = s_{i2}^3$, so $r_i = 1$. Therefore, in the absence of international trade costs, all exporters face the same latent competitor in countries 1 and 2.

In Appendix 2, we derive analytic expressions for s_{ij}^l and s_i^l for $i = 1, 2$ in terms of the model's parameters, using our assumptions on the distributions of \bar{z} and \bar{z}' . We also show that r_1 and r_2 are both decreasing in the level of trade costs D . The higher the trade costs, the less likely it is for exporters to face the same latent competitor in both countries.

5.2. Fluctuations in prices

In the previous section, we characterized the set of exporters, matched products, and the country of production for their latent competitors, when time variation in demand shocks, cost shocks, and wages was assumed to be very small. In particular, for any $\varepsilon > 0$, there is a value for $\bar{\sigma}$ such that if $\sigma_z < \bar{\sigma}$, $\sigma_a < \bar{\sigma}$, and $\sigma_w < \bar{\sigma}$, then the cumulative distribution of a_{knirt}/c_{knt} differs by less than ε from a time-invariant exponential distribution, and the identity of active producers and latent competitors remains constant.

We now characterize the behavior of prices in the presence of positive but small time-varying shocks (i.e.: $0 < \sigma_z < \bar{\sigma}$, $0 < \sigma_a < \bar{\sigma}$, and $0 < \sigma_w < \bar{\sigma}$). We first consider the case of perfect competition and then the case of Bertrand competition.

Perfect Competition: Product-level real exchange rates

Under perfect competition, prices of active products are set equal to the marginal cost of the lowest cost producer.²² Changes in prices are given by:

$$\Delta P_{nirt} = \log(P_{nirt}/P_{nirt-1}) = \Delta \log(c_{nirt}^{1st}).$$

The change in marginal cost is equal to the change in the product of the wage and the temporary component of the firm's idiosyncratic marginal cost. Hence, the variance of price changes in each region and country is:

$$\text{Var}^{\Delta P} = 2(\sigma_z^2 + \sigma_w^2).$$

Exporters are subject to the same shock to marginal cost irrespective of whether the good is sold domestically or abroad. Therefore, for exported products ($n \in N_{x1} \cup N_{x2} \cup N_{x3}$), the percentage change in the relative price between region r in country i and region r' in country j is:

$$\Delta Q_{nijrr't} = \Delta P_{nirt} - \Delta P_{njr't} = \Delta c_{nirt}^{1st} - \Delta c_{njr't}^{1st} = 0. \quad (5.2)$$

Thus, both intra-national and international product-level RERs remain constant over time:

$$\text{Var}^{\text{intra}} = \text{Var}^{\text{inter}} = 0,$$

and price changes are perfectly correlated within and across countries:

$$\text{Correl}^{\Delta P^{\text{intra}}} = \text{Correl}^{\Delta P^{\text{inter}}} = 1.$$

For matched products that are domestically produced in each country ($n \in N_d$), shocks to the temporary component of the firm's idiosyncratic marginal cost and shocks to the wage are equal within countries but can differ across countries. Therefore, $\Delta Q_{niirr't} = 0$ and $\Delta Q_{ni-irr't} \neq 0$, so:

$$\begin{aligned} \text{Var}^{\text{intra}} &= 0, \text{ and } \text{Var}^{\text{inter}} > 0, \\ \text{Correl}^{\Delta P^{\text{intra}}} &= 1, \text{ and } \text{Correl}^{\Delta P^{\text{inter}}} < 1. \end{aligned}$$

²²Consider an alternative version of our model with monopolistic competition in which each variety can only be supplied by one single producer in the world. In this model, prices are set at a constant markup over marginal cost. This model shares the same predictions on fluctuations in international relative prices as our model with perfect competition.

Note that these patterns of intra- and international correlation of price changes for matched domestically produced goods are independent of the size of international trade costs, given fixed choices of production locations.

Perfect Competition: Aggregate real exchange rates

We now consider movements in aggregate RERs to a change in relative labor costs. These are 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, from (5.2), product-level RERs are constant over time. Hence, aggregate RERs are also constant over time, $\Delta Q_t = 0$. Movements in RERs for matched exported products are equal to zero because changes in prices equal changes in marginal costs, and changes in marginal cost are the same whether the product is sold domestically or exported.

In contrast, for matched products that are domestically produced in each country ($n \in N_d$), changes in product-level RERs are equal to the relative change in marginal costs across countries. The change in the aggregate RER is:

$$\begin{aligned} \Delta Q_t &= \int_{N_d} \psi_{n21AA_{t-1}} \Delta Q_{n21AA_t} dn & (5.3) \\ &= \int_{N_d} \psi_{n21AA_{t-1}} (\Delta c_{n2At}^{1st} - \Delta c_{n1At}^{1st}) dn \\ &= \Delta W_{2t} - \Delta W_{1t} , \end{aligned}$$

where $\psi_{n21AA_{t-1}}$ is the average share of product n in total expenditures in countries 1 and 2, region A, over the products in set N_d , and add up to one. In (5.3), we used the assumption that the movements in idiosyncratic marginal costs have mean zero and are independent across regions, products, and time, and hence average-out if we integrate across a continuum of products. Once again, the magnitude in the movement of aggregate RERs is independent of the level of international trade costs.

Bertrand competition: product-level real exchange rates

Under Bertrand competition, prices of active products are given by (4.2). We assume, for simplicity, that the elasticity of demand η is sufficiently close to one so that the monopoly price is very high and the limit price $\frac{a_{nirt}^{1st}}{a_{nirt}^{2nd}} c_{nirt}^{2nd}$ is always binding. Hence, changes in prices

are given by:

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

Given that demand shocks are uncorrelated with cost shocks and across producers, the variance of price changes in each region and country is:

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

The change in the product-level RER for matched products n between region r in country i , and region r' in country j is:

$$\Delta Q_{nijrr't} = \Delta P_{nirt} - \Delta P_{njr't} = \Delta a_{nirt}^{1st} - \Delta a_{njr't}^{1st} - \Delta a_{nirt}^{2nd} + \Delta a_{njr't}^{2nd} + \Delta c_{nirt}^{2nd} - \Delta c_{njr't}^{2nd}. \quad (5.4)$$

Consider movements in product-level RERs across regions within the same country. If σ_z and σ_a are sufficiently small, then active products face the same latent competitor in both regions within the same country, so $\Delta c_{niAt}^{2nd} = \Delta c_{niBt}^{2nd}$. Therefore, intra-national changes in product-level RERs are given by:

$$\Delta Q_{niABt} = \Delta a_{niAt}^{1st} - \Delta a_{niBt}^{1st} - \Delta a_{niAt}^{2nd} + \Delta a_{niBt}^{2nd}.$$

Hence, product-level intra-national RERs move solely due to the presence of product/region specific demand shocks.

The correlation of price changes between regions A and B in country i is:

$$\begin{aligned} \text{Correl}^{\Delta P_{\text{intra}}} &= \text{Correl}(\Delta P_{niAt}, \Delta P_{niBt}) \\ &= \frac{2\rho_a\sigma_a^2 + \sigma_z^2 + \sigma_w^2}{2\sigma_a^2 + \sigma_z^2 + \sigma_w^2}. \end{aligned} \quad (5.5)$$

In the absence of demand shocks ($\sigma_a^2 = 0$), or if demand shocks are perfectly correlated across regions ($\rho_a = 1$), then $\text{Correl}^{\Delta P_{\text{intra}}} = 1$. With demand shocks that are imperfectly correlated across regions within countries, $\text{Correl}^{\Delta P_{\text{intra}}} < 1$.

Consider now movements in product-level RERs across countries. From (5.4), these can move either because demand shocks vary across countries, or because producers face latent competitors with different cost shocks across countries. For producers facing the same latent competitor in both countries, $\Delta c_{n1At}^{2nd} = \Delta c_{n2At}^{2nd}$, and changes in product-level RERs are solely driven by demand shocks. For producers facing a different latent competitor in each country (which are subject to different cost shocks), $\Delta c_{n1At}^{2nd} \neq \Delta c_{n2At}^{2nd}$, and changes in product-level RERs are driven both by demand and cost shocks.

Using this logic, the correlation of price changes between region A in country 1 and region A in country 2 for matched products within a set N_{xi} is:

$$\begin{aligned}\text{Correl}_i^{\Delta P^{\text{inter}}} &= \text{Correl}(\Delta P_{n1Bt}, \Delta P_{n2At}) \\ &= \frac{\sigma_z^2 + \sigma_w^2}{2\sigma_a^2 + \sigma_z^2 + \sigma_w^2} r_i.\end{aligned}\tag{5.6}$$

This expression can be understood as follows. Suppose first that prices are only driven by cost shocks ($\sigma_a = 0$). Then, price movements are perfectly correlated across countries for exporters facing the same latent producer in both countries (because the latent competitor is hit by the same cost shock in both countries), and price movements are uncorrelated across countries for exporters facing a different latent competitor in each country (because the cost shocks to each latent competitor are uncorrelated). Hence, $\text{Correl}_i^{\Delta P^{\text{inter}}}$ is a weighted average of 0 and 1, with a weight of r_i assigned to the latter. Suppose now that price movements are solely driven by demand shocks. Given that these shocks are uncorrelated across countries, then $\text{Correl}_i^{\Delta P^{\text{inter}}} = 0$. Finally, introducing cost shocks that are more likely to be carried over across countries than demand shocks, we get that $\text{Correl}_i^{\Delta P^{\text{inter}}}$ is increasing in the importance of cost shocks in the variance of price changes, $\frac{\sigma_z^2 + \sigma_w^2}{2\sigma_a^2 + \sigma_z^2 + \sigma_w^2}$.

There is a direct mapping between the inter- and intra-national correlation of price changes, and the ratio of inter-to-intra-national variances of product-level RERs (see expression 3.5):

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

A high inter/intra-national ratio of RER variances 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.

