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

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Abstract

A central question in international macroeconomics is why relative prices across countries are so volatile over time. In this paper, we document new facts on international relative price movements using product-level data, and formulate a model that can account for these facts.

We use wholesale price data for common products sold in the US and Canada over the period 2004-2006, together with information on the country of production for individual products. We find that international relative prices at the level of individual products are roughly 3 to 4 times as volatile as the US-Canada nominal exchange rate at quarterly frequencies. This pattern holds both for non-traded matched products that are domestically produced in each country, as well as for traded matched goods that are produced in one country and sold in the two countries. Moreover, in response to the appreciation of the Canadian dollar over this period, prices in Canada rose substantially relative to prices in the US both for traded and non-traded products. These large movements in international relative prices for traded goods are in conflict with the hypothesis of relative purchasing power parity.

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. Aggregate price data shows that movements in RERs are accounted for, to a large extent, by large changes in nominal exchange rates and small changes in nominal prices (Mussa 1986). This observation led to the design of models in which nominal prices change infrequently.

Recent data at the level of individual products, however, shows large and frequent movements in prices (Bils and Klenow, Klenow and Krystov 2008), and large fluctuations over time in relative prices of individual products across locations (Crucini and Telmer 2007, Broda and Weinstein 2008). The variability of relative prices of individual products is much larger than that of nominal exchange rates. This observation challenges pricing models based on infrequent price changes, and models that abstract from product-level fluctuations in prices.[1]

In this paper, we use detailed product-level data on prices in the US and Canada together with information on the country of production of each product. We document large movements in international relative pricing both for products that are actually traded, as well as for products that are potentially tradeable but are domestically produced in each country. These large movements in relative prices for traded products conflict with the hypothesis of relative purchasing power parity — namely, that the relative price of a traded good produced in the same location and sold in two different countries should remain constant over time. In light of these findings, we construct a model of international trade that can account for product-level and aggregate RER movements for both traded and non-traded products.

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.[2] For each product and each location, we observe wholesale prices paid by the retailer during the period 2004 through 2006. In order to measure movements in international relative prices at the level of individual products, we construct a set of common, or matched products, sold in both countries. For each match, we observe the country of production (separately for US and Canadian sales) at one point in time.

As in Broda and Weinstein (2008) and Crucini and Telmer (2007), we find that movements

[1] Kehoe and Midrigan (2007) show that sticky price models are also unable to account for variation in RER movements across different product categories.

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

in international relative prices are very large at the level of individual products. In particular, in our data, product-level RER's are roughly four times as volatile as the US-Canada nominal exchange rate at quarterly frequencies. In addition, we show that this pattern holds both for matched products that are domestically produced in each country (i.e. non-traded), as well as for goods that we identify as exported and sold in both countries (i.e. traded). These movements in product-level RERs are two to three times as volatile across regions in different countries than across regions within the same country.

Next, we construct measures of aggregate RERs based on average price changes in each country over a large set of matched products. We find, as in other studies using product-level data (e.g. Broda and Weinstein 2008, Crucini and Telmer 2007, and Gopinath, Gourinchas and Hsieh 2008), that movements in aggregate RERs closely track movements in nominal exchange rates. Importantly, we show that this is true both for traded and non-traded matched products. We also find evidence that product- and aggregate RER movements are somewhat larger for non-traded matched products than for traded matched products, and for non-US exported products than for US exported products. These findings complement those in Fitzgerald (2008), who uses micro data on domestic and export prices set by Irish producers to show that relative prices systematically track changes in nominal exchange rates.

Documenting our price observations separately for traded and non-traded goods allows us to assess the plausibility of two alternative pricing models in accounting for our data. First, consider a model in which changes in relative prices across countries simply reflect movements in relative production costs across locations. This model can account for movements in relative prices for products that are domestically produced in each country, but less so for goods that are produced in one country and sold in both countries. Instead, we interpret the large observed movements in relative prices for traded goods produced in a common location as the outcome of pricing-to-market by exporters. This is the practice by which exporters systematically change the markup at which they sell their output in two different locations.

Our model builds upon the pricing-to-market literature pioneered by Dornbusch (1987) and Krugman (1987),[3] 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 in Atkeson and Burstein (2007 and 2008)

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

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 non-traded 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 Canadian exporters.

We provide a simple analytical characterization to illustrate the model's ability to match our key pricing observations. The main force driving the model is that, with Bertrand competition and limit pricing, prices are determined by a combination of 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. The likelihood that exporters face the same latent competitor across countries is largely determined by the size of international trade costs.

In the model, a higher likelihood that exporters compete with the same latent competitor in both countries, carries two additional implications. First, it lowers the volatility of product-level RERs across countries because producers that face the same latent competitor across countries set domestic and export prices that are highly correlated. Second, as in Atkeson and Burstein (2007), a higher likelihood that exporters compete with the same latent competitor across countries leads to smaller 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 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 related to a large literature on exchange-rate pass-through.[4] While these studies focus on the response of prices in a country to movements in the exchange rate, we aim to understand why exporters systematically change the relative price at which they sell their output in two countries. Our paper is also related to a large literature that attempts to infer the extent of intra-and international trade frictions using observed deviations from the law of one price for individual products, or deviation from relative PPP based on aggregate price indices.[5] Instead, our analysis focuses on intra- and international price changes for products that are actually traded. We interpret these deviations from relative PPP through the lens of a model of pricing-to-market by exporters.

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 our 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 in 25 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. 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.

[4] See, for example, Gopinath, Itskhoki, and Rigobon (2007), Goldberg and Hellerstein (2008), and the survey in Goldberg and Knetter (1995).

[5] See, for example, Broda and Weinstein (2007), Crucini and Shintani (2007), Crucini, Telmer and Zachariadis (2005), and Gopinath, Gourinchas, and Hsieh (2008) for studies based on product-level data, and Engel and Roger (1996) and Gorodnichenko and Tesar (2008) for studies based on aggregate price indices.

Our analysis primarily focuses on wholesale prices to abstract from local retail distribution services, and other retail pricing considerations such as multi-product pricing.[6]

2.1. Aggregation across space and time

The retailer pricing policy is based on pricing areas. A pricing area is a geographic region with a common retail price across the stores therein. We aggregate stores in each pricing region and we end up with 24 pricing regions in Canada and 114 in the US. We use this classification of pricing areas as our benchmark regions for wholesale prices.[7] 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.

We compute our price statistics over three broad geographic areas. Area 1 covers all pricing regions in the US and Canada. Since the geographic dispersion in Canada is smaller than in the US, we consider two additional geographic areas. Area 2 includes stores in British Columbia in Canada and North California in the US. Both are located in the west coast and, most importantly, cover the stores where the country of production was identified (more on this below). Geographic Area 3 is broader than Area 2 but narrower than Area 1. It includes all 24 pricing regions in Canada, and 51 pricing regions in the US, chosen to roughly match the geographic coverage in Canada. They include the pricing regions in California, Oregon, Washington, Idaho, Montana, and Wyoming. Area 3 has the advantage of increasing the scope of our data, while maintaining geographic comparability between the US and Canada.

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. Quarterly prices are computed as average weekly prices within the quarter.[8]

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

[6] Burstein, 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%.

[7] If wholesale prices differ across stores within a region, we calculate the "pricing region wholesale price" for each week as the median wholesale price across stores within the pricing region.

[8] Relatedly, Nakamura (2008) argues that idiosyncratic cost and demand shocks are more likely to drive price fluctuations at lower than weekly frequencies. Our results are largerly unaffected if quarterly prices are constructed as median prices within the quarter.

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 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".

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 the US and in Canada. In the US, this information is publicly available as reported by the retailer in its online store for sales in Northern California. In Canada, we obtained this information by visiting a specific store in the Vancouver area during the months of May-June 2008, recording the label information for each matched product. For both countries we complemented this information by calling some of the individual manufacturers. We abstract from retailer brand because we lack information on the identity of the manufacturer.

We end up with four 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

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. With respect to the second caveat, we separately report our findings for our geographic Area 2, where we identified the production information (i.e. British Columbia and North California).

