How Much Wider Is the Border Now?

Revisiting the Border Effect in North America

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Abstract

This paper extends the influential study by Engel and Rogers (1996) and examines the persistence of the U.S.-Canada border effect on price volatility by covering the period 1998-2024. I first find that despite globalization and trade agreements, the border effect has not weakened over the past 30 years. An estimated border width was 22,800 miles for 1978-1997 but increased to 23,500 miles for 1998-2024. However, by splitting the period at 2008, the U.S.-Canada economic integration improved during 1998-2007, reducing the border width by approximately 4,500 miles compared to 1978-1997. The 2008-2024 period recorded the highest border width, suggesting that global economic shocks intensify market segmentation and disrupt cross-border integration. Extending the analysis to Mexico using national CPI data, I find that border widths for Mexico–U.S. and Mexico–Canada were far larger than that of the U.S.–Canada but declined notably post-NAFTA. These results provide evidence that free trade agreements like NAFTA and USMCA have significantly enhanced trilateral market integration in North America.

1. Introduction

The volatility of exchange rates remains a central puzzle in international macroeconomics. Persistent price differences for similar goods across regions or countries indicate the failure of the law of one price (LOOP) and suggest that markets are not fully integrated. A large body of literature shows that international market segmentation is significantly greater than intranational market segmentation. An influential paper by Engel and Rogers (1996) (henceforth ER) analyzes price data from 1978 to 1994 for cities in the U.S. and Canada and emphasizes the significant role that distance and international borders play in driving price disparities across regions. Their findings reveal that crossing the U.S.-Canada border is equivalent to increasing the distance between two cities by approximately 75,000 miles—roughly three times the Earth's circumference (about 24,900 miles). Despite the fact that Canada and the U.S. have fewer trade barriers than other international trade partners and share similar cultural and political traditions, the mere existence of a border generates the violation of the LOOP. ER's work complements earlier findings by McCallum (1995), who uses a gravity model to identify the "border effect" between the U.S. and Canada—a trade phenomenon that illustrates the impact of the border in reducing trade volumes between the two countries.[1]

The existence of the border effect is not entirely unexpected. ER suggested several plausible explanations for why it remains significant. National borders distinguish one country from others, which have their own culture, consumer preferences, markups, cost and market structures, political regimes, currencies, and more. Crossing a border also imposes direct costs

[1] McCallum (1995) examined trade volumes, while Engel and Rogers (1996) focused on relative prices. Since their findings are complementary—both highlighting that borders impose frictions on economic integration—I interpret border width as follows: a wider border width indicates a stronger border effect (greater market segmentation), while a narrower border width suggests a weaker border effect (greater market integration).

such as tariffs, regulatory barriers, and transportation costs. These trade frictions reduce the likelihood that prices will converge across borders and achieve international market integration. One might then expect the border effect to diminish over time as two countries achieve higher degrees of economic and cultural integration—raising the question of whether the U.S. and Canada have become more integrated in recent years.

This paper aims to revisit the framework of ER by incorporating over 30 years of updated data. Examining the past three decades is important because of significant shifts in global society that may have changed the "width" of the border (i.e., increased or decreased border effect). Several factors suggest stronger market integration between the U.S. and Canada over time. First, there have been free trade agreements—particularly the North American Free Trade Agreement (NAFTA) implemented in 1994, which was the last year included in ER's study. Policies on trade liberalization may have deepened economic ties between the affected countries. NAFTA superseded the bilateral Canada-U.S. Free Trade Agreement (CUSFTA), which entered into force in 1989[2]. NAFTA effectively incorporated and improved provisions on CUSFTA and extended its scope to include Mexico. One of the primary goals of NAFTA was to reduce trade barriers among the U.S., Canada, and Mexico by eliminating most tariffs, quotas, and prohibitions over a 15-year period. Since the U.S. and Canada already had a stronger trade relationship under CUSFTA, NAFTA had a more dramatic impact on Mexico's trade relations compared to U.S.-Canada. For instance, the Executive Office of the President (1997) reported that Mexico's average tariffs on U.S. imports fell from 10% in 1993 to about 2.9% by 1997. By comparison, Canada's average tariffs on all imports from the U.S decreased slightly from 0.37% to 0.22%, but

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[2] Engel and Rogers (1996) examined CUSFTA's impact by splitting their sample at 1990 and found slightly larger border coefficients post-1989. However, their four-year post-agreement window (1990-1994) may have been too short to capture long-term effects. Also, unlike the bilateral CUSFTA, NAFTA expanded trade integration to Mexico, a developing economy.

the decline was largely due to pre-existing CUSFTA provisions. Nevertheless, this multilateral trade agreement quadrupled trade among the three countries and further strengthened U.S.-Canada trade relations. Moreover, several industries—including textile and apparel, the automotive industry, and agriculture—especially experienced large gains from NAFTA's duty-free provisions (Congressional Research Service, 2017). These key beneficiary industries are relevant to ER's subject of study, as they analyzed price data across various categories of goods. Ultimately, this landmark trade agreement contributed to a rapid growth in trade and investment and benefited the economic integration of North America; this might have affected ER's results post-NAFTA, reducing the U.S.-Canada border effect.

Second, globalization and technological advancements have greatly increased connectivity by making local products, cultures, and ideas more available across borders. For example, lower transportation costs (both in terms of price and time) have made international travel more common and frequent. Trips abroad enable consumers to develop greater familiarity with and preference for foreign goods. Along with this, through the use of social media, people are more exposed to international trends and mass-market products, which contributes to the homogenization of consumer preferences. This increased interconnectedness would then homogenize demand responses to price changes across countries. As a result, national borders could have a weaker influence on consumption patterns.

Third, digitalization—such as online shopping, video calls, and virtual education—has significantly reduced the costs associated with physical distance. Consumers can now easily access international markets, compare prices across borders, and purchase goods without the need for physical travel. ER emphasized the role of distance in explaining real exchange rate volatility. However, the expansion of e-commerce and digital communication may have weakened this traditional role of physical distance, thereby reducing cross-border price dispersion.

Finally, while free trade agreements, globalization, and digitalization may help integrate international markets, major global economic shocks in the 21st century—specifically, the Global Financial Crisis (GFC) in 2008 and the COVID-19 pandemic in 2020—have disrupted the global economic environment. These crises can be identified by several indicators, including a decline in GDP and employment rates, as well as travel restrictions. These factors have led to a reevaluation of global supply chains and trade policies, which may have temporarily strengthened the border effect. Taken together, the four forces discussed above suggest that the border effect may have changed since ER's findings, making it necessary to reassess using recent data.

I address two main questions. First, has the border between the U.S. and Canada become wider or narrower since the publication of ER's "How Wide Is the Border?" Based on ongoing literature on the border effect, the border effect appears to persist today even in this globalized, connected society. Yet, I hypothesize that the forces of globalization may have led to its narrowing over the last three decades. Meanwhile, the 21st century experienced two major economic shocks, the GFC of 2008 and the COVID-19 pandemic. This leads to the second question: what role, if any, have the GFC and COVID-19 played in altering the width of the border? I hypothesize that the border effect is likely to be stronger (widened borders), temporarily during these economic downturns due to intensified market frictions.

Ultimately, I show that the U.S. and Canada have made little to no progress in reducing the border effect when comparing the periods 1978-1997 and 1998-2024. While the border appears slightly wider today than during ER's study period (1978-1994), the difference is minimal, around 700 miles. However, there was notable progress in integration between 1998 and 2007 (during the Great Moderation) by cutting the border width approximately 4,500 miles. In contrast, the period from 2008 to 2024—periods for major economic disruptions including the GFC and COVID-19 pandemic—reached the highest measured border effect across all periods.

By having the two major economic shocks, the progress for market integration was disrupted. As a result, current levels of market integration appear to have returned back to those observed in the pre-2000 sample period. These findings reinforce that large global shocks indeed have a lasting impact on cross-border economic integration.

As an extension, I include Mexico in the analysis to examine the effects of trade agreements more broadly. During 1978–1997, the border widths for Mexico–U.S. and Mexico–Canada were over 20 times larger than the U.S.–Canada border width. This implies that countries with differing economic status (i.e. developed vs. developing countries) are more segmented. Although NAFTA was implemented in 1994 (midway through the first sample period, 1978-1997), the subsequent three years (1995-1997) were likely insufficient to fully capture the gradual effects of NAFTA. In the 1998-2024 period, however, the border widths for both Mexico-U.S. and Mexico-Canada showed a rapid decline to roughly one-tenth of their prior levels. While they are still wider than the U.S.-Canada border width, the differences are now modest. This suggests that markets among the U.S., Canada, and Mexico made significant progress toward integration, which captures the effects of free trade agreements.

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature on the border effect and price dispersion. Section 3 describes my dataset and highlights revisions to the data selection process compared to ER. Section 4 outlines the baseline model employed in the study. Section 5 presents the regression results and their interpretation. Section 6 extends the study by incorporating Mexico to examine the trilateral border effect. Section 7 concludes.

2. Literature Review

Following the work of McCallum (1995) and Engel and Rogers (1996) on border effects in deviations from the LOOP, subsequent studies have sought to further explain and refine the role of borders in trade and price dispersion. In the context of globalization and technological advancements, Boivin et al. (2010) explored how information flows and market segmentation influence the border effect in a digital context. Using online bookselling data from the U.S. and Canada, they found that even in environments with reduced (physical) frictions, borders continued to affect price dispersion. The authors explained this puzzling result by pointing to price stickiness, information frictions (such as consumers being unaware of arbitrage opportunities in international online markets), and uncertainty related to international shipping.

Several studies focused on the Eurozone and demonstrated the persistence of the border effect in a globally and economically integrated region. Beck et al. (2020) analyzed barcode-level price data for Belgium, Germany, and the Netherlands from 2005 to 2008. Despite the absence of traditional trade barriers like tariffs or different currencies, they found that roughly 75% of sampled goods experienced price discontinuities at the borders. The authors explained that border costs still exist in these countries with close economic ties because consumers tend to engage in cross-border shopping for goods that are purchased frequently and are relatively cheaper; that is, the border effect persists for other types of goods. Similarly, Messner et al. (2024) explored the German-Austrian border for the period from 2008 to 2018 and highlighted that national borders still matter, affecting retail prices even in highly integrated areas. They suggested non-monetary arbitrage costs as an explanation, similar to Boivin et al. (2010). These include a lack of cross-border advertising and differences in product labeling, as well as existing logistics and supply chain structures, as contributors to national price segmentation.

While these studies claimed that national borders still matter, others examined how the border effect evolved over time. Parsley and Wei (2000) investigated the border effect between the U.S. and Japan from 1976 to 1997. They reported that international market segmentation tends to decline over time by about 0.4% per year. In contrast, Clark and Wincoop (2001) found no significant evidence of a decline in the border effect when they compared the U.S.-EU and France-Germany between the 1960s and the 1990s. It is important to note, however, that these studies relied on data from the 20th century and may not capture the impacts of globalization in more recent decades, as I outlined in the Introduction. More recent studies have incorporated social and cultural aspects and revealed that these elements can influence trade. For example, Fielding et al. (2015) built on ER's regression model, but they explored the impact of language and religion on the border effect. Their findings suggested that differences in language and culture lead to higher trade costs. Similarly, Bailey et al. (2021) measured social connectedness between 170 countries and 332 European regions by using de-identified data from social media. They highlighted that greater social connectedness reduced the impact of geographic distance and national borders on trade. These findings pointed to the role of globalization—particularly, social and cultural integration—in potentially moderating the border effect.

Recent research has taken a more critical perspective on the interpretation of border effects, emphasizing the distinction between inter- and intra-national price dispersion. Chahrour and Stevens (2020) analyzed the U.S.-Canada border effect and concluded that internal market segmentation, rather than international segmentation, contributed to violations of the LOOP. On the contrary, Beck et al. (2020) examined the Eurozone and found minimal price differences in intranational regions. The complexity of border dynamics was explained by Coughlin and Novy (2021), who demonstrated the inherent heterogeneity of border effects. The heterogeneity indicates that generalizing the border effect is difficult, as it changes based on specific regional or economic contexts. They introduced the concept of spatial attenuation effect—when smaller regions are aggregated into one larger region, the new, larger region has smaller border effects. This effect occurs because aggregation includes more regions and increases internal trade costs due to spatial frictions. Since border effects capture the trade costs of crossing a national border relative to trading within the same country, the increasing intranational costs make cross-border trade less costly in comparison. They highlighted this by linking higher GDP levels (economically large regions) to reduced border effects.

Much of the existing literature has primarily explored border effects within the contexts of U.S.-Canada or the Eurozone—regions with strong economic integration. My study focuses on the U.S.-Canada border and provides an updated analysis of the previous findings and discourse. This research incorporates recent data from 1978 to 2024 and examines the impacts of globalization, technological change, and major economic disruptions in the 21st century. By investigating whether the forces of globalization have weakened the traditional role of borders in economic transactions, this study contributes to the ongoing debate about the evolution of the border effect. Moreover, analyzing the impact of the GFC and COVID-19 on the border effect can offer insights into how economic crises influence global trade dynamics and consumer behavior; these shocks may reverse integration progress and reinforce price segmentation. Finally, extending the analysis to include Mexico enables the study of regions that are not highly integrated and provides a broader, trilateral view of North American trade integration. It highlights how free trade agreements have benefited market integration among countries with differing levels of economic development. These findings present important policy implications for the design of trade agreements and the role of cultural and social connectivity in promoting economic integration.

3. Data

To evaluate whether the U.S.-Canada border effect has been wider or narrower over time, I start by adopting the methodology used by Engel and Rogers (1996). ER studied the consumer price data from 14 U.S. cities and 9 Canadian cities for 14 baskets of goods from September 1978 to December 1994. Therefore, I first compare Consumer Price Index (CPI) data between September 1978 and December 1997 to ER's results from September 1978 to December 1994, and then I examine more recent CPI data from January 1998 to September 2024. As ER noted, the U.S. and Canada serve as ideal subjects for this analysis due to their strong social and economic connections: first, both countries are socially connected with the use of same language (except for a few regions in Canada that speak French) and similar cultural and political values; and second, although they are separated by a physical border, they have relatively low trade frictions, facilitated by the Free Trade Agreement.

3.1 Data Sources and Scope

I examine the CPI data published by the Bureau of Labor Statistics (BLS) for the U.S. and by Statistics Canada for Canada. These data were also used by ER. To directly assess changes in the border effect over time, this study builds on ER's framework: I use a comparable dataset of price data from 17 U.S. and Canadian regions (11 U.S. cities and 6 Canadian provinces) across 10 categories of goods, covering the period from September 1978 to December 2024.