Bertrand competition: Aggregate real exchange rates

Consider now the response of aggregate RERs to a change in relative wages across countries. For matched exported products from country i , we have

$$\begin{aligned}\Delta Q_{it} &= \int_{N_{xi}} \psi_{n21AA_{t-1}} \Delta Q_{n21AA_{t-1}} dn \\ &= \int_{N_{xi}} \psi_{n21AA_{t-1}} (\Delta c_{n2At}^{2nd} - \Delta c_{n1At}^{2nd}) dn \\ &= \frac{1}{m_{i,-i}} [(s_{i2}^1 - s_{i1}^1) \Delta W_{1t} + (s_{i2}^2 - s_{i1}^2) \Delta W_{2t} + (s_{i2}^3 - s_{i1}^3) \Delta W_{3t}] ,\end{aligned}\tag{5.8}$$

where s_{ij}^l and $m_{i,-i}$ were derived in Section 5.1. The second line uses (5.4) together with the assumption that demand shocks have mean zero for each product and hence average-out. The third line uses the assumption that movements in idiosyncratic marginal costs have mean zero for each product, and that with Bertrand limit-pricing the average price change in response to a change in country l 's wage is proportional to the fraction of exporters facing a latent competitor producing in country l , which equals $s_{ij}^l/m_{i,i}$. Using $m_{ij} = \sum_{l=1}^3 s_{ij}^l$ and (5.1), we can express ΔQ_{it} as:

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

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 face a country 3 latent competitor ($s_{i1}^3 \simeq 0$) and the change in the aggregate RER is:

$$\Delta Q_{it} = (1 - r_i) \Delta (W_{2t}/W_{1t}) \quad (5.9)$$

This expression indicates that aggregate RERs are more responsive to movements in relative wages the lower is the fraction of exporters facing the same latent competitor in both countries (i.e.: low r_i). A low r_i indicates that exporters are likely to compete with local producers in each country. Hence, prices are more responsive to the local wage in the destination country. With costless international trade ($D = 1$), we have $r_i = 1$ 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 $s_{i1}^3 > 0$. Suppose that the wage 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:

$$\Delta Q_{it} = \left(1 - r_i + \frac{s_i^3 - s_{i1}^3}{m_{i,-i}} \right) \Delta (W_{2t}/W_{1t}) \quad (5.10)$$

Note that, with $(s_i^3 - s_{i1}^3)/m_{i,-i} \leq 0$, the movement in the aggregate RER is smaller than that in (5.9). To understand this, recall that $(s_{i1}^3 - s_i^3)$ 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 suggests that this term is relatively small.

5.3. Discussion

In the preceding sub-sections, we derived the implications of our model on price movements under two alternative assumptions: perfect competition (or constant markups), and Bertrand competition with limit pricing. In this sub-section, we assess the ability of the models to account 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 are more volatile across countries than within countries, implying large deviations from relative PPP. These patterns hold both for matched products that are exported, and for matched products that are domestically produced in each country. The perfect competition 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, it is in sharp contrast with the data in predicting that product-level RERs should be constant across regions in different countries for traded products. On the other hand, the Bertrand model with time variation in costs and demand is consistent with the data in predicting that product-level RERs for traded goods should move both within and across countries. Furthermore, it predicts that international movements of RERs should be larger than intra-national movements of RERs if idiosyncratic shocks (cost and demand) 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.²³

Our data also shows large swings in aggregate RERs for matched products in response to movements in relative costs across countries. This pattern holds for matched products that are actually traded, as well as for matched products that are domestically produced in each country. The perfect competition model is consistent with the data in predicting that aggregate RERs should move for matched domestically produced products. However, it is inconsistent with the data in predicting that aggregate RERs should remain constant

²³Our model with $D > 1$, both under Perfect and Bertrand competition, is also consistent with the findings in Gopinath, Gourinchas, and Hsieh (2008) in predicting that international dispersion in price levels is higher than intranational 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.

for matched traded products. On the other hand, the Bertrand model is consistent with the data in predicting that aggregate RERs should move with changes in relative costs across countries for matched traded products, as long as exporters compete with local latent producers in each country.

The Bertrand model also predicts a negative relation between the international correlation of price changes, $\text{Correl}^{\Delta P^{\text{inter}}}$, and the magnitude of movements in aggregate RERs, ΔQ . Everything else equal, the smaller the fraction of exporters facing the same latent competitor in both countries (i.e.: low r), the lower is $\text{Correl}^{\Delta P^{\text{inter}}}$ and the higher is ΔQ . This negative relation is supported by our data in Section 3 when we compare $\text{Correl}^{\Delta P^{\text{inter}}}$ and ΔQ across various product categories.²⁴

Alternative models in which international market segmentation plays a minor role in pricing and prices move only in response to region-specific demand shocks can also reconcile the patterns of intra- and international correlations of price changes if these shocks are more correlated within than across countries. However, such models do not generate large movements of aggregate RERs for traded goods in response to movements in relative labor costs, and they do not have sharp predictions on the relation between $\text{Correl}^{\Delta P^{\text{inter}}}$ and ΔQ . Models that feature shocks to wholesale distribution costs that are region- and product-specific can also partly account for our price observations. However, if wholesale distribution costs account for a modest share of wholesale prices (16% for US nondurable goods as reported in Burstein, Neves, and Rebelo 2003), these shocks would have to be extremely large to account for the large volatility of relative prices documented in Section 3. Finally, models with sticky prices in local currency can generate large movements in aggregate RERs in response to changes in unit labor costs. However, prices in our data change quite frequently and by large magnitudes.²⁵

We now discuss the role of the international border, parameterized by D , in shaping our

²⁴An alternative way of gauging the performance 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 the role of the border has the advantage that it circumvents this difficult measurement problem.

²⁵Kehoe and Midrigan (2007) and Gopinath and Itskhoki (2008) investigate whether sticky price models can account for the variation across product categories in the extent of RER movements, exchange-rate pass-through, and frequency of price adjustment.

pricing results. In our model, higher international trade costs reduce the volume of international trade, and the fraction of exporters facing the same latent competitor in both countries. Therefore, everything else 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 of aggregate RERs for matched traded products in response to a change in relative costs across countries.

Are differences in the volatility of intra- and international product-level RERs sufficient to gauge the role of international trade costs? No. A high ratio $\text{Var}^{\text{inter}}/\text{Var}^{\text{intra}}$ can result either from high international trade costs, or from cost and demand shocks that are more correlated within countries than across countries.²⁶

Our predictions hold more generally. Recall that 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. Suppose instead that (i) the cross-country correlation of product-level demand shocks is $\rho_a^{\text{inter}} > 0$, and that (ii) producers face different marginal costs of supplying each region and are subject to intra-national trade costs of shipping goods across regions within countries, so that a fraction r_i^{intra} of producers face the same latent competitor in both regions within the same country (in our baseline model with small time varying shocks, $r_i^{\text{intra}} = 1$). In this extended model, the ratio of inter-to-intra-national variances of product-level RERs is:

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

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

Finally, our analysis also suggests that data on product-level and aggregate RER fluctuations for matched products that are domestically produced in each country are not very informative to gauge the extent of pricing-to-market and international trade costs. This is

²⁶These implications of our model are closely related to Gorodnichenko and Tesar (2008). They show that differences in inter-and-intranational RER movements can result from country differences in intranational RER movements. We extend this result and show that, even with symmetric countries, international RER movements can exceed intranational RER movements if product-level shocks are more correlated within than across countries.

because, in order to account for this data, we cannot discriminate between our model with variable markups, and a model with perfect competition 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.

6. Quantitative Results

In this section we ask whether our model, when parameterized to match key observations on the volume of trade and intra-national movements of prices in US and Canada, can account quantitatively for the observations on product-level and aggregate real exchange rates presented in Section 3. Motivated by our analytic results that the model with perfect competition is unable to replicate many basic features of our pricing data, we only report our findings under Bertrand competition.

Model parameterization

We refer to countries 1, 2, and 3 as the US, Canada, and ROW, respectively. The parameters of our model include the elasticity of substitution across varieties, η , 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 , the international trade cost between countries 1 and 2, D , and between these two countries and country 3, D^* , the average productivity loss in multinational production, determined by λ , the volatility of temporary demand and cost shocks, σ_a and σ_z , the intra-national correlation of demand shocks across regions within country, ρ_a , and the movement of wages in each country.

Based on our analysis in Section 4, these parameters can be broadly divided into two groups. First, θ , K_1, K_2, K_3 , D , D^* , and λ determine the shares of international trade and multinational production in each country, through the expressions presented in Appendix 2. The parameter θ affect these shares only through D^θ and $(D^*)^\theta$, and K_3 affect those shares only through $K_3/(D^*)^\theta$. These parameters also determine the measures of latent competitors in each country. Second, the parameters η , σ_z , σ_a , ρ_a , and the movement of wages in each country determine how prices change over time. Recall that in deriving these analytical results, we assumed that θ is large relative to σ_z , σ_a , and wage movements, in order to abstract from switching in the identity of active producers and latent competitors. We also assumed that η is close to one so that the monopoly price is not binding.

Table 4 summarizes the parameter values and targets of our baseline parameterization. We choose K_2 , $K_3/(D^*)^\theta$, $(D)^\theta$, and λ to match the following four observations: (i) the US expenditure share of imports from Canada is 2%, (ii) the Canadian expenditure share of imports from the US is 25%, (iii) the average expenditure share in the US and Canada of imports from the rest of the world is 10%,²⁷ 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 chemical products, food products, beverages, and tobacco reported by Source OECD.²⁸ These values are quite close to the import shares for our sample of products 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 also experimented with higher and lower values of K_1 . Conditional on matching our targets, our results remain roughly unchanged.²⁹ We set $\theta = 0.3$, which is at the high range of values considered in Eaton and Kortum (2002). Recall that θ determines the switching of producers and latent competitors when time varying-shocks are large. For robustness, we also report our findings when $\theta = 0.2$ and $\theta = 0.45$.

We assume that one period in our model corresponds to one 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 US exporters in our baseline statistics. In particular, we target $\text{Var}^{\Delta P} = 0.08^2$ and $\text{Correl}^{\Delta P_{\text{intra}}} = 0.82$, which are roughly equal to the average values in Canada and the US. In our baseline calibration, we assume that demand shocks are uncorrelated across regions ($\rho_a = 0$). We also report our findings when ρ_a is chosen to target the international correlation of price movements for US exporters observed in our data, $\text{Correl}^{\Delta P_{\text{inter}}} = 0.08$, conditional on matching the other targets. Our baseline calibration assumes $\eta = 1.01$, as in our analytical approximation. In spite of the low value of η , the model implies an average average markup of 30%.³⁰ For robustness, we also report our findings when $\eta = 2$.

²⁷In order to separately match the import share from the ROW in US and Canada, we would need to include in our model a different trade cost for US and Canada with the ROW.

²⁸Note that, with balanced trade in each country, import shares in gross output equal to import shares in absorption.

²⁹We need to assume $K_1 \geq 14$ in order to be able to match our targets with $K_2 \geq 2$.

³⁰The model also implies that exporters have a higher markup than non-exporters. Given that value-added per worker is proportional to the markup, the model is consistent with the productivity premium of

We simulate 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 Canadian/US relative unit labor cost in the period 2004-2006. This aggregate experiment resembles the recent global depreciation of the US dollar. To check the accuracy of our analytical approximation, we also report our findings when time-varying shocks are very small i.e. $\text{Var}^{\Delta P} \simeq 0$ and $\Delta W_2 = \Delta W_3 \simeq 0$.

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 statistic that was targeted in our calibration procedure is the intra-national correlation of price changes, $\text{Correl}^{\Delta P_{\text{intra}}}$, for US exporters (equal to 0.82). The three main quantitative findings are as follows.