2.4. Descriptive statistics

Table 1 provides descriptive statistics of our matched products, for US and Canada, in each of our three geographical areas.

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 roughly 40% of total expenditures in the US, and 50% in Canada.[9]

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, roughly 90% of expenditures in our set of products (or 85% of the total number of products) are domestically produced. Imports from Canada and the rest of the world (ROW) account for roughly 2% and 8% of expenditures, respectively. In Canada, roughly two thirds of expenditures in our set of products are domestically produced (or roughly 50% of the number of products). Imports from the US account for a sizeable expenditure share of roughly 30%, and imports from ROW account for an expenditure share of 3%.[10]

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 2lt in Canada is matched with Coca Cola 12 Oz and Coca-Cola 24 Oz in the US. Our matching process yields roughly $14,000$ matches in geographic Area 1, $9,000$ in Area 2, and

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

[10] Interestingly, these import share are quite similar to OECD-based import shares for chemicals, food products, beverages, and tobacco over the period 1997-2002.

$11,000$ in Area 3.

Of these matches, roughly 45% are produced in the US for US and Canada sales, 1.5% are produced in Canada for US and Canada sales, 3.5% are produced in a common third country for US and Canada sales, and as much as 50% 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 sample uncertainty.

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 $n = 1, 2, ..$, time periods by $t = 1, ..., T$, countries by $i = 1$ (US) and $i = 2$ (Canada), and regions by $r = A, ..., R_i$. In order to measure movements in relative prices, we first need to define a "reference region". This is the region with respect to which relative prices are computed. For each product, we identify the reference region as the pricing region in Northern California (for the US) and British Columbia (for Canada) which has the longest available time series.[11] We denote the reference region in each country by $r = A$.

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 individuals products are referred to as product-level RERs. The relative price of product n between region r in country j and the reference region in country i is denoted by:

$$Q_{nijrt} = P_{njrt}/P_{niAt}.$$

The logarithmic percentage change in the price of an individual product between periods t and $t-1$ is denoted by:

$$\Delta P_{nirt} = \log\left(P_{nirt}\right) - \log\left(P_{nirt-1}\right).$$

Similarly, the percentage change over time in the relative price between the reference region

[11] Alcoholic beverages are not sold in British Columbia by our retailer. For these categories we choose the reference region as the one with the most available data across all Canadian provinces.

in country i and region r in country j is denoted by:

$$\Delta Q_{nijrt} = \log\left(Q_{nijrt}\right) - \log\left(Q_{nijrt-1}\right) = \Delta P_{njrt} - \Delta P_{niAt}.$$

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.

Aggregate price indices are defined as average changes in prices over a set of products N sold in country i in region r:

$$\Delta P_{it} = \sum_{n \in N} \psi_{nir} \log\left(P_{nirt}/P_{nirt-1}\right), \tag{3.1}$$

where ψ_{nir} denotes the expenditure share of product n in country i, region r, over all the products belonging to set N. The percentage change in aggregate prices between countries (also referred to as aggregate RERs) is given by $\Delta Q_t = \Delta P_{2t} - \Delta P_{1t}$.

To be more concrete, Figure 1 provides an example of price movements 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 depicts the 11 quarterly growth rate of prices (all expressed in US dollars), ΔP_{nirt}, in three regions: the reference region in the US (in northern California), the reference region in Canada (in British Columbia), and a second region in the US (in northern California). The middle panel shows the percentage change in the relative price between the two US regions, ΔQ_{n11rt}, and the two reference regions in US and Canada, ΔQ_{n12rt}. The lower panel depicts the cumulative change in the aggregate RER for all US exported matched products over our sample period, $\sum_{t=1}^{12} \Delta Q_t$.

3.2. Measuring 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 intranational (i.e. between regions of the same country) and international (i.e. between regions of different countries) product-level RERs. In particular, the intranational variance of product-level RERs in country i over a set of products N based on country i's reference store is defined as:

$$\mathrm{Var}_i^{\mathrm{intra}} = \sum_{t=1}^{T-1} \sum_{r=B}^{R_i} \sum_{n \in N} \frac{1}{\bar{n}} \left(\Delta Q_{niirt} - \overline{\Delta Q_{intra,i}}\right)^2, \tag{3.2}$$

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 based on country i's reference store is defined as:

$$\mathrm{Var}_i^{\mathrm{inter}} = \sum_{t=1}^{T-1} \sum_{r=A}^{R_{-i}} \sum_{n \in N} \frac{1}{\bar{n}} \left(\Delta Q_{ni,-irt} - \overline{\Delta Q_{inter,i}} \right)^2 \ , \tag{3.3}$$

$\mathrm{Var}_i^{\mathrm{intra}}$ and $\mathrm{Var}_i^{\mathrm{inter}}$ can be approximated by:

$$\begin{aligned} \mathrm{Var}_i^{\mathrm{intra}} &\simeq 2\mathrm{Var}_i^{\Delta P} \left(1 - \mathrm{Correl}_i^{\Delta P \mathrm{intra}}\right) \ , \\ \mathrm{Var}_i^{\mathrm{inter}} &\simeq \left(\mathrm{Var}_i^{\Delta P} + \mathrm{Var}_{-i}^{\Delta P}\right) \left(1 - \mathrm{Correl}_i^{\Delta P \mathrm{inter}}\right) \ . \end{aligned} \tag{3.4}$$

Here, $\mathrm{Var}_i^{\Delta P}$ denotes the variance of price changes (i.e. ΔP_{nirt}) for products $n \in N$ sold in the different regions considered in country i. $\mathrm{Correl}_i^{\mathrm{intra}}$ denotes the correlation of price changes between the reference region $r = A$ and regions $r = B, ..., R_i$, all in country i. $\mathrm{Correl}_i^{\mathrm{inter}}$ denotes the correlation of price changes in the reference region $r = A$ in country i, and regions $r = A, ..., R_{-i}$ in country $-i$. Expression (3.4) holds exactly if the variance of price changes in reference region A, country i, is equal to the variance of price changes in the other regions $r = B, ..., R_i$ in country i.

Using (3.4), the ratio of international to intranational RER variances based on country i's reference store can be approximated by:

$$\frac{\mathrm{Var}_i^{\mathrm{inter}}}{\mathrm{Var}_i^{\mathrm{intra}}} \simeq \left(\frac{\mathrm{Var}_i^{\Delta P} + \mathrm{Var}_{-i}^{\Delta P}}{2\mathrm{Var}_i^{\Delta P}} \right) \left(\frac{1 - \mathrm{Correl}_i^{\mathrm{inter}}}{1 - \mathrm{Correl}_i^{\mathrm{intra}}} \right) . \tag{3.5}$$

Note that international product-level RERs can be more volatile than intranational RERs either because (i) prices changes are more volatile in country $-i$ relative to country i, i.e. $\mathrm{Var}_{-i}^{\Delta P} > \mathrm{Var}_i^{\Delta P}$, or (ii) price changes are more correlated within than across countries, i.e. $\mathrm{Correl}_i^{\mathrm{intra}} > \mathrm{Correl}_i^{\mathrm{inter}}$. Note also that the ratio of international to intranational variances can differ with the choice of base country if the variance of price changes $\mathrm{Var}_i^{\Delta P}$ differs 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

Table 2 presents product-level price statistics based on US and Canada reference regions, for our three geographic areas and various country-of-production sets. We report intra- and international correlations of price changes, $\text{Correl}_i^{\text{intra}}$, $\text{Correl}_i^{\text{inter}}$, and standard deviations of intra- and inter RERs, $\sqrt{\text{Var}_i^{\text{intra}}}$ and $\sqrt{\text{Var}_{US}^{\text{inter}}}$. We report standard deviations, instead of variances, to facilitate the comparison of our numbers with standard measures of nominal and real-exchange rate volatility. Appendix 1 provides a detailed discussion of the way the various statistics are constricted.