3.2 Data Availability

Over the past three decades, the BLS and Statistics Canada have comprehensively revised their data to reflect changes in population and geographical samples. These updates introduce certain data availability challenges and require adjustments in the dataset used in this study, creating differences in terms of the number of regions and items utilized in original ER's analysis.

First, both BLS and Statistics Canada have implemented significant geographical and structural changes in their datasets. The BLS CPI data have undergone two major revisions: in 1998 (which modified item structure) and in 2018 (which adjusted geographical coverage). Due to Pittsburgh and St. Louis' population falling below the expected threshold, monthly CPI data for both cities was discontinued in 1998, becoming only semi-annual or annual. Moreover, by the 2018 geographic revision, combined Washington-Baltimore index was split into two independent city indexes[3]; Baltimore changed its frequency from odd to even months; St. Louis changed its frequency from semi-annual to bi-monthly; and Pittsburgh was entirely removed after the 2018 revision[4]. The changes in the data collection have been more substantial in Statistics Canada. With the introduction of the 1992 basket in January 1995, the city-level data became largely unavailable except for the shelter category. Instead, Canadian price data shifted its focus to provincial-level data instead. This shift makes it impossible to conduct an identical reproduction of ER's analysis with the U.S.-Canadian "city" pairs.

Second, the list of items in BLS has also gone through some changes. In 1998, "Entertainment" was redefined to "Recreation," and "Apparel and Upkeep" was modified to "Apparel." In addition, similar to the city-level data limitations in Canada, some items in the current series—Men's and Boys' Apparel, Women's and Girls' Apparel, Footwear, Public Transportation, and Personal Care—are now available only at the national level rather than for metropolitan areas. Therefore, I have adjusted and reduced the list of items to 10, while still maintaining a focus on the major expenditure categories.

3.3 Modified Approach

In this section, I outline how I adjust the data analysis based on availability. Instead of focusing on U.S.-Canadian city pairs, I examine pairs of U.S. cities and Canadian provinces.

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[3] For Washington, DC, and Baltimore, I manually integrated both current and discontinued (old) data to maintain consistency.

[4] I attempted to include Baltimore and St. Louis with their dummy variables, but the result was distorted and not interpretable. Ultimately, I excluded Baltimore, St. Louis, and Pittsburgh from the U.S. city dataset.

Specifically, this analysis includes 11 U.S. cities (excluding Baltimore, St. Louis, and Pittsburgh) and the 6 Canadian provinces that share a border with the U.S. I intend to replicate the regression conducted by ER over the period from 1978 to 1997 and compare my findings (U.S. cities-Canadian provinces) with their results (U.S.-Canadian cities). If my findings for the U.S. cities-Canadian provinces align with those for the U.S.-Canadian city pairs, it will provide strong evidence to confidently utilize the Canadian province-level data in my updated analysis. I extend the period up until 1997 (but do not stop at 1994) for consistency because it is the period before the BLS' item structure change; in 1998, some cities' publication frequency is modified, such as from odd months to even months.[5]

In terms of the list of items, I have narrowed it down to 10 categories: Good 1—Food at Home; Good 2—Food away from Home; Good 3—Alcoholic Beverages; Good 4—Shelter; Good 5—Fuels and Utilities; Good 6—Household Furnishings and Operations; Good 7—Apparel; Good 8—Transportation; Good 9—Medical care; and Good 10—Recreation.[6] ER used "Men's and Boys' Apparel," "Women's and Girls' Apparel," and "Footwear" in BLS, but those will be consolidated into a broader category, "Apparel" (Good 7). Accordingly, in Statistics Canada, I will compare "Clothing and Footwear" with "Apparel" in BLS. Moreover, since "Public Transportation" data is unavailable at the U.S. city level, I will use a general category of "Transportation," which encompasses both private and public transportation. I will remove "Personal Care" since this item is no longer available at the U.S. city level today.

Tables 1.1 and 1.2 summarize the goods and regions included in this study. Given that

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[5] Similar to the method used by ER, I only attempted to pair odd-odd or even-even months for comparison. A direct comparison between the periods 1978-1994 and 1995-2024 was not possible due to differences in location pairs following the 1998 item structure change. Dallas, Miami, and Philadelphia experienced frequency changes in 1998 similar to Baltimore in 2018, but I chose to remove only Baltimore, as its change occurred in 2018, midway through my sample period (1998-2024).

[6] The item names listed here follow the terminology used by the BLS. For the equivalent item names used by Statistics Canada, please refer to Table 1.1.

Canadian province-level data is available from September 1978, I will first analyze the 10 categories from September 1978 to December 1997 to compare my results with those of ER. Following this, I will proceed with the more recent data between January 1998 and September 2024.

3.4 Extension

As an extension of this study, I incorporate one more North American country—Mexico—and compare its CPI with those of U.S. cities and Canadian provinces. The inclusion of Mexico is particularly relevant for several reasons: first, the U.S., Mexico, and Canada have been bound by the North American Free Trade Agreement (NAFTA) in 1994, which was replaced by the United States-Mexico-Canada Agreement (USMCA) in 2020; second, Mexico also shares a border with the U.S. that is opposite to that of Canada; and third, Mexico is an emerging economy, contrasting with the more developed economies of the U.S. and Canada. By analyzing price data from Mexico, I can evaluate the influence of economic and cultural factors on the border effect within a trilateral context. The CPI data for Mexico are obtained from the National Institute of Statistics and Geography (INEGI). Further details of this analysis will be discussed in Section 6.

4. Model

My analysis focuses on the effect of distance and the existence of a border on the volatility of the real exchange rate. The baseline regression model, as estimated by ER, is specified as follows[7]:

$$\sigma_{j,k}^{i} = \beta_0^i + \beta_1^i ln\, d_{j,k} + \beta_2^i B_{j,k} + u_{j,k}^{i}$$

where *i* denotes one of the 10 categories of goods, $\sigma_{j,k}^{i}$ is the standard deviation of the growth rate

[7] ER also includes city dummy variables. Since including city dummy does not affect my conclusion, I have excluded them for simplicity.

of the relative price series for category *i* between locations *j* and *k*, $ln\, d_{j,k}$ is the natural logarithm of the distance (log distance) between two locations *j* and *k*, $B_{j,k}$ is a border dummy variable equal to the value 1 if locations *j* and *k* are separated by an international border and zero otherwise, and $u^i_{j,k}$ is an error term. Note that (j, k) pairs can be city-city (U.S. pairs), city-province (cross-border pairs), or province-province (Canada pairs).

4.1 Calculation of $\sigma^i_{j,k}$

Let $P^i_{j,t}$ and $P^i_{k,t}$ represent the price indices for a basket of goods *i* in location *j* and *k* at time *t*, respectively. These price indices, combined with the nominal exchange rate, determine the real exchange rate. Define $e^i_{j,k,t}$, the real exchange rate for basket *i* in the location pair (j, k) at time *t*, as:

$$e^i_{j,k,t} = \frac{\varepsilon_{j,k,t} \cdot P^i_{k,t}}{P^i_{j,t}}$$

where $\varepsilon_{j,k,t}$ is the nominal exchange rate between locations *j* and *k* at time t, calculated as the price of the currency used in location *k* in terms of units of currency used in location *j*. If the two locations are in the same country, i.e., if (j, k) pair is U.S.-U.S. or Canada-Canada, $\varepsilon_{j,k,t}$ is 1. For cross-border pairs (U.S. city-Canadian province), all the prices are converted into U.S. dollars using the nominal exchange rate[8].

Like ER, I calculate the two-month difference in the logarithm of the real exchange rate in order to account for the fact that several locations only report CPI data bi-monthly (in either even or odd months). The two-month percentage change in the real exchange rate can be expressed using a logarithmic approximation. Let $\Delta\, ln\, e^i_{j,k,t}$ describe the two-month difference in

[8] The data for the U.S.-Canada exchange rate is sourced from FRED (EXCAUS).

the logarithm of the real exchange rate for basket i between locations j and k. This logarithmic difference approximates the percentage change in the real exchange rate over two months. Finally, the volatility of the real exchange rate $\sigma^i_{j,k}$ (the independent variable in the regression equation) is measured as the standard deviation of $\Delta \, ln \, e^i_{j,k,t}$ over time. This term captures fluctuations in the real exchange rate, with higher values indicating greater deviations from the LOOP.

4.2 Distance

Unlike the ER's study, which utilized 14 U.S. cities and 9 Canadian cities, I incorporate 11 U.S. cities and 6 Canadian provinces. The distance between two cities can be calculated directly using their latitude and longitude coordinates through a great-circle distance calculator.[9] However, to estimate the distance between a U.S. city and a Canadian province, or between two Canadian provinces, I select two major cities from each Canadian province. This results in a total of 12 Canadian cities selected for calculating distance. The "major" cities are defined as those with the largest populations.[10] Specifically, for the provinces of Alberta, Quebec, and Ontario, I use the same two cities as ER. For Saskatchewan, British Columbia, and Manitoba, I include an additional city that has either the largest or second-largest population. Consequently, my approach incorporates the 9 Canadian cities used by ER, along with one additional city for three provinces, ensuring that the distance calculation uses two cities for each of the provinces. Table 2.1 provides a detailed list of the Canadian provinces, their corresponding two major cities, and their respective population.

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[9] Latitude and longitude coordinates can be obtained from Google Maps. I then use a great-circle distance calculation available online, and the source is GPS visualizer.

[10] Since CPI data publication depends on population thresholds (as mentioned earlier for Pittsburgh and St. Louis in Section 3), I define major cities based on these population criteria.

For city-province and province-province pairs, I use the weighted average of distances, with the population of each corresponding Canadian city serving as the weighting factor. The general weighted average formula is:

$$Weighted\ Average = \frac{\sum_{i=1}^{n} x_i w_i}{\sum_{i=1}^{n} w_i}$$

where w_i represents the weights (i.e., the populations of the corresponding Canadian cities), and x_i represents the data values to be averaged (i.e., the distances between locations j and k).

4.2.1 City-Province Distance. When location j is a city in the U.S. and k is a Canadian province A (which includes two major cities A_1 and A_2), the weighted distance of the city-province is calculated as:

$$\mathrm{D} = \frac{D(j, A_1) \cdot P_{A1}}{P_{A1} + P_{A2}} + \frac{D(j, A_2) \cdot P_{A2}}{P_{A1} + P_{A2}}$$

where $D(j, A_1)$ is the distance between a U.S. city and a Canadian city A_1, $D(j, A_2)$ is the distance between a U.S. city and the other Canadian city A_2, and P_{A1} and P_{A2} are the populations of the respective Canadian cities, taken as weights in this formula.

4.2.2 Province-Province Distance. Similarly, for calculating the distance between two Canadian provinces A and B, there are four corresponding cities ($A_{1,}$ A_2 for A and B_1, B_2 for B), which have four city-pair combinations (A_1B_1, A_1B_2, A_2B_1, A_2B_2). The formula becomes:

$$\mathrm{D} = \frac{D(A_1,B_1)\cdot(P_{A1}+P_{B1})+D(A_1,B_2)\cdot(P_{A1}+P_{B2})+D(A_2,B_1)\cdot(P_{A2}+P_{B1})+D(A_2,B_2)\cdot(P_{A2}+P_{B2})}{2(P_{A1}+P_{A2}+P_{B1}+P_{B2})}$$

For the purposes of this study, I only choose two major Canadian cities for each province. However, it is possible to incorporate multiple cities per province. Assume that province A contains n cities ($A_{1,}$ A_2, $\cdots$ A_n) and province B has m cities ($B_{1,}$ B_2, $\cdots$ B_m). Let P_{Ai} represent the population of city A_i in province A, P_{Bi} indicate the population of city B_i in province B, and

D(A_i, B_j) denote the distance between city A_i in A and city B_j in B. The general formula for calculating the weighted average distance D_{AB} between provinces A and B is as follows:

$$D_{AB} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} D(A_i, B_j) \cdot (P_{Ai} + P_{Bj})}{m \cdot \sum_{i=1}^{n} P_{Ai} + n \cdot \sum_{i=1}^{m} P_{Bj}}$$

5. Statistical Results

For each good *i*, I analyze 124 location pairs for the first period (1978-1997) and 121 pairs for the second period (1998-2024) across 10 categories of goods, resulting in 1,240 and 1,210 observations, respectively. The set of location pairs is different between the two periods because the 1998 item structure revision in BLS changed the publication frequencies of three cities,[11] and I eliminate pairs that do not align with the same publication frequencies (i.e., odd-odd or even-even). For example, I excluded the Boston-Miami pair from the second period since Miami changed its publication schedule in 1998 from odd to even months, while Boston continued publishing data only in odd months. For each of the 124 and 121 location pairs, I first calculate the volatility of the real exchange rate between *j* and *k* over the respective sample periods, following the methodology detailed in Section 4.1. I then regress the calculated price volatility on the log of the distance and the border dummy variable for each good *i*.

5.1 First Period: September 1978-December 1997

5.1.1 Intranational vs. International Volatility. Table 3.1 reports the average volatility of the real exchange rate for each of the 10 goods during the period between 1978 and 1997, distinguishing between intranational or international location pairs: U.S.-U.S., Canada-Canada,

[11] Three cities include Dallas (even to odd), Miami (odd to even), and Philadelphia (monthly to even).

and U.S.-Canada. In general, U.S.-U.S. pairs exhibit higher standard deviation compared to Canada-Canada pairs, except for three goods: Food at home, Transportation, and Medical care. ER explained that the U.S., as a more heterogeneous country, experiences greater price differences with more local market segmentation than Canada. However, the prices for the cross-border pairs (U.S. city-Canada province) are even more volatile than the U.S.-U.S. pairs, evidence of stronger international segmentation. The cross-border real exchange rate volatility is mostly the highest, except for one good—Good 5 (Fuels and Utilities) is more volatile in the U.S. pairs rather than U.S.-Canada pairs.[12] Still, these results are consistent with ER, who also found higher international volatility compared to intranational volatility. Figure 1 visually compares these deviations and shows that the international deviation of the LOOP is higher than intranational volatility in most cases.

5.1.2 Baseline Regression. The regression results for the first period using the baseline regression model outlined in Section 4 are presented in Table 4.1. Several changes in my study may explain differences in coefficients and significance levels compared to ER: first, I reduced the number of categories from 14 to 10 and the number of U.S. cities from 14 to 11 due to data limitations; second, I utilize CPI data of Canadian provinces instead of cities and calculate the distance between Canadian provinces and U.S. cities or between two Canadian provinces using population-weighted averages[13]; and third, my study period extends to December 1997, compared to ER's 1994 cutoff.

