

Price Dispersion and the Border Effect*

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September 2019

Abstract

Cross-country price differences could reflect regional market segmentation within countries or national segmentation at the border. In a search-based model of price setting, identifying national versus regional segmentation requires data on regional trade flows. A calibration to U.S. and Canadian data implies predominantly regional frictions: U.S. producers are three times more likely to sell in their home region than another U.S. region and Canadian producers are seven times more likely to sell in their home region than another Canadian region. Frictions vis-a-vis foreign regions are only slightly higher. Models that ignore regional segmentation can misstate the severity of frictions at the border.

Keywords: Law of one price, Real exchange rates, Trade barriers, Home bias

JEL Codes: F41, F30, E30

*We would like to thank Emi Nakamura, Jaromir Nosal, John Shea, Jón Steinsson, Rosen Valchev, and seminar participants at the Federal Reserve Bank of Boston, Boston College, and Columbia University for very helpful comments. We are grateful to João Ayres for excellent research assistance. Contact: ryan.chahrour@bc.edu and stevens@econ.umd.edu.

1 Introduction

A large literature in international macroeconomics measures the frictions that hinder the arbitrage of price differences across countries. The seminal paper of [Engel and Rogers \(1996\)](#) documented significant border frictions using semi-aggregated price indices for goods sold in the United States and Canada. Subsequent work has sought to refine these estimates using increasingly disaggregated data. Empirical work by [Gopinath et al. \(2011\)](#), [Burstein and Jaimovich \(2012\)](#), [Broda and Weinstein \(2008\)](#), and [Crucini and Telmer \(2012\)](#) has shown that product-level price differences across countries are consistent with a very large degree of segmentation at the national border. Following [Gorodnichenko and Tesar's \(2009\)](#) criticism of reduced-form treatment of cross-border relative price data, and their call for a more structural approach, the empirical evidence has been complemented by structural work reinforcing the conclusion that high cross-country segmentation is crucial for generating realistic good-level violations of the law of one price.

We demonstrate an identification problem—even within structural frameworks—in disentangling segmentation that is induced by national borders from the segmentation that exists between regions or markets within a country. Using a two-country multi-region model of trade, we show that cross-country price and trade data are not sufficient for determining if international price dispersion arises from a friction inhibiting trade across countries or from a friction that inhibits trade across regions internally. We also show that adding data on regional trade patterns is precisely what is needed to separately identify the parameters governing within-country and across-country trade frictions, and we estimate these two levels of segmentation for the United States and Canada.

Our central finding is that much of the measured market segmentation occurs at the subnational regional level. To arrive at this result, we calibrate our model to match a set of facts regarding good-level violations of the law of one price across the United States–Canada border, as well as both international and internal levels of trade for the two countries. Matching both sets of facts simultaneously requires a calibration in which regional markets are strongly segmented and the national border generates little additional segmentation.

We obtain our results using a search-based model of international trade in which retailers engage in costly sequential search for the best price among the producers that are active in the retailers’ local markets. The search friction, combined with a distribution of producer-specific productivity shocks, gives rise to endogenous price dispersion in equilibrium. Generating significant price dispersion at the local level is relevant for measuring the severity of international border frictions because, as demonstrated by [Gorodnichenko and Tesar \(2009\)](#), the existence of price dispersion within countries can bias estimates of the “size” of the border.

The model allows for heterogeneous segmentation across regions, with the mass of producers that are headquartered in one region and active in another depending on both market sizes and on a pure *market bias* parameter. This specification enables us to quantify the degree of domestic and international segmentation for each country, while taking into account differential trade patterns that reflect market size differences. The model nests regionally and nationally segmented markets. Under regional segmentation, producers headquartered in one region are less likely to set up shop in other regions, while under national segmentation, producers are equally likely to set up shop in the

regions within their own country, but less likely to set up shop in the other country. We use price and trade flows data to estimate the size of these relative biases.

Applied to United States and Canada data, our model implies that the apparent segmentation at the national border is primarily a reflection of regional segmentation. Splitting the United States in two equal-sized regions, we estimate that on average producers are 3 times more likely to sell to retailers in their own region than to retailers in the “away” U.S. region. Hence, there are significant barriers to the flow of goods across U.S. regions. Crossing the national border further reduces access, but this barrier is less severe than the regional barrier, with American producers only 23% more likely to sell in the “away” domestic region than to a Canadian region.

Furthermore, we uncover substantial asymmetry across countries in the severity of these frictions. Canadian producers are 7 times more likely to sell in their own region than in the “away” Canadian region, and 11 times more likely to sell in their own region than in an American region. Overall, regional bias is a major component of the national home bias, and it appears more severe for Canadian producers.

Our measures of relative bias provide a simple way to parameterize all the frictions and barriers to trade, either bilateral or unilateral, which may affect the likelihood of transacting across regions. These include informational advantages that ease access to the chain of production in one’s own market, and external barriers that make transacting with firms located outside one’s own network more difficult. Together with the size of each market, the segmentation parameters determine how producers are matched with the retailers of different regions, which pins down the distribution of prices available in each region. The model generates pricing to market, as producers charge different prices

in different regions, depending on local demand conditions and competitive pressures. In turn, pricing to market contributes to cross-border price differentials, consistent with the empirical evidence emphasized by [Burstein and Gopinath \(2014\)](#).

Our paper relates to an extensive literature examining violations of the law of one price, recently surveyed by [Burstein and Gopinath \(2014\)](#). [Alessandria \(2004, 2009\)](#) and [Alessandria and Kaboski \(2011\)](#) also use a search friction to motivate cross-border price differences, although these papers do not emphasize the distinction between frictions that occur across markets within countries versus those that occur at the border. Other search models of the product market that focus on price dispersion across stores in a single market include [Kaplan and Menzio \(2015\)](#) and [Menzio and Trachter \(2015, 2018\)](#).

Our approach resembles that of [Gopinath et al. \(2011\)](#) and [Burstein and Jaimovich \(2012\)](#) in that we consider a model with a real friction in goods markets, coupled with country heterogeneity in the distribution of firm costs. [Burstein and Jaimovich \(2012\)](#) model within-country regions and point out an identification problem using prices alone to distinguish between differences in demand-shock correlations and differences in markup elasticities across markets. However, the forces they discuss map to *within-region* price dispersion in our economy.¹ We assume perfect correlation of demand conditions within countries, but show there is nevertheless an identification problem regarding the level at which markets are segmented. Other related papers using product-level price data include [Baxter and Landry \(2017\)](#), [Goldberg and Hellerstein \(2013\)](#), [Fitzgerald and Haller \(2014\)](#), and [De Loecker et al. \(2016\)](#). Alternative structural frameworks are considered by [Atkeson and Burstein \(2008\)](#), [Drozd and Nosal \(2012\)](#) and [Candian \(2019\)](#).

¹Prices are dispersed within regions in our economy, but not in [Burstein and Jaimovich \(2012\)](#).

Methodologically, our paper is distinct from the earlier literature because it incorporates price and quantity data simultaneously. An exception is [Boivin et al. \(2012\)](#), who undertake a nonstructural analysis using price and quantity data from a retailer in the online book market, and find substantial international market segmentation.

Our results are also related to gravity models of trade. [McCallum \(1995\)](#) finds that large border frictions are required to account for within- versus across-country trades levels between the United States and Canada. [Anderson and van Wincoop \(2003\)](#) show that the estimated border effect on trade is much smaller once theoretically motivated measures of multilateral resistance are added to the estimation. [Wolf \(2000\)](#) and [Millimet and Osang \(2007\)](#) focus on intranational trade barriers. Other papers in this area include [Chen \(2004\)](#), [Hillberry and Hummels \(2008\)](#), and [Atkin and Donaldson \(2015\)](#).

2 Model

We develop a multi-region, multi-sector two-country model in which search frictions generate price dispersion both within and across regions. We model the search friction as in [Reinganum \(1979\)](#), whose model of homogeneous buyers and heterogeneous sellers we develop into a general equilibrium framework with producers, retailers and consumers. We then extend the model to a two-country world with two regions in each country, featuring producers selling the same good to retailers in multiple regions.

2.1 Single-Region Economy

The economy features a representative consumer, a perfectly competitive nontradable sector, and a monopolistically competitive tradable goods sector. We focus on the tradable goods sector since the puzzle is that the law of one price also fails to hold for traded

goods, for which arbitrage should—but does not—eliminate price differences.

Consumers: The representative consumer buys goods in sectors N and T (which represent nontradables and tradables in the two-country model) and supplies labor to solve

$$\max_{C_T, C_N, L} \log \left(C_T^\phi C_N^{1-\phi} \right) - \Psi \frac{L^{1+1/\psi}}{1 + 1/\psi} \quad (1)$$

$$P_T C_T + P_N C_N \leq WL + \Pi, \quad (2)$$

where C_N and C_T denote aggregate consumption in the two sectors, P_N and P_T are the respective price indices, L is labor supply, W the economy-wide nominal wage, and Π nominal firm profits. The parameter $\phi \in (0, 1)$ governs the share of sector T in consumption, and $\psi > 0$ is the Frisch elasticity of labor supply. Consumer optimization implies that expenditure is allocated across the two sectors according to $P_T C_T / P_N C_N = \phi / (1 - \phi)$, and labor supply is given by $L^{1/\psi} = \phi W / \Psi P_T C_T$.