Product-level RERs are very volatile across countries. For example, combining all matched products in Area 2, $\sqrt{\text{Var}_{US}^{\text{inter}}} = \sqrt{Var_{Can}^{\text{inter}}} = 12\%$. To put these numbers in perspective, the standard deviation of quarterly changes in the US-Canada nominal exchange rate and in the CPI-based RER between 1998 and 2007 is roughly 3%. Product-level RER across countries are roughly 4 times as volatile as nominal exchange rates and RERs.[12]

Note that product-level RERs are very volatile for matched products that are domestically produced in each country, and also for matched products that are produced in one country and exported to other countries. For example, $\sqrt{Var_{US}^{\text{inter}}}$ is equal to 11% for US exported products, 19% for Canadian exported products, and 13% for exported products by other ROW countries and for matched products that are domestically produced in each country. These large movements in relative prices across countries for exported products suggest the practice of pricing-to-market by which exporters change the relative price at which they sell their output in different countries.

Table 2 also shows that product-level RERs are significantly more volatile across countries than within countries. In our geographic area 2, $\sqrt{Var_{US}^{\text{intra}}} = 6\%$, and $\sqrt{Var_{Can}^{\text{intra}}} = 4\%$. This implies that the ratio of inter-to-intra standard deviations is 2 when based on the US-reference region, and is equal to 3 when based on the Canadian-reference region.[13]

To understand these differences in intra-inter volatilities, we can use expression (3.5). Note that the variance of price changes, $\text{Var}_i^{\Delta P}$, is roughly equal in the US and Canada. Hence, differences in intra-inter RER volatilities are accounted for by differences in cor-

[12] These large movements in product-level RERs are not an artifact of sticky nominal prices. In fact, in our data, the fraction of matched products for which we observe at least one change in the modal quarterly price is 3/4.

[13] Our finding that $Var_{US}^{\text{intra}} > Var_{Can}^{\text{intra}}$ echoes the findings in Gorodnichenko and Tesar (2008). Note also that Var_{US}^{intra} and Var_{Can}^{intra} are higher within Area 3 (which is geographically more dispersed) than within Area 2.

relation of price changes within and across countries. Given that $Var_i^{\text{inter}} > Var_i^{\text{intra}}$, $\text{Correl}_i^{\text{inter}} < \text{Correl}_i^{\text{intra}}$. For example, for exported products in Area 2, $\text{Correl}_{US}^{\text{intra}} = 0.76$, $\text{Correl}_{Can}^{\text{intra}} = 0.88$, and $\text{Correl}_{US}^{\text{inter}} = \text{Correl}_{Can}^{\text{inter}} = 0.08$.

Hence, the key challenge to understand the differences in 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 location of production

The results in Table 2 suggest that there are differences in the measures of intra- and inter 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 country. This implies that when we compare our statistics across 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 production sets we wish to compare.[14] We compare the value of $\text{Correl}^{\Delta P\text{inter}}$ between the following 3 pairs 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.

Table 3, Panel A reports the differences in $\text{Correl}^{\Delta P\text{inter}}$ for the three comparison pairs, as well as the number of product categories that are included in each comparison. Our findings are as follows. First, US exported products and US-Canada-ROW products both have a higher international correlation of price movements relative to domestically produced products. Second, US exported products have a higher international correlation of price movements relative to Canada-ROW exported products. In Area 2, these differences in correlations range from 0.07 to 0.17.[15]

These findings suggest that there are systematic differences in the magnitude of $\text{Correl}^{\Delta P\text{inter}}$

[14] For example, when comparing the statistics between matched exported goods and matched products domestically products, we only include those product categories for which these two production sets account for at least 1% of total expenditures.

[15] Our findings are consistent with those in Knetter (1990 and 1993). Those papers use information on export unit values to show that pricing-to-market by US exporters is lower than pricing-to-market by exporters from other major industrialized countries.

for US exporters relative to other exporters, and for all exporters relative to domestically produced products. Note that 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 2 depicts the cumulative movement of aggregate RERs for our set of matched products. We also display the cumulative change in the US-Canada nominal exchange rate. We display the aggregate RER for the following production sets locations: US exported products, Canada-ROW exported products, US-Canada-ROW exported products, domestically produced products, and the union of all four production sets. The top row reports our findings for Area 3, while the bottom row reports our findings for Area 2.

Consider, for example, the rise in the aggregate RER for US exported products in our geographic Area 3. Over our sample period, prices in Canada (denominated in US dollars), rose relative to prices in the US for matched products sold by US exporters. This cumulative change in the RER represents 93% of the appreciation of the Canadian dollar. Our plot shows that all our sets of matched products exhibit very large swings in aggregate RERs.[16]

Our findings for Area 2 also reveal movements in aggregate RERs that are significantly higher than zero, but lower than those in Area 3. We suspect that, in the face of large product-level idiosyncratic price movements, the small number of districts in Area 2 lead to larger sample uncertainty.

Comparison across production locations

To compare the extent of movements in aggregate RERs across our different location of production sets, we follow the procedure described in Section 3.3 to minimize the potential category composition bias. Panel B in Table 3 reports the difference in the movement of aggregate RERs for the three pairs of production sets that we considered above. We find that Canada-ROW exported matched products and domestically produced products display larger movements in aggregate RERs than US exported products. These differences are large, as they represent 10% of the overall RER movements. However, they should be taken with caution given the small number of categories that have a combination of products from different production locations.

[16] Atkeson and Burstein (2008) document large movements in export prices relative to domestic prices for manufactured goods based on aggregate price indices constructed by the BLS. Our aggregate prices improve upon those price indices because they only include matched products that are sold both domestically and abroad.

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 nominal exchange rate (as we show later, our model has a clear prediction regarding this relation). We group 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 accounted for by exported products. For each product category, we then calculate $\text{Correl}^{\Delta P_{\text{inter}}}$ and the cumulative change in the category-wide RER.

Panel C in Table 3 reports results of regressing $\text{Correl}^{\Delta P_{\text{inter}}}$ on a constant and on the cumulative change in the category-wide RER. We report our findings for three alternative cases: (*i*) using only information from Area 2 (in column 1), (*ii*) using only information from Area 3 (in column 2), and (*iii*) using price correlations from Area 2 and RER movements from Area 3 (in column 3). The rationale for our third case is as follows. Aggregate prices, which average idiosyncratic price movements, are subject to less sample uncertainty in Area 3 than in Area 2 because Area 3 includes significantly more observations than Area 2. On the other hand, Area 2 is less geographically dispersed than Area 3, leading to more homogeneous measures of international price correlations.

All of our regression coefficients are negative and, in many cases, 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 the nominal exchange rate.

3.6. Sensitivity analysis

To be added.

Summary of data findings

Our data findings can be summarized as follows. We find that both nontraded and traded goods exhibit very large movements in product-level international RERs (four times as volatile as nominal exchange rates, and two to three times as volatile as intranational RERs), which are accounted for primarily by a low correlation of price changes across countries. Our results also suggest that $\text{Correl}^{\Delta P_{\text{inter}}}$ is systematically higher for US exporters relative to

other exporters, and for all exporters relative to domestically produced products. We also document, for all of our sets of matched products, including those that are actually exported, large swings in aggregate RERs that closely follow the appreciation of the Canadian dollar during our sample period. Our data also suggests that these aggregate RER movements are larger for Canada-ROW exported products and domestically produced products than for US exported products. Finally, we show 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 the nominal exchange rate.

4. Model

In this section we present a tractable model of international trade, multinational production, and intra- and international pricing that we use to account for 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 implies an analytically very tractable account of prices and markups.[17] With these preferences, consumers in country i, region r choose to purchase the product k with the highest demand/price ratio, a_{knirt}/P_{knirt}, and buy a quantity equal to $y_{nirt} = (P_{knirt}/P_{irt})^{-\eta} y_{irt}$. 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. In particular, demand shocks for a product in a country are distributed according to:

$$\begin{pmatrix} \log(a_{kniAt}) \\ \log(a_{kniBt}) \end{pmatrix} \sim N \begin{pmatrix} \sigma_a^2 & \rho_a \sigma_a^2 \\ \rho_a \sigma_a^2 & \sigma_a^2 \end{pmatrix}.$$

Here, σ_a denotes the standard deviation, and ρ_a the intranational correlation of demand shocks.[18] Our specific shock distributions are chosen to simplify our analytical characterization of prices in Section 5.