[12] Unlike my results, ER noted that there was one notable exception with subcategories for Apparel, where U.S.-U.S. pairs display slightly larger deviations compared to U.S.-Canada pairs. This was not the case for my results.

[13] To test whether the weighted average method contributed to the insignificance of the distance coefficient, I re-estimated the model using a simplified approach: selecting the most populous city in each Canadian province and directly calculating city-to-city distances. The results remained consistent, with the log of distance still not statistically significant. This suggests that the weighting method is not the primary issue.

The log of distance mostly shows positive coefficients, indicating that greater distances are associated with higher price volatility. Yet, three goods have negative coefficients, and all of them are not statistically significant. Of the 10 goods, three goods are statistically significant at 5% and one good at 10%. The coefficients for the border dummy variable are all positive and highly significant at less than 1%, except for only one good showing insignificance. The border coefficient represents the average increase in the standard deviation of the growth rate of the relative prices for (j, k) pairs when a border is present, holding the log of distance constant.

The pooled regression results for all 10 goods are also included, with coefficients for the log of the distance and the border dummy at 0.0004649 (not significant) and 0.007973 (significant at 1%), respectively. The pooled regression coefficients are the average of each coefficient for individual goods. Compared to ER's results (0.00106 for the log of the distance and 0.0119 for the border), the values of both independent variables on the volatility become smaller in my model due to the use of Canadian province-level data. This change in coefficients aligns with the study by Coughlin and Novy (2021) on the spatial attenuation effect: aggregation leads to weaker border effect, decreasing the cost of trading across borders compared to within borders.[14] For instance, when they drop large states like California and New York, they acquired more negative international border dummy coefficients. Conversely, dropping small states resulted in border coefficients moving toward zero. This suggests that when the sample is more aggregated, the border coefficient becomes smaller in absolute magnitude, which is also seen in my result. Likewise, aggregating to provinces likely introduces averaging or measurement error,

[14] I am cautious in using the term "border effect," as their definition of border effect pertains to trade volumes and costs, whereas I refer to border width using price data. To properly cite their work, I maintain their terminology here. For my calculation of border width, a smaller border coefficient does not necessarily indicate a smaller border effect (or smaller border width), as the border width is determined by the interplay between the distance and the border coefficients. Please see Section 5.1.3. for detailed border width calculation.

smooths out heterogeneity of localized effects, and reduces the precision of distance measurements. Notably, the coefficient for the log of distance is not significant in the pooled regression, while border dummy remains highly significant. This indicates that distance does not strongly explain deviations from the LOOP, but the existence of a border significantly matters.

Despite these differences, my results still closely align with ER's city-city data in the sense that most coefficients have positive values and most of them are statistically significant, particularly for the border dummy. While the insignificance of the distance coefficient implies that aggregating at the province level may weaken the relationship between distance and real exchange rate volatility, the strong significance of the border dummy highlights that national borders remain a dominant factor in price dispersion. This suggests that utilizing the province level does not fundamentally distort the key findings about the border effect. Given my focus on broader cross-border trends, I will proceed with U.S. city and Canadian province data for the remainder of this analysis.

5.1.3 Border "Width" Calculation. Before moving into the second period (1998-2024), I recalculate how "wide" the border is during the period between 1978 and 1997, using U.S. city and Canadian province data. ER finds that the U.S.-Canada border adds 75,000 miles, calculated as

$$e^{\frac{\beta_2}{\beta_1}} = e^{\frac{0.0119}{0.00106}} \approx 75{,}000\ (miles)$$

However, their method can be misleading. Parsley and Wei (2001) pointed out that their calculation fails to account for the change in the units of distance measurement (from miles to kilometers, for example).[15] In addition, due to the compounding nature of exponential function,

[15] Parsley and Wei (2001) exemplified that if the distance unit were kilometers, the result would be interpreted as 75,000 kilometers, since the coefficients are not affected by the change in units.

small changes in the coefficients can lead to large changes in the estimated outcome. This can result in an unrealistic increase in the distance (such as more than the distance between the Earth and the Moon). Thus, I use a different calculation method from ER. Following Schmitt-Grohe, Uribe, and Woodford (2022, Chapter 9), I utilize total differentials to see how much the distance needs to be increased when the impact of the border is removed in order to achieve the same level of

real exchange rate volatility. Recall the baseline regression equation now with the ER's coefficients:

$$\sigma_{j,k}^i = \beta_0^i + 0.00106 ln\, d_{j,k} + 0.0119 B_{j,k} + u_{j,k}^i$$

By taking the change to all terms, the equation becomes:

$$\Delta\sigma_{j,k}^i = 0.00106 \frac{\Delta\, d_{j,k}}{d_{j,k}} + 0.0119 \Delta B_{j,k}$$

I want to keep the volatility constant, $\Delta\sigma_{j,k}^i = 0$, and the border dummy is removed, $\Delta B_{j,k} = -1$ (from 1 to 0).

$$0 = 0.00106 \frac{\Delta\, d_{j,k}}{d_{j,k}} - 0.0119$$

Rearranging it in terms of change in distance,

$$\Delta\, d_{j,k} = \frac{0.0119}{0.00106} \cdot\ d_{j,k}$$

Since the average distance between all city pairs in Table 2 in ER's paper is about 1,218 miles,

$$\Delta\, d_{j,k} = \frac{0.0119}{0.00106} \cdot 1{,}218 \approx 13{,}700\ miles$$

Compared to ER's reported value of 75,000 miles, my calculation of the border width shrinks the border about 5 times. I will now use this new value (13,700) calculated from ER's regression results to compare with my results for the first period. My regression result for the period between 1978 and 1997 is as follows:

$$\sigma_{j,k}^{i} = \beta_0^{i} + 0.0004649 ln\, d_{j,k} + 0.007973 B_{j,k} + u_{j,k}^{i}$$

Since the average distance between all 124 location pairs is about 1,330 miles,

$$\Delta\, d_{j,k} = \frac{0.007973}{0.0004649} \cdot 1{,}330 \approx 22{,}800\; miles$$

This calculation implies that the existence of the border increases the distance between two locations by approximately 22,800 miles. Compared to ER's report, utilizing Canadian province-level data rather than city-level data increases the border by about 9,000 miles. This increase in border width in this context does not imply the status of economic integration between the U.S. and Canada. Since the comparison involves the same period (pre-2000 sample), the difference mostly arises due to geographical aggregation and measurement effects. For instance, using Canadian provinces increases the average distance, which can be one factor that increases the border width. I now use this value, 22,800 miles, to compare with the results for the second period and determine if the border has become wider or narrower in recent years.

5.2 Second Period: January 1998-December 2024

5.2.1 Real Exchange Rate Volatility Patterns

***5.2.1.1 Intranational vs. International Volatility*.** The average volatility of the real exchange rate for each of the 10 goods for the period between 1998 and 2024 is reported in Table 3.2. In general, my findings are consistent with both ER's results and my earlier analysis: the U.S. experienced higher price volatility than Canada for most goods, with the exception of Good 5 (Fuels and Utilities), where Canada exhibited greater price dispersion. As expected, cross-border real exchange rate volatility remains much higher than that observed within the U.S.-U.S. and Canada-Canada pairs. Figure 2.1 visualizes the data from Tables 3.1 and 3.2. Compared to the first period, price volatility increased across all three types of location pairs in the second period.

In particular, the average cross-border price volatility rose sharply from 0.0282 in the first period to 0.0390 in the second period. The result is somewhat puzzling, considering that the U.S. and Canada reduced trade barriers through free trade agreements, which should, in theory, lead to lower price dispersion. One explanation lies in the concept of nominal price rigidity. As ER noted, sticky nominal prices can make the countries appear to be segmented, even when real integration exists. According to the real exchange rate equation in Section 3.1, volatility in the real exchange rate can stem from fluctuations in either the nominal exchange rate or the price ratio. If prices are slow to adjust (i.e., if the price ratio does not easily change), nominal exchange rate movements directly translate into real exchange rate fluctuations. In fact, the percentage change of the nominal exchange rate exhibited higher fluctuations in the second period, as illustrated in Figure 2.3.[16] When prices are rigid, these nominal exchange rate fluctuations amplify cross-border relative prices, while the two countries remain integrated. Another plausible explanation is that the two global economic shocks (the GFC and pandemic) contributed to greater cross-border price deviations. I explore this hypothesis in greater detail in Section 5.3.

***5.2.1.2 Cross-border Price Volatility: Tradable vs. Non-Tradable Goods*.** Figure 2.2 compares only the U.S.-Canada real exchange rate volatility between the first and second periods and reveals a clear pattern of divergence across goods categories, some consistently exhibiting high or low volatility. The 10 goods can be broadly classified into tradable and non-tradable goods based on their market characteristics. These two groups show distinct cross-border volatility patterns across both periods. Tradable goods include Good 1 (Food at Home), Good 3 (Alcoholic Beverages), Good 5 (Fuels and Utilities), Good 6 (Household Furnishings and Operations), Good 7 (Apparel), Good 8 (Transportation), and Good 10 (Recreation). Among

[16] The percentage change in the nominal exchange rate over time ($\Delta\varepsilon_t$) is calculated as a proxy for its volatility. The second period displays greater fluctuations (larger amplitudes).

them, fuels and apparel are particularly tradable, being heavily subject to international trade and global pricing. Non-tradable goods include Good 2 (Food away from home), Good 4 (Shelter), and Good 9 (Medical Care). These are typically services (e.g., haircut and healthcare) or locally produced and consumed goods that make them difficult or impossible to trade internationally. However, this classification is not definitive. For example, Good 8 contains both tradable components (like vehicles) and non-tradable ones (like insurance and maintenance services). For simplicity, I classify Good 8 as tradable since tradable components carry greater weight in the broader category.[17]

Figure 2.2 exhibits a consistent pattern that Good 5 and Good 7 (both highly tradable) show the highest cross-border volatility in both periods. On the other hand, non-tradable goods like Good 2 and Good 4 tend to display the lowest volatility. This outcome highlights a clear empirical pattern: tradable goods exhibit higher real exchange rate volatility, while non-tradables have lower volatility. At first glance, this result appears to contradict theoretical expectations. In theory, prices of tradable goods should converge and result in lower price dispersion across countries due to arbitrage opportunities and demand-supply mechanisms. For example, if T-shirts are cheaper in Country 1 than Country 2, consumers and retailers would buy them in Country 1 and resell them in Country 2, where prices are higher. This arbitrage increases demand for T-shirts in Country 1, which will increase prices, while an increase in supply in Country 2 decreases prices of T-shirts until prices reach a common equilibrium.

In practice, however, market frictions such as tariffs and transportation costs limit perfect arbitrage. In addition, prices of tradable goods tend to be more flexible than those of non-tradables. They often respond more quickly to changes in exchange rates and global market

[17] I refer to the relative importance of components in the Consumer Price Indexes table (U.S. City Average, CPI-U) provided by BLS.

conditions. These faster price adjustments result in variations in relative prices across borders, thereby increasing real exchange rate volatility. By contrast, prices for non-tradable goods are based on local conditions. This indicates that while the absolute price levels of non-tradables may differ substantially across countries, their relative price movements tend to be stickier and more stable over time, producing lower cross-border price volatility.

The notable spikes in volatility for Good 5 and Good 7 suggest unique characteristics of these industries beyond the U.S.-Canada nominal exchange rate and their relative price ratios. Both categories are highly tradable and connected to global market dynamics. Good 5 (Fuels and Utilities) include items such as fuel oils and electricity. Their prices may depend on geopolitical events and infrastructure constraints. While fuels are globally traded, utilities such as electricity are typically subject to regional supply constraints. Nonetheless, prices of electricity are influenced by fuel costs. This combination of global exposure and localized constraints can lead to asymmetric price movements across the U.S.-Canada border, contributing to higher volatility. Good 7 (Apparel) is a highly import-dependent industry in both the U.S. and Canada, as noted by ER. This implies that the countries would face greater variation in international trade barriers. Moreover, apparel prices are inherently volatile due to seasonality, fashion trends, and differing consumer preferences. When consumer tastes or demand patterns diverge between the U.S. and Canada, cross-border price dispersion tends to rise.

5.2.2 Regression Results. Regression results for the second period can be found in Table 4.2. The estimated coefficients for the log of distance are mostly positive. One good has a negative coefficient, but again, it is not statistically significant and not intuitive. Among the 10 goods, Good 3 (Alcoholic Beverages) and Good 8 (Transportation) are statistically significant at the 1% level, while Good 7 (Apparel) is significant at 10%. The border dummy coefficients are all positive and highly significant, with nine goods significant at 1% and one good at the 5%

level. In the pooled regression, the coefficient for the log of distance is 0.0001027 (significant at 10%), and the border dummy coefficient is 0.017635. Overall, in the second period, the relationship between price volatility, distance, and border remains consistent, as greater distance and the presence of a border lead to higher price deviation. However, compared to the first period, the average coefficients for both variables have increased, suggesting that the impact of distance and the border on price volatility has strengthened over time.

5.2.3 How Much Wider Is the Border Now? The regression model for the second period (1998-2024) is:

$$\sigma_{j,k}^{i} = \beta_0^i + 0.001027 ln\, d_{j,k} + 0.017635 B_{j,k} + u_{j,k}^{i}$$

Given that the average distance between all 121 location pairs is about 1,370 miles,[18] I calculate the implied border width as follows:

$$\Delta\, d_{j,k} = \frac{0.017635}{0.001027} \cdot 1{,}370 \approx 23{,}500\; miles$$

Compared to the estimated border width in the first period (22,800 miles), the border has become widened by approximately 700 miles in the second period. However, since this difference is too little, I interpret this as little to no progress in U.S.-Canada market integration over time. This finding contradicts my initial hypothesis about declining border effect over time—over the three decades, the U.S. and Canada has not become integrated even though many factors such as globalization and digitalization appear to increase connectivity between countries.

However, can we conclude here that the U.S. and Canada made no indication of progress for economic integration at all over the past 30 years? The 21st century have experienced two

[18] Recall that my location pairs for the first and second period are different due to data structure change in BLS in 1998. This results in different number of pairs (124 and 121 pairs) and different values for distance (1330 and 1370 miles) from the first period.

major global shocks, namely the GFC in 2008 and COVID-19 pandemic in 2020. These recessions negatively affected global countries' economic activity and led to increased protectionist policies around the world. These shocks may have temporarily widened the border effect, disrupting any long-term trend toward integration. To examine this further, I split the second period into two sub-periods: January 1998-December 2007 (Non-Turbulent Period) and January 2008-December 2024 (Turbulent Period). The Non-Turbulent Period corresponds to the Great Moderation, a period of economic stability, while the Turbulent Period includes both the GFC and COVID-19, which introduced significant economic disruptions. Comparing these two sub-periods is helpful to determine whether economic integration had improved before the outbreak of these global crises and whether the border effect has changed by these external shocks.