Sector T is monopolistically competitive, with a continuum of goods indexed by i and a continuum of varieties ν for each good. At each level, consumption is aggregated using

$$C_T = \left(\int_0^1 c_i^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} \quad \text{and} \quad c_i = \left(\int_0^1 c_{i\nu}^{\frac{\eta_i-1}{\eta_i}} d\nu \right)^{\frac{\eta_i}{\eta_i-1}}, \quad (3)$$

where $\varepsilon > 1$ is the elasticity of substitution across goods and $\eta_i > 0$ is the elasticity of substitution across varieties of good i . The price indices are $P_T \equiv \left(\int_0^1 p_i^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}$ and $p_i \equiv \left(\int_0^1 p_{i\nu}^{1-\eta_i} d\nu \right)^{\frac{1}{1-\eta_i}}$. Demand at the good and variety level are given by

$$c_i = p_i^{-\varepsilon} P_T^\varepsilon C_T \quad \text{and} \quad c_{i\nu} = p_{i\nu}^{-\eta_i} p_i^{\eta_i} c_i. \quad (4)$$

Sector N is competitive, with a homogeneous good produced by a representative firm.

Retailers: A unit mass of multi-product retailers indexed by ν search for goods on behalf of consumers. Retailers know the distribution of prices posted by the producers (or distributors) of each good, but they do not know which producer sells at what price. Instead, they pay a fixed search cost to sample from the distribution of producer prices. Upon meeting a producer, each retailer either purchases its entire demand at the sampled price, or pays the search cost again to meet a new producer. Search continues until each retailer has settled on a single supplier for each good. Retailers then costlessly differentiate each good i into a retailer-specific variety, which they sell to consumers.

Placing the search friction at the retailer level is motivated by the evidence that retail markups do not vary much with nominal exchange rates (Goldberg and Hellerstein, 2008; Gopinath et al., 2011), that retail-level price changes follow changes in wholesale costs (Goldberg and Hellerstein, 2013; Eichenbaum et al., 2011), and that overall “distribution wedges” are stable over time (Berger et al., 2012). We abstract from the local cost component by assuming that retailers costlessly differentiate goods because prior work has found that such costs are also insensitive to exchange rate movements.

Each retailer maximizes total per-period profits across all the goods it sells,

$$\pi_\nu^R = \int_0^1 \pi^r(p_{i\nu}, \hat{p}_{i\nu}) di, \quad (5)$$

$$\pi^r(p_{i\nu}, \hat{p}_{i\nu}) = (p_{i\nu} - \hat{p}_{i\nu}) c_{i\nu} - \kappa n_{i\nu}, \quad (6)$$

where $\hat{p}_{i\nu}$ is the producer price upon which retailer ν settles after completing the search for good i in the period, $c_{i\nu}$ is demand given by (4), $\kappa > 0$ is the fixed search cost, and $n_{i\nu}$ is the number of times the retailer searches for a potential supplier of good i . Since differentiation at the retail level is costless, the retailer charges a constant markup over

the producer price, $p_{i\nu} = \mu_i \widehat{p}_{i\nu}$, with $\mu_i \equiv \eta_i / (\eta_i - 1)$.

The search process is independent across goods (since we assume that there are different suppliers for different goods) and each retailer's variety competes with the varieties of the same good from other retailers. As a result, the retailer maximizes profits good by good. The sequential nature of search implies that a retailer's choice to continue looking for a better price is independent of the number of producers already sampled. Given the currently sampled price $\widehat{p}_{i\nu}$ and the distribution f_i of producer prices available to the retailer, the retailer's search decision maximizes the value function

$$V(\widehat{p}_{i\nu}; f_i) = \max\{V^s(f_i), V^{ns}(\widehat{p}_{i\nu})\}, \quad (7)$$

where $V^s(f_i)$ is the value of continuing to search, which integrates over the distribution of possible producer prices, and $V^{ns}(\widehat{p}_{i\nu})$ is the value of halting the search, which yields the maximum value at the currently sampled price:

$$V^s(f_i) = \int V(\widehat{p}; f_i) f_i(\widehat{p}) d\widehat{p} - \kappa, \quad (8)$$

$$V^{ns}(\widehat{p}_{i\nu}) = \max_p \pi^r(p, \widehat{p}_{i\nu}). \quad (9)$$

The optimal search strategy is a stopping rule defined by a unique reservation price \bar{r}_i for each good that equates the value of searching to that of stopping the search. All retailers sampling a price less than or equal to this threshold stop searching and purchase all their demand for good i at the sampled price, and all retailers sampling a price above it continue to search for a better offer.

Producers: For each good i , there is a unit mass of potential producers j characterized by the production function $y_{ij} = A_{ij} h_{ij}$, where A_{ij} is idiosyncratic productivity and h_{ij} is

the labor input. Each producer potentially sells to multiple retailers. Since the producer does not engage in price discrimination among the retailers in a given market and since retailers are symmetric, each retailer who settles on a given producer demands the same quantity. Letting χ_{ij} denote the mass of retailers who settle on producer j (determined in equilibrium), a producer setting price $\hat{p}_{i,j}$ faces total demand

$$x_{ij} = \begin{cases} \chi_{ij} \hat{p}_{i,j}^{-\eta_i} \bar{p}_i^{\eta_i} c_i & \text{if } \hat{p}_{i,j} \leq \bar{r}_i \\ 0 & \text{if } \hat{p}_{i,j} > \bar{r}_i. \end{cases} \quad (10)$$

The producer maximizes profits given by $(\hat{p}_{i,j} - W/A_{ij})x_{ij}$, where W is the aggregate wage. The optimal price is then a constant markup over marginal cost, up to the retailers' reservation price, $\hat{p}_{i,j} = \min\{\mu_i W/A_{ij}, \bar{r}_i\}$, where μ_i is the good-level markup. Since search is undirected, the producer cannot use price to affect the mass of customers, so $\chi_{ij} = \chi_i$ is the same across all producers j . However, since demand is elastic, lower-cost producers set prices below the reservation price to capture more demand per customer.

Search Equilibrium: An equilibrium in the producer-retailer market for good i is a retail reservation price \bar{r}_i and a distribution of producer prices f_i such that (a) given f_i , retailers choose the optimal stopping rule governed by \bar{r}_i and (b) given \bar{r}_i , producers maximizing profits generate f_i . There is no search in equilibrium, since all producers either post prices that are weakly below this reservation price or shut down.

Let the cumulative distribution of marginal costs across producers of good i be de-

noted by G_i . The resulting cumulative distribution of producer prices is given by

$$F_i(\widehat{p}) = \begin{cases} G_i\left(\frac{\widehat{p}}{\mu_i}\right) & \text{if } \widehat{p} \leq \bar{r}_i \\ 1 & \text{if } \widehat{p} > \bar{r}_i \end{cases}. \quad (11)$$

Since there is a unit mass of retailers and a unit mass of potential producers, the mass of retailers per active producer of each good i is then given by $\chi_i = 1/(1 - G_i(\bar{r}_i))$.

In models of search with homogeneous goods, arbitrarily small search costs can result in a collapse of the price distribution at the monopoly price—the [Diamond \(1971\)](#) paradox. In our setup, heterogeneous production costs and elastic demand generate a non-degenerate distribution of prices, as shown by [Reinganum \(1979\)](#) for a single product with many buyers and sellers. The degree of dispersion in prices depends on the cross-sectional dispersion of producer costs, and the out-of-equilibrium threat of search leads to incomplete pass-through of marginal cost for high-cost producers: markups are constant for all producers with marginal costs less than \bar{r}_i/μ_i , and are decreasing for active producers with costs above this threshold.²

2.2 Multi-Region Economy

We now consider two countries, United States and Canada, each with two regions. The countries differ along several dimensions: size, severity of trade and search frictions, the realization of aggregate and good-specific shocks, and the distribution of idiosyncratic productivity shocks. These asymmetries give rise to pricing-to-market, where a given producer charges different prices to retailers located in different regions. To reduce notation, we drop the product subscript i wherever there is no confusion.

²Other ways to break the Diamond paradox are heterogeneity in consumer search costs, preferences, or information, e.g., [Salop and Stiglitz \(1977\)](#), and non-sequential search, e.g., [Burdett and Judd \(1983\)](#).

Market Segmentation: Let m_{rx} denote market access, defined as the proportion of producers from region r who have the option to sell to region x retailers. We assume

$$m_{rx} = \frac{\beta_{rx}s_r s_x}{s_r + s_x}, \quad (12)$$

where s_r is the mass of producers in the source region r , s_x is the mass of retailers in destination region x , and $\beta_{rx} \in [0, 1]$ is a bias parameter specific to each source-destination pair. A larger market attracts more producers from all regions, and it also sends more producers to other regions. To these market size forces we add the bias parameter, which may limit the trade potential between region pairs. This specification allows us to define what it means for two regions to be fully open to trading with each other ($\beta_{rx} = 1$), while accounting for relative size differences. We borrow this function from labor market models with search frictions ([den Haan et al. \(2000\)](#)).

The bias parameters β_{rx} capture any bilateral and unilateral frictions that make transacting across regions less likely than within regions. They may reflect informational advantages that ease access to the chain of distribution in certain markets, or external barriers that make transacting with firms located outside one's own network more difficult. Such features are specific to each source-destination pair and may be asymmetric within the pair. For simplicity, we assume that they are exogenous. The exogeneity assumption can be relaxed without significantly affecting our conclusions, as long as market access remains orthogonal to *short-run* relative prices differences between regions.

Equilibrium Price Distributions: Market access determines the distribution of producer prices from which retailers in each region can sample. Equilibrium in each region is associated with a distribution of producer prices and a retailer reservation price. Pricing

to market arises from producers selling in regions with different reservation prices.