First, the model implies an international correlation of price changes, $\text{Correl}^{\Delta P_{\text{inter}}}$, for US exporters (0.29) that is significantly lower than $\text{Correl}^{\Delta P_{\text{intra}}}$. This is due to the presence of international trade costs that segment the extent to which producers face the same latent competitor in different countries. The ratio of inter-to-intra-national standard deviation of product-level RERs is roughly 2.³¹

Note that the model's implied $\text{Correl}^{\Delta P_{\text{inter}}}$ for US exporters is larger than the one observed in our data (0.08). In order to lower $\text{Correl}^{\Delta P_{\text{inter}}}$, we can raise the correlation of demand shocks within countries, ρ_a , and increases the size of demand shocks relative to cost shocks. The results under this alternative parameterization are reported in Column 2, Table 5. Note that the ratio of inter-to-intra-national standard deviations of RERs increases to 2.3 as we raise ρ_a . This illustrates our finding that this ratio is not only determined by the size of international trade costs, but also by the extent to which demand shocks are more correlated within than across countries. Note also that the size of the movements of aggregate RERs remain roughly unchanged.

Second, the model also generates differences between $\text{Correl}^{\Delta P_{\text{inter}}}$ and $\text{Correl}^{\Delta P_{\text{intra}}}$ (and hence also high ratios of inter/intra-national volatilities of product-level RERs) for matched products exported by Canadian and ROW producers, and also for matched products that are domestically produced in each country. In fact, consistent with our data, $\text{Correl}^{\Delta P_{\text{inter}}}$ is

exporters relative to non-exporters observed in US plant level data (see Bernard, et. al. 2003).

³¹Our idiosyncratic price statistics are roughly unchanged if we set wage movements in our model to zero. This suggests, consistent with our data, that movements in aggregate costs across countries (ie: nominal exchange rates in our data), have a small role in shaping product-level RER fluctuations.

the highest for US exported matched products. This is because US exporters in our model engage in less pricing-to-market than exporters from Canada and ROW. This asymmetry is driven by the relatively high number of US potential producers K_1 , which implies that US producers are more likely to export and, conditional on exporting, are more likely to compete with the same US latent producer in both countries. In contrast, if $K_1 = K_2 = K_3$ and $D = D^*$, the model would imply that $\text{Correl}^{\Delta P_{\text{inter}}}$ is equal for all matched exported products.

Third, the model generates large movements in aggregate RERs for matched products in response to movements in aggregate costs across countries. Figure 5 displays the cumulative changes in relative unit labor costs W_2/W_1 , and the cumulative change in aggregate RERs, ΔQ , for each set of matched products. Panel B in Table 5 reports the ratio of the cumulative change in RER to the cumulative change in relative wages. Recall that this ratio is equal to zero under Perfect competition. We find that the model with Bertrand competition generates large movements in aggregate RERs for all sets of matched products. For US exporters, the ratio of RER movements to relative wage movements is 0.64 (in our data this ratio is roughly 0.8).³² Moreover, non-US exported matched products display larger movements in aggregate RERs than US exported products. This asymmetry is driven by the fact that $K_1 > K_2$ and $K_1 > K_3$, which implies that US exporters are more likely to face the same US latent competitor in both countries.

We conclude that our baseline parameterization can, to a large extent, reproduce the major features of product-level and aggregate RERs documented in Section 3.

Pricing implications: Sensitivity Analysis

We now examine the sensitivity of our results to alternative targets and parameter values. We adjust the remaining parameters to match the unchanged targets. The findings are presented in Table 6. Column 1 reports results under our baseline parameterization with $\rho_a = 0$.

Column 2 reports the results when time-varying shocks are very small. That is, we target $\text{Var}^{\Delta P} \simeq 0$ and $\Delta W_2 = \Delta W_3 \simeq 0$ in our calibration. The results correspond to those using the expressions from our analytical approximation in Section 5.2. For example, $\text{Correl}^{\Delta P_{\text{inter}}} = 0.22$ for US exporters is the product of $r_1 = 0.28$ (i.e. the fraction of US exporters facing the same latent competitor in both countries), and $(\sigma_z^2 + \sigma_w^2) / (2\sigma_a^2 + \sigma_z^2 + \sigma_w^2) =$

³²If we introduced local distribution costs at the wholesale level, this ratio would increase and be closer to the level observed in our data. These results are available upon request.

0.82 (i.e. the importance of cost shocks in price movements). On the other hand, for Canadian exporters we have $r_2 = 0.18$, leading to $\text{Correl}^{\Delta P_{\text{inter}}} = 0.15$.

Relative to our baseline with large shocks, this alternative parameterization generates a slightly lower $\text{Correl}^{\Delta P_{\text{inter}}}$ (0.22 versus 0.29, for US exporters) and larger movements in aggregate RER for matched products (0.71 vs. 0.64, for US exporters). 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 of the latent competitor changes with the wage movements). If they hadn't switched, they would likely have changed their relative price across countries. By eliminating switchers from our price statistics in the face of large time-varying shocks, we are reducing the extent of relative price movements for matched products.

Column 3 reports our results when we target a lower level of $\text{Correl}^{\Delta P_{\text{intra}}}$. We target a correlation equal to 0.6, instead of our baseline level of 0.82. This alternative parameterization requires demand shocks that are more important in overall price movements, hence reducing $\text{Correl}^{\Delta P_{\text{inter}}}$ from 0.29 to 0.21 for US exporters. Note, however, that our aggregate RER statistics remain roughly unchanged.

Column 4 reports our results if we reduce the competitiveness of multinational production 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. Everything else the same, 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 roughly unchanged.

Columns 5 and 6 report our results if we consider a higher and lower dispersion of permanent costs across products, parameterized by θ . The results, while remaining roughly unchanged, illustrate that the accuracy of our analytical approximation deteriorates as we lower θ . To see this, note that the analytical results in column 2 are closer to those in Column 5 than Column 4. This is because a higher level of θ increases the role of permanent differences in costs in 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, $\text{Correl}^{\Delta P^{\text{inter}}}$ increases slightly for US exporters (from 0.29 to 0.35), and remains roughly unchanged for Canadian exporters. Aggregate movements in RERs fall as a fraction of relative wage movements (from 0.64 to 0.53 for US 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 (4.2) and this reduces the extent of variable markups in pricing decisions. Note, however, that movements in product-level and aggregate RERs are still substantial.

7. Conclusions

In this paper, we provided new observations on aggregate and product-level RERs using non-durable goods' price data from a Canada-US retailer, distinguishing between goods that are produced in one country and exported to others, and common goods that are locally produced in each country. Our data reveals large deviations from relative PPP for traded goods and substantial regional pricing-to-market, particularly across countries. We then constructed a model of pricing-to-market and international trade that helps rationalize our data. The international border plays an important role by segmenting competitors across countries, leading to the practice of pricing-to-market by exporters in response to idiosyncratic shocks and changes in relative labor costs.

Our model was designed to gain analytical tractability. In doing so, we abstracted from important industrial organization considerations such as richer demand systems, interactions between retailers and wholesalers, and long-term relations between producers and retailers. Incorporating these elements into our analysis is an important task for future research.³³

Our framework is also suited to study the design of optimal trade- and exchange-rate policy, which partly shape the extent of international border costs and movements in relative unit labor costs. These policies have welfare consequences by inducing relative price changes for common products across countries.

³³See Goldberg and Hellerstein (2008) and Nakamura (2008) for recent models of incomplete pass-through with rich demand systems.

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8. Appendix 1: Data

Constructing time series of prices

For each product, the retailer keeps record 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 is presented to us in the following way. For each product/store/week, we observe total revenues and total profits it generates to the retailer from sales of that product (i.e.: excluding other operation 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.

Each store is assigned to one of the 114 pricing regions in the US, and one of the 24 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 is aggregated to quarterly data by averaging the data over the weeks within the quarter.

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 US (vector 1), (ii) both pricing regions in Canada (vector 2), and (iii) one pricing region in Canada and the other in the US (vector 3). $\text{Var}_i^{\text{intra}}$ is equal to the variance of vector 1 for $i = \text{US}$ and vector 2 for $i = \text{Canada}$. $\text{Var}^{\text{inter}}$ 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 nominal US 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:

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

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 at least one international product-level RER growth rate between these two quarters. The change in the aggregate RER, ΔQ_t , is given by:

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

For accuracy, we require a minimum of 100 growth rates within a quarter. Otherwise, we treat ΔQ_t in that specific quarter as missing.

We construct ΔQ_t separately for each of the 94 product categories. With these measures, we can aggregate RERs, both at the category-wide level (used in Figure 3), and for the union of all product categories using a weighted average of the different RER's of the various product categories (depicted in Figure 2).

Appendix 2: Model's matched products and latent competitors.

Characterizing the sets of matched products

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

$$N_{x1} = \left\{ n \in N \text{ s.t. } D \min \{ \bar{z}_{kn} \}_{k=1}^{K_1} \leq \min \left\{ \{ \bar{z}'_{kn} \}_{k=1}^{K_1} \cup \{ \bar{z}_{kn} \}_{k=K_1+1}^{K_1+K_2} \cup D^* \min \{ \bar{z}_{kn}, \bar{z}'_{kn} \}_{k=K_1+K_2+1}^K \right\} \right\}. \quad (8.1)$$

That is, in order for a variety n to belong to this set, the exporter with the minimum marginal cost, $D \min \{ \bar{z}_{kn} \}_{k=1}^{K_1}$, must have a lower marginal cost than (i) all potential multinationals from country 1, $\{ \bar{z}'_{kn} \}_{k=1}^{K_1}$, (ii) all local producers from country 2, $\{ \bar{z}_{kn} \}_{k=K_1+1}^{K_1+K_2}$, and (iii) all potential exporters from country 3, $D^* \min \{ \bar{z}_{kn} \}_{k=K_1+K_2+1}^K$. Note that if conditions (ii) and (iii) are satisfied, then product n will be also sold domestically.

This set exactly coincides with the mass of exporters from country 1 to country 2, which has a mass equal to m_{12} . Therefore:

$$m_{12} = \text{Prob} \left(D^{1/\theta} \min \{ \bar{u}_{kn} \}_{k=1}^{K_1} \leq \min \left\{ \{ \bar{u}'_{kn} \}_{k=1}^{K_1} \cup \{ \bar{u}_{kn}, \bar{u}'_{kn} \}_{k=K_1+1}^{K_1+K_2} \cup D^{*1/\theta} \min \{ \bar{u}_{kn}, \bar{u}'_{kn} \}_{k=K_1+K_2+1}^K \right\} \right)$$

where we used the assumption that $\bar{z} = (\min \{ \bar{u}, \bar{u}' \})^\theta$. Solving for this integral, we obtain:

$$m_{12} = \begin{cases} \frac{K_1 D^{-1/\theta}}{K_1 (D^{-1/\theta} + \lambda) + K_2 (1 + \lambda) + K_3 D^{*-1/\theta} (1 + \lambda)} & \text{if } D > 1 \\ \frac{K_1 (1 + \lambda) D^{-1/\theta}}{K_1 (D^{-1/\theta} + \lambda) + K_2 (1 + \lambda) + K_3 D^{*-1/\theta} (1 + \lambda)} & \text{if } D = 1 \end{cases}, \quad (8.2)$$

where we used the assumption that \bar{u}_{kn} and \bar{u}'_{kn} are exponentially distributed.^{34,35}

Similarly, the set of matched products that are supplied by the same producer located in

³⁴We use the three following properties of exponential distributions. Suppose $u \sim \exp(\mu)$ and $u' \sim \exp(\lambda)$ are independent, and $d > 0$, then (i) $du \sim \exp(\mu/d)$, (ii) $\min \{x, y\} \sim \exp(\mu + \lambda)$, and (iii) $\text{Prob}(x \leq y) = \mu/(\mu + \lambda)$.