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. Exports are subject to iceberg costs $D \geq 1$. Multinational production is subject to a foreign idiosyncratic productivity $1/z'$ that is typically lower than domestic productivity, $1/z$. Firms from country 3 can only serve countries 1 and 2 by producing domestically and exporting (subject to an iceberg cost $D^* \geq 1$). International trade is costless when $D = D^* = 1$.

[17] Atkeson 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.

[18] Our assumption that demand shocks are independently distributed over time is without loss of generality for the results that follow. Moreover, we will later show that a key determinant of movements in product-level RERs is the difference between the international and intranational correlation of demand shocks. For simplicity, but without loss of generality, we assume the first is equal to zero.

We abstract from frictions in intranational goods markets by assuming that producers have equal costs of supplying both regions within each country.[19]

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.

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 $z' \geq z$, a firm faces a nontrivial choice of supplying country 2: it can export subject to iceberg costs, or alternatively produce abroad subject to a productivity loss. We assume that 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 produces domestically product k, variety n by z_{knt}. 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, the permanent component of marginal cost is determined from the draw of two

[19] We also abstract from multinational production by country 3 firms.

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:

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

These assumptions closely follow those in Ramondo and Rodriguez-Clare (2008). A higher value of λ lowers 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. 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.[20]

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 cost 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

[20] Our model assumes that prices are flexible and abstracts from other sources of endogenous dynamics. Hence, the assumption of iid wages is without loss of generality.

producer by a_{nirt}^{1st} and c_{nirt}^{1st}, respectively. The price of variety n in country i, region r, is:

$$P_{nirt} = c_{nirt}^{1st}. \tag{4.1}$$

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:

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

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.

4.5. Matched products

Guided by our data analysis in Section 2, we focus on the pricing implications 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 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_i^{inter}, and the change in aggregate prices across countries, 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 the price changes for products that belong to the same set 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 of the derivation 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, $a_{knirt}/\left(z_{knt}W_{tt}\right)$ and $a_{knirt}/\left(z'_{knt}W_{it}\right)$ converge in distribution to time-invariant random variables $1/\bar{z}_{kn}$ and $1/\bar{z}'_{kn}$ that are exponentially distributed.[21] 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.[22] 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 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}.

Note that, on the other hand, goods exported by country 3 to country 1 are not necessarily

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

[22] In 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.

exported to country 2 (and viceversa).[23] Hence, the mass of the set of matched products that are exported from country 3, N_{x3}, is weakly lower than m_{31} and m_{32}.

In Appendix 2 we provide simple expressions for m_{12}, m_{21}, m_{31}, m_{32}, and for the measure of the set N_{x3}, 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.[24]

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 $m_{ij} = \sum_{l=1}^{3} s_{ij}^l$.

A fraction r_i of the exporters from country i face the same latent competitor when selling in countries 1 and 2.[25] 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:

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

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 $s_i^3 = s_{i1}^3 = s_{12}^3$, so $r_i = 1$. Therefore, in the absence of international trade costs, all exporters face the same latent competitor in countries 1 and 2.

[23] For example, even though country 3 producers have the same cost of supplying these countries, they might be productive enough to serve country 1 (beating producers from country 1 and exporters from country 2) but not productive enough to serve country 2 (losing against producers from country 2 producing therein).

[24] See Bernard, Eaton, Jensen, and Kortum (2003).

[25] In our definitions, latent producers that would engage in MP if they were active are assumed to be latent competitors from the country of production, and not from the country of origin. Thus, according to this definition, a producer can face the same latent competitor only if this is an exporter from country 1, 2, or 3, but not a MP producer.

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, so changes in prices are given by:[26]

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

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:

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

Exporters face 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 A in country i and region r in country j is:

$$\Delta Q_{nijrt} = \Delta P_{nirt} - \Delta P_{njAt} = \Delta c_{nirt}^{1st} - \Delta c_{njAt}^{1st} = 0.$$

[26] Consider 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.

Thus, both intranational and international product-level real exchange rates remain constant over time:

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

and price changes are perfectly correlated within and across countries:

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

On the other hand, 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 can differ across countries. Therefore, $\Delta Q_{iirnt} = 0$ and $\Delta Q_{i,-irnt} \neq 0$, so:

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

Note that these patterns of intra- and international correlation of price changes for matched domestically produced products are independent of the extent of international trade costs.

Perfect Competition: Aggregate real exchange rates

We now consider the response of aggregate prices and RERs to a change in the wage, ΔW_{it}. For matched products exported from country i, the average change in prices charged in region A, country $j = 1, 2$ is:

$$\Delta P_{ijt} = \int_{N_{xi}} \psi_{njA} \Delta P_{njAt} dn = \Delta W_{it} \ , \tag{5.2}$$

where ψ_{njA} is the share of product n in country j, region A's total expenditures. Note that, with a continuum of matched products, idiosyncratic shocks average out. The change in the aggregate RER is $\Delta Q_t = \Delta P_{i2t} - \Delta P_{i1t} = 0$. Aggregate RERs for matched exported products remain constant over time because changes in prices are equal to changes in marginal cost, and changes in marginal cost are the same whether the product is sold domestically or exported.

On the other hand, for matched products that are domestically produced in each country ($n \in N_d$), changes in aggregate prices are $\Delta P_{d1t} = \Delta W_{1t}$ and $\Delta P_{d2t} = \Delta W_{2t}$, implying $\Delta Q_t = \Delta W_{2t} - \Delta W_{1t}$. 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 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:

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

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

$$\Delta Q_{nijrt} = \Delta P_{nirt} - \Delta P_{njAt} = \Delta a_{nirt}^{1st} - \Delta a_{njAt}^{1st} - \Delta a_{nirt}^{2nd} + \Delta a_{njAt}^{2nd} + \Delta c_{nirt}^{2nd} - \Delta c_{njAt}^{2nd} \quad (5.3)$$

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 $\Delta c_{nirt}^{2nd} = \Delta c_{niAt}^{2nd}$. Therefore, intranational changes in product-level RERs are given by:

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

Hence, product-level intranational real exchange rate change solely due to demand shocks. The correlation of price changes between regions A and B in country i is:

$$\begin{aligned} \mathrm{Correl}^{\Delta P_{\mathrm{intra}}} &= \mathrm{Correl}\left(\Delta P_{niBt}, \Delta P_{niAt}\right) \\ &= \frac{2\rho_a\sigma_a^2 + \sigma_z^2 + \sigma_w^2}{2\sigma_a^2 + \sigma_z^2 + \sigma_w^2}. \end{aligned} \quad (5.4)$$

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

Consider now movements in product-level RERs across countries. From (5.3), these can move either because demand shocks vary across countries, or because producers face latent competitors with different cost shocks across countries. If a producer faces the same latent competitor in both countries, then $\Delta c_{n1At}^{2nd} = \Delta c_{n2At}^{2nd}$ and product-level RERs change solely

due to demand shocks. However, if a producer faces a different latent competitor in each country (which are subject to different cost shocks), then $\Delta c_{n1At}^{2nd} \neq \Delta c_{n2At}^{2nd}$, and product-level RERs move due to both demand and cost shocks. 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:[27]

$$\begin{aligned} \text{Correl}_i^{\Delta P\text{inter}} &= \text{Correl}\left(\Delta P_{n1Bt}, \Delta P_{n2At}\right) \\ &= \frac{\sigma_z^2 + \sigma_w^2}{2\sigma_a^2 + \sigma_z^2 + \sigma_w^2} r_i. \end{aligned} \tag{5.5}$$

This expression can be understood as follows. Note first that if a producer competes with the same latent producer in both countries, this latent producer must be a potential exporter that is hit by the same cost shock when selling at home and abroad. Suppose 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, and price movements are uncorrelated for exporters facing a different latent competitor in both countries. 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, on the other hand, that price movements are solely driven by demand shocks. If these shocks are uncorrelated across countries, then $\text{Correl}_i^{\Delta P\text{inter}} = 0$. More generally, if cost shocks are more likely to be carried over across countries than demand shocks, $\text{Correl}_i^{\Delta P\text{inter}}$ is increasing in the importance of cost shocks in overall price movements, captured by $\frac{\sigma_z^2+\sigma_w^2}{2\sigma_a^2+\sigma_z^2+\sigma_w^2}$.[28]

There is a direct mapping between the inter- and intra-national correlation of price changes and the variance of inter- and intra product-level RERs (see expression (3.5) in Section 3), which is given by:

$$\frac{\text{Var}_i^{\text{inter}}}{\text{Var}^{\text{intra}}} = \frac{1 - \text{Correl}_i^{\Delta P\text{inter}}}{1 - \text{Correl}^{\Delta P\text{intra}}} = \frac{1 + \frac{\left(\sigma_z^2+\sigma_w^2\right)}{2\sigma_a^2}\left(1 - r_i\right)}{1 - \rho_a} \tag{5.6}$$

A high inter-intra ratio of RER variances can be the outcome of (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.