Exchange Rate and Wages: To close the model, we make assumptions that permit a simple link between exchange rates and real labor costs. Money demand follows a standard velocity equation, with fixed velocity normalized to one,

$$P_T^{us} Y_T^{us} + P_N^{us} Y_N^{us} = M^{us}, \quad (13)$$

$$P_T^{ca} Y_T^{ca} + P_N^{ca} Y_N^{ca} = e M^{ca}, \quad (14)$$

where an increase in the nominal exchange rate e represents a depreciation of the U.S. dollar. Nominal wages adjust incompletely in each country k , according to

$$W^k = \alpha W_{ss}^k + (1 - \alpha) W_{flex}^k, \quad (15)$$

where W_{ss}^k is the nominally fixed wage that is state-invariant, W_{flex}^k is the flexible equilibrium wage given by the household's optimality condition for labor supply in country k , and $\alpha \in (0, 1)$. We introduce sticky wages and persistence to generate substantial fluctuations in the exchange rate and differences in real unit labor costs between countries, consistent with the evidence of [Burstein and Jaimovich \(2012\)](#).

Shocks and Heterogeneity: We include three sources of exogenous variation, each of which plays an important role in driving observed levels of price dispersion. First, idiosyncratic producer productivity A_{ij} is drawn independently each period from a log-normal distribution with mean zero and country-specific variance σ_k^2 . These shocks drive price heterogeneity within and across regions and appear frequently in the related literature.

Second, the elasticity of substitution among varieties fluctuates independently across goods i and countries k , with $\eta_{ik} = \bar{\eta} \exp(\xi_{ik})$, where ξ_{ik} is drawn from a normal distri-

bution with mean zero and variance σ_η^2 . These shocks to desired markups average out across goods, which makes them a valuable source of cross-country dispersion that does not contribute to aggregate fluctuations.

Third, relative money supply M^{us}/M^{ca} is exogenous and follows an $AR(1)$ process with persistence ρ_m and standard deviation of innovations σ_m . These nominal shocks drive realistic fluctuations in the real exchange rate and are important for the model's ability to capture observed correlations in cross-country price changes.

2.3 Identification of Regional and National Frictions

Our goal is to estimate β_{rx} within and across countries. We normalize the home region parameter, $\beta_{rr} = 1$, implying that firms always have the option to sell in their own region (though they may choose not to, depending on costs and demand conditions). We also impose within-country symmetry in terms of market size, market access, and all other structural parameters. Internally, this means that it is just as easy for producers from region r to sell to retailers in region r' as it is for producers from region r' to sell to retailers in region r . Internationally, this means that producers from either region of one country face the same bias when attempting to access either region of the other country. Symmetry is supported by evidence that price differentials are centered around zero within U.S. and Canadian regions (Gopinath et al., 2011), and that average changes in relative prices within these countries are also zero (Burstein and Jaimovich, 2012).³

With these assumptions, we seek to identify four bias parameters: the average bias between U.S. regions $\beta_{us,us}$, the average bias between Canadian regions $\beta_{ca,ca}$, the average bias that American suppliers face when attempting to sell in any Canadian region $\beta_{us,ca}$,

³In Section 3 we document the robustness of our results to the definition of regions inside each country.

and the average bias that Canadian suppliers face in the American regions $\beta_{ca,us}$.

The definition of access to each region (12) determines the probability of a foreign producer servicing retailers in the domestic country, relative to that of a domestic producer. This probability is determined by relative country sizes, together with a measure of *national bias* of country k , which is given by

$$X_k = \frac{2\beta_{k',k}}{1 + \beta_{k,k}}, \quad (16)$$

Equation (16) illustrates the identification problem: national bias is a composite of internal and international parameters. Once we allow for the possibility of internal trade frictions, the price dispersion statistics that have often been taken to indicate large frictions and strong segmentation at the national border cannot disentangle the bias toward one's own region from that toward one's own country.

This lack of identification is not an idiosyncrasy of our model, but rather a feature common to a wide class of models that generate pricing to market across countries. This concern is mentioned by [Burstein and Jaimovich \(2012\)](#). Here we formalize it, in the context of our model, and furthermore, in the next section, we provide actual estimates of the relative strength of these two levels of segmentation.

To overcome the identification challenge, and to also test if regions are integrated within countries, we compute the internal import share of a region, defined as the demand satisfied by the producers from the “away” region in the same country, as a fraction of the demand satisfied by producers from either the home or the away region in the country.

Assuming equal-sized regions, the internal import share for each country k is⁴

$$z_k = \frac{\beta_{k,k}}{1 + \beta_{k,k}}. \quad (17)$$

Equations (16)-(17) show that data on X_k and z_k are sufficient to identify the full set of bias parameters. In Section 3, we parameterize the model to target price dispersion and cross-country trade moments, to identify the national bias parameters; we then use these estimates of composite trade frictions together with the internal trade data to separately identify the within-country regional bias and any additional national border bias.

3 Segmentation Estimates

We use price dispersion and trade flows data to identify the export bias parameters across regions within each country and across countries. Our estimates disentangle the degree of segmentation that is truly coming from the national border from the segmentation that exists at the regional level. They also identify asymmetries, providing a more nuanced characterization of the pattern of trade frictions, compared with estimates of a single segmentation parameter between country pairs.

3.1 Data Moments

We use data for the U.S. and Canada due to comparability (the two economies are similar in terms of structure and level of development, operate inside a free-trade agreement, and also share a language and a physical border), and to relate to prior work on the severity of trade frictions between these two countries.

⁴We assume the regions are of equal size for expository purposes, but this assumption does not have any bearing on our results.

Prices: We consider data on the relative prices of identical products sold in multiple locations from a common source (*e.g.* variation in the relative price of a two-liter bottle of Canada Dry Ginger Ale sold in a region of the U.S. and in a region of Canada, and produced in Canada). Let the period- t log price of good i , produced in region r and sold in region x be denoted by $p_{it}(r; x)$. Then, comparing prices in two destinations, x and x' , the period- t product-level RER of good i is

$$d_{it}(r; x, x') \equiv p_{it}(r; x) - p_{it}(r; x') - e_t(x', x). \quad (18)$$

where $e_t(x', x)$ is the log nominal exchange rate that converts region x' currency into region x currency, and an increase in $e_t(x', x)$ is a depreciation of x' 's currency.

In a frictionless world, d_{it} would be zero across all origins and destinations, and absolute purchasing power parity (PPP) would hold. With permanent differences across locations (*e.g.* if some regions are permanently more expensive), d_{it} would be a nonzero constant, but relative PPP would still hold. In practice, product-level real exchange rates are very volatile, and the RER aggregated across goods closely tracks the NER.⁵

The statistics that pin down the parameters of our model concern the volatility of changes over time in these product-level RERs across different region pairs. To measure the volatility of price dispersion within the U.S, we compute the standard deviation of Δd_{it} across regions of the U.S., for goods made in the U.S., $\sigma_{us,us}^{\Delta d}$, and separately, for goods made in Canada, $\sigma_{ca,us}^{\Delta d}$. Analogous measures for Canada are $\sigma_{ca,ca}^{\Delta d}$ and $\sigma_{us,ca}^{\Delta d}$. For cross-border dispersion, we consider the volatility of price differentials between U.S.-Canada region pairs, separately for U.S.-made goods and for Canada-made

⁵This well-known aggregate fact has been reconstructed from micro-level data in various forms, and holds across many countries and time periods, for consumer and at-the-dock prices. See [Burstein and Gopinath \(2014\)](#) for a recent review of the evidence.

goods: $\sigma_{us,across}^{\Delta d}$ and $\sigma_{ca,across}^{\Delta d}$. These statistics eliminate time-invariant sources of price differences, such as some areas being permanently more expensive than others.

For all empirical estimates, we use the numbers reported by [Burstein and Jaimovich \(2012\)](#). Their barcode level data comes from a major retail chain that operates hundreds of stores in multiple Canadian provinces and U.S. states, hence we can map it to our multi-region, two-country structure. Crucially, the authors collect information on the country of production of each good, and report statistics separately for each origin-destination country pair. These cuts of the data are necessary to isolate the role of segmentation as distinct from the role played by different destinations being subjected to different shocks and characterized by different market structures.

The statistics are constructed by aggregating the weekly wholesale prices of thousands of products to the quarterly frequency, and cover the period 2004-2006. We use the statistics for traded products that are “broadly matched” across all pricing regions. Broad matches are defined using items within product categories that have the same brand, manufacturer, and at least one other product characteristic.⁶

For products made in the U.S., the standard deviation is 13% for changes in cross-border product-level RERs versus 8% across U.S. regions, and 6% across Canadian regions. For products made in Canada, the standard deviations are 17% for cross-border deviations, 10% inside the U.S., and 4% in Canada. The numbers illustrate two facts. First, not only are deviations from relative price parity very large, but they are larger

⁶[Burstein and Jaimovich \(2012\)](#) also report versions of these statistics with narrower, more exact matches. But since the differences in dispersion statistics are fairly modest across the different product classification methods, our segmentation estimates are robust to targeting these other matches. See [Burstein and Jaimovich \(2012\)](#) for additional details about the data coverage. [Gopinath et al. \(2011\)](#) also use data from the same chain in their study of relative costs and markup differences across the two countries.

when comparing relative prices across countries than within. Second, these deviations are larger in the U.S. than in Canada, regardless of the producer's home country. These differences help us pin down asymmetries across the two countries.