³⁵In the specific case where there are no iceberg costs, $D = 1$, there is no multinational production and the fraction $\lambda/(1 + \lambda)$ of producers with identical cost of exporting and producing abroad choose to export.

country 2 is given by:

$$N_{x2} = \left\{ n \in N \text{ s.t. } D \min \{ \bar{z}_{kn} \}_{k=K_1+1}^{K_1+K_2} \leq \min \left\{ \{ \bar{z}_{kn} \}_{k=1}^{K_1} \cup \{ \bar{z}'_{kn} \}_{k=K_1+1}^{K_1+K_2} \cup D^* \min \{ \bar{z}_{kn} \}_{k=K_1+K_2+1}^K \right\} \right\}, \quad (8.3)$$

and the mass of this set is given by:

$$m_{21} = \begin{cases} \frac{K_2 D^{-1/\theta}}{K_1(1+\lambda) + K_2(D^{-1/\theta} + \lambda) + K_3(1+\lambda)D^{*-1/\theta}} & \text{if } D > 1 \\ \frac{K_2(1+\lambda)D^{-1/\theta}}{K_1(1+\lambda) + K_2(D^{-1/\theta} + \lambda) + K_3(1+\lambda)D^{*-1/\theta}} & \text{if } D = 1. \end{cases} \quad (8.4)$$

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

$$N_{x3} = \left\{ n \in N \text{ s.t. } D^* \min \{ \bar{z}_{kn} \}_{k=K_1+K_2+1}^K \leq \min \left\{ \{ \bar{z}_{kn} \}_{k=1}^{K_1} \cup \{ \bar{z}_{kn} \}_{k=K_1+1}^{K_1+K_2} \right\} \right\}. \quad (8.5)$$

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 domestic marginal cost, $D^* \min \{ \bar{z}_{kn} \}_{k=K_1+K_2+1}^K$ has a lower marginal cost than all potential local producers in country 1 and country 2, $\min \left\{ \{ \bar{z}_{kn} \}_{k=1}^{K_1} \cup \{ \bar{z}_{kn} \}_{k=K_1+1}^{K_1+K_2} \right\}$. The mass of this set is given by:

$$\text{Mass of set } N_{x3} = \frac{K_3(1+\lambda)D^{*-1/\theta}}{K_1(1+\lambda) + K_2(1+\lambda) + K_3(1+\lambda)D^{*-1/\theta}}.$$

Note that products that are exported from country 3 to country 1 are not necessarily exported to country 2 (and viceversa). Even though country 3 producers have the same cost of supplying both countries, country 1 and country 2 producers have different supply costs if $D > 1$. To see this, note that the measures of exporters from country 3 to country 1 and country 2 are, respectively:

$$m_{31} = \frac{K_3(1+\lambda)D^{*-1/\theta}}{K_1(1+\lambda) + K_2(D^{-1/\theta} + \lambda) + K_3(1+\lambda)D^{*-1/\theta}}, \quad (8.6)$$

and

$$m_{32} = \frac{K_3 D^{*-1/\theta}}{K_1(D^{-1/\theta} + \lambda) + K_2(1+\lambda) + K_3(1+\lambda)D^{*-1/\theta}}. \quad (8.7)$$

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:

$$N_{d1} = \left\{ \begin{array}{l} n \in N \text{ s.t.} \\ \min \{ \bar{z}_{kn} \}_{k=1}^{K_1} \leq \min \left\{ \{ D \bar{z}_{kn}, \bar{z}'_{kn} \}_{k=K_1+1}^{K_1+K_2} \cup D^* \min \{ \bar{z}_{kn} \}_{k=K_1+K_2+1}^K \right\} \\ \& \min \{ \bar{z}'_{kn} \}_{k=1}^{K_1} \leq \min \left\{ D \min \{ \bar{z}_{kn} \}_{k=1}^{K_1} \cup \{ \bar{z}_{kn} \}_{k=K_1+1}^{K_1+K_2} \cup D^* \min \{ \bar{z}_{kn} \}_{k=K_1+K_2+1}^K \right\} \\ \& \arg \min \{ \bar{z}_{kn} \}_{k=1}^{K_1} = \arg \min \{ \bar{z}'_{kn} \}_{k=1}^{K_1} \end{array} \right\} \quad (8.8)$$

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) the lowest marginal cost of exporters from country 3, $D^* \min \{\bar{z}_{kn}\}_{k=K_1+K_2+1}^K$. 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), $\min \{\bar{z}_{kn}\}_{k=1}^{K_1}$, (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, $D^* \min \{\bar{z}_{kn}\}_{k=K_1+K_2+1}^K$. Finally, for consistency, the same producer from country 1 sells in both countries, $\arg \min \{\bar{z}_{kn}\}_{k=1}^{K_1} = \arg \min \{\bar{z}'_{kn}\}_{k=1}^{K_1}$.

N_{d2} is defined in a similar way for country 2 producers:

$$N_{d2} = \left\{ \begin{array}{l} n \in N \text{ s.t.} \\ \min \{\bar{z}_{kn}\}_{k=1+K_1}^{K_1+K_2} \leq \min \left\{ \{D\bar{z}_{kn}, \bar{z}'_{kn}\}_{k=1}^{K_1} \cup D^* \min \{\bar{z}_{kn}\}_{k=K_1+K_2+1}^K \right\} \\ \& \min \{\bar{z}'_{kn}\}_{k=1+K_1}^{K_1+K_2} \leq \min \left\{ D \min \{\bar{z}_{kn}\}_{k=1+K_1}^{K_1+K_2} \cup \{\bar{z}_{kn}\}_{k=1}^{K_1} \cup D^* \min \{\bar{z}_{kn}\}_{k=K_1+K_2+1}^K \right\} \\ \& \arg \min \{\bar{z}_{kn}\}_{k=1+K_1}^{K_1+K_2} = \arg \min \{\bar{z}'_{kn}\}_{k=1+K_1}^{K_1+K_2} \end{array} \right\} \quad (8.9)$$

We do not provide a simple analytical expression for the mass of these sets.

Characterizing measures of latent competitors

We now derive the measures of exporters from country 1 facing the same latent competitor in both countries, based on our definitions in Section 5. 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:

$$s_{12}^1 = s_1^1 = Pr \left(D \min \{\bar{z}_{kn}\}_{k=1}^{K_1} \leq \min \left\{ \{\bar{z}'_{kn}\}_{k=1}^{K_1} \cup \{\bar{z}_{kn}\}_{k=K_1+1}^{K_1+K_2} \cup D^* \min \{\bar{z}_{kn}\}_{k=K_1+K_2+1}^K \right\} \right)$$

This is mass of the set of 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.

Similarly, the mass of country 1 exporters facing a latent competitor from country 2 when selling in country 1, s_{12}^1 , is:

$$s_{11}^2 = s_1^2 = Pr \left(\begin{array}{l} D \min \{\bar{z}_{kn}\}_{k=1}^{K_1} \leq \min \left\{ \{\bar{z}'_{kn}\}_{k=1}^{K_1} \cup \{\bar{z}_{kn}\}_{k=K_1+1}^{K_1+K_2} \cup D^* \min \{\bar{z}_{kn}\}_{k=K_1+K_2+1}^K \right\} \\ \& \min \{D\bar{z}_{kn}\}_{k=K_1+1}^{K_1+K_2} \leq \min \left\{ \min_2 \{\bar{z}_{kn}\}_{k=1}^{K_1} \cup \{\bar{z}'_{kn}\}_{k=K_1+1}^{K_1+K_2} \cup D^* \min \{\bar{z}_{kn}\}_{k=K_1+K_2+1}^K \right\} \end{array} \right)$$

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

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

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

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

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

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

Note that $s_1^3 \leq s_{11}^3$ and $s_1^3 \leq s_{12}^3$.

We now derive closed form solution for these expressions. We introduce the following notation:

$$\begin{aligned} d &= D^{1/\theta} \\ k_3 &= (1 + \lambda) K_3 / (D^*)^{1/\theta} \\ \bar{u} &\sim \exp(1) \\ \bar{u}_1 &= \min \{\bar{u}_k\}_{k=1}^{K_1} ; \quad \bar{u}_2 = \min \{\bar{u}_k\}_{k=K_1+1}^{K_1+K_2} ; \quad \bar{u}_3 = \min \{\bar{u}_k, \bar{u}'_k\}_{k=K_1+K_2+1}^K \\ \bar{u}' &\sim \exp(\lambda) \\ \bar{u}'_1 &= \min \{\bar{u}'_k\}_{k=1}^{K_1} ; \quad \bar{u}'_2 = \min \{\bar{u}'_k\}_{k=K_1+1}^{K_1+K_2} \\ \bar{u}_1^{2nd} &= \min \{\bar{u}_k\}_{k=1}^{K_1} ; \quad \bar{u}_2^{2nd} = \min \{\bar{u}_k\}_{k=K_1+1}^{K_1+K_2} \end{aligned}$$

Define a random variable $\tilde{w} \sim \exp(K_2 + k_3 + \lambda(K_1 + K_2))$. Then,

$$\begin{aligned} s_{12}^3 &= \Pr(d\bar{u}_1 \text{ and } d\bar{u}_1^{2nd} < \min\{\bar{u}'_1, \bar{u}_2, \bar{u}'_2, \bar{u}_3\}) = \Pr\{\bar{u}_1 < \tilde{w}/d, \bar{u}_1^{2nd} < \tilde{w}/d\} \\ &= (K_2 + k_3 + \lambda(K_1 + K_2)) \times \\ &\quad \int_0^\infty \Pr\{\bar{u}_1 < \tilde{w}/d, \bar{u}_1^{2nd} < \tilde{w}/d\} \exp(-\tilde{w}(K_2 + k_3 + \lambda(K_1 + K_2))) d\tilde{w} \\ &= 1 - \frac{(K_2 + k_3 + \lambda(K_1 + K_2))}{K_1/d + K_2 + k_3 + \lambda(K_1 + K_2)} \\ &\quad - \frac{K_1(K_2 + k_3 + \lambda(K_1 + K_2))}{(K_1 - 1)/d + K_2 + k_3 + \lambda(K_1 + K_2)} + \frac{K_1(K_2 + k_3 + \lambda(K_1 + K_2))}{K_1/d + K_2 + k_3 + \lambda(K_1 + K_2)} \end{aligned}$$