5.3 Sub-Second Periods: Non-Turbulent vs. Turbulent Period

5.3.1 Average Price Volatility Comparison. Table 3.2.1 and 3.2.2 present the average volatility of the real exchange rate for each of the 10 goods during the Non-Turbulent and Turbulent periods. Examining both periods again confirms that the U.S. is more heterogeneous than Canada and that cross-border volatility is generally the highest. However, there is an exception in the Non-Turbulent period, where the price volatility of Good 5 (Fuels and Utilities) for Canada is the highest, exceeding even international volatility. Recall that for the first period, the U.S. had the highest volatility for this good. This implies that fuels and utilities have unique characteristics that drive intranational price dispersion more than international price fluctuations. Since both the U.S. and Canada participate in global energy markets, price movements for fuels and utilities should affect them in a similar way. When both economies respond to the same external shocks, it reduces the price volatility between the two countries, which leads to lower cross-border price dispersion. Along with this, fuels and utilities display the highest volatility among all goods. A possible explanation is that energy prices are highly sensitive to various external factors, including weather conditions, seasonal demand, geopolitical events, and infrastructure constraints. Moreover, fuels and utilities are considered inelastic goods. This means consumer demand is not very responsive to price changes for these goods. Since these commodities are essential and have limited substitutes, consumers need to purchase them although the prices are high. Thus, price fluctuations can be larger than for other goods, resulting in higher overall volatility.

The average cross-border price volatility for the Non-Turbulent period is 0.0389, and that for the Turbulent period is 0.0381. Although the Non-Turbulent period exhibits slightly higher volatility, the difference is too minimal. The similar levels of cross-border price dispersion before and after the two major shocks suggest that the GFC and COVID-19 pandemic do not seem to have a reasonable impact on international price volatility. One plausible explanation lies in how volatility is measured. I calculate price volatility as the standard deviation of the growth rate of the “relative price series” for each good between two locations. The GFC and COVID-19 were “global” or “aggregate” shocks that affected all countries, rather than asymmetric shocks that affected either only the U.S. or only the Canada. While absolute price levels may have significantly fluctuated due to these shocks, the real exchange rate only captures relative price movements. For example, if both countries have the same level of increase in prices, the price ratio would still stay the same. As a result, the relative price deviations between the U.S. and Canada remained stable in the second period. Therefore, revisiting the hypothesis posed in 5.2.1—whether the two global economic shocks played a role in increasing the cross-border price volatility in the second period (0.0390) compared to the first period (0.0282)—the evidence suggests that the GFC and COVID-19 did not increase international price volatility because both countries were equally affected by these crises.

5.3.2 Regression Analysis. Table 4.2.1 and 4.2.2 summarize the regression results for the Non-Turbulent and Turbulent period. Consistent with my earlier findings, the coefficients for the log of distance are positive in most cases, except for one or two goods. Meanwhile, the coefficients for the border dummy variable are all positive and mostly significant at 1%, reaffirming the strong explanatory power of the border on price dispersion. The pooled regression results show that the coefficients for the log of distance and border are 0.001274 (not significant) and 0.016877 (significant at 1%), respectively, for the Non-Turbulent period (1998-2007). For the Turbulent period (2008-2024), the coefficients are 0.0008274 (not significant) and 0.01765 (significant at 1%), respectively. Although the border coefficients are slightly higher in the Turbulent period, I am cautious to conclude whether the border effect has strengthened—I need to consider the interaction between the border coefficient, the distance coefficient, and the average distance. This is examined in the next section through the calculation of border width.

A notable pattern in the entire second period and the two sub-second period results is that the log of distance is largely not statistically significant across goods, except for three categories: Good 3 (Alcoholic Beverage) and Good 8 (Transportation), which are statistically significant at 5% or 1%, and Good 7 (Apparel), which is significant at the 10% level. There are several possible explanations for why these specific goods maintain a significant distance effect. First, transportation costs play a direct role in price variation for these goods. For transportation services themselves, greater distance naturally leads to higher shipping and labor expenses, which makes distance a key explanation for price volatility. Similarly, transportation costs can affect prices of alcoholic beverage and apparel. Unlike perishable goods such as food, which are often produced and consumed locally, alcoholic beverage and apparel are more likely to be traded and transported across long distances. As a result, the farther the regions apart, the more significant price differences are created. Second, regulations and market variations can contribute to price dispersion. Alcoholic beverages are often subject to differing regional regulations, taxes, and distribution laws. These variations are stronger across locations. Likewise, apparel prices may be influenced by regional fashion trends and consumer preferences, which may lead to different price strategies between locations. Overall, goods that are highly tradable and subject to strong regional variations are more likely to exhibit a significant distance effect.

5.3.2. The GFC and COVID-19 on the Border Effect. My regression result for the period between 1998 and 2007 is as follows:

$$\sigma_{j,k}^{i} = \beta_0^{i} + 0.001274 ln\, d_{j,k} + 0.016877 B_{j,k} + u_{j,k}^{i}$$

Using the coefficients, the estimated border width for the Non-Turbulent period is:

$$\Delta\, d_{j,k} = \frac{0.016877}{0.001274} \cdot 1{,}370 \approx 18{,}100\; miles$$

For the period between 2008 and 2024, the regression results are:

$$\sigma_{j,k}^{i} = \beta_0^{i} + 0.000827\, d_{j,k} + 0.01765 B_{j,k} + u_{j,k}^{i}$$

This gives the border width for the Turbulent period as:

$$\Delta\, d_{j,k} = \frac{0.01765}{0.000827} \cdot 1{,}370 \approx 29{,}200\; miles$$ [19]

The results indicate that the border width increased by more than 10,000 miles in the Turbulent period. This underscores the devastating impact of the two global economic shocks on the market integration between the U.S. and Canada. This finding directly answers my second research question: the global economic shocks substantially increased the border effect.

[19] When applying ER's method to calculate border width, I obtained 28 million miles for the first period, 28.8 million miles for the second period, 566 thousand miles for the Non-Turbulent period, and 1.8 billion miles for the Turbulent period. Despite the variation in magnitude, the overall pattern remains consistent with my conclusion.

Meanwhile, recall that the border width for the first period (1978-1997) was 22,800 miles. The border width for the Non-Turbulent period (1998-2007) is even smaller at 18,100 miles—a reduction of approximately 4,700 miles. This highlights that prior to the GFC, the U.S. and Canada were making notable progress in market integration. However, the financial crisis and subsequent pandemic ended this progress, making the two countries more isolated.[20]

Reassessing the long-term trend, the border width for the entire second period (1998-2024) is approximately 23,500 miles—less than 1,000 miles wider than the first period. This does not necessarily indicate that there was little or no progress in integration over the last 30 years. Instead, it illustrates that after two global shocks, the level of integration has returned back to those observed in the last 20th century. The impact of the GFC and COVID-19 on economic segmentation appears to have erased much of the progress in integration achieved during the early 2000s.

6. The Border Effect and Market Integration with Mexico

This section extends ER's study by incorporating Mexico into the analysis. The main objective is to address the first research question: how much wider are the Mexico-U.S. and Mexico-Canada borders compared to the U.S.-Canada border today? This question is of interest for two key reasons. First, Mexico is a developing country with cultural and economic characteristics that differ substantially from those of the U.S. and Canada. This inclusion is notable because many studies on the border effect have focused on seemingly well-integrated economies, such as the U.S.-Canada relationship or the European unions. I hypothesize that due to its differing economic

[20] I further divide the second period into 1998–2017 (not reported) and compare its estimated border width with that of 1998–2024. The results show that the border width was approximately 27,600 miles in 1998–2017, whereas it decreased to 23,500 miles for the entire second period. This suggests that the GFC had a more severe impact on price volatility and economic fragmentation than the COVID-19 pandemic.

status, the border width between Mexico-U.S. and Mexico-Canada will be greater than that between the U.S. and Canada. Second, examining the border effects among the U.S., Canada, and Mexico allows for a direct analysis of how free trade agreements—specifically, NAFTA and its successor USMCA—have impacted North American integration. Mexico shifted from a protectionist stance to a more open economy, notably through NAFTA's implementation in 1994. I hypothesize that NAFTA's reduction of trade barriers significantly enhanced market integration between Mexico and its North American partners.

6.1 Data

To analyze price dispersion involving Mexico, I use the CPI data published by the National Institute of Statistics and Geography (INEGI). Unlike the U.S. and Canada, Mexico does not provide city- or state-level CPI data disaggregated by individual expenditure categories. Therefore, I instead utilize national-level CPI data for Mexico. Accordingly, I match Mexico country with each U.S. city and Canadian province used in earlier analyses. The category of items for Mexico tend to be broader than the U.S. and Canada. For instance, items like food, drinks, and tobacco are aggregated into a single category. To align this data with the 10 categories used for the U.S. and Canada, I follow ER's methods and apply weights (the relative importance of components in CPI) provided by BLS to disaggregate broader categories and manually reconstruct comparable categories. Table 1.3 reports how each Mexican CPI category corresponds to the 10 goods. Further calculation details can be found in the appendix. The Mexico's country CPI data are published monthly. I examine the same periods covering from September 1978 to December 1997 (Period 1) and from January 1998 to December 2024 (Period 2) in order to analyze the evolution of the border width among the three countries over time.

6.2 Model

I use the same baseline regression model from Section 4, now extended to include three distinct border dummy variables: the U.S.-Canada, Mexico-U.S., and Mexico-Canada. The regression model is specified as:

$$\sigma_{j,k}^{i} = \beta_0^i + \beta_1^i ln\, d_{j,k} + \beta_2^i USCA_{j,k} + \beta_3^i USM_{j,k} + \beta_2^i CAM_{j,k} + u_{j,k}^i$$

where *i* denotes the good category, $\sigma_{j,k}^{i}$ is the standard deviation of the growth rate of the real exchange rate for good *i* between locations *j* and *k*[21], $ln\, d_{j,k}$ is the log of the geographic distance between *j* and *k*, $USCA_{j,k}$ is a border dummy variable equal to 1 for U.S.-Canada pairs (same as $B_{j,k}$ in Section 4), $USM_{j,k}$ is a border dummy variable between the U.S. and Mexico, which takes value 1 for 11 U.S. cities and Mexico country pairs, $CAM_{j,k}$ is a border dummy variable equal to 1 for 6 Canadian provinces and Mexico country pairs, and $u_{j,k}^i$ is an error term. As a result, the location pairs (j, k) now include city-city (within the U.S.), city-province (the U.S.-Canada pairs), province-province (within Canada), city-country (Mexico-U.S.) and province-country (Mexico-Canada) combinations.

The distance between Mexico country and 11 U.S. cities and between Mexico country and 6 Canadian provinces are calculated using weighted average method described in Section 4.2. Specifically, I use Mexico City and Tijuana—the two most populous cities in Mexico—to represent the country. Each city's populations are used as the weighting factor. Table 2.2 summarizes information on these cities. The calculations for city-county and province-country distance exactly follow the distance formulas from section 4.2.1 and 4.2.2., respectively.

6.3. Statistical Results

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[21] Monthly nominal exchange rate data for Mexico-U.S. and Mexico-Canada are sourced from fxtop.com for the period 1978-1993. From 1993 to 2024, data are obtained from FRED (Mexico-U.S.) and Statistics Canada (Mexico-Canada).

The expanded dataset includes 11 Mexico-U.S. city pairs and 6 Mexico-Canada province pairs in addition to the previous U.S.-Canada combinations. This expansion results in 141 location pairs for the first period (1978-1997) and 138 pairs for the second period (1998-2024) for each good *i*. Across 10 categories of goods, this yields 1,410 in the first and 1,380 observations in the second period. As mentioned earlier, the difference in the number of location pairs between the two periods reflects changes in the availability of U.S. city data due to a shift in the publication frequency change in BLS. For each of the 141 and 138 location pairs, I calculate the volatility of the real exchange rates between *j* and *k* over the respective sample periods, following the model detailed in Section 6.2. I then regress the calculated price volatility on the log of the distance and the three border dummy variables for each good *i*.

6.3.1. Real Exchange Rate Volatility Patterns

6.3.1.1 Price Volatility: Period 1 vs. Period 2. Table 5.1 and 5.2 report the three countries' average cross-border volatility for each of the 10 goods during the period 1978-1997 and 1998-2024, respectively. These tables include previously reported U.S.-Canada volatility data from Tables 3.1 and 3.2 and introduce new volatility values for Mexico-U.S. and Mexico-Canada pairs. The main objective is to compare price dispersion across U.S.-Canada pairs with those involving Mexico.

During the first period (September 1978 to December 1997), the average real exchange rate volatility for both Mexico-U.S. and Mexico-Canada pairs behaved closely at approximately 0.2—nearly ten times higher than that of the U.S.-Canada pair. Yet, compared to the U.S.-Canada volatility, the variation across 10 goods remained relatively stable, except for Good 8 (Transportation), where the two Mexico-related pairs exhibited the highest price volatility. Figure 3.1 visualizes the values in Table 5.1 and highlights two key insights. First, the gap in price volatility between U.S.-Canada and pairs involving Mexico is substantial: the price dispersion for

Mexico-U.S. and Mexico-Canada pairs is sharply higher than that of U.S.-Canada. Higher price volatility indicates that the LOOP does not hold well between the U.S., Canada, and Mexico, likely due to frictions such as tariffs and trade costs. Supporting this, the Executive Office of the President (1997) reported that Mexico's average tariff on all imports from the U.S. in 1993—a year before NAFTA—was 10%, compared to only 0.37% for Canadian tariffs on U.S. goods. From the U.S. perspective, this made Mexican goods significantly more expensive relative to Canada. Second, volatility patterns for Mexico-U.S. and Mexico-Canada were nearly identical, with both Mexico-related lines nearly overlapping in Figure 3.1. This overlap suggests that prior to NAFTA, Mexico maintained a similar level of protectionism toward both the U.S. and Canada, which leads to equally high levels of price dispersion across Mexico border.

Moving on to the second period (1998-2024), cross-border price volatility declined significantly for both Mexico-related pairing. In particular, the average Mexico-U.S. price volatility declined sharply from 0.2 in the first period to 0.05 in the second period, and Mexico-Canada volatility dropped to around 0.04, approaching the U.S.-Canada level. Figure 3.2, which visualizes Table 5.2, shows that the gap in real exchange rate volatility between the three country pairs is much smaller than in the first period. This convergence points to improved market integration and more consistent pricing behavior across North America. Given its timing and scope, NAFTA's reduction of trade barriers is likely a driver of this integration.