[27] In deriving this expression, we used the following property of correlations. Suppose we have two nx1 vectors, $x = [x_1; x_2]$ and $y = [y_1; y_2]$, where x_1,y_1 are of dimension n_1x1, and x_2,y_2 are of dimension n_2x1, with $n = n_1 + n_2$. Suppose x_i and y_i have equal mean and variance, and that $\text{correl}(x_i, y_i) = \rho_i$. Then, $\text{correl}(x, y) = \frac{n_1}{n}\rho_1 + \frac{n_2}{n}\rho_2$.

[28] If demand shocks were also internationally correlated, then $\text{Correl}_i^{\Delta P\text{inter}} = \frac{2\rho_a^{inter}+\sigma_z^2+\sigma_w^2}{2\sigma_a^2+\sigma_z^2+\sigma_w^2} r_i$.

Bertrand competition: Aggregate real exchange rates

Consider now the response of aggregate prices to a one time change in the wage equal to ΔW_{it}. For matched exported products from country i, the average change in prices charged in country $j = 1, 2$ is:

$$\begin{aligned} \Delta P_{ijt} &= \int_{N_{xi}} \psi_{njAt} \Delta P_{njrt} dn \\ &= \frac{1}{m_{i,-i}} \left[s_{ij}^1 \Delta W_{1t} + s_{ij}^2 \Delta W_{2t} + s_{ij}^3 \Delta W_{3t} \right] , \end{aligned} \tag{5.7}$$

where s_{ij}^l and $m_{i,-i}$ were derived in Section 5.1. 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 $s_{ij}^l / m_{i,i}$. If this ratio is less than one, there is incomplete pass-through from a change in the wage to the aggregate price.

The change in the aggregate RER for matched products produced by country i exporters is:

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

For simplicity, suppose that international trade costs 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:

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

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.

Consider now the general case with $s_{i1}^3 > 0$. Suppose that the wage in country 1 increases relative to the wage in countries 2 and 3 (i.e. $\Delta W_{3t} = \Delta W_{2t}$). Then, the change in the aggregate RER is:

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

The term $\frac{s_{i1}^3 - s_i^3}{m_{i,-i}} \geq 0$ indicates the fraction of country i exporters that face a latent competitor from country 3 in country 1 and face a different latent competitor in country 2. Our quantitative analysis confirms that this term is relatively small.

5.3. Discussion

In the preceding sections, we derived the implications of our model on price movements under two alternative assumptions: perfect competition, and Bertrand competition with limit pricing. In this 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 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 is consistent with the data in predicting that product-level RERs should fluctuate across countries for matched products that are domestically produced in each countries. However, it is in sharp contrast with the data in predicting that product-level RERs should be constant across regions within countries, and also across countries for traded products. On the other hand, the model with Bertrand limit pricing 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 intranational 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.[29]

Our data also shows large swings in aggregate RERs 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 for matched traded products.

[29] Our 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 region/variety-specific shocks that equally affect the cost of all K potential suppliers within that variety in that region. We can show that the dispersion of these cost shocks 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.

On the other hand, the model with Bertrand limit pricing 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 model with Bertrand limit pricing also predicts a connection between the international correlation of price changes and the magnitude of movements in aggregate RERs. Everything else equal, the smaller the fraction of exporters facing the same latent competitor in both countries (i.e.: r), the lower is $\text{Correl}^{\Delta P^{\text{inter}}}$ and the higher is ΔQ. The model also implies that if country 1 accounts for a higher share of total exports than countries 2 and/or 3 (due, for example, to differences in the number of potential producers across countries), then exported products from country 1 display a higher $\text{Correl}^{\Delta P^{\text{inter}}}$ and a lower ΔQ than exported products from countries 2 and 3. We confirm these results numerically in Section 6. These predictions are supported by our data when we compare the relation between $\text{Correl}^{\Delta P^{\text{inter}}}$ and ΔQ across different product categories, and across US, Canadian, and ROW exporters. Alternative models in which common cost shocks play a minor role and prices move only in response to region-specific cost and/or demand shocks can reconcile the patterns of intra and international correlations of price changes. However, such models are inconsistent with the relation between $\text{Correl}^{\Delta P^{\text{inter}}}$ and ΔQ observed in the data.[30]

We now discuss the role of the international border, parameterized by D, in shaping our pricing results. In our model, higher international trade costs reduce the volume of international trade, and the fraction of exporters facing the same latent competitor in both countries, r. 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 volatility of product-level RERs, and increases the movements of aggregate RERs for matched traded products in response to a movement in costs across countries.

Are differences in 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 trade costs (which imply a low r), or from cost and demand shocks that are more correlated within countries than across countries.[31] On the other hand, movements in aggregate RERs

[30] Wholesale distribution costs that are region- and product-specific can partly account for our price observations. It remains an open empirical question to assess the importance of these shocks in our data.

[31] These 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

for matched traded products in our model are the sole outcome of trade costs that lead to international segmentation of latent competitors.

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 on the role of international trade costs. This is because, in order to account for this data, we cannot distinguish 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 trade costs have no bearing on the size of these 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 intranational 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

movements can exceed intranational RER movements if product-level shocks are more correlated within than across countries.

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. Note 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 $K_2, K_3/\left(D^*\right)^\theta, \left(D\right)^\theta$, 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%,[32] 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.[33] These figures 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 $K_1 = 28$, so that the resulting value of K_2 is equal to 4, [34] and $\theta = 0.3$, 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, as in our data. 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 Area 2 of our data (we choose to match the average figures in the US and Canada). In particular, we target $\text{Var}^{\Delta P} = 0.08^2$ and $\text{Correl}^{\Delta P_{\text{intra}}} = 0.82$. 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 in Area 2 observed

[32] In 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.

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

[34] We experimented with different values of K_1 and, as long as the resulting value of K_2 is a whole number, our results are essentially unchanged.

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%.[35] For robustness, we also report our findings when $\eta = 2$.

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 dollar against the US dollar 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-intranational standard deviation of product-level RERs is roughly 2.[36]

Note that $\text{Correl}^{\Delta P\text{inter}}$ is larger than the one observed in Area 2 of our data (0.07). In order to match it exactly, we can raise the correlation of demand shocks within countries, ρ_a, which also requires an increases in the size of demand shocks relative to cost shocks. The fall in the relative importance of cost shocks leads to a further reduction in $\text{Correl}^{\Delta P\text{inter}}$. The results with correlated demand shocks are reported in Column 2, Table 5. Note that the ratio of inter-to-intranational standard deviations of RERs increases to 2.3 as we raise ρ_a. This illustrates that this ratio is not only determined by the size of international trade

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

[36] Our 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.

costs, but also by the extent to which demand shocks are more correlated within than across countries.[37]

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 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 the highest for US exported matched products. This suggest that US exporters in our model engage in less pricing-to-market than exporters from Canada and ROW. This pattern 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 (for both $\rho_a = 0$ in column 1 and $\rho_a > 0$ in column 2). Recall that, under perfect competition, aggregate RERs for matched products remain constant. For US exporters, the ratio of RER movements to wage movements is 0.64. This is higher than the ratio reported for Area 2 in our data, but lower than the ratio reported for Area 3. Note that, consistent with our data, non-US exported matched products display larger movements in aggregate RERs relative to US exported products. This pattern 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.