Define $\tilde{w} \sim \exp(k_3 + \lambda(K_1 + K_2))$. Then,

$$\begin{aligned}
s_{11}^2 &= \Pr \{ \bar{u}_1 < \bar{u}_2/d, \bar{u}_2 < \tilde{w}/d, \bar{u}_1^{2nd} > d\bar{u}_2 \} \\
&= K_1 K_2 (k_3 + \lambda(K_1 + K_2)) \times \\
&\quad \int_0^\infty \int_0^{\tilde{w}/d} (1 - \exp(-\bar{u}_2/d)) \exp(-\bar{u}_2 d (K_1 - 1) - \bar{u}_2 K_2) dy \exp(-\tilde{w} (k_3 + \lambda(K_1 + K_2))) d\tilde{w} \\
&= K_1 K_2 (k_3 + \lambda(K_1 + K_2)) \times \\
&\quad \left[\frac{1}{((K_1-1)d+K_2)(k_3+\lambda(K_1+K_2))} - \frac{1}{((K_1-1)d+K_2)((K_1-1)+K_2/d+k_3+\lambda(K_1+K_2))} \right. \\
&\quad \left. - \frac{1}{(1/d+(K_1-1)d+K_2)(k_3+\lambda(K_1+K_2))} + \frac{1}{(1/d+(K_1-1)d+K_2)(1/d^2+K_1-1+K_2/d+k_3+\lambda(K_1+K_2))} \right]
\end{aligned}$$

Define the random variable $\tilde{w} \sim \exp(K_2 + \lambda(K_1 + K_2))$. Then,

$$\begin{aligned}
s_1^3 &= \Pr \{ \bar{u}_3 < \tilde{w}, \bar{u}_1 < \bar{u}_3/d, \bar{u}_1^{2nd} > \bar{u}_3 \} \\
&= K_1 (K_2 + \lambda(K_1 + K_2)) k_3 \times \\
&\quad \int_0^\infty \int_0^{\tilde{w}} (1 - \exp(-\bar{u}_3/d)) \exp(-\bar{u}_3 (K_1 - 1)) \exp(-\bar{u}_3 k_3) \exp(-\tilde{w} (K_2 + \lambda(K_1 + K_2))) d\bar{u}_3 d\tilde{w} \\
&= K_1 (K_2 + \lambda(K_1 + K_2)) k_3 \left[-\frac{1}{(K_2+\lambda(K_1+K_2))(1/d+K_1-1+k_3)} + \frac{1}{(K_1-1+k_3)(K_2+\lambda(K_1+K_2)+K_1-1+k_3)} \right. \\
&\quad \left. - \frac{1}{(K_2+\lambda(K_1+K_2))(K_1-1+k_3)} + \frac{1}{(1/d+K_1-1+k_3)(K_2+\lambda(K_1+K_2)+1/d+K_1-1+k_3)} \right]
\end{aligned}$$

Define the random variable $\tilde{w} \sim \exp(K_2 + \lambda(K_1 + K_2))$. Then,

$$\begin{aligned}
s_{12}^3 &= \Pr \{ \bar{u}_3 < \tilde{w}, \bar{u}_1 < \bar{u}_3/d, \bar{u}_1^{2nd} > \bar{u}_3/d \} \\
&= K_1 (K_2 + \lambda(K_1 + K_2)) k_3 \times \\
&\quad \int_0^\infty \int_0^{\tilde{w}} (1 - \exp(-\bar{u}_3/d)) \exp(-\bar{u}_3/d (K_1 - 1)) \exp(-\bar{u}_3 k_3) d\bar{u}_3 \exp(-\tilde{w} (K_2 + \lambda(K_1 + K_2))) d\tilde{w} \\
&= K_1 (K_2 + \lambda(K_1 + K_2)) k_3 \left[\frac{1}{((K_1-1)/d+k_3)((K_2+\lambda(K_1+K_2)))} - \frac{1}{((K_1-1)/d+k_3)(K_2+\lambda(K_1+K_2)+(K_1-1)/d+k_3)} \right. \\
&\quad \left. - \frac{1}{(K_1/d+k_3)(K_2+\lambda(K_1+K_2))} + \frac{1}{(K_1/d+k_3)(K_2+\lambda(K_1+K_2)+K_1/d+k_3)} \right]
\end{aligned}$$

Define the random variable $\tilde{w} \sim \exp(\lambda(K_1 + K_2))$. Then,

$$\begin{aligned}
s_{11}^3 &= \Pr \{ \bar{u}_1 < \bar{u}_2/d, \bar{u}_1 < \bar{u}_3/d, \bar{u}_1 < \tilde{w}/d, \bar{u}_3 < d\bar{u}_2, \bar{u}_3 < \tilde{w}, \bar{u}_1^{2nd} > \bar{u}_3 \} \\
&= \Pr \{ \bar{u}_3 < \bar{u}_2, \bar{u}_3 < \tilde{w}, \bar{u}_1 < \bar{u}_3/d, \bar{u}_1^{2nd} > \bar{u}_3 \} \\
&\quad + \text{Prob} \{ \bar{u}_2 < \bar{u}_3 < d\bar{u}_2, \bar{u}_3 < \tilde{w}, \bar{u}_1 < \bar{u}_2/d, \bar{u}_1^{2nd} > \bar{u}_3 \} \\
&= s_1^3 + \Pr \{ \bar{u}_2 < \bar{u}_3 < d\bar{u}_2, \bar{u}_3 < \tilde{w}, \bar{u}_1 < \bar{u}_2/d, \bar{u}_1^{2nd} > \bar{u}_3 \}
\end{aligned}$$

Therefore,

$$\begin{aligned}
s_{11}^3 - s_1^3 &= \Pr \{ \bar{u}_2 < \bar{u}_3 < d\bar{u}_2, \bar{u}_3 < \tilde{w}, \bar{u}_1 < \bar{u}_2/d, \bar{u}_1^{2nd} > \bar{u}_3 \} \\
&= K_2 k_3 \times \\
&\quad \int_0^\infty \int_{\bar{u}_2}^{d\bar{u}_2} K_1 (1 - \exp(-\bar{u}_2/d)) \exp(-\bar{u}_3(K_1 - 1)) \times \\
&\quad \exp(-\bar{u}_3 \lambda (K_1 + K_2)) \exp(-\bar{u}_3 k_3) \exp(-\bar{u}_2 K_2) d\bar{u}_3 d\bar{u}_2 \\
&= \frac{K_1 K_2 k_3}{\bar{K}} \left[\frac{1}{K_2 + \bar{K}} - \frac{1}{K_2 + d\bar{K}} - \frac{1}{1/d + K_2 + \bar{K}} + \frac{1}{1/d + K_2 + d\bar{K}} \right]
\end{aligned}$$

where $\bar{K} = K_1 - 1 + \lambda(K_1 + K_2) + k_3$.

We can show that s_{12}^1/m_{12} , s_{11}^2/m_{12} , and s_1^3/m_{12} are all decreasing in d . Therefore, r_1 is also decreasing in d . The proof is available upon request.

Figure 1: Price Movements for a US Exported Product in the "Processed Fruit Juices" Category

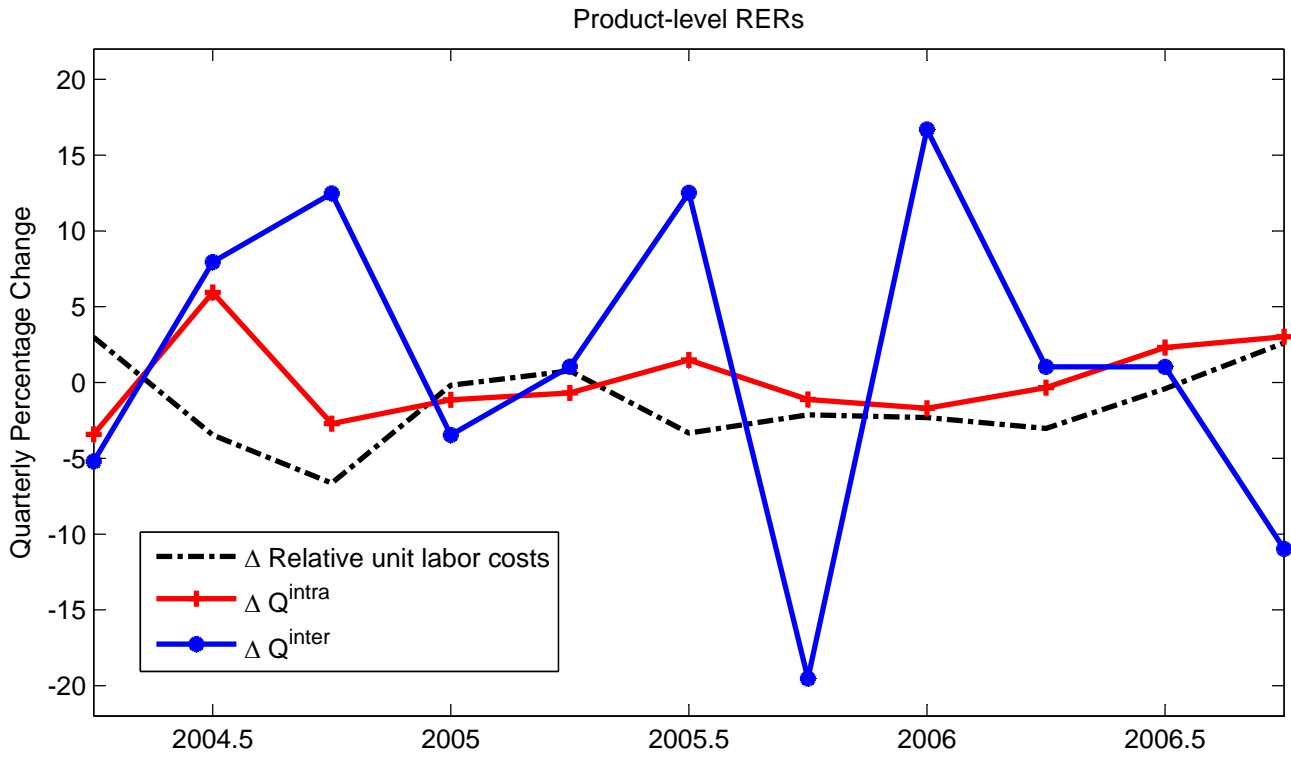
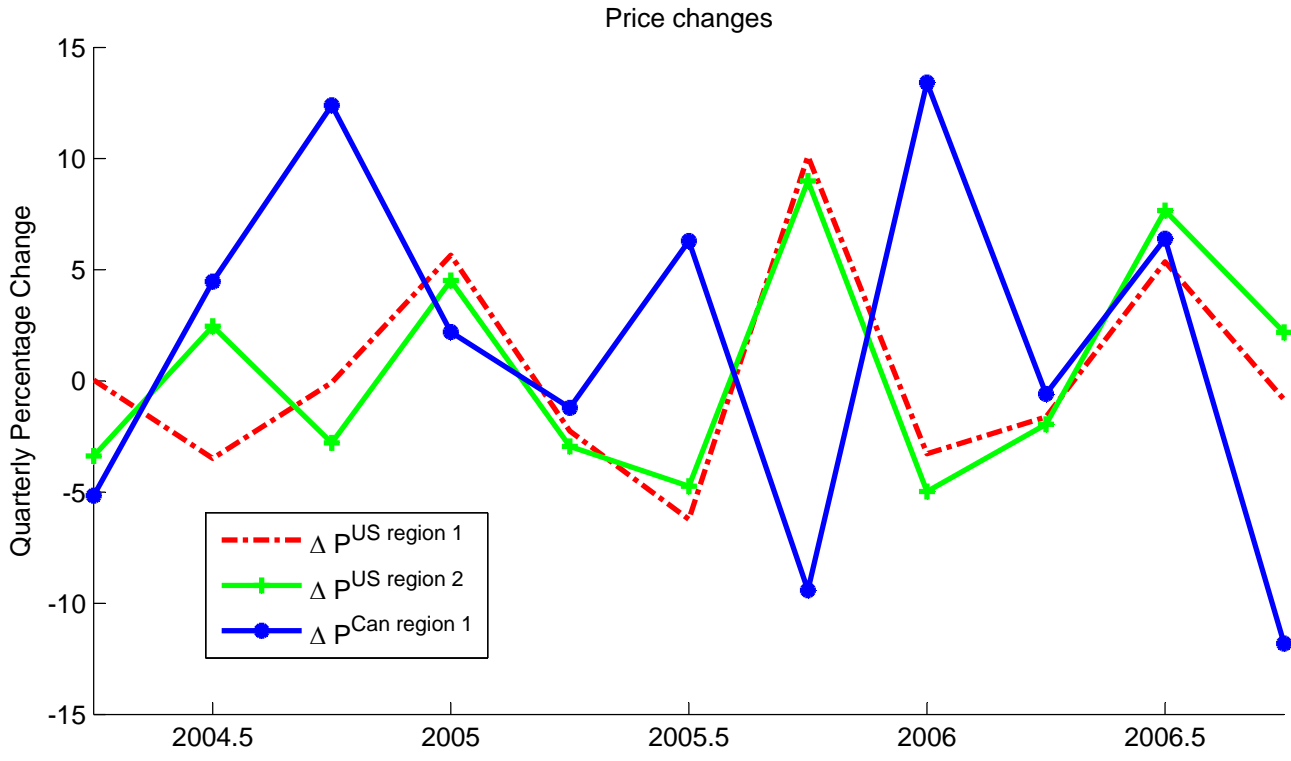