Quantities: We complement the price dispersion statistics with inter-provincial trade data from *Statistics Canada* and interstate U.S. trade data from the Commodity Flow Survey (CFS) produced by the *U.S. Department of Transportation*. We obtain cross-country gross trade flows in goods from the U.S. *Census Bureau* and *National Income and Product Accounts*, and U.S. markup data from the Census Bureau's *Wholesale Trade Survey*. Since the state-level trade data available from the CFS are from 2007, we use 2007 as our base year for computing all trade quantities and markup levels.

We use data for internal trade for ten Canadian provinces plus three territories, and for all U.S. states. For simplicity, we combine these geographic units into two economic markets inside each country. Geographic distinctions (for instance, East versus West) provide a natural way to split the countries in two, but to ensure that our choice of geography is not influencing our results, we consider a broader set of regional definitions. For the U.S., we first combine the states into 12 different subregions, according to the Department of Transportation classification. We then consider all possible combinations of these subregions into two markets, regardless of geography or distance. The only requirement is that the resulting two markets have an economic output that is roughly equal (within 10% of the other). This procedure yields 464 roughly equal-sized two-region splits of the U.S. For Canada, we follow an identical procedure, after first combining the data for the three territories of Canada (Northwest Territories, Nunavut, and Yukon). Considering 10 provinces plus one combined territory, we obtain 108 two-region splits of

Canada of roughly equal size in terms of total economic output.

3.2 Model Parameters and Targets

Table 1 presents the parameter values of the model and Table 2 presents the targets for the joint optimization. The model statistics are derived from the equilibrium with both idiosyncratic and aggregate shocks, aggregated over many periods.⁷

The top panel of Table 1 shows the aggregate and preference parameters that are calibrated to standard values. We set the relative size of the two countries $s_{us}/s_{ca} = 8$, to match the ratio of goods production between the U.S. and Canada. We set the volatility and persistence of relative money supply shocks to match an unconditional auto-correlation of the NER of 0.95 and a standard deviation of changes in the NER of 3.0%, as reported by [Burstein and Jaimovich \(2012\)](#). These targets imply $\rho_m = 0.95$ and $\sigma_m = 0.057$. We normalize the fixed component of the nominal wage to be equal to the equilibrium wage when aggregate shocks are at their steady-state values, and we set the wage rigidity parameter $\alpha = 0.85$ to capture large short-run stickiness in nominal wages. Persistence in relative money supply and sticky nominal wages generate fluctuations in both NER and RER. Lower wage rigidity boosts the volatility of the NER, and increases cross-country correlations in price changes, but does not meaningfully impact price dispersion. We fix the share of traded goods in the final good consumption aggregator $\phi = 0.66$, the Frisch elasticity of labor supply $\psi = 1$ and the multiplicative factor in labor disutility $\Psi = 5$, which yields a steady state labor supply value of 0.4.⁸

⁷ Statistics based on the stochastic steady state equilibrium with idiosyncratic shocks and no aggregate shocks are very similar and are reported in the Supplementary Appendix.

⁸The literature uses a range of values for the Frisch elasticity and for the degree of wage rigidity. The Supplementary Appendix discusses existing estimates of these two parameters and presents robustness results for different values. The resulting statistics are similar to the baseline results.

The bottom panel of Table 1 reports the values for the parameters that we optimize. These parameters are estimated so as to minimize the squared deviations from the data of the nine moments on U.S.-Canada trade and on relative price differences listed in Table 2. We estimate the elasticity of substitution at the sector level $\varepsilon = 2.4$, the mean elasticity of substitution between varieties in a sector $\bar{\eta} = 5.1$, and the standard deviation of this elasticity across sectors, $\sigma_{\eta} = 0.16$. The retailers' search costs are $\kappa_{us} = 0.0058$ and $\kappa_{ca} = 0.0023$. These values are small, representing 1.8% of revenues for U.S. retailers and 0.7% of revenues for Canadian retailers. Together with the estimated elasticity parameters, the search costs play an important role in determining firms' pricing power. Although modest, the estimated values limit markups well below their steady-state monopoly value, but still allow for the substantial price dispersion seen in the data. In particular, the model generates a sales-weighted unconditional markup equal to 15.2% for U.S. producers and 14.6% for Canadian producers.

For the level of idiosyncratic productivity dispersion, we estimate $\sigma_{us} = 0.127$ and $\sigma_{ca} = 0.089$. The relatively larger dispersion across U.S. firms is important for matching the higher level of within-country price dispersion. In turn, matching this differential is necessary for a proper structural identification of the border effect as distinct from country heterogeneity, as shown by [Gorodnichenko and Tesar \(2009\)](#).

The composite bias parameters defined in equation (16) are $X_{us} = 0.13$ for relative Canadian access to the U.S. market, and $X_{ca} = 0.44$ for the access of American firms to the Canadian market. These estimates imply a strong home country bias, especially against Canadian producers. This result confirms a long line of work that has documented that such a home bias exists and can be quite large (going back to the seminal work of

McCallum (1995) and Engel and Rogers (1996)). However, our estimates also uncover substantial asymmetry: Canada appears to be much more open to U.S. products than the U.S. is to Canadian products, controlling for country size differences.

These bias parameters affect both the price dispersion statistics and the share of domestic U.S. demand met by imports from Canada and the equivalent object from the Canadian perspective. U.S. imports from Canada account for $\Gamma_{us} = 2.1\%$ of final U.S. demand, while imports by Canada of goods from the U.S. account for $\Gamma_{ca} = 17.5\%$ of domestic demand in Canada. Our model matches the U.S. value exactly, while generating a slightly higher import share for Canada, at 17.9%. We next turn to our main result, estimating regional versus national export bias.

3.3 Bias in Trade

Baseline Segmentation: Table 3 reports our estimates for the degree of regional versus national segmentation for the U.S. and Canada. The table reports the median, minimum and maximum value of the export bias estimates, where the statistics are computed over all similarly sized regional splits of the two countries. We find a median value for the average U.S. regional bias of $\beta_{us,us} = 0.32$. This means that an American supplier is about three times more likely to sell to their own region than to the other region in the U.S. How we aggregate U.S. regions into two equal sized markets matters to some extent, with $\beta_{us,us}$ varying between 0.24 and 0.39. This variation suggests uneven economic integration across sub-regions in the U.S.⁹

The national border further reduces access, with a median bias $\beta_{us,ca} = 0.25$. Hence,

⁹In the Supplementary Appendix we document that proximity plays a role in segmenting regions, but its explanatory power is quite limited. We leave for future work a theory of endogenous regional bias.

an American producer is about four times more likely to have access to its own region than to either Canadian region. Interestingly, there is little variation in this estimate across all possible equal-sized splits of the two economies, suggesting that producers from across the U.S. face uniform difficulties accessing the Canadian market.

Overall, the bulk of the segmentation (the distance from the full access value of 1) comes from home bias at the regional level. Indeed, a parameterization in which all segmentation is entirely driven by the regional frictions, without any additional impediments at the border, generates results that are very similar to our baseline estimates, as discussed further below.

Market segmentation faced by Canadian producers is larger than that faced by American producers, both internally and across the border. We estimate a median value of $\beta_{ca,ca} = 0.14$ for the regional bias faced by Canadian producers, and $\beta_{ca,us} = 0.09$, for the U.S. bias they face. Hence, a Canadian producer is seven times more likely to sell in its own region than in the “away” Canadian region, and 11 times more likely to sell in its own region than in either U.S. region. Once again, regional home bias is a major component of the national home bias.

The Relevance of Regional Bias: Our results indicate that segmentation within countries is non-negligible and is in fact responsible for a big portion of the segmentation observed across countries. To put the strength of this result in context, consider an experiment in which we assume that there is only regional bias. We impose the restriction that an American supplier has the same access to a Canadian region as it does at home, to the “away” U.S. region, and similarly for the Canadian supplier, namely, that $\beta_{us,ca} = \beta_{us,us}$ and $\beta_{ca,us} = \beta_{ca,ca}$. We use the median value for the regional bias parameters from

the internal trade data, and we report the results in the column titled “Regional” of Table 2. In this experiment, both countries are more open to each other, with import shares increasing from 2.1% to 2.8% for the U.S. and from 17.9% to 23.4% for Canada. But the price dispersion moments are only marginally affected. Overall, the data are not far from the case in which we impose that all trade frictions come from a region-level bias that is symmetric for all regions, be they in one’s own country or not.

The Degree of Cross-Country Openness: Where do our estimates lie on the continuum between full openness and autarky? Consider the extreme in which we remove both internal and international trade biases. In this case, the key determinants of trade flows and deviations from price parity across the two countries become relative market sizes and relative markups. The column of Table 2 titled *Open* reports the model-implied moments from this counterfactual exercise. Not surprisingly, trade levels would be much higher between the two countries, more than doubling. But beyond that, opening up to trade has asymmetric effects on the U.S. and Canada. Since the U.S. economy is so much larger, the additional imports from Canada do not meaningfully affect competition in the U.S. As a result, the average markup remains unchanged and the volatility of price dispersion for U.S. goods actually increases, since lower trade barriers enable producers with more dispersed costs to be active. For Canada, the resulting competitive pressures are quite strong. As the country opens up to its much larger trading partner, a large mass of low cost U.S. producers enter the Canadian market, putting downward pressure on both markups and price dispersion. The average markup in Canada falls to 10% from the baseline value of 15%. The contrast with the baseline economy demonstrates that cross-border market frictions have a substantial effect on firms’ pricing decisions and

asymmetrically affect cross-border pricing differentials.

These two counterfactual exercises suggest partial market segmentation that supports the finding of [Gopinath et al. \(2011\)](#) that international markets are strongly segmented; but unlike these authors, we attribute much of this segmentation to regional, rather than international frictions.