These finding suggest that our model is consistent, both qualitatively and quantitatively, with 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,

[37] Recall that $\text{Correl}^{\Delta P\text{inter}}$ would also fall if we incorporated region specific distribution shocks into our model.

$\text{Correl}^{\Delta P\text{inter}} = 0.22$ for US exporters is the product of $r_1 = 0.28$ (the fraction of US exporters facing the same latent competitor in both countries), and $(\sigma_z^2 + \sigma_w^2) / (2\sigma_a^2 + \sigma_z^2 + \sigma_w^2) = 0.82$ (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 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 $\text{Correl}^{\Delta P\text{intra}} = 0.6$ (which roughly corresponds to the intranational correlation of price movements for US exporters in Area 3 of our data) instead of $\text{Correl}^{\Delta P\text{intra}} = 0.82$. 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 price statistics are 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 to for Canadian exporters). To understand these differences, note that with a higher level of η, the optimal monopoly price becomes more binding 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

To be added

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8. Appendix 1: Data

Constructing time series of prices

For each product, the retailer keeps record of retail prices and replacement costs of the product, 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. 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 (ie: 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 obtain 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.

Despite the high quality of scanner data, there are several potential sources of measurement error associated with our price measure. First, some products are sold at a discount to customers who have a loyalty card. Second, some products are discounted with coupons. Third, some products include two (or more) for one promotions. If there are changes over time in the fraction of customers who take advantage of these types of discounts, then our procedure for computing prices would produce spurious price changes. Since in our analysis we average weekly prices into quarterly prices, this measurement error is less of a concern.

Calculating product-level statistics

We first calculate the percentage change over time in the relative price between the reference region and the other regions, ΔQ_{nijrt}, 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 consolidate, for each product, all the growth rates across pricing regions and quarters into four different vectors: US regions relative to the US reference region (vector 1), Canadian regions relative to the same US reference region (vector 2), US regions relative to the Canadian reference region (vector 3), and Canadian regions relative

to the same Canadian reference region (vector 4). $\text{Var}_i^{\text{intra}}$ is equal to the variance of vector 1 for i =US and vector 4 for i =Canada. $\text{Var}_i^{\text{inter}}$ is the variance of vector 2 for i =US, and vector 3 for i =Can.

To calculate the correlation of price changes, we proceed as follows. We construct the correlations using the reference region growth rate as one of the elements in the pair of price changes. In particular, for each product belonging to a set N, we construct the following matrix based on the growth rates of prices in periods $t = 1, ..., T$ and regions $r = A, ..., R$, for $i = 1, 2$, and $j = 1, 2$:

$$\begin{pmatrix} \Delta P_{niA2} & \Delta P_{njA2} \\ ... & ... \\ \Delta P_{niAT} & \Delta P_{njAT} \\ \Delta P_{niA2} & \Delta P_{njB2} \\ ... & ... \\ \Delta P_{niAT} & \Delta P_{njBT} \\ \Delta P_{niA2} & \Delta P_{njC2} \\ ... & ... \\ \Delta P_{niAT} & \Delta P_{njCT} \\ \Delta P_{niA2} & \Delta P_{njR2} \\ ... & ... \\ \Delta P_{niAT} & \Delta P_{njRT} \end{pmatrix}$$

We leave empty those rows for which we do not observe price growth rates, and also those with ΔP_{niAt} both in the first and second columns (ie: we don't match the reference store with itself). We then stack these matrices across all products $n \in N$. $\text{Correl}_i^{\text{intra}}$ is calculated as the correlation coefficient between the first and second columns of this stacked matrix with $j = i$. Similarly, $\text{Correl}_i^{\text{inter}}$ is calculated as the correlation coefficient between the first and second columns with $j = -i$. For accuracy, we require a minimum of 100 growth rates to evaluate these correlations. This constraint only binds when we compute correlations for individual product categories.

Calculating aggregate real-exchange-rates

We first construct ψ_{nir}, the expenditure share of product n in country i, region r, over all products, as follows:

$$\psi_{nir} = \frac{\sum_{t=1}^{T} P_{nirt} y_{nirt}}{\sum_n \sum_{t=1}^{T} P_{nirt} y_{nirt}} ,$$

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 price 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 a price growth rate

between these two quarters. The change in the aggregate price index, ΔP_{it}, is given by:

$$\Delta P_{it} = \sum_{n \in \tilde{N}_t} \tilde{\psi}_{nirt} \log \left(P_{niAt} / P_{niAt-1} \right) \ ,$$

where $\tilde{\psi}_{nirt} = \psi_{nir} / \sum_{n \in \tilde{N}_t} \psi_{nir}$. For accuracy, we require a minimum of 100 growth rates within a quarter. Otherwise, we treat ΔP_{it} in that specific quarter as missing.

We construct ΔP_{it} separately for each of the 94 product categories With these measures, we can aggregate RERs, both at the category-wide level (used in Panel C in Table 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:

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

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 $\bar{z} = \left(\min \{\bar{u}, \bar{u}'\} \right)^{\theta}$. Solving for this integral, we obtain:

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

where we used the assumption that $\bar{u}_{kn}$ and $\bar{u}'_{kn}$ are exponentially distributed.[38,39]

Similarly, the set of matched products that are supplied by the same producer located in country 2 is given by:

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

and the mass of this set is given by:

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

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

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

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:

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

and

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

[38] We 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) $\text{Prob}(x \leq y) = \mu/(\mu+\lambda)$.

[39] In 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.

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

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

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:

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

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:

$$s_{12}^1 = s_1^1 = Pr\left(D \min_2 \{\bar{z}_{kn}\}_{k=1}^{K_1} \leq \min\left\{\{\bar{z}'_{kn}\}_{k=1}^{K_1} \cup \{\bar{z}_{kn}\}_{k=K_1+1}^{K_1+K_2} \cup D^* \min\{\bar{z}_{kn}\}_{k=K_1+K_2+1}^{K}\right\}\right)$$

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:

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

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

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

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

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

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

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

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:

$$\begin{aligned}
d &= D^{1/\theta} \\
k_3 &= (1+\lambda) K_3 / (D^*)^{1/\theta} \\
\bar{u} &\sim \exp(1) \\
\bar{u}_1 &= \min\{\bar{u}_k\}_{k=1}^{K_1} \ ; \ \bar{u}_2 = \min\{\bar{u}_k\}_{k=K_1+1}^{K_1+K_2} \ ; \ \bar{u}_3 = \min\{\bar{u}_k, \bar{u}'_k\}_{k=K_1+K_2+1}^{K} \\
\bar{u}' &\sim \exp(\lambda) \\
\bar{u}'_1 &= \min\{\bar{u}'_k\}_{k=1}^{K_1} \ ; \ \bar{u}'_2 = \min\{\bar{u}'_k\}_{k=K_1+1}^{K_1+K_2} \\
\bar{u}_1^{2nd} &= \min_2\{\bar{u}_k\}_{k=1}^{K_1} \ ; \ \bar{u}_2^{2nd} = \min_2\{\bar{u}_k\}_{k=K_1+1}^{K_1+K_2}
\end{aligned}$$