6.3.1.2 Cross-Border Price Volatility: Tradable vs. Non-tradable Goods. In Section 5.2.1.2, I found that tradable goods tend to exhibit higher cross-border price volatility between the U.S. and Canada. Here, I examine whether this pattern also holds in the trilateral context. During the first period, price volatility for Mexico-U.S. and Mexico-Canada pairs did not have a large fluctuation across all goods, except for Good 8 (Transportation), which stood out with particularly high volatility. Prior to NAFTA, Mexico had not yet liberalized trade with the U.S.

and Canada. As a result, nominal exchange rate movements and trade-related costs may not have significantly influenced prices. This could explain the relatively stable volatility across all sample goods, especially if we assume that non-tradable goods have more stable price behavior. However, Transportation category appears to be an outlier. A plausible explanation has to do with Mexico's protectionist auto decrees and its subsequent revisions. Beginning in the 1960s, Mexico imposed a series of Auto Decrees that promoted domestically-produced automotive products. This led to a high import tariffs (as high as 25%) and restrictions on foreign auto firms. However, the final decree in 1989 substantially liberalized Mexican policy on the auto sector even though the restrictions were not entirely removed such as export requirement (Congressional Research Service, 2017). Still, these shifting policies—from protectionist to openness—may have contributed to higher volatility for Good 8 in the first period.

After NAFTA came into effect, a new pattern emerged: all three cross-border pairs behaved similarly with Good 5 and Good 7 having the highest volatility. Unlike the U.S.-Canada, Good 8 also showed higher volatility for Mexico-related pairs, following Goods 5 and 7. This result likely reflect the fact that the automotive industry in Mexico benefited significantly from NAFTA's trade liberalization. For example, between 1993 and 2016, U.S. auto exports to Mexico increased by 262%, and imports from Mexico rose by 765%. By 2016, Mexico had become the U.S.'s top auto supplier, surpassing Canada (Congressional Research Services, 2017). Accordingly, Good 8 became highly tradable, similar to Good 5 and 7, and its volatility became higher. Thus, the pattern found for the U.S.–Canada case that tradable goods tend to exhibit higher cross-border volatility also holds in the case of Mexico.

6.3.2. Regression Results: Period 1 vs. Period 2. Table 6.1 and 6.2 summarize the regression results for the first and second period. Overall, the regression results are consistent with those found in the U.S.-Canada analysis: the coefficients on the log of distance are mostly positive, except for one to three goods. However, the coefficients for all three border dummies are positive and highly significant at or below the 5% level.

In the first period (1978-1997), the distance coefficient is only significant for Good 3 and Good 8 (highly significant at or below the 5% level) and for Good 1 and 5 (significant at the 10% level). The border dummy for the U.S.-Canada is all highly significant except for Good 5, while that for Mexico-related pairs are all highly significant at 1%. The pooled regression results show that the coefficient for the log of distance is 0.000538 (not significant) and U.S.-Canada border, Mexico-U.S. border, and Mexico-Canada border are 0.008003, 0.183566, and 0.183738 (all border coefficients are significant at 1%), respectively. Like the similar price volatility trend observed for Mexico-U.S. and Mexico-Canada in the first period (Section 6.3.1), the border coefficients of the two Mexico-related pairs are similar at around 0.18. These values (0.18) are significantly larger than that of U.S.-Canada pairs (0.008), meaning that the existence of Mexico border increases North American price volatility sharply. Given the shared distance coefficient, based on the border width equation in Section 5.1.3., these differences in the border coefficients lead to larger border widths for Mexico-related pairs.

In the second period (1998-2024), the coefficient for the log of distance is highly significant for Good 3 and 8 (at 1%) and slightly significant for Good 1 and 7 (at 10%). It is important to note that throughout the whole sample period, distance strongly explain price volatility for Good 3 (Alcoholic beverage) and Good 8 (Transportation) only—those likely to be subject to transportation costs. This result is similar to U.S-Canada regression outputs in Section 5.3.2. The border dummy for U.S.-Canada and Mexico-U.S. are all significant at 5% level or below, while that for Mexico-Canada is significant at 1% except for three goods. Still, the pooled regression shows that all border coefficients have a strong explanatory power. The regression results show that the log distance coefficient is 0.0009746 (not significant), and the U.S.-Canada border, Mexico-U.S. border, and Mexico-Canada border are 0.01765, 0.0307, and 0.0215 (all border coefficients are significant at 1%), respectively. Compared to the first period, the difference between the three border coefficients became smaller, but still, border dummy for Mexico-related pairs remain larger than the U.S.-Canada coefficient. Again, this pattern is similar to the figure 3.2 where the gap in price dispersion between the three country pairs has narrowed over time.

6.3.3. Border Width Comparison. For the period between September 1978 and December 1997, the regression results are as follows (intercept and error terms are omitted):

$$\sigma_{j,k}^{i} = 0.000538 ln\ d_{j,k} + 0.008003 USCA_{j,k} + 0.183566 USM_{j,k} + 0.183738 CAM_{j,k}$$

Now, I can use the distance coefficient and three different border dummy coefficients to calculate border width for each U.S.-Canada, Mexico-U.S., and Mexico-Canada pair. For the actual distance term, I calculate the average distance of the corresponding location pairs. For example, Mexico-Canada border width calculation involves average distance of 6 Mexico country and Canadian province pairs. The average distance of the 124 U.S.-Canada pairs (including within country pairs) is 1,330 miles (same as Section 5.1.3), that of the 11 Mexico-U.S. pairs is 1,661 miles, and that of the 6 Mexico-Canada pairs is 2,164 miles. The following values represent the border width of U.S.-Canada, Mexico-U.S., and Mexico-Canada, respectively. To make it clear, I denote (j, k) as country names, but the actual location pair involve cities for the U.S. and province for Canada.

$$\Delta\ d_{US,Canada} = \frac{0.008003}{0.000538} \cdot 1{,}330 \approx 19{,}800\ miles$$

$$\Delta\ d_{Mexico,US} = \frac{0.183566}{0.000538} \cdot 1{,}661 \approx 566{,}800\ miles$$

$$\Delta\ d_{Mexico,Canada} = \frac{0.183738}{0.000538} \cdot 2{,}164 \approx 739{,}000\ miles$$

Recall that in Section 5.1.3., the border width between the U.S. and Canada in the first period was 22,800 miles. The U.S.-Canada border width after including Mexico pairs results in 19,800 miles, similar to the previous finding. This reaffirms the status of U.S.-Canada market integration during 1978-1997.

The Mexico-related border widths, by contrast, are strikingly large. The Mexico–U.S. border width is over 29 times larger than the U.S.–Canada width, while Mexico–Canada is more than 37 times larger. To contextualize, these border widths exceed even the average distance between the Earth and the Moon (about 238,900 miles), highlighting the extreme degree of market segmentation between Mexico and its northern neighbors before NAFTA. Several factors may explain this result. First, the U.S. and Canada are both developed countries, while Mexico is a developing country. Developed-developing country pairs have more segmented markets because developing countries tend to have higher tariffs to protect domestic industries. This was indeed true in Mexico as they reduced about 7.1% tariff on U.S. goods right after NAFTA went into effect (Clinton, 1997). Developing countries also tend to have less developed infrastructure and weaker distribution network, which increases production and transportation costs. This makes cross-border trade more costly. Second, Mexico does not share similar culture and language like the U.S. and Canada. As Fielding et al. (2015) found, differences in language and religion increase trade costs and reduce integration.

In Section 6.3.1., I found that the cross-border price volatility for the two Mexico-related pairs was similar because Mexico's trade policies were generally protectionist toward both neighboring countries. However, similar volatility of real exchange rate does not necessarily mean that the extent of economic integration is also the same. Comparing Mexico-U.S. and Mexico-Canada border width, Mexico had a stronger border effect with Canada than the U.S. In fact, trade between Mexico and Canada was relatively limited before NAFTA. U.S. export to

Mexico reached \$41.6 billion in 1993, compared to \$0.6 billion Canadian export to Mexico.[22] Mathematically, different border width is resulted from the different distance value since the two Mexico-related pairs share the same distance coefficient and similar border dummy coefficient. Mexico is geographically closer to the U.S. than Canada (1,661 < 2,164 miles). It seems that due to geographical distance and less developed bilateral economic ties, market between Mexico and Canada was more segmented before NAFTA.

For the second period (1998-2024), the pooled regression results can be expressed as:

$$\sigma_{j,k}^{i} = 0.0009746 ln\, d_{j,k} + 0.0176476 USCA_{j,k} + 0.0306859 USM_{j,k} + 0.0214549 CAM_{j,k}$$

The average distance of the 121 U.S.-Canada pairs is 1,370 miles (as reported in Section 5.2.3), that for the 11 Mexico-U.S. pairs and 6 Mexico-Canada pairs is 1,661 miles and 2,164 miles, respectively. Using these values, the estimated border widths for U.S.-Canada, Mexico-U.S., and Mexico-Canada in the second period are as follows:

$$\Delta\, d_{US,Canada} = \frac{0.0176476}{0.0009746} \cdot 1{,}370 \approx 24{,}800\ miles$$

$$\Delta\, d_{Mexico,US} = \frac{0.0306859}{0.0009746} \cdot 1{,}661 \approx 52{,}300\ miles$$

$$\Delta\, d_{Mexico,Canada} = \frac{0.0214549}{0.0009746} \cdot 2{,}164 \approx 47{,}600\ miles$$

The border width between the U.S. and Canada, at approximately 24,800 miles, closely aligns with the previous estimate obtained in Section 5.3.2. (23,500 miles) when Mexico-related pairs were not included. This consistency reinforces the earlier conclusion that the slight increase in U.S.-Canada border width over time can be attributed to the disruptive impact of the two major shocks in the 21st century.

What stands out, however, is the substantial narrowing of the border widths for the

[22] The sources are from UN Comtrade Database. The trade values are reported in U.S. dollars.

Mexico-U.S. and Mexico-Canada pairs. Although these border widths remain twice larger than the U.S.-Canada value and even higher than 29,200 miles reported for the U.S.-Canada border in the Turbulent Period (Section 5.3.2.), the reduction is meaningful. The Mexico-U.S. border width decreased by approximately 10%, while the Mexico-Canada border width dropped by about 60% relative to the previous period. This sharp decline in the border effect demonstrates notable progress in market integration across North America. One compelling contributor to this improvement is the implementation of NAFTA in 1994. As mentioned in Introduction, NAFTA significantly liberalized trade between the U.S., Canada, and Mexico. This reduction in trade frictions likely played a central role in narrowing price gaps and improving market integration, as reflected in the lower border widths. Ultimately, the positive effect of NAFTA outweighed the devastating effect of the global shocks such that North American market integration has improved overall in the post-NAFTA period.

It is important to highlight that a reduced border width (weaker border effect) does not necessarily imply overall economic growth or welfare improvement. NAFTA has been subject to considerable debate regarding its impact on labor, wages, and inequality—particularly in Mexico. Nevertheless, the findings here indicate that cross-border price behavior moved more closely together, which suggests reduced market segmentation and increased arbitrage opportunities.

7. Conclusion

This paper examines price differences across North America countries—the U.S., Canada, and Mexico—building upon Engel and Roger (1996)'s study on the U.S-Canada border effect. The primary objective was to update their findings using more recent data and to broaden the scope by incorporating Mexico, allowing for a trilateral evaluation of border effects. Using CPI data from 1978 to 2024, I first compare U.S.-Canada border effects across two periods: 1978-1997 and

1998-2024. I then further split the second period to assess the role of global economic shocks, distinguishing between 1998-2007 and 2008-2024. After U.S.-Canada analysis, I integrate national-level CPI data for Mexico and investigate how the U.S.-Canada, Mexico-U.S., and Mexico-Canada border effects have evolved over time. The key findings of this study are as follows. First, U.S.-Canada market integration improved up until the GFC, as reflected by a notable decline in border width. Second, the two global shocks (the GFC and COVID-19) reversed this progress by significantly increasing the border effect and contributing to renewed market segmentation. Third, the analysis confirms that countries at different stages of development—such as Mexico relative to the U.S. and Canada—experience wider border effects due to higher trade frictions. Finally, the implementation of free trade agreements such as NAFTA and its successor, USMCA, increased trade and investment flows. These trade agreements played a critical role in reducing trilateral border effects, fostering market integration among the participating countries.

In terms of the real exchange rate volatility, this paper also provides three takeaways. First, U.S.-Canada price volatility was largely unaffected by the GFC and COVID-19 since these shocks were global (but not regional) shocks that affected both countries similarly. Second, the increase in U.S.-Canada price volatility during the second period is likely explained by sticky prices, as higher nominal exchange rate movement increases real exchange rate volatility. Third, my results for all North American countries across all periods indicate that tradable goods show higher volatility, while non-tradable goods tend to be less volatile. The notion of flexible and sticky prices may also explain this pattern since prices tend to fluctuate more for tradable goods, depending on nominal exchange rates, trade policy changes, and global demand shifts.

While national borders continue to be a strong explanatory power in determining price volatility, the coefficient on distance is generally insignificant in my regressions. This finding differs from Engel and Rogers (1996) and could be due to several methodological differences: the use of national- or province-level CPI data (as opposed to city-level pairs), a reduced number of U.S. cities in the sample, and broader item classifications. The weighted average method used to calculate distances between locations other than city pairs does not appear to explain the insignificance of the distance variable. However, it may also imply a structural change: physical distance simply matters less in the age of globalization and internet shopping. This result remains open for further investigation. Nevertheless, the broader conclusion of this paper is clear: despite increasing globalization and liberalization of trade, borders still matter. Price convergence across countries remains incomplete, and markets continue to exhibit segmentation—especially during times of economic crisis or between countries with different levels of economic development. The evolution of border effects in North America thus reflects both the progress and limitations of market integration in a globalized world.

References

Bailey, M., Gupta, A., Hillenbrand, S., Kuchler, T., Richmond, R., & Stroebel, J. (2021). "International Trade and Social Connectedness." *Journal of International Economics,* 129.

Beck, G. W., Kotz, H. H., & Zabelina, N. (2020). "Price Gaps at the Borders: Evidence from Multi-country Household Scanner Data." *Journal of International Economics*, 127.

Boivin, J., Clark, R., & Vincent, N. (2012). "Virtual Borders." *Journal of International Economics*, 86, 327-335.

Chahrour, R., & Stevens, L. (2020). "Price Dispersion and the Border Effect." *Journal of Monetary Economics*, 116, 135-146.

Clark, T. E., & Wincoop, V. E. (2001). "Borders and Business Cycles." *Journal of International Economics*, 55, 59-85.

Clinton, B. (1997). *Study on the operation and effects of the North American Free Trade Agreement.* Washington, D.C.: President of the U.S.