Figure 2: Distribution of Movements of Product-Level Real Exchange Rates

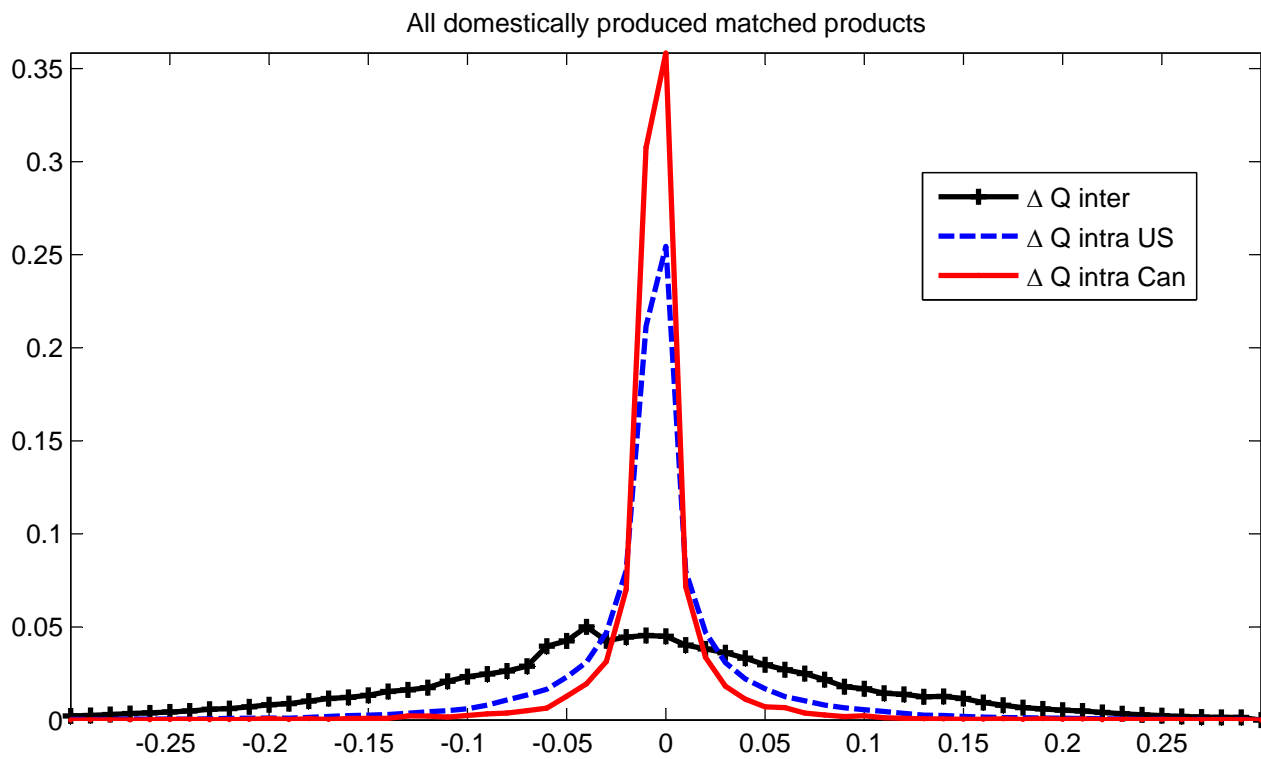
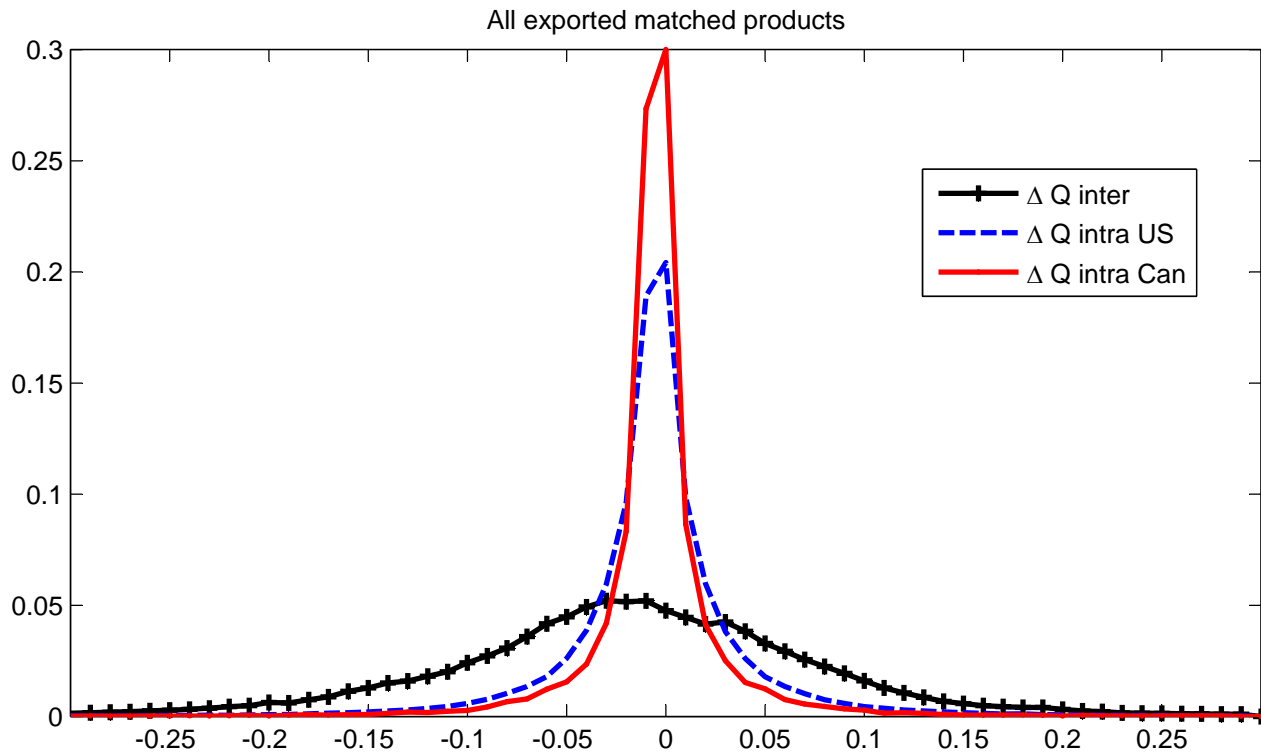