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

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

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

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

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

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

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

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

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

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

Therefore,

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

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

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

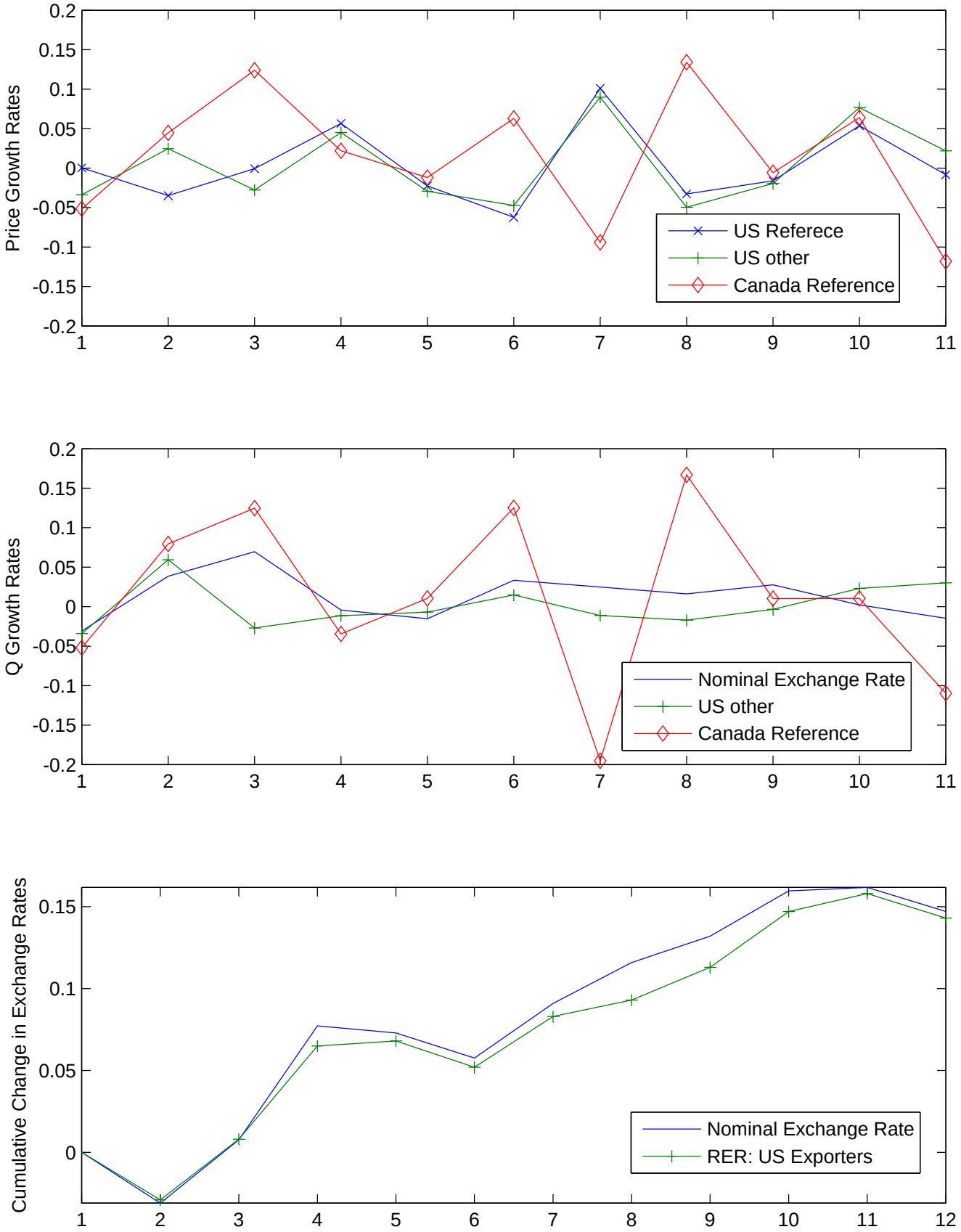
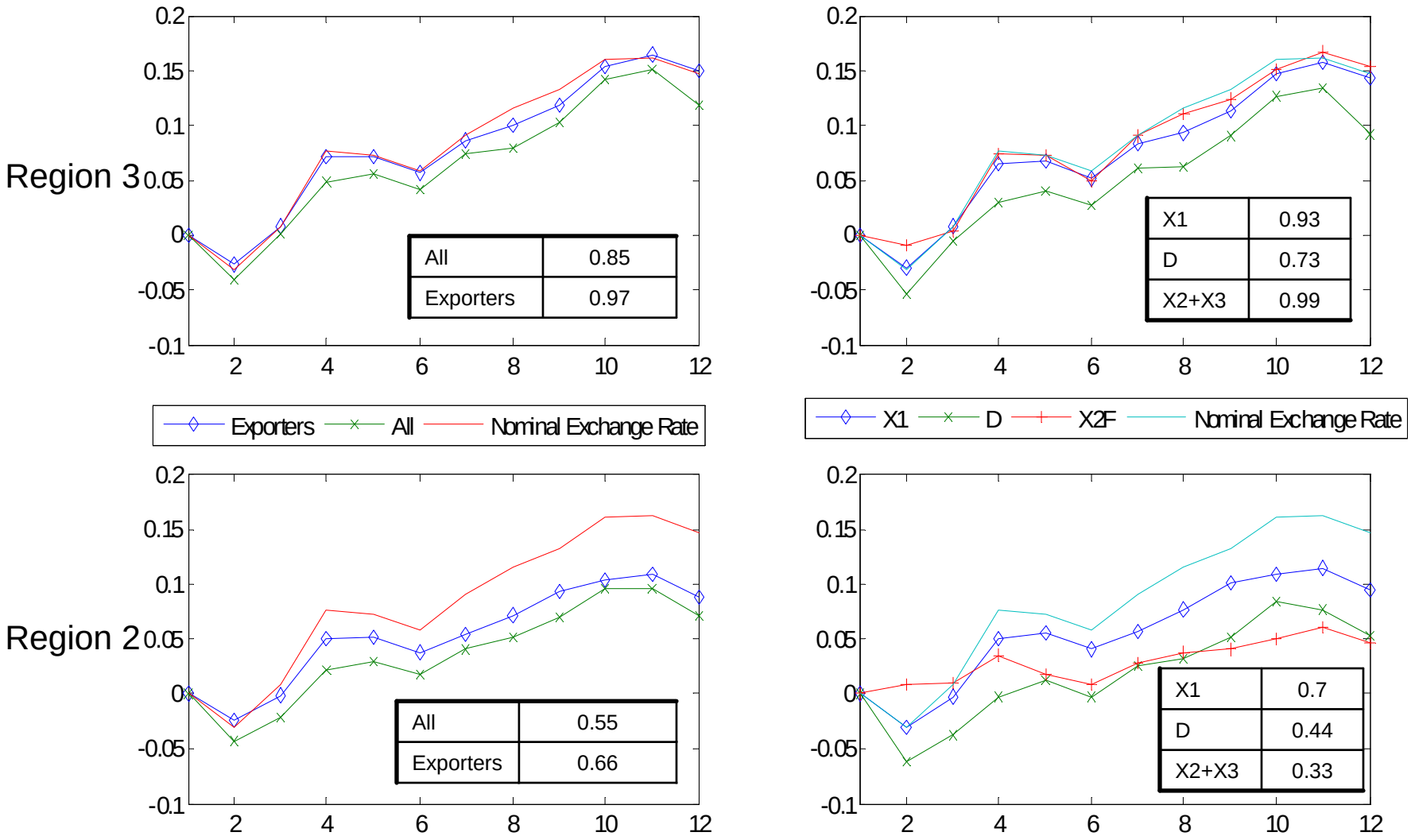


Figure 2: Cumulative Aggregate RERs



X1 = US exporters; X2 = Canadian exporters;
X3 = ROW exporters; D = Domestic produced products sold in Canada and US