The model has a fractal-like quality: if we successively disaggregate the economy in sub-regions, sub-sub regions and so on, more disaggregated biases may arise. We interpret the search friction as summarizing all the frictions that may exist at lower levels of aggregation, e.g. between neighboring towns or between stores across the street from each other. Further disaggregation could help determine at which level within-country frictions arise, which may be of independent interest; but it will not change the conclusion about the relative importance of cross-country vs. within country frictions. Many of the economic policy questions for which our results are relevant depend primarily on this level of segmentation. If international borders do not currently create meaningful impediments to trade, as our results suggest, then border-specific policies such as reducing customs delays, tariffs, and cross-country informational frictions, would generate relatively modest benefits.

The Role of Pricing-to-Market: In the model, the distributions of prices differ across countries because of pricing to market by each producer active in the two markets and also because of differences in the composition of active producers. Pricing to market arises due to differences between countries in structural parameters (such as the dispersion in local producer productivities) and shock realizations (such as aggregate demand). The partial segmentation across markets enables producers to post different prices in different

countries in response to these structural differences. Moreover, differences in market sizes and bias parameters imply that the mass of producers from different regions differs across destination markets, resulting in compositional differences across markets.

We investigate how strong pricing-to-market is in our model by considering an alternative parameterization in which search costs are high enough that the threat of retailer search is effectively shut down. In this case, producers always charge a constant monopoly markup relative to their marginal cost. The last column of Table 2 shows that under this calibration price dispersion is much larger, as the threat of search no longer limits markups. Moreover, the amount of additional price dispersion created by the border in the baseline model largely disappears. This calibration indicates that pricing-to-market plays a very important role in explaining cross-border price differentials, a finding that is consistent with both [Gopinath et al. \(2011\)](#) and [Burstein and Jaimovich \(2012\)](#).

4 Robustness

Non-targeted Moments: Table 4 shows that the model can match other moments in the data as well. A particularly striking fact about the micro data is that price changes are far more correlated within countries than across countries: within-country correlations of price changes range between 68% and 89%, while across countries, the correlation is 5% or less. This fact has been taken as evidence in favor of large frictions across countries. But our model is able to replicate these facts, as well as generating a high positive correlation for real and nominal aggregate exchange rates, even though frictions are mostly concentrated at the regional level.

The model matches movements in relative unit labor costs, aggregate nominal and

real exchange rates, and average markups. These moments limit overall volatility in the economy. Nevertheless, one potential concern may be that in order to generate the large level of price dispersion, the model requires shocks that yield implausibly large movements in output and other real aggregate variables. However, this is not the case: as in the data, aggregate variables are only modestly volatile. For example, the standard deviation of aggregate hours is 1.8% in both countries, which is very close to the standard deviation of detrended hours in U.S. data.

The Importance of Trade Flows: We estimate very strong segmentation based on detailed micro price data but fairly aggregated trade data across regions. One important question is how sensitive our results might be to using more disaggregated trade data, for instance at the same level of aggregation as the data underlying our price statistics. In the absence of such data, we instead ask the following question: How much would our international trade bias estimates be affected if the internal trade data were underestimated by 20%? Table 5 reports the resulting segmentation estimates, which confirm that internal regional bias would drop significantly, with firms now more likely to transact across regions within each country. However, the degree of international segmentation remains largely unchanged, suggesting that the international estimates are robust to measurement error of internal trade flows.

Robustness to Nominal Rigidities: The analysis incorporates nominal wage rigidities, but abstracts from nominal price rigidities, which are an important source of relative price dispersion.¹⁰ We find that our estimates of market segmentation are robust to a

¹⁰Woodford (2003), Yun (2005), Burstein and Hellwig (2008) and more recently Sheremirov (2019) are key references discussing price dispersion induced by time-dependent and state-dependent nominal

version of the model that features nominal price frictions. We consider an extension in which producers change prices in each market subject to a fixed adjustment cost. In each period, producers make their pricing decision by comparing the value of paying the menu cost and changing their price to the value of retaining the previous period’s price.¹¹ Combined with the retailer search frictions and the heterogeneous costs across both producers and countries, this gives rise to both real and nominal sources of price dispersion. We re-estimate the model, fixing the international access parameters X_{us} and X_{ca} at the values estimated in the flexible price model, and we target the same set of moments. The model can match the price dispersion targets for both low and high values of the fixed adjustment cost—and hence high and low frequencies of nominal price adjustment. A parameterization with higher menu costs requires larger idiosyncratic productivity shocks and slightly smaller retailer search costs. Intuitively, the model trades off one friction for another. In the absence of segmentation across markets, price dispersion—whatever its source—stimulates trade. The gap between the trade flows that would be generated by the non-segmented model and the data then pins down market segmentation. We conclude that the segmentation parameters can be identified across classes of models with different sources of within-region price dispersion, as long as both price dispersion and trade flow moments are matched. The Supplementary Appendix presents this extension of the model in more detail.

price rigidities in closed economy models.

¹¹Search models augmented with nominal frictions are considered in the closed economy setting by [Benabou \(1988\)](#), [Benabou and Gertner \(1993\)](#), and, more recently, [Burdett and Menzio \(2017\)](#), who focus on the resulting price dispersion and its relationship with aggregate inflation and monetary policy effectiveness.

5 Conclusion

We have demonstrated that a model of price dispersion via retailer search can replicate the most prominent facts about good-level real exchange rates without relying on extreme segmentation at the international border. Evidence on intranational trade from the United States and Canada strongly indicates that in fact the national border plays a rather limited role in segmenting markets. Instead, internal regional segmentation seems the much bigger driver of large price differentials across countries. Whether real or nominal, the friction that generates within-market price dispersion also appears to play a limited role in determining the severity of segmentation across markets. Our estimates suggest that there is substantial scope for further reduction of intra-national barriers to the flow of goods. Our approach estimates reduced-form wedges to quantify the relative severity of regional versus national frictions. We leave for future work endogenizing these wedges with respect to the price distributions and distribution networks in each country.

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Table 1: Baseline Model Parameterization

Parameter		Value	Explanation
Calibrated			
<i>Aggregates</i>			
Relative country sizes	s_{us}/s_{ca}	8	U.S./Canada production
Persistence of relative money supply	ρ_m	0.95	0.95 NER autocorrelation
St. dev. relative money supply shocks	σ_m	0.057	3% st. dev. NER changes
Nominal wage rigidity	α	0.85	High wage rigidity
<i>Consumers</i>			
Share of tradables in consumption	ϕ	0.66	Lombardo and Ravenna (2012)
Frisch elast. of labor supply	ψ	1	Intermediate value
Multiplicative factor in labor disutility	Ψ	5	$L^{ss} = 0.4$
Optimized			
<i>Consumers</i>			
Elasticity of sub across traded goods	ε	2.4	Joint optimization
Mean elasticity of sub across varieties	$\bar{\eta}$	5.1	Joint optimization
St. dev. of elasticity across varieties	σ_η	0.16	Joint optimization
<i>Retailers</i>			
U.S. retailers search cost	κ_{us}	0.0058	Joint optimization
Canadian retailers search cost	κ_{ca}	0.0023	Joint optimization
<i>Producers</i>			
U.S. st. dev. of id. productivity shocks	σ_{us}	0.127	Joint optimization
Canadian st. dev. of id. prod. shocks	σ_{ca}	0.089	Joint optimization
Foreign rel. to domestic access to U.S.	X_{us}	0.133	Joint optimization
Foreign rel. to domestic access to Canada	X_{ca}	0.436	Joint optimization

Note: The targets for the joint optimization are described in Table 2. The Supplementary Appendix reports results for alternative values of the Frisch elasticity and the degree of nominal wage rigidity.

Table 2: Targets for Joint Parameter Optimization

Statistic		Data	Base	Regional	Open	No PTM
Share of US demand met by CA firms	Γ_{us}	0.021	0.021	0.028	0.060	0.021
Share of CA demand met by US firms	Γ_{ca}	0.175	0.179	0.237	0.438	0.189
Sales-weighted US producer markup	$\bar{\mu}_{us}$	0.148	0.152	0.152	0.152	0.238
St. dev. of product-level <i>rer</i> changes						
across US regions, US-made goods	$\sigma_{us,us}^{\Delta d}$	0.08	0.09	0.09	0.09	0.25
across CA regions, US-made goods	$\sigma_{us,ca}^{\Delta d}$	0.06	0.05	0.06	0.06	0.25
across all regions, US-made goods	$\sigma_{us,all}^{\Delta d}$	0.13	0.14	0.15	0.17	0.26
across US regions, CA-made goods	$\sigma_{ca,us}^{\Delta d}$	0.10	0.09	0.07	0.02	0.18
across CA regions, CA-made goods	$\sigma_{ca,ca}^{\Delta d}$	0.04	0.04	0.04	0.01	0.18
across all regions, CA-made goods	$\sigma_{ca,all}^{\Delta d}$	0.17	0.14	0.14	0.15	0.19

Note: Product-level RER moments are from Table 5, Panel B of [Burstein and Jaimovich \(2012\)](#). The baseline parameterization (*Base*) sets model parameters to values that minimize the squared percentage deviations from the data of the nine moments listed in the table. The *Regional* parameterization imposes regional-only export bias, setting $\beta_{us,ca} = \beta_{us,us}$ for American suppliers and $\beta_{ca,us} = \beta_{ca,ca}$ for Canadian suppliers. The *Open* parameterization imposes no bias either internally or internationally ($\beta_{rk} = 1$). The no pricing to market (*No PTM*) parameterization imposes arbitrarily high search costs for retailers, so that producers charge constant (monopoly) markups.