Congressional Research Service (2017). *The North American Free Trade Agreement (NAFTA)*. https://www.congress.gov/crs-product/R42965.

Coughlin C. C., & Novy, D. (2021) "Estimating Border Effects: The Impact of Spatial Aggregation." *International Economic Review*, 62(4), 1453-1487.

Engel, C., & Rogers, J. H. (1996). "How Wide Is the Border?" *American Economic Review*, 86 (5), 1112–1125.

Fielding, D., Hajzler, C., & Macgee, J. (2015). "Distance, Language, Religion, and the Law of One Price: Evidence from Canada and Nigeria." *Journal of Money, Credit, and Banking,* 47(5), 1007-1029.

McCallum, J. (1995). "National borders matter: Canada-U.S. Regional trade patterns." *American*

Economic Review, 85 (3), 615–623.

Messner, T., Rumler, F., & Strasser, G. (2024). “Cross-country Price Dispersion: Retail Network or National Border?” *Journal of International Economics*, 152.

Parsley, C. D., & Wei, S. (2001). “Explaining the Border Effect: The Role of Exchange Rate Volatility, Shipping Costs, and Geography.” *Journal of International Economics*, 55, 87-105.

Schmitt-Grohe, S., Uribe, M., & Woodford, M. (2022). *International Macroeconomics: A Modern Approach*. Princeton, NJ: Princeton University Press.

Data Appendix

All price data used in this study are seasonally unadjusted. The 10 categories of goods follow the BLS classification and are listed on the left-hand side of Table 1.1. I use comparable price data for Canada obtained from Statistics Canada and Mexico from the National Institute of Statistics and Geography. Since the price indexes do not exactly match across countries, I utilize the Relative Importance of components in the CPI (2022 weights) provided by BLS to construct comparable series. For example, Mexico reports a single aggregated category of Food, Drinks, and Tobacco. According to BLS weights, Food and beverages accounts for 14.409 and Tobacco and smoking products for 0.542, totaling 14.951. I then apply the relative shares of the subcategories: Food at home – 8.167, Food away from home – 5.388, and Alcoholic beverages – 0.854. Therefore, Good 1 is calculated as (8.167/14.951)*Food, Drinks, and Tobacco; Similarly, Good 2 = (5.388/14.951)*Food, Drinks, and Tobacco; and Good 3 = (0.854/14.951)*Food, Drinks, and Tobacco. Table 1.1 and 1.3 provide details how each series is derived.

Monthly price data are used for 6 Canadian provinces and the national CPI for Mexico. Since I only match odd-odd or even-even pairs, I choose odd-numbered months for all monthly-monthly pairing to calculate real exchange rate volatility. For BLS data, only Chicago, New York, and Los Angeles provided monthly data across both periods. Philadelphia provided monthly data only in the first period. In the first period, three cities—Boston, Miami, and Washington, DC—publish data in odd-numbered months, while the remaining four cities—Dallas, Detroit, Houston, and San Francisco—publish in even-numbered months. In the second period, Dallas, Miami, and Philadelphia changed its publication frequency. Accordingly, Boston, Dallas, and Washington, DC provide data in odd months, while Detroit, Houston, Miami, Philadelphia, and San Francisco publish in even months. These changes in publication frequency result in different sets of location pairs for the first and second periods.

Table 1.1. Categories of Goods in CPI: BLS and Comparable Statistics Canada

	U.S.	Canada
1	Food at home	Food purchased from stores
2	Food away from home	Food purchased from restaurants
3	Alcoholic beverages	Alcoholic beverages
4	Shelter	Shelter – 0.1077*(Water, fuel, and electricity)
5	Fuel and other utilities	Water, fuel, and electricity
6	Household furnishings and operations	Household operations, furnishings and equipment
7	Apparel	Clothing and footwear
8	Transportation	Transportation
9	Medical care	Health care
10	Recreation	0.9808*(Recreation) + 0.0192*(Reading material)

Table 1.2 Regions Used

	U.S. (city)	Canada (Province)
1	Boston	Alberta
2	Chicago	Quebec
3	Dallas	Ontario
4	Detroit	Saskatchewan
5	Houston	British Columbia
6	Los Angeles	Manitoba
7	Miami	
8	New York	
9	Philadelphia	
10	San Francisco	
11	Washington, DC	

Table 1.3. Categories of Goods in CPI: BLS and Comparable INEGI

	U.S.	Mexico
1	Food at home	0.5463*(Food, Drinks, Tobacco)
2	Food away from home	0.3604*(Food, Drinks, Tobacco)
3	Alcoholic beverages	0.0571*(Food, Drinks, Tobacco)
4	Shelter	0.8031*(Housing)
5	Fuel and other utilities	0.0969*(Housing)
6	Household furnishings and operations	Furniture, appliances, and household accessories
7	Apparel	Clothes, shoes, and accessories
8	Transportation	Transport
9	Medical care	0.7725*(Health and personal care)
10	Recreation	0.6807*(Education and leisure)

Notes: Each item category for Mexico has been translated into English.

Table 2.1 Canadian States, Corresponding Cities, and Population

Province	Major Cities	2021 Census of Population
Alberta	Calgary	1,305,550
	Edmonton	1,151,635
Quebec	Montreal	1,762,949
	Quebec	549,459
Ontario	Toronto	2,794,356
	Ottawa	1,017,449
Saskatchewan	*Saskatoon	266,141
	Regina	226,404
British Columbia	Vancouver	662,248
	*Surrey	568,322
Manitoba	Winnipeg	749,607
	*Brandon	51,313

Notes: The mark * denotes the cities introduced in this study as a purpose to calculate the distance between city-province and province-province pairs. Other 9 cities are used in ER's 1996 paper.

Table 2.2 Mexico: Corresponding Cities, and Population

Country	Major Cities	2020 Population and Housing Census
Mexico	Mexico City	9,209,944
	Tijuana	1,922,523

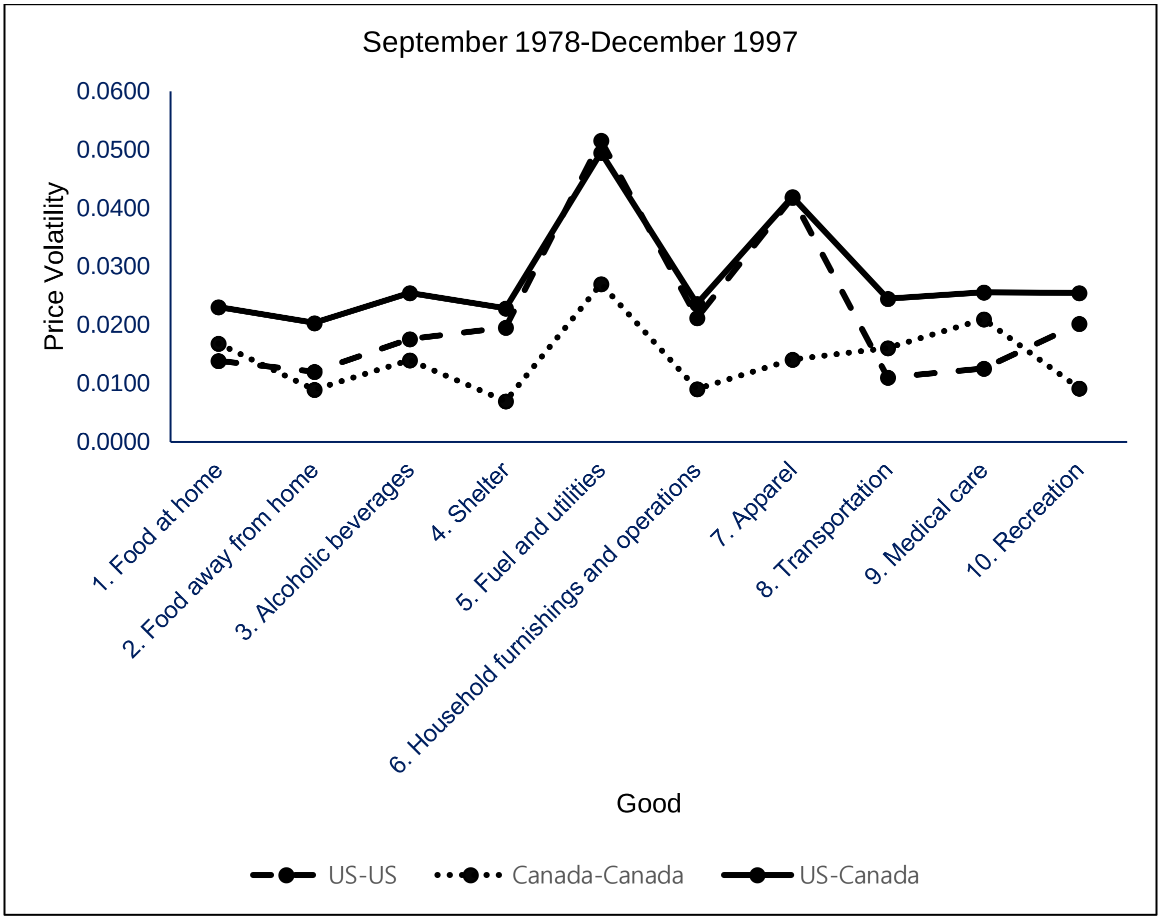
Table 3.1. U.S.-Canada: Average Price Volatility (September 1978-December 1997)

1978-1997	Location pairs		
Good	US-US	Canada-Canada	US-Canada
1	0.0138	0.0169	0.0231
2	0.0120	0.0089	0.0204
3	0.0176	0.0140	0.0255
4	0.0196	0.0070	0.0229
5	0.0516	0.0270	0.0495
6	0.0212	0.0090	0.0236
7	0.04185	0.0140	0.04188
8	0.0110	0.0161	0.0245
9	0.0125	0.0210	0.0256
10	0.0202	0.0092	0.0255
1-10 (average)	0.0221	0.0143	0.0282
Distance (miles)	1,190 (43 pairs)	1,150 (15 pairs)	1,461 (66 pairs)

Table 3.2. U.S.-Canada: Average Price Volatility (January 1998-December 2024)

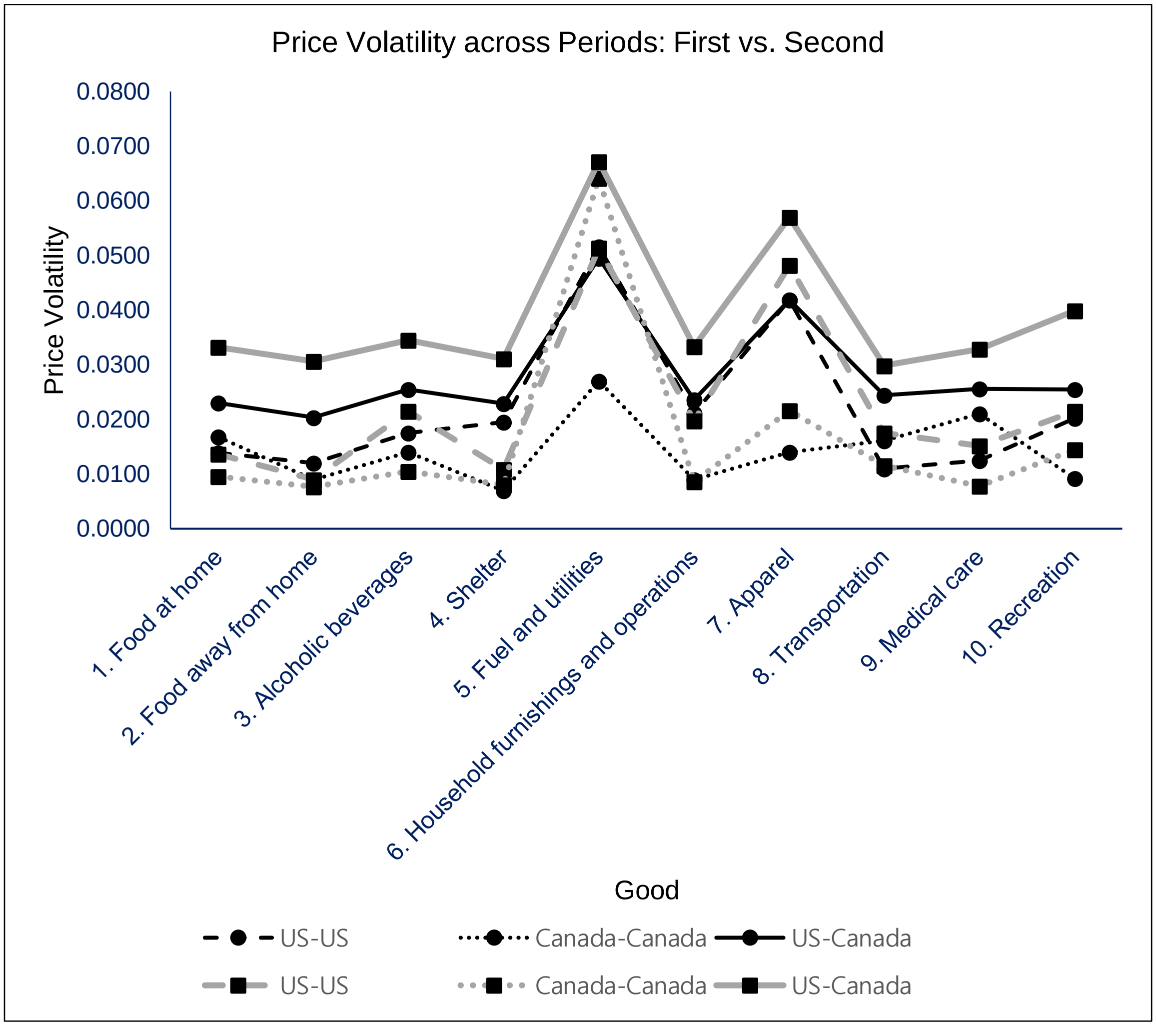
1998-2024	Location pairs		
Good	US-US	Canada-Canada	US-Canada
1	0.0137	0.0095	0.0332
2	0.00902	0.00767	0.0307
3	0.0215	0.0105	0.0345
4	0.0108	0.0080	0.0310
5	0.0513	0.0641	0.0672
6	0.0198	0.0086	0.0333
7	0.0482	0.0216	0.0570
8	0.0175	0.0115	0.0299
9	0.0152	0.0078	0.0329
10	0.0215	0.0145	0.0399
1-10 (average)	0.0228	0.0164	0.03897
Distance (miles)	1,301 (40 pairs)	1,150 (15 pairs)	1,461 (66 pairs)

Figure 1. U.S.-Canada: Intranational and International Price Volatility (September 1978-December 1997)