Figure 3: Aggregate RERs Implied by Model

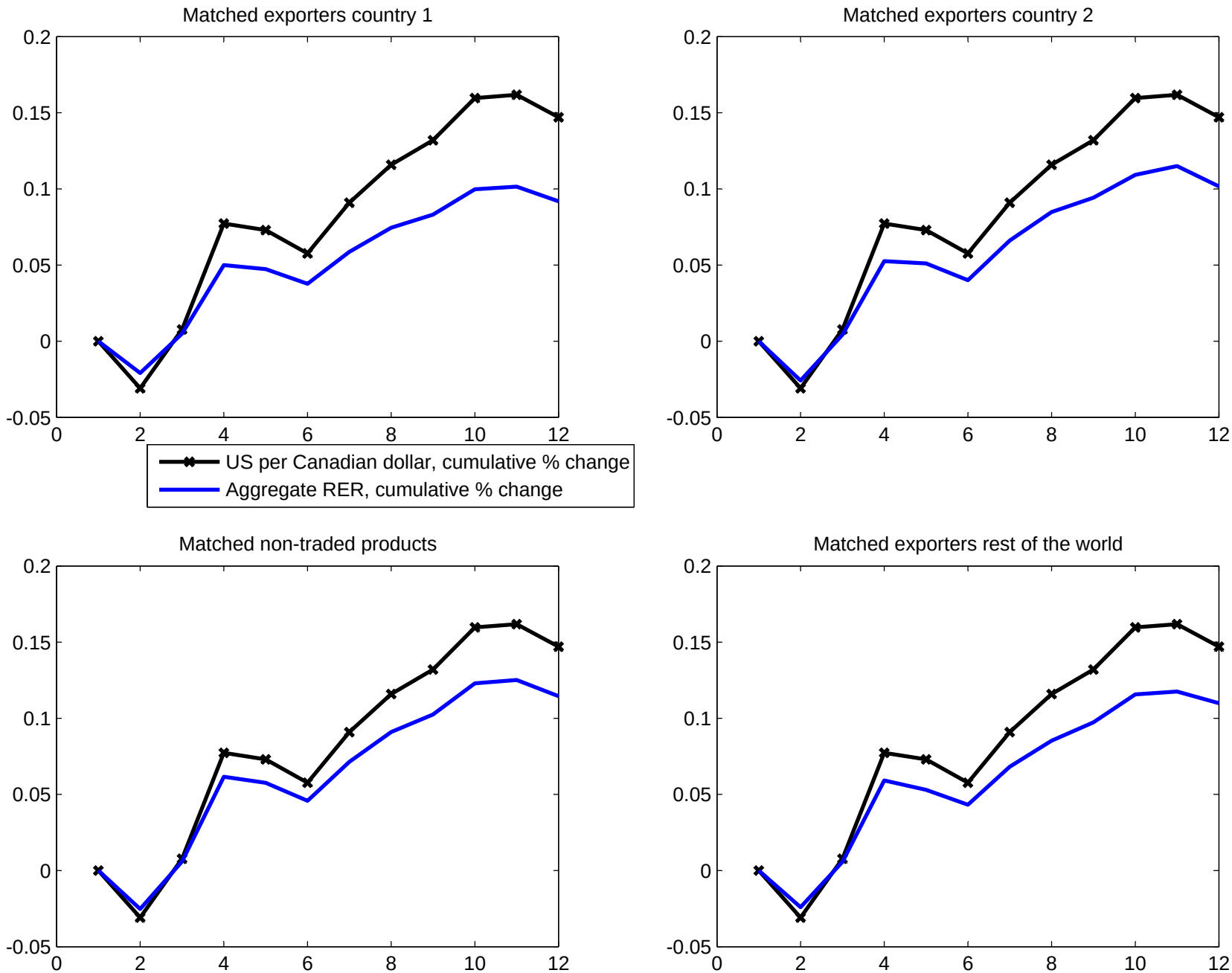


Table 1: Descriptive Statistics

		US			Canada		
		Area 1	Area 2	Area 3	Area 1	Area 2	Area 3
1	Expenditure share of matched products out of total expenditure	0.38	0.36	0.36	0.52	0.51	0.52
	Expenditure share of unique products produced in:						
2	US	0.90	0.87	0.89	0.29	0.30	0.29
3	Canada	0.02	0.01	0.02	0.68	0.67	0.68
4	ROW (Same Country)	0.08	0.11	0.09	0.03	0.03	0.03
	Number of unique products produced in:						
5	US	6,380	4,185	5,278	1,522	1,477	1,522
6	Canada	311	161	238	1,925	1,727	1,925
7	ROW (Same Country)	854	470	636	418	303	418
	Number of matched products:						
8	Both produced in the US	6,205	4,504	5,496	6,205	4,504	5,496
9	Both produced in Canada	226	124	191	226	124	191
10	Produced and sold in the US and Canada[b]	7,307	4,187	5,385	7,307	4,187	5,385
11	Both produced in ROW (same country)	503	236	367	503	236	367
12	Number of pricing regions:	114	14	51	24	5	24

Table 2: Intra- and International Product-Level Price Statistics

		Area 1	Area 2						Area 3					
		All	All	All Exporters	X1	X2	X3	D	All	All Exporters	X1	X2	X3	D
1	$Std^{intra,U.S.}$	0.07	0.06	0.06	0.05	0.09	0.07	0.06	0.07	0.07	0.07	0.09	0.08	0.07
2	$Std^{intra,Can}$	0.04	0.04	0.04	0.04	0.03	0.07	0.04	0.05	0.05	0.04	0.04	0.07	0.04
3	$Std^{inter,U.S.-Can}$	0.12	0.12	0.11	0.11	0.19	0.13	0.13	0.12	0.12	0.11	0.18	0.14	0.12
4	$Std^{inter,Can-U.S.}$	0.12	0.12	0.11	0.10	0.16	0.14	0.13	0.12	0.11	0.11	0.14	0.13	0.12
5	$Correl^{intra,U.S.}$	0.65	0.78	0.76	0.77	0.76	0.75	0.79	0.67	0.63	0.63	0.70	0.63	0.71
6	$Correl^{intra,Can}$	0.84	0.89	0.88	0.88	0.95	0.79	0.90	0.84	0.82	0.83	0.90	0.78	0.85
7	$Correl^{inter,\ U.S.-Can}$	0.06	0.07	0.08	0.08	-0.01	0.13	0.05	0.06	0.07	0.08	-0.02	0.05	0.04
8	$Correl^{inter,\ Can-U.S.}$	0.07	0.07	0.08	0.08	0.07	0.10	0.06	0.07	0.06	0.06	0.08	0.07	0.08

X1: Products produced by US exporters

X2: Products produced by Canadian exporters

X3: Products produced by ROW exporters

D: Products domestically produced in each country

Table 3: International Price Statistics Across Production Locations and Product Categories

		Area 2			Area 3		
		D vs. X1	X1X2X3 vs. D	X2X3 vs. X1	D vs. X1	X1X2X3 vs. D	X2X3 vs. X1
	Panel A: Difference in correlations						
	US (Ref) - Can						
1	Value	-0.17	0.14	-0.12	-0.08	0.08	-0.10
2	Num. of comparable product categories	20	25	11	25	26	16
	Can (Reference) - US						
3	Value	-0.14	0.10	-0.07	-0.08	0.07	-0.10
4	Num. of comparable product categories	20	25	11	25	26	16
	Panel B: Difference in prices						
5	Value	0.019	0.013	0.029	0.016	0.000	0.093
6	Num. of comparable product categories	7	8	3	8	12	3

X1: Products produced by US exporters
X2 Products produced by Canadian exporters
X3 Products produced by ROW exporters
D Products produced domesically and sold in each country

	Panel C: Regressions results	Case I	Case II	Case III
7		-0.43***	-0.33*	-0.46***
	US (Ref) - Can	(0.19)	(0.20)	(0.23)
8		-0.28*	-0.26*	-0.50***
	Can (Ref) - USA	(0.176)	(0.176)	(0.24)

*** Significant in the 5% level
* Significant in the 15% level

Case I - Region 2 Prices and Region 2 Correlations
Case II - Region 3 Prices and Region 3 Correlations
Case III - Region 3 Prices and Region 2 Correlations

Table 4 : Baseline Parameterization: Parameter Values and Targets

Panel A: Parameter values

	Parameters that determine trade patterns		
1	K_1	28	
2	K_2	4	
3	K_3	5	
4	D	1.58	
5	D*	1.15	
6	λ	0.35	
7	θ	0.3	
	Parameters that determine price movements	**Uncorrelated demand shocks**	**Correlated demand shocks**
8	σ_z	0.057	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			
	US Exporters		
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
	Canadian Exporters		
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
	ROW Exporters		
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
	Domestically produced		
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	*US Exporters*	0.64	0.63
14	*Canadian Exporters*	0.75	0.73
15	*ROW Exporters*	0.76	0.73
16	*Domestically produced*	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								
	US Exporters							
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
	Canadian Exporters							
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
	ROW Exporters							
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
	Domestically produced							
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	*US Exporters*	0.64	0.71	0.64	0.64	0.66	0.59	0.53
14	*Canadian Exporters*	0.75	0.81	0.76	0.77	0.77	0.72	0.69
15	*ROW Exporters*	0.76	0.83	0.76	0.79	0.78	0.71	0.67
16	*Domestically produced*	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.