Table 3: Estimated Regional and National Bias Parameters

		United States			Canada		
		Median	Min	Max	Median	Min	Max
Cross-region bias	β_{rx}	0.32	0.24	0.39	0.14	0.12	0.16
Cross-country bias	β_{rx^*}	0.25	0.25	0.26	0.09	0.08	0.09

Note: Within-region bias is normalized to 1. Cross-region bias is the relative bias against the “away” region of one’s own country. Cross-country bias is the bias against either one of the two foreign regions, relative to one’s own region. The median, minimum and maximum values are computed over all similarly-sized two-region splits of each country. $N_{us} = 464$ possible equal-sized U.S. splits, and $N_{ca} = 108$ possible equal-sized Canadian splits.

Table 4: Non-Targeted Moments

Statistic	Symbol	Data	Base	Regional	Open	No PTM
Correlation of product-level price changes						
across US regions, US-made goods	$\rho_{us,us}^{\Delta p}$	0.68	0.69	0.68	0.67	0.09
across CA regions, US-made goods	$\rho_{us,ca}^{\Delta p}$	0.81	0.84	0.82	0.88	0.09
across all regions, US-made goods	$\rho_{us,all}^{\Delta p}$	0.05	0.02	0.02	0.01	0.01
across US regions, CA-made goods	$\rho_{ca,us}^{\Delta p}$	0.74	0.63	0.77	0.98	0.18
across CA regions, CA-made goods	$\rho_{ca,ca}^{\Delta p}$	0.89	0.88	0.93	1.00	0.18
across all regions, CA-made goods	$\rho_{ca,all}^{\Delta p}$	0.04	0.03	0.03	0.01	0.02
Correlation of RER and NER	$\rho_{rer,ner}$		0.99	0.97	0.95	0.99
Sales-weighted CA producer markup	$\bar{\mu}_{ca}$		0.15	0.14	0.10	0.24

Note: Product-level real exchange rate data moments are from Table 5, Panel B of [Burstein and Jaimovich \(2012\)](#). The *Regional* parameterization imposes regional-only export bias, setting $\beta_{us,ca} = \beta_{us,us}$ for American suppliers and $\beta_{ca,us} = \beta_{ca,ca}$ for Canadian suppliers. In the *Open* calibration, all bias parameters are equal to 1. The *No PTM* calibration imposes arbitrarily high search costs for retailers, so that producers charge constant (monopoly) markups.

Table 5: Alternative Regional and National Bias Parameters

		United States			Canada		
		Median	Min	Max	Median	Min	Max
Cross-region bias	β_{rx}	0.41	0.30	0.51	0.18	0.15	0.20
Cross-country bias	β_{rx^*}	0.26	0.25	0.26	0.09	0.09	0.10

Note: Alternative bias estimates for the case in which trade is 20% higher than reported in the aggregate data. Within-region bias is normalized to 1. Cross-region bias is the relative bias against the “away” region of one’s own country. Cross-country bias is the bias against either one of the two foreign regions, relative to one’s own region. The median, minimum and maximum values are computed over all similarly-sized splits of each country. $N_{us} = 464$ possible equal-sized U.S. splits, and $N_{ca} = 108$ possible equal-sized Canadian splits.

Supplementary Appendix for Price Dispersion and the Border Effect

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September 18, 2019

A Model Details

Countries are $k \in \{US, CA\}$, sectors/goods are indexed by $i \in [0, 1]$ and retailers are indexed by $\nu \in [0, 1]$.

Retailers

The problem of the retailers in each region is described in the main text. Each retailer's profit function is the sum of profits obtained from selling its own variety of each good, (ν, i) . All retailers in country k face the same constant elasticity of demand for each good, η_{ik} , distributed according to $\eta_{ik} \sim f_\eta$. Retailers therefore charge a constant markup $\mu_{ik} = \frac{\eta_{ik}}{\eta_{ik}-1}$ over marginal cost. Since differentiation of each good i into the retailer-specific variety is costless, the retailer's marginal cost is the producer price at which it stops the search and purchases all its demand, $\hat{p}_{i\nu k}$. Maximized profits as a function of the sampled price, \hat{p} , are given by

$$\pi^{r*}(\hat{p}) = (\mu_{ik} - 1)(\mu_{ik})^{-\eta_{ik}}(\hat{p})^{1-\eta_{ik}}(P_{ik})_{ik}^\eta C_{ik}.$$

The retailer's search decision depends on distribution of prices posted in sector i in country k , f_{ik} . After sampling a price from this distribution, the retailer decides whether to quit searching (ns) and purchase all demand at the sampled price, or search again (s).

For a given draw \hat{p} from the distribution f_{ik} , the retailer's value function is:

$$V(\hat{p}; f_{ik}) = \max\{V^{ns}(\hat{p}), V^s(f_{ik})\}$$

where

$$V^{ns}(\hat{p}) = \pi^{r*}(\hat{p})$$

is the profit the retailer earns if they do not continue to search and

$$V^s(f_{ik}) = E[V(\tilde{p}; f_{ik})] - \kappa_k$$

is the value of repeating the search. Optimal search policy consists of country and sector specific reservation price \bar{r}_{ik} above which retail firms chose s , and below which they choose ns .

Producers

Producers in sector i post potentially different prices in each market. Because we have assumed that regions within the same country are symmetric, they post the same price in markets within the same country. Retailers that settle on a given producer have elastic demand. Hence optimal prices that are below the reservation price will be a constant markup over producer marginal cost. Since the retailers pass on the demand from the consumers, producers set the same markup μ_{ik} over marginal cost. Producers whose marginal cost is high enough such that they earn no profits at the reservation price choose to shut down.

A firm producing in country k' and selling in country k faces the problem

$$\max_{\hat{p}_j} (\hat{p}_j - mc_j)x_{ik}(\hat{p}_j)$$

where

$$x_{ik}(\hat{p}_j) = \begin{cases} \chi_{ik}(\mu_{ik}\hat{p}_j)^{-\eta_{ik}}(p_{ik})^{\eta_{ik}}C_{ik} & \text{if } \hat{p}_j \leq \bar{r}_{ik} \\ 0 & \text{if } \hat{p}_j > \bar{r}_{ik} \end{cases}$$

and $mc_j = \frac{w_{k'}}{A_j}$, $A_j \sim f_{Ak}$, and χ_{ik} is the mass of *active* retailers-per-producer in sector i in country k at the time. We have assumed that the mass of retailers is equal to the mass of *potential* producers, so that $\chi_{ik} \geq 1$, with strict inequality only when some producers find it optimal to shutdown for the period given retailer's reservation prices.

Denote the optimal price of the producing in country k' and selling in k with $\widehat{p}_{ijk',k}^*$. The corresponding implied labor demand of the firm is $l_{ijk',k} = x_{ik}(\widehat{p}_{ijk',k}^*)/A_j$. The total labor demanded by country- k' traded-good producers is

$$L_k^T = \underbrace{\int_0^1 \int_0^1 l_{ijk',k} \mathbf{1}[p_{ijk',k}^* - mc_j > 0] dj di}_{\text{labor supplied to exports}} + \underbrace{\int_0^1 \int_0^1 l_{ijk',k'} \mathbf{1}[p_{ijk',k'}^* - mc_j > 0] dj di}_{\text{labor supplied to domestic sales}}. \quad (\text{A.1})$$

where $\mathbf{1}(\cdot)$ is an indicator function indicating when producer choose to become active.

General Equilibrium and Market Clearing

Individual firm level prices and quantities must be consistent with general equilibrium in the economy. In addition to the expression for traded-good labor (A.1) above, it must be that

$$C_{ik} = \left(\int_0^1 (C_{ivk})^{\frac{\eta_{ik}-1}{\eta_{ik}}} d\nu \right)^{\frac{\eta_{ik}}{\eta_{ik}}} \quad (\text{A.2})$$

$$C_k^T = \left(\int_0^1 (C_{ik})^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} \quad (\text{A.3})$$

$$p_{ik} = \left(\int_0^1 p_{ivk}^{1-\eta_{ik}} d\nu \right)^{\frac{1}{1-\eta_{ik}}} \quad (\text{A.4})$$

$$P_k^T = \left(\int_0^1 P_{ik}^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}} \quad (\text{A.5})$$

$$P_k^N = W_k \quad (\text{A.6})$$

$$C_k^T = \phi M_k / P_k^T \quad (\text{A.7})$$

$$C_k^N = (1 - \phi) M_k / P_k^N \quad (\text{A.8})$$

$$L_k^N = C_k^N / \bar{A} \quad (\text{A.9})$$

$$L_k = L_k^T + L_k^N \quad (\text{A.10})$$

Given the values for $\{M_k\}$ for each country and distributions $\{f_{Ak}\}$ and f_η , equilibrium in the economy is summarized by a set of reservation prices $\{\bar{r}_{ik}\}$ selected by retailers, a distribution of wholesale prices posted $\{f_{ik}\}$ selected by producers, the sets of general equilibrium objects summarized above, $\{\Omega_k\}$, where

$$\Omega_k \equiv \{ \{C_{ik}, p_{ik}\}, C_k^T, C_k^N, L_k^T, L_k^N, L_k, P_k^T, P_k^N, W_k \},$$

and an exchange rate e that ensures balanced trade.