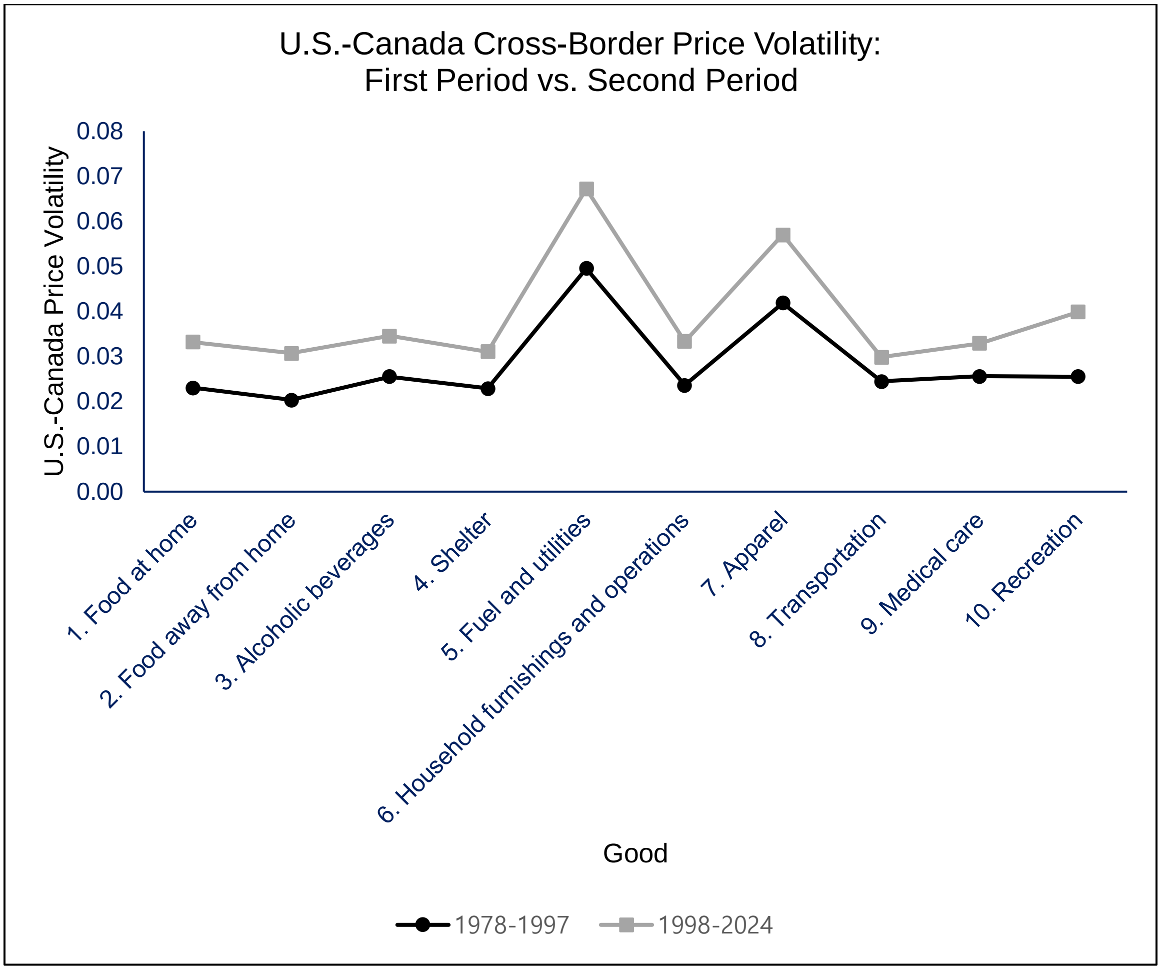
Notes: Figure 1 presents a visual representation of the values in Table 3.1, highlighting which goods and location pairs exhibit higher price dispersion.

Figure 2.1. Comparison of Price Volatility for All Location Pairs: 1978-1997 and 1998-2024



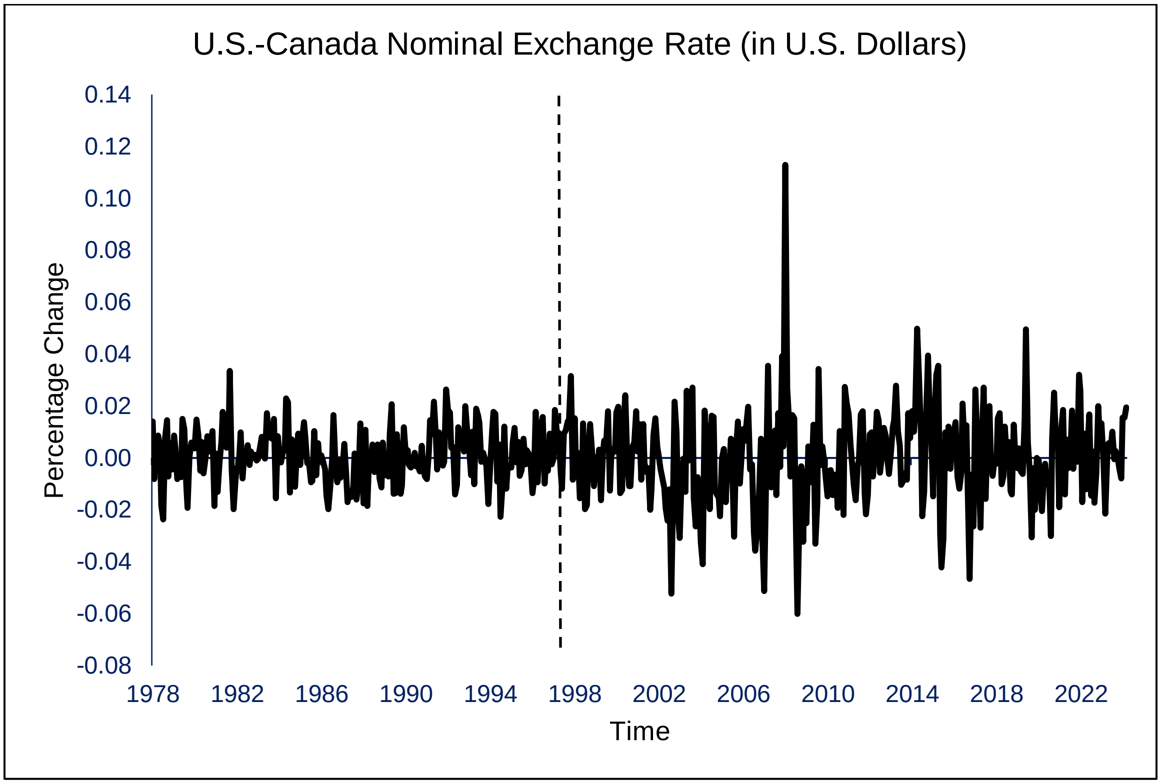
Notes: Figure 2.1 visually represents the values from Table 3.1 and Table 3.2. Price volatility for the first period (Table 3.1) is depicted with a black line and circular markers, while the second period (Table 3.2) is shown with a light grey line and square markers. Figure 2 clearly illustrates that price volatility is generally higher in the second period.

Figure 2.2. Comparison of Cross-Border Price Volatility: 1978-1997 and 1998-2024



Notes: Figure 2.2 only compares cross-border price volatility for U.S.-Canada across all periods, as presented in Figure 2.1. Price volatility for the first period (Table 3.1, US-Canada column) is shown with a black line and circular markers, while the second period (Table 3.2, US-Canada column) is represented by a light gray line and square markers.

Figure 2.3. U.S.-Canada Percentage Change of Nominal Exchange Rate (1978-2024)



Notes: Figure 2.3 illustrates the percentage change in the nominal exchange rate (in U.S. dollars) between the U.S. and Canada from September 1978 to December 2024. The dotted vertical line separates Period 1 from Period 2. Greater fluctuations are visible in the second period.

Table 3.2.1. U.S.-Canada: Average Price Volatility for the Non-Turbulent Period (January 1998-December 2007)

1998-2007	Location pairs		
Good	US-US	Canada-Canada	US-Canada
1	0.0148	0.0107	0.0320
2	0.00699	0.00615	0.0278
3	0.0205	0.0097	0.0314
4	0.0123	0.0104	0.0316
5	0.0573	0.0913	0.0827
6	0.0199	0.0085	0.0317
7	0.0489	0.0226	0.0594
8	0.0162	0.0111	0.0285
9	0.0127	0.0060	0.0296
10	0.0189	0.0108	0.0346
1-10 (average)	0.0229	0.0187	0.0389
Distance (miles)	1,301 (40 pairs)	1,150 (15 pairs)	1,461 (66 pairs)

Table 3.2.2. U.S.-Canada: Average Price Volatility for the Turbulent Period (January 2008-December 2024)

2008-2024	Location pairs		
Good	US-US	Canada-Canada	US-Canada
1	0.0129	0.0088	0.0336
2	0.00999	0.00843	0.0317
3	0.0218	0.0109	0.0351
4	0.0092	0.0057	0.0302
5	0.0473	0.0400	0.0547
6	0.0196	0.0086	0.0337
7	0.0478	0.0211	0.0554
8	0.0183	0.0118	0.0302
9	0.0163	0.0087	0.0343
10	0.0228	0.0163	0.0423
1-10 (average)	0.0226	0.0140	0.0381
Distance (miles)	1,301 (40 pairs)	1,150 (15 pairs)	1,461 (66 pairs)

Table 4.1. U.S.-Canada: Baseline Regression (September 1978-December 1997)

Good	Log distance		Border		Adjusted R^2
1	0.000664	**	0.008211	***	0.81
	(0.000269)		(0.000376)		
2	0.000438	*	0.009030	***	0.80
	(0.000257)		(0.000461)		
3	0.000938	***	0.008535	***	0.74
	(0.000306)		(0.000498)		
4	0.000364		0.006445	***	0.35
	(0.000503)		(0.000884)		
5	0.002430		0.003429		0.02
	(0.001682)		(0.002704)		
6	-0.000201		0.005662	***	0.25
	(0.000607)		(0.000881)		
7	-0.001186		0.007633	***	0.10
	(0.001240)		(0.001966)		
8	0.000648	**	0.011930	***	0.87
	(0.000308)		(0.000426)		
9	-0.000081		0.010909	***	0.29
	(0.000778)		(0.001443)		
10	0.000635		0.007945	***	0.49
	(0.000566)		(0.000790)		
ALL	0.000465		0.007973	***	0.10
	(0.000450)		(0.000704)		
E&R	0.00106	***	0.0119	***	0.77
	(0.000325)		(0.000420)		

Notes: Heteroscedasticity-robust standard errors are reported in parentheses. ER's results are presented in the last row, labeled as "E&R." The dependent variable, the volatility of real exchange rates, is calculated for the period between September 1978 and December 1997. Each good *i* includes 124 observations (location pairs). Statistical significance is denoted by the following: * indicates significance at the 5% to 10% level, ** at the 1% to 5% level, and *** at less than 1% (highly significant).

Table 4.2. U.S.-Canada: Baseline Regression (January 1998-December 2024)

Good	Log distance		Border		Adjusted R^2
1	0.000370		0.020606	***	0.97
	(0.000229)		(0.000331)		
2	0.000009		0.022035	***	0.99
	(0.000172)		(0.000239)		
3	0.001329	***	0.015744	***	0.76
	(0.000460)		(0.000899)		
4	-0.000037		0.021000	***	0.93
	(0.000406)		(0.000586)		
5	0.003696		0.011500	**	0.05
	(0.002909)		(0.004481)		
6	0.000128		0.016582	***	0.82
	(0.000495)		(0.000776)		
7	0.002109	*	0.015539	***	0.43
	(0.001129)		(0.001851)		
8	0.001965	***	0.013486	***	0.86
	(0.000375)		(0.000546)		
9	0.000509		0.019607	***	0.91
	(0.000369)		(0.000625)		
10	0.000187		0.020250	***	0.84
	(0.000637)		(0.000795)		
ALL	0.001027	*	0.017635	***	0.24
	(0.000623)		(0.000920)		

Notes: Heteroscedasticity-robust standard errors are reported in parentheses. The dependent variable, the volatility of real exchange rates, is calculated for the period between January 1998 and December 2024. Each good *i* includes 121 observations (location pairs).
* indicates significance at the 5% to 10% level.
** indicates significance at the 1% to 5% level.
*** indicates significance at less than 1%.

Table 4.2.1. U.S.-Canada: Baseline Regression (January 1998-December 2007)

Good	Log distance		Border		Adjusted R^2
1	0.000373		0.018252	***	0.95
	(0.000267)		(0.000385)		
2	0.000078		0.021061	***	0.99
	(0.000152)		(0.000185)		
3	0.001648	***	0.013387	***	0.66
	(0.000514)		(0.000995)		
4	0.000152		0.019733	***	0.86
	(0.000498)		(0.000769)		
5	0.006256		0.014541	**	0.03
	(0.004607)		(0.007218)		
6	-0.000555		0.015009	***	0.72
	(0.000620)		(0.000903)		
7	0.002231	*	0.017078	***	0.44
	(0.001219)		(0.001966)		
8	0.002088	***	0.013219	***	0.85
	(0.000350)		(0.000578)		
9	0.000135		0.018716	***	0.92
	(0.000361)		(0.000541)		
10	0.000337		0.017770	***	0.82
	(0.000592)		(0.000778)		
ALL	0.001274		0.016877	***	0.13
	(0.000809)		(0.001242)		

Notes: Heteroscedasticity-robust standard errors are reported in parentheses. The dependent variable, the volatility of real exchange rates, is calculated for the period between January 1998 and December 2007. Each good *i* includes 121 observations (location pairs).
* indicates significance at the 5% to 10% level.
** indicates significance at the 1% to 5% level.
*** indicates significance at less than 1%.

Table 4.2.2. U.S.-Canada: Baseline Regression (January 2008-December 2024)

Good	Log distance		Border		Adjusted R^2
1	0.000337		0.021657	***	0.97
	(0.000245)		(0.000373)		
2	-0.000004		0.022114	***	0.98
	(0.000246)		(0.000320)		
3	0.001147	**	0.016017	***	0.75
	(0.000496)		(0.000945)		
4	-0.000169		0.022047	***	0.92
	(0.000506)		(0.000643)		
5	0.001728		0.008983	***	0.07
	(0.002116)		(0.002869)		
6	0.000537		0.016932	***	0.83
	(0.000469)		(0.000787)		
7	0.002013	*	0.014389	***	0.36
	(0.001211)		(0.001994)		
8	0.001894	***	0.013218	***	0.82
	(0.000428)		(0.000617)		
9	0.000649		0.019937	***	0.87
	(0.000434)		(0.000757)		
10	0.000143		0.021204	***	0.82
	(0.000705)		(0.000889)		
ALL	0.000827		0.017650	***	0.34
	(0.000532)		(0.000746)		

Notes: Heteroscedasticity-robust standard errors are reported in parentheses. The dependent variable, the volatility of real exchange rates, is calculated for the period between January 2008 and December 2024. Each good *i* includes 121 observations (location pairs).
* indicates significance at the 5% to 10% level.
** indicates significance at the 1% to 5% level.
*** indicates significance at less than 1%.