Figure 3: Canada-US Aggregate-Real Exchange Rates

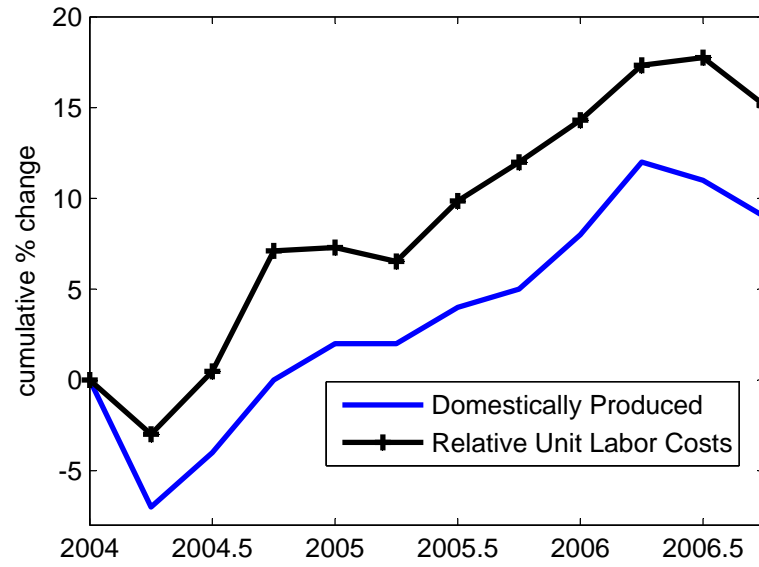
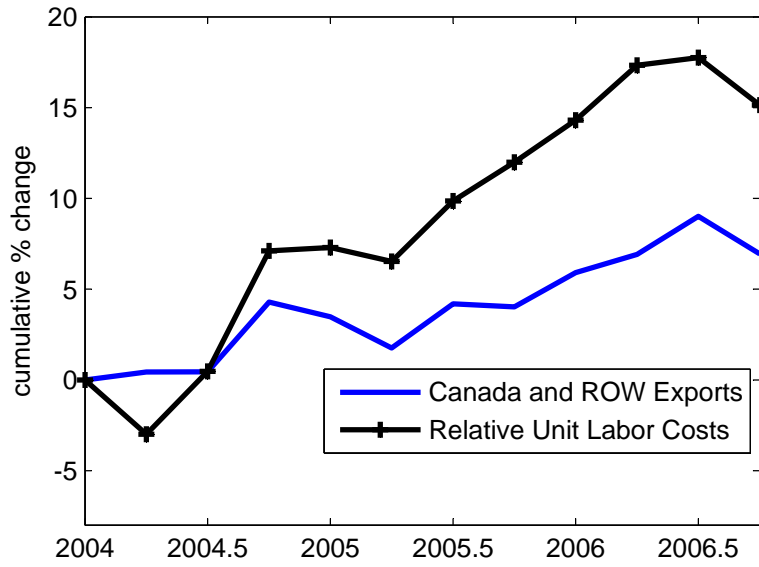
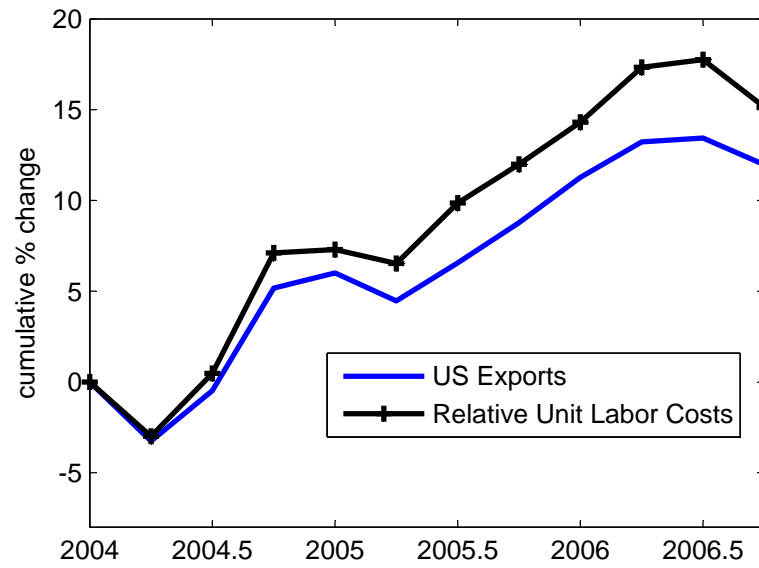
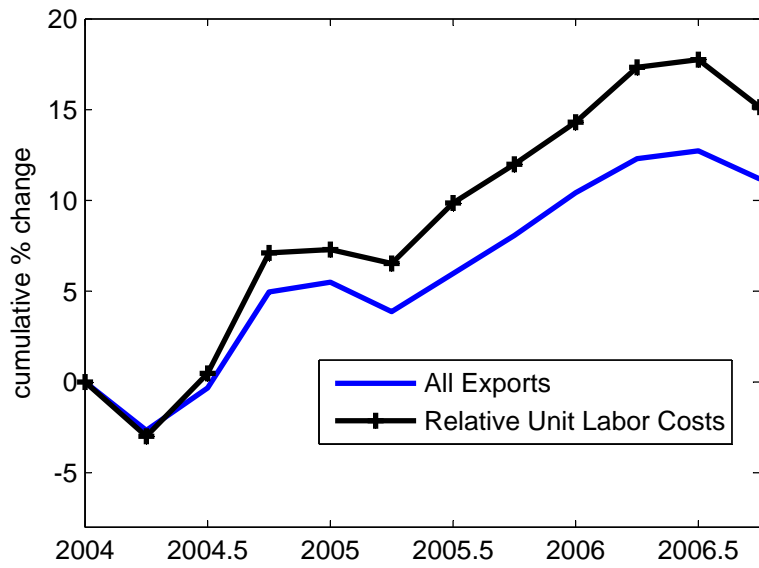
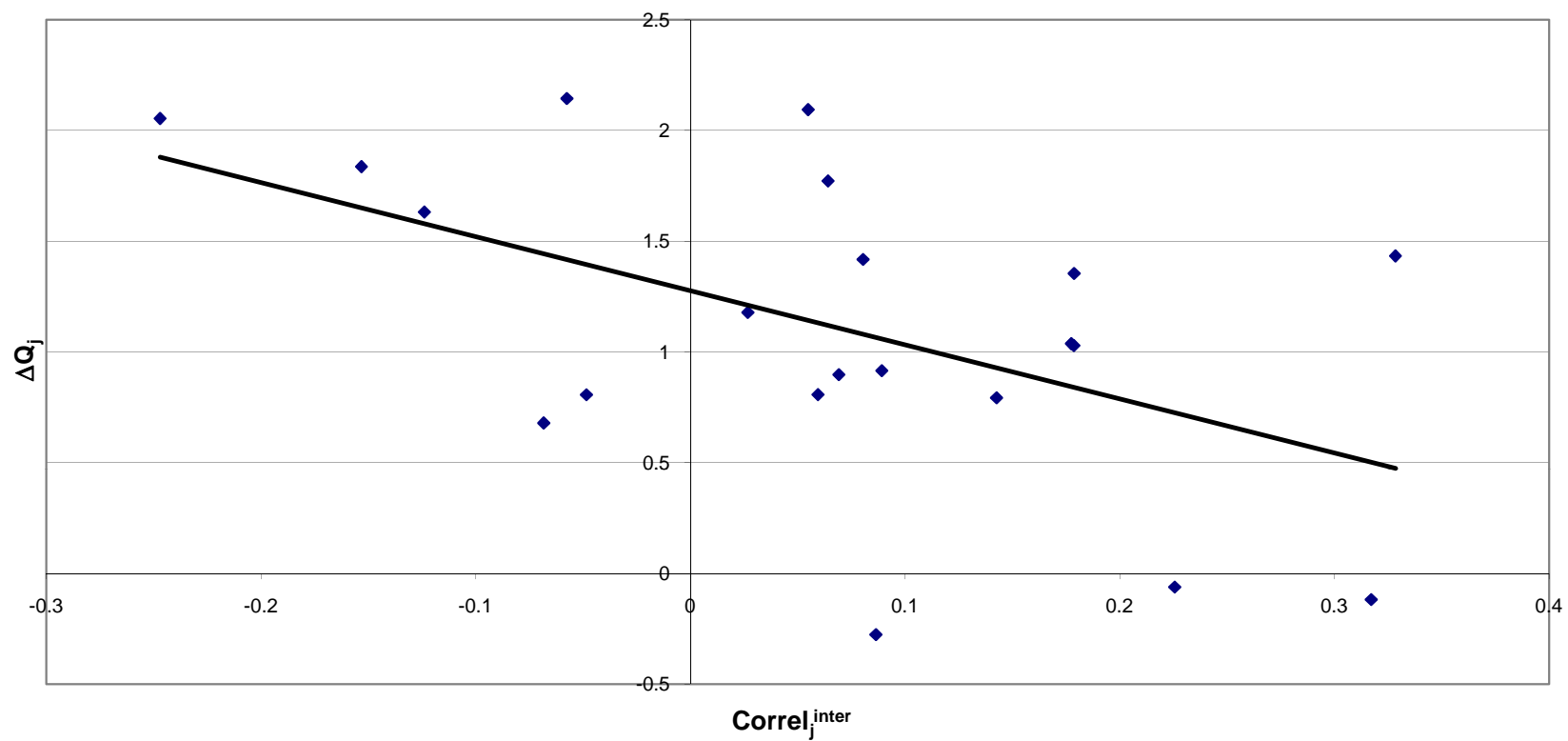


Figure 4: Relation between Product and Aggregate Real Exchange Rates across Product Categories



	<i>Coeff.</i>	<i>Std. Err.</i>	<i>t Stat</i>
Intercept	1.277	0.148	8.625
X Variable	-2.441	0.938	-2.603

Figure 5: Model's Aggregate Real Exchange Rates

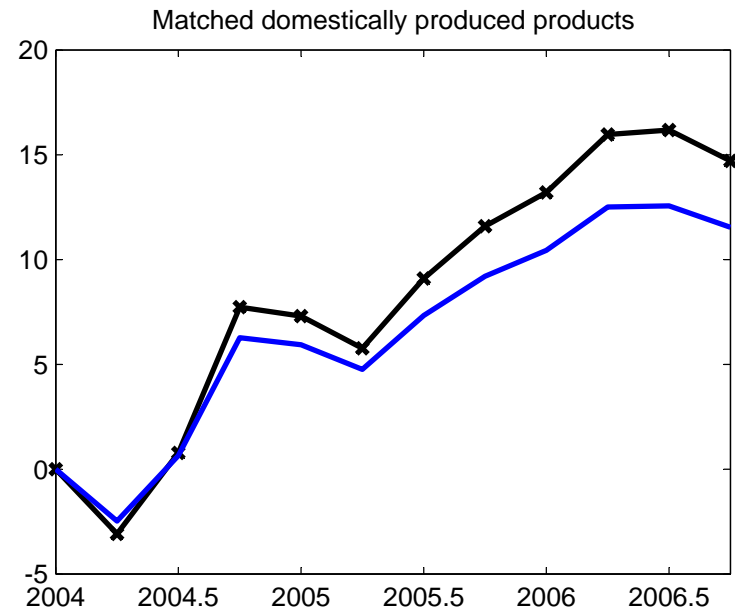
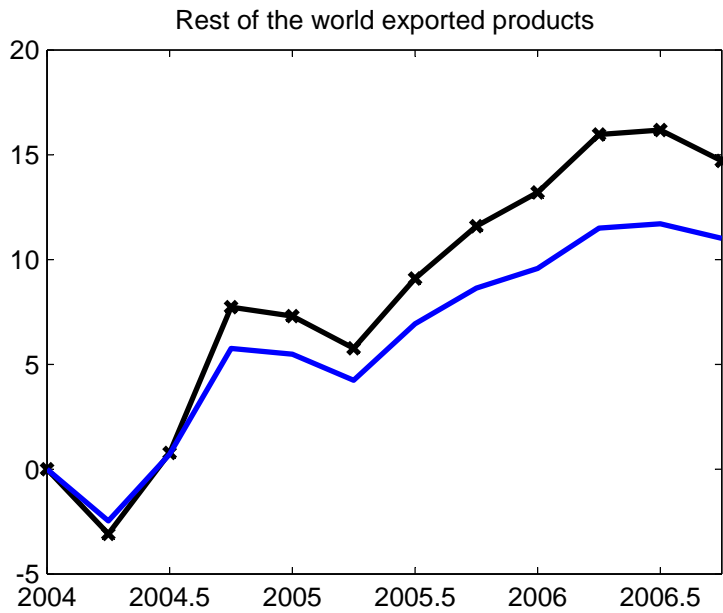
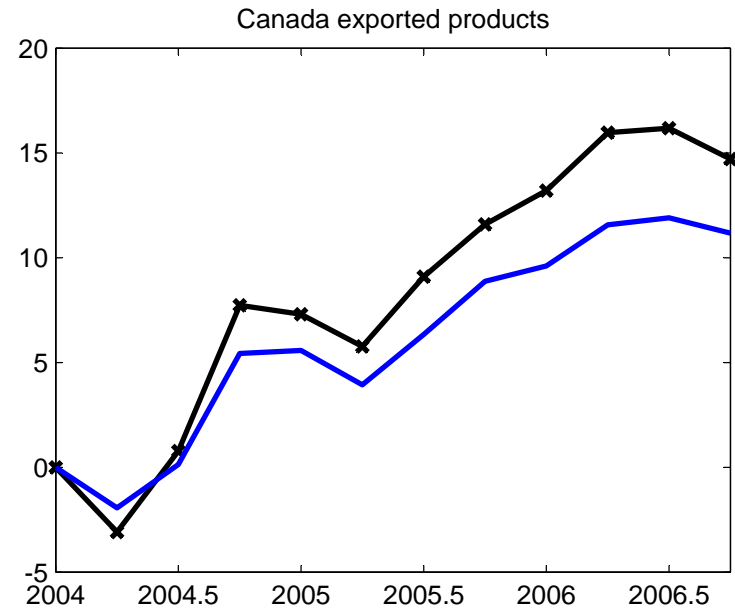
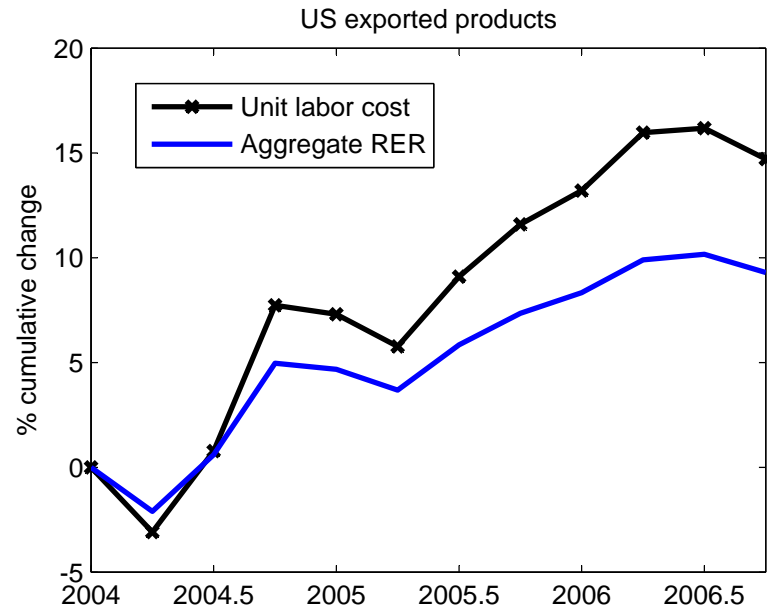