Regional Bias Measures

The measure of firms from k with an opportunity to sell in region k' is given by the matching function

$$m_{kk'} = \frac{\beta_{kk'} S_k S_{k'}}{S_k + S_{k'}}.$$

Hence, imposing symmetric sized regions within each country, the total sales opportunities for firms in region a of the US is given by

$$m_{aa} + m_{ab} = \frac{(1 + \beta_{ab}) S_a^2}{2 S_a} = S_a \frac{1 + \beta_{ab}}{2}.$$

The probability that a given region- a firm has a domestic selling opportunity is then just

$$\frac{m_{aa} + m_{ab}}{S_a} = \frac{1 + \beta_{ab}}{2}.$$

Similarly, the probably that a given region- a firm has foreign selling opportunity is

$$\frac{m_{ac} + m_{ad}}{S_a} = \frac{2\beta_{ac} S_c}{S_a + S_c}.$$

Hence the relative probabilities of accessing the foreign market relative to the domestic market — the parameter that is pinned down by the pricing moments we target — is

$$R_{us} = \frac{2\beta_{ac}}{1 + \beta_{ab}} \times \frac{2S_c}{S_a + S_c}.$$

In turn, this pins down the measure of pure bias,

$$X_{us} = \frac{2\beta_{ac}}{1 + \beta_{ab}}.$$

National bias is a composite of both regional bias and additional bias that comes from crossing the border. To separately identify the regional bias, we derive a relationship between this parameter and the domestic import share. Given within-country symmetry, sales per firm have the same distribution regardless of the domestic region of origin. Hence, we need only compute the ratio of e.g. the number of region b firms with selling opportunities in region a compared to the total number of firms selling in region a ; this will be equal to the import share. This is given by

$$\phi_a \equiv \frac{m_{ba}}{m_{ba} + m_{aa}} = \frac{\beta_{ab}}{1 + \beta_{ab}}.$$

Hence the internal bias parameters are uniquely identified by trade-quantities alone. Together with the expression for X_{us} , this fully identifies our bias parameters. Identical calculations delivers analogous expressions for the Canada.

B Extension with Menu Costs

As a robustness check, we consider a steady-state version of the economy in which all shocks remain i.i.d., but producing firms face a menu cost τ_k of changing a price posted in country k from the previous period. Firms entering a given period with a price that is close enough to their optimal price choose not change their price in the current period.

Let

$$\Pi(\hat{p}_j) \equiv (\hat{p}_j - mc_j)x_i^c(\hat{p}_j)$$

be the contemporaneous profit of a firm producing firm in sector i charging price \hat{p}_j and let \hat{p}^{*c} be the price that maximizes [B](#). Then, the value function of a producer entering the period with inherited price $\hat{p}_{j,t-1}$ is

$$V^{pc}(\hat{p}_{j,t-1}) = \max \{ \Pi(\hat{p}^{*c}) - \tau^c + E[V^{pc}(\hat{p}^{*c})], \Pi(\hat{p}_{j,t-1}) + E[V^{pc}(\hat{p}_{j,t-1})], \}. \quad (\text{B.1})$$

As before, we assume that firms who would earn negative profits if they posted a price and produced choose to shutdown, and inherit their past price for the subsequent period.

C Numerical Procedure

In order to solve the model, we discretize the state-space and the set of prices that producing firms may post. There are three states that need to be discretized. We approximate the distribution of log marginal cost using 200 equally spaced grid between -5 and +5 standard deviations. The distribution of sectoral elasticities is approximated by using 16 gaussian hermite grid points to approximate the bivariate normal distribution for elasticities in each sector for both countries. Finally, the set of aggregate monetary shocks is approximated for each country using the Rouwenhorst (Kopecky and Suen (2010)) approach to create a 3 point discrete markov process that approximates and AR(1) process with persistence 0.95. Finally, optimal prices are computed on a grid of 600 equally-spaced grid of potential (log) prices.

We use an iterative approach to solve for the equilibrium of the economy. We conjecture an initial set of general equilibrium prices and quantities (summarized above), compute optimal pricing decision by firms, find implied quantities and labor demand, and use the results to update the general equilibrium quantities. Since this is a steady-state model, we require balanced trade. Our iterative procedure adjusts the nominal exchange rate to ensure trade is balanced.

Given the number of discrete choices in the model, the iterative algorithm sometime oscillates between very similar solutions without fully converging. We have found that this can generally be avoided by assuming that firms' choice to shutdown or operate adjust continuously in the neighborhood of zero profits, rather than discretely shutting on or off. We implement this using the an exponential function, so that the probability of shutting down is

$$p^{shut} = \frac{\exp(V^{shut}/\lambda)}{\exp(V^{shut}/\lambda) + \exp(V^{open}/\lambda)},$$

with $\lambda = 0.0002$. This ensures that, in equilibrium, p^{shut} is numerically zero or one for all but a small number of firms very close to indifferent between operating and shutting

down.

For each state in the aggregate state-space, our numerical algorithm can be summarized as an iteration $l = 0, 1, \dots$ on the following steps:

1. Conjecture a set of general equilibrium objects in both countries, including k - and i -specific prices and quantities, reservation prices, general equilibrium quantities $\{\Omega_k\}_l$, and the bilateral exchange rate.
2. Given the entries in $\{\Omega_k\}_l$ and the reservation prices, compute the optimal prices (or shutdown decision) for producers from each country and for each value of the marginal cost grid. This implies a distribution of prices posted in each country, f_{ik} .
3. Given $\{f_{ik}\}$, compute the optimal search decision of retailers and update reservation prices, $\{\bar{r}_{ik}\}$.
4. Given the distribution of $\{f_{ki}\}$ and $\{\bar{r}_{ik}\}$, compute the implied quantities and price indexes and update (or partially update) the entries of $\{\Omega_k\}_{l+1}$.
5. Check if $|\{\Omega_k\}_{l+1} - \{\Omega_k\}_l| \approx 0$. If not, return to step 1.

D Additional Results

Alternative model versions: Table D.1 presents results for the steady state and for the best-fitting menu cost model. The first column presents values for the baseline estimation; the second column presents values for the stochastic steady state with idiosyncratic shocks but no aggregate shocks; and the third column presents values for the best-fitting menu cost model.

When we compare the model to the data, we compute the model statistics based on the equilibrium with both idiosyncratic and aggregate shocks, aggregated over many periods. Our empirical moments are based on data during “normal times”, with no recession or large expansion during the sample period. Nevertheless, the statistics at the steady state with no aggregate shocks are close to the baseline statistics.

For the menu cost model, the national bias parameters, X_{us} and X_{ca} , are kept fixed at values we estimated in our baseline model. We then re-estimate the model, targeting the same set of moments as the baseline model, along with a price change frequency of 1/3 in both the U.S. and Canada. The model generates dispersion statistics that are similar to those generated by the flexible price model. Since these moments are obtained with the same values for the international access parameters, the estimation implies exactly the same coefficients for regional versus international segmentation. We conclude that adding nominal rigidities does not alter our inference regarding the severity of regional versus national trade frictions. Introducing the nominal price rigidity does affect some of the other estimated parameters. In particular, it yields larger idiosyncratic productivity shocks and smaller markup shocks, compared with the flexible price model. Since nominal rigidities generate endogenous variation in realized markups, the model requires smaller elasticity shocks to generate the same level of price dispersion. The estimation also yields higher search and menu costs for Canada compared with the U.S.

Robustness: Table D.2 presents sensitivity results to alternative parameterizations. For the Frisch elasticity, the article reports results for an intermediate value of the Frisch elasticity equal 1. Here, we report results for 0.4 (which is closer to the estimates based on micro data) and 1.5 (which is towards the high end of the values used in macro models), per Chetty et al. (2011) and Keane and Rogerson (2012). Results are modestly affected. In particular, a higher Frisch elasticity raises markups, and hence price dispersion, and generates a lower correlation of price changes both within and across countries, but our conclusions do not change qualitatively. Note that although the micro literature suggests small elasticities, structural work has shown that small micro elasticities can coexist with large macro elasticities, which means that higher values are warranted for representative agent macro models like ours.

For the degree of wage rigidity, the article reports results for a high wage rigidity parameterization ($\alpha_w = 0.85$). To a simple approximation, this level of rigidity is equivalent to assuming a Calvo model in which wages are reoptimized roughly every six quarters. This is somewhat higher than the micro-based estimates of Barattieri et al. (2014), who report an estimated duration of 4 to 5 quarters, based on survey data corrected for mea-

surement error. The values estimated in DSGE models typically range from 2.8 quarters (Christiano, Eichenbaum and Evans, 2005) to nearly 4 quarters (Smets and Wouters, 2007). Our relatively higher degree of wage rigidity reflects the fact that what matters for aggregate dynamics is the extent to which wages incorporate new information, which is affected by both the frequency of adjustment and the degree of noise and inertia conditional on adjustment. Below, we report results for a lower degree of wage rigidity equal to 0.65 (close to the CEE estimates). Overall, our results are very robust to changes in the degree of wage rigidity. With a lower degree of wage rigidity, both the volatility of the NER and the correlation of price changes across the border (which is an untargeted moment) increase. The remaining statistics do not change in significant ways.

Lastly, our baseline results estimate a small amount of volatility in the elasticity of substitution among varieties. As discussed in the main text, this volatility in desired markups enables us to generate large price dispersion without also generating large aggregate fluctuations. Below we report results for the case of an even smaller variation in this elasticity (0.04 instead of 0.16). We find that this generates less trade, less cross-country price dispersion, and a much lower correlation of price changes.