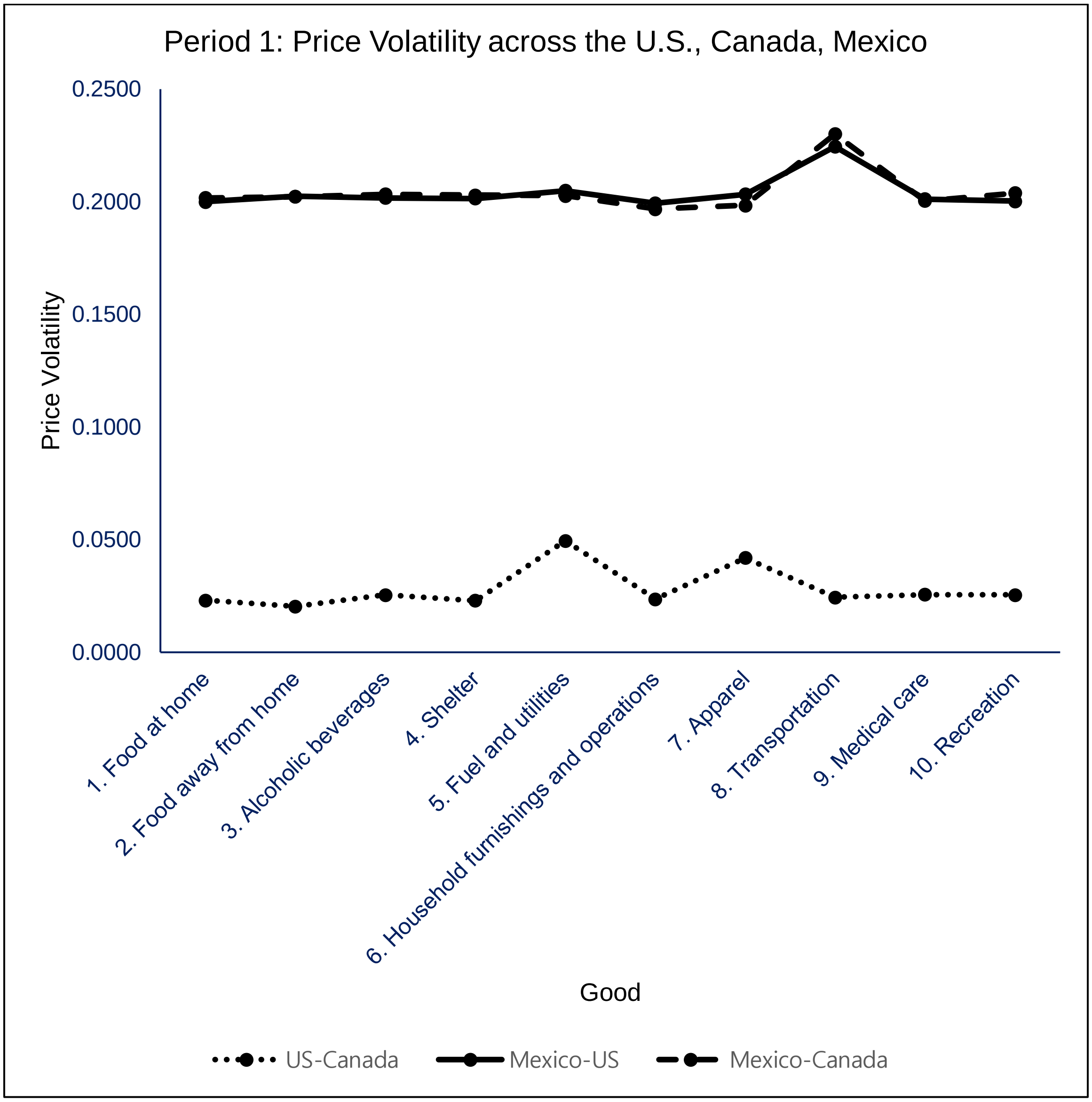
Table 5.1. U.S.-Canada-Mexico: Average Cross-Border Price Volatility (September 1978-December 1997)

1978-1997	Location pairs		
Good	US-Canada	Mexico-US	Mexico-Canada
1	0.0231	0.2000	0.2018
2	0.0204	0.2024	0.2023
3	0.0255	0.2018	0.2033
4	0.0229	0.2015	0.2030
5	0.0495	0.2049	0.2027
6	0.0236	0.1993	0.1969
7	0.04188	0.20333	0.19841
8	0.0245	0.2245	0.2300
9	0.0256	0.2012	0.2004
10	0.0255	0.2003	0.2039
1-10 (average)	0.0282	0.2039	0.2043
Distance (miles)	1,461 (66 pairs)	1,661 (11 pairs)	2,164 (6 pairs)

Table 5.2. U.S.-Canada-Mexico: Average Cross-Border Price Volatility (January 1998-December 2024)

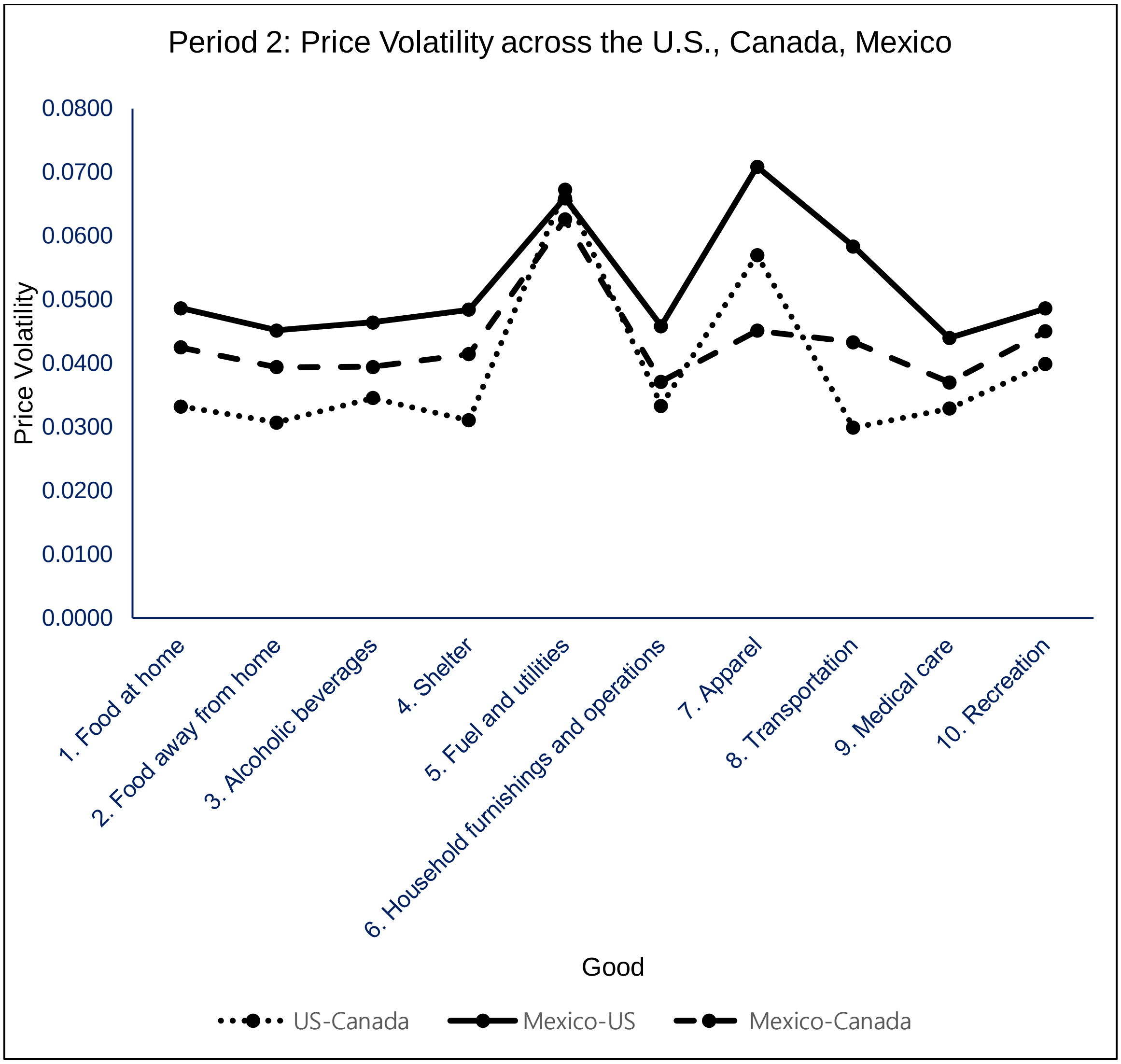
1998-2024	Location pairs		
Good	US-Canada	Mexico-US	Mexico-Canada
1	0.0332	0.0487	0.0425
2	0.0307	0.0451	0.0394
3	0.0345	0.0464	0.0394
4	0.0310	0.0484	0.0414
5	0.0672	0.0659	0.0626
6	0.0333	0.0458	0.0371
7	0.0570	0.0709	0.0451
8	0.0299	0.0584	0.0433
9	0.0329	0.0440	0.0370
10	0.0399	0.0486	0.0450
1-10 (average)	0.03897	0.0522	0.0433
Distance (miles)	1,461 (66 pairs)	1,661 (11 pairs)	2,164 (6 pairs)

Figure 3.1. U.S.-Canada-Mexico: International Price Volatility (September 1978-December 1997)



Notes: Figure 3.1 presents a visual representation of the values in Table 5.1.

Figure 3.2. U.S.-Canada-Mexico: International Price Volatility (January 1998-December 2024)



Notes: Figure 3.2 presents a visual representation of the values in Table 5.2.

Table 6.1. U.S.-Canada-Mexico: Baseline Regression (September 1978-December 1997)

Good	Log distance		US-Canada		Mexico-US		Mexico-Canada		Adjusted R^2
1	0.000551	*	0.008163	***	0.184981	***	0.186609	***	0.999
	(0.000286)		(0.000387)		(0.000581)		(0.000549)		
2	0.000348		0.008912	***	0.190888	***	0.190692	***	0.999
	(0.000291)		(0.000482)		(0.000661)		(0.000559)		
3	0.000897	***	0.008480	***	0.184555	***	0.185789	***	0.998
	(0.000312)		(0.000505)		(0.000679)		(0.000519)		
4	0.000398		0.006385	***	0.184905	***	0.186299	***	0.995
	(0.000504)		(0.000890)		(0.001387)		(0.000984)		
5	0.002803	*	0.003929		0.158671	***	0.155584	***	0.931
	(0.001647)		(0.002727)		(0.002803)		(0.002666)		
6	-0.000176		0.005777	***	0.181536	***	0.179094	***	0.994
	(0.000590)		(0.000876)		(0.001161)		(0.000939)		
7	-0.000632		0.007879	***	0.169470	***	0.164744	***	0.967
	(0.001269)		(0.001981)		(0.002529)		(0.002165)		
8	0.000747	**	0.011710	***	0.211575	***	0.216852	***	0.998
	(0.000360)		(0.000448)		(0.002539)		(0.000609)		
9	-0.000234		0.010862	***	0.186520	***	0.185751	***	0.983
	(0.000779)		(0.001456)		(0.001367)		(0.001168)		
10	0.000679		0.007930	***	0.182557	***	0.185967	***	0.995
	(0.000563)		(0.000795)		(0.000984)		(0.001047)		
1-10	0.000538		0.008003	***	0.183566	***	0.183738	***	0.963
	(0.000439)		(0.000701)		(0.000974)		(0.001335)		

Notes: Heteroscedasticity-robust standard errors are reported in parentheses. The dependent variable, the volatility of real exchange rates, is calculated for the period between September 1978 and December 1997. Each good *i* includes 141 observations (location pairs). US-Canada, Mexico-US, and Mexico-Canada represent the three border dummy variables.
* indicates significance at the 5% to 10% level.
** indicates significance at the 1% to 5% level.
*** indicates significance at less than 1%.

Table 6.2. U.S.-Canada-Mexico: Baseline Regression (January 1998-December 2024)

Good	Log distance		US-Canada		US-Mexico		Canada-Mexico		Adjusted R^2
1	0.000379	*	0.020603	***	0.035947	***	0.029682	***	0.98
	(0.000227)		(0.000333)		(0.000561)		(0.000417)		
2	-0.000026		0.022044	***	0.036504	***	0.030754	***	0.99
	(0.000173)		(0.000241)		(0.000563)		(0.000294)		
3	0.001220	***	0.015771	***	0.027382	***	0.020008	***	0.83
	(0.000459)		(0.000904)		(0.001140)		(0.000999)		
4	0.000011		0.020988	***	0.038340	***	0.031361	***	0.95
	(0.000401)		(0.000589)		(0.000774)		(0.000744)		
5	0.003580		0.011528	**	0.009422	**	0.005005		0.03
	(0.002875)		(0.004509)		(0.003972)		(0.013336)		
6	0.003580		0.011528	**	0.009422	**	0.005005		0.03
	(0.002875)		(0.004509)		(0.003972)		(0.013336)		
7	0.002048	*	0.015554	***	0.028986	***	0.002601		0.54
	(0.001117)		(0.001861)		(0.002464)		(0.002355)		
8	0.001874	***	0.013509	***	0.041596	***	0.025980	***	0.95
	(0.000374)		(0.000549)		(0.000786)		(0.000592)		
9	0.000421		0.019629	***	0.030614	***	0.023535	***	0.93
	(0.000371)		(0.000629)		(0.001055)		(0.000684)		
10	0.000114		0.020268	***	0.028989	***	0.025328	***	0.87
	(0.000632)		(0.000799)		(0.001157)		(0.001288)		
1-10	0.000975		0.017648	***	0.030686	***	0.021455	***	0.31
	(0.000614)		(0.000921)		(0.001195)		(0.001780)		

Notes: Heteroscedasticity-robust standard errors are reported in parentheses. The dependent variable, the volatility of real exchange rates, is calculated for the period between January 1998 and December 2024. Each good *i* includes 138 observations (location pairs). US-Canada, Mexico-US, and Mexico-Canada represent the three border dummy variables.
* indicates significance at the 5% to 10% level.
** indicates significance at the 1% to 5% level.
*** indicates significance at less than 1%.