Table 1: Descriptive Statistics

		1	2	3	4
		North California	British Columbia	Center West US	Center West Canada
1	Expenditure share of matched products out of total expenditure	0.36	0.51	0.36	0.52
	Expenditure share of unique products produced in:				
2	US	0.87	0.30	0.89	0.29
3	Canada	0.01	0.67	0.02	0.68
4	ROW (Same Country)	0.11	0.03	0.09	0.03
	Number of unique products produced in:				
5	US	4,185	1,477	5,278	1,522
6	Canada	161	1,727	238	1,925
7	ROW (Same Country)	470	303	636	418
	Number of matched products:				
8	Both produced in the US	4,504	4,504	5,496	5,496
9	Both produced in Canada	124	124	191	191
10	Produced and sold in the US and Canada	4,187	4,187	5,385	5,385
11	Both produced in ROW (same country)	236	236	367	367
12	Number of pricing regions:	14	5	51	24

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

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

	North California and British Columbia					
	All	All Exporters	US Exporters	Can Exporters	ROW Exporters	Domestic
1 Std ^{intra,U.S.}	0.06	0.06	0.05	0.09	0.07	0.06
2 Std ^{intra,Can}	0.04	0.04	0.04	0.03	0.05	0.03
3 Std ^{inter}	0.12	0.11	0.11	0.15	0.14	0.13
5 Correl ^{intra,U.S.}	0.78	0.76	0.76	0.73	0.74	0.79
6 Correl ^{intra,Can}	0.88	0.85	0.85	0.95	0.84	0.89
7 Correl ^{inter}	0.07	0.08	0.08	0.07	0.10	0.07

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

A: Identical UPC							B: "Liberal" Matches					
	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic
1 Std ^{intra,U.S.}	0.07						0.06	0.06	0.05	0.10	0.07	0.07
2 Std ^{intra,Can}	0.06						0.04	0.04	0.03	0.02	0.08	0.04
3 Std ^{inter}	0.13						0.13	0.11	0.11	0.17	0.14	0.15
4 Correl ^{intra,U.S.}	0.72						0.77	0.74	0.75	0.68	0.74	0.79
5 Correl ^{intra,Can}	0.81						0.93	0.89	0.90	0.96	0.74	0.94
6 Correl ^{inter}	0.08						0.07	0.05	0.06	-0.04	0.09	0.09
C: Center-West							D: One store in Seattle and one store in British Columbia					
	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic
1 Std ^{intra,U.S.}	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	0.12	0.11	0.11	0.15	0.15	0.12
4 Correl ^{intra,U.S.}	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	0.07	0.06	0.05	0.08	0.10	0.08
E: Four Stores: British Colum., Manitoba, North Cali, Illinois							F: Prices Demeaned by Category-wide price					
	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic
1 Std ^{intra,U.S.}	0.08	0.08	0.08	0.10	0.09	0.08	0.06	0.06	0.05	0.09	0.07	0.06
2 Std ^{intra,Can}	0.04	0.05	0.04	0.04	0.07	0.04	0.04	0.04	0.04	0.03	0.05	0.04
3 Std ^{inter}	0.12	0.11	0.11	0.20	0.15	0.13	0.12	0.11	0.11	0.21	0.13	0.13
4 Correl ^{intra,U.S.}	0.61	0.59	0.57	0.84	0.62	0.62	0.78	0.76	0.76	0.71	0.74	0.79
5 Correl ^{intra,Can}	0.87	0.82	0.82	0.92	0.78	0.91	0.88	0.86	0.86	0.95	0.84	0.90
6 Correl ^{inter}	0.06	0.07	0.08	-0.03	0.06	0.05	0.07	0.09	0.09	0.00	0.13	0.06
G: Prices Demeaned by Nominal Wage												
	All	All exp.	US exp.	Can. exp.	ROW exp.	Domestic						
1 Std ^{intra,U.S.}	0.06	0.06	0.05	0.09	0.07	0.06						
2 Std ^{intra,Can}	0.04	0.04	0.04	0.03	0.05	0.03						
3 Std ^{inter}	0.12	0.11	0.10	0.15	0.13	0.13						
4 Correl ^{intra,U.S.}	0.78	0.76	0.76	0.73	0.74	0.79						
5 Correl ^{intra,Can}	0.88	0.85	0.85	0.95	0.84	0.89						
6 Correl ^{inter}	0.08	0.10	0.10	0.07	0.11	0.07						

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	Correlated
		demand shocks	
8	σ_z	0.057	0.0004
9	$\sigma_z^2 / (\sigma_z^2 + \sigma_a^2)$	0.919	0.438
10	ρ_a	0	0.75

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	US-Canada exchange rate, overall apreciation 2004-2006	15%	IFS

Table 5: Quantitative Results, Baseline Parameterization

	1	2
	Uncorrelated demand shocks	Correlated demand shocks
Panel A: Product-level price statistics		
<i>US Exporters</i>		
1 Correlation intranational prices	0.83	0.83
2 Correlation international prices	0.29	0.07
3 St. dev. inter / intra RER	2.03	2.33
<i>Canadian Exporters</i>		
4 Correlation intranational prices	0.82	0.82
5 Correlation international prices	0.21	0.06
6 St. dev. inter / intra RER	2.20	2.42
<i>ROW Exporters</i>		
7 Correlation intranational prices	0.82	0.82
8 Correlation international prices	0.19	0.06
9 St. dev. inter / intra RER	2.22	2.41
<i>Domestically produced</i>		
10 Correlation intranational prices	0.82	0.82
11 Correlation international prices	0.19	0.05
12 St. dev. inter / intra RER	2.20	2.40
Panel B: Aggregate price statistics		
Change in RER / Change in relative wages		
13 <i>US Exporters</i>	0.64	0.63
14 <i>Canadian Exporters</i>	0.75	0.73
15 <i>ROW Exporters</i>	0.76	0.73
16 <i>Domestically produced</i>	0.78	0.79

Table 6: Quantitative Results, Sensitivity Analysis

	1	2	3	4	5	6	7
	Baseline $\rho_a = 0$	Small shocks $\sigma_z \simeq 0, \Delta W_2 \simeq 0$	Correl intra $= 0.6$	Lower MP $\lambda = 0.15$	$\theta = 0.45$	$\theta = 0.2$	$\eta = 2$
Panel A: Product-level price statistics							
<i>US Exporters</i>							
1 Correlation intranational prices	0.83	0.82	0.61	0.82	0.83	0.82	0.82
2 Correlation international prices	0.29	0.22	0.21	0.27	0.27	0.34	0.35
3 Variance inter / intra RER	2.03	2.21	1.41	2.00	2.06	1.92	1.93
<i>Canadian Exporters</i>							
4 Correlation intranational prices	0.82	0.82	0.58	0.81	0.82	0.81	0.78
5 Correlation international prices	0.21	0.15	0.15	0.19	0.18	0.24	0.21
6 Variance inter / intra RER	2.20	2.33	1.51	2.20	2.22	2.13	1.96
<i>ROW Exporters</i>							
7 Correlation intranational prices	0.82	0.82	0.60	0.81	0.82	0.82	0.79
8 Correlation international prices	0.19	0.13	0.14	0.15	0.17	0.23	0.24
9 Variance inter / intra RER	2.22	2.36	1.52	2.22	2.24	2.15	1.99
<i>Domestically produced</i>							
10 Correlation intranational prices	0.82	0.82	0.60	0.81	0.82	0.81	0.79
11 Correlation international prices	0.19	0.15	0.14	0.16	0.17	0.24	0.12
12 Variance inter / intra RER	2.20	2.34	1.51	2.20	2.22	2.10	2.13
Panel B: Aggregate price statistics							
Change in RER / Change in relative costs							
13 <i>US Exporters</i>	0.64	0.71	0.64	0.64	0.66	0.59	0.53
14 <i>Canadian Exporters</i>	0.75	0.81	0.76	0.77	0.77	0.72	0.69
15 <i>ROW Exporters</i>	0.76	0.83	0.76	0.79	0.78	0.71	0.67
16 <i>Domestically produced</i>	0.78	0.82	0.78	0.83	0.80	0.75	0.87

In all cases we adjust the remaining parameters to match the other calibration targets.