The Role of Asymmetries: We incorporate multiple dimensions of asymmetry in our parameterization: market size, trade bias, productivity dispersion among producers, and search costs for retailers. While the last two dimensions are crucial for matching the price dispersion data, the first two are particularly important for matching trade volumes, as shown in Table D.3, which reports results for two alternative specifications: one in which the two countries are both equal to the average between the U.S. and Canada, and one in which the two countries have the same retailer search costs and the same producer productivity dispersion, and these parameters are set to the average between the U.S. and Canada.

Regional Heterogeneity Our results show that how the subregions are aggregated matters for estimates of *internal* segmentation, especially for the U.S. But they also suggest that the bias against foreign producers is roughly symmetric: the ranges of values for $\beta_{us,ca}$ and $\beta_{ca,us}$ are quite narrow.

For the U.S., the regional bias coefficients range from 0.24 to 0.39. This means that economic integration is uneven across subregions. It is indeed the case that proximity plays a role in segmenting U.S. regions, as shown in Figure D.1, but its explanatory power is quite limited. For Canada, regional segmentation is more severe, but it is also more narrow. Furthermore, there is virtually no correlation with distance, and there also does not appear to be a stronger regional bias between Quebec and the rest of Canada. We leave for future work a theory of endogenous regional bias, which would likely require modeling the network structure of each country.

Table D.1: Model Versions

		Baseline	Steady state	Menu cost
Optimized parameters				
<i>Consumers</i>				
Elasticity of sub across traded goods	ε	2.40	2.40	2.40
Mean elasticity of sub across varieties	$\bar{\eta}$	5.13	5.13	5.13
St. dev. of elasticity across varieties	σ_{η}	0.16	0.16	0.14
<i>Retailers</i>				
U.S. retailers search cost	κ_{us}	0.0058	0.0058	0.0058
Canadian retailers search cost	κ_{ca}	0.0023	0.0023	0.0023
<i>Producers</i>				
U.S. st. dev. of id. productivity shocks	σ_{us}	0.127	0.127	0.139
Canadian st. dev. of id. prod. shocks	σ_{ca}	0.089	0.089	0.107
Foreign to domestic access to U.S.	X_{us}	0.133	0.133	0.133
Foreign to domestic access to Canada	X_{ca}	0.436	0.436	0.436
U.S. menu cost	τ_{us}	0	0	0.0015
Canadian menu cost	τ_{us}	0	0	0.0029
Targeted moments				
Share of US demand met by CA firms	Γ_{us}	0.0206	0.0207	0.0207
Share of CA demand met by US firms	Γ_{ca}	0.179	0.180	0.180
Sales-weighted US producer markup	$\bar{\mu}_{us}$	0.152	0.152	0.152
Frequency of price changes in US	$f r_{us}$	1	1	0.34
Frequency of price changes in Canada	$f r_{ca}$	1	1	0.34
St. dev. of product-level <i>rer</i> changes				
across US regions, US-made goods	$\sigma_{us,us}^{\Delta d}$	0.09	0.09	0.09
across CA regions, US-made goods	$\sigma_{us,ca}^{\Delta d}$	0.05	0.05	0.06
across all regions, US-made goods	$\sigma_{us,all}^{\Delta d}$	0.14	0.14	0.13
across US regions, CA-made goods	$\sigma_{ca,us}^{\Delta d}$	0.09	0.09	0.10
across CA regions, CA-made goods	$\sigma_{ca,ca}^{\Delta d}$	0.04	0.05	0.05
across all regions, CA-made goods	$\sigma_{ca,all}^{\Delta d}$	0.14	0.13	0.13
Untargeted moments				
Sales-weighted CA producer markup	$\bar{\mu}_{ca}$	0.146	0.151	0.142
Correlation of product-level price changes				
across US regions, US-made goods	$\rho_{us,us}^{\Delta p}$	0.69	0.68	0.57
across CA regions, US-made goods	$\rho_{us,ca}^{\Delta p}$	0.84	0.82	0.78
across all regions, US-made goods	$\rho_{us,all}^{\Delta p}$	0.02	0.00	0.00
across US regions, CA-made goods	$\rho_{ca,us}^{\Delta p}$	0.63	0.85	0.82
across CA regions, CA-made goods	$\rho_{ca,ca}^{\Delta p}$	0.88	0.62	0.48
across all regions, CA-made goods	$\rho_{ca,all}^{\Delta p}$	0.03	0.00	0.00

Table D.2: Robustness

	Base	Low Frisch	High Frisch	Low α_w	Low σ_η
Targeted moments					
Share of US demand met by CA firms	0.0206	0.0210	0.0206	0.0207	0.0202
Share of CA demand met by US firms	0.179	0.181	0.180	0.180	0.177
Sales-weighted US producer markup	0.152	0.140	0.160	0.152	0.153
St. dev. of product-level <i>rer</i> changes					
across US regions, US-made goods	0.09	0.07	0.10	0.09	0.09
across CA regions, US-made goods	0.05	0.04	0.06	0.05	0.05
across all regions, US-made goods	0.14	0.13	0.15	0.14	0.08
across US regions, CA-made goods	0.09	0.07	0.10	0.09	0.09
across CA regions, CA-made goods	0.04	0.03	0.05	0.04	0.04
across all regions, CA-made goods	0.14	0.12	0.14	0.13	0.08
Untargeted moments					
Sales-weighted CA producer markup	0.146	0.135	0.155	0.148	0.153
Correlation of product-level price changes					
across US regions, US-made goods	0.69	0.78	0.64	0.70	0.16
across CA regions, US-made goods	0.84	0.88	0.82	0.85	0.39
across all regions, US-made goods	0.02	0.05	0.02	0.08	0.08
across US regions, CA-made goods	0.63	0.77	0.55	0.65	0.13
across CA regions, CA-made goods	0.88	0.93	0.85	0.88	0.48
across all regions, CA-made goods	0.03	0.06	0.03	0.10	0.11

Note: Product-level real exchange rate moments are from Table 5, Panel B of ?. The baseline parameterization (*Base*) sets model parameters to values that minimize the squared deviations from the data of the nine target moments. The subsequent columns report results for high Frisch elasticity (1.5) and low Frisch elasticity (0.4), versus the baseline value of 1; low wage rigidity (0.65 versus the baseline value equal to 0.85); and low standard deviation of elasticity shocks (0.04 versus the baseline value of 0.16).

Table D.3: Role of Asymmetries

	Base	Same sizes	Same structure
Targeted moments			
Share of US demand met by CA firms	0.021	0.089	0.021
Share of CA demand met by US firms	0.179	0.101	0.182
Sales-weighted US producer markup	0.152	0.142	0.146
St. dev. of product-level <i>rer</i> changes			
across US regions, US-made goods	0.09	0.08	0.07
across CA regions, US-made goods	0.05	0.05	0.04
across all regions, US-made goods	0.14	0.14	0.13
across US regions, CA-made goods	0.09	0.10	0.12
across CA regions, CA-made goods	0.04	0.05	0.08
across all regions, CA-made goods	0.14	0.14	0.15
Untargeted moments			
Sales-weighted CA producer markup	0.146	0.148	0.164
Correlation of product-level price changes			
across US regions, US-made goods	0.69	0.71	0.77
across CA regions, US-made goods	0.84	0.87	0.91
across all regions, US-made goods	0.02	0.03	0.03
across US regions, CA-made goods	0.63	0.54	0.46
across CA regions, CA-made goods	0.88	0.86	0.71
across all regions, CA-made goods	0.03	0.04	0.03

Note: The baseline parameterization (*Base*) sets model parameters to values that minimize the squared deviations from the data of the nine target moments. The next column reports results for the case in which both countries are of equal sizes, set to the average between U.S. and Canada. The last column reports results for the case in which the countries are of different sizes, but have the same retailer search costs and the same producer productivity dispersion. The values for these parameters are each set to the average between the U.S. and Canada.

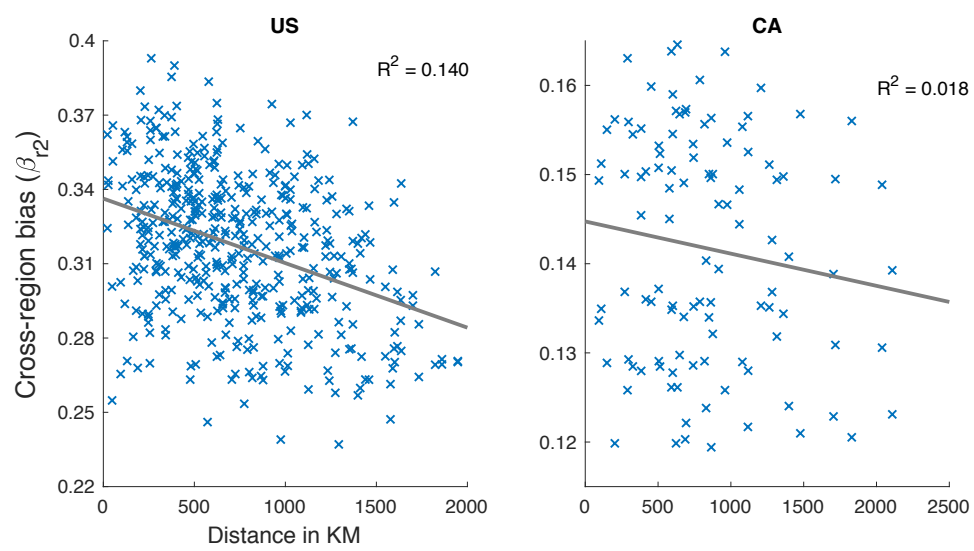


Figure D.1: Scatter plot of regional bias against distance

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