Intra-national Trade Costs: Assaying Regional Frictions*†

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Abstract

The effects of intra-regional, inter-regional and international frictions on the trade flows of Canada's provinces are disentangled by gravity model techniques. Unexplained Trade Barriers (UTBs) are the difference between inter-provincial trade barriers inferred from pair fixed effects and from bilateral distance and contiguity. The estimates reveal large intra-national trade costs and UTBs that vary significantly across Canada's provinces. Decomposition of UTBs into relative border effects and a systematic residual UTB is based on a novel Cobb-Douglas aggregator of intra-provincial and pure inter-regional trade costs. Variation of both components across provinces is big.

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*Acknowledgments will be added later. The geological "assay" metaphor of our subtitle refers to the repeated crunching, sifting and weighing of original and generated data. This research is supported by the Public Policy Forum, Industry Canada, and the Internal Trade Secretariat, Canada. All errors and opinions are our own.

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"In an era of ongoing global economic uncertainty, an integrated, competitive and vibrant domestic economy is more important than ever. Enhanced internal trade helps businesses expand across regions, strengthens productivity, encourages greater labour mobility, lowers costs and attracts investment. As Canada considers new approaches for driving economic performance, we need to evaluate how trade across provinces and territories can become more efficient."

Paul Ledwell, Executive Vice-President,
Public Policy Forum Canada, October, 2013

1 Introduction

Intra-national trade barriers are large and they present a substantial hurdle for domestic trade (Beaulieu et al., 2003).[1] As such, internal distribution frictions have important implications for gains from trade, for economic development, and for other economic outcomes. For example, Ramondo *et al.* (2016) demonstrate that the variation of internal trade costs helps resolve puzzles in the open economy macro literature.[2] Furthermore, as evident from the opening quote of our study, policy makers also recognize the prominent role of intra-national trade frictions for strengthening national economies within the world trading system. However, despite their potential importance, intra-national obstacles to trade are less-studied and less-understood than international trade frictions.[3] This paper provides detailed measures of the effects of intra-regional, regional border and inter-regional frictions on the trade of Canada's provinces. Novel techniques solve a subtle inference problem.

[1] Beaulieu et al. (2003) offer ample anecdotal evidence for the existence of significant inter-provincial barriers to trade within Canada including home-biased government procurement, province-specific occupational licenses, and local marketing boards within the agricultural sector.

[2] Due to scale effects, endogenous growth models imply that larger countries should be richer than smaller countries. Similarly, standard trade models imply that real income per capita (domestic trade shares and relative income levels) increases too steeply with country size. Ramondo *et al.* (2016) demonstrate that these counterfactual implications are mitigated/disappear when the standard, but unrealistic, assumption of frictionless domestic trade is relaxed.

[3] "One of the most significant challenges [that] continue to restrict internal market is the inability of policymakers, economists and researchers to truly understand the economic impact of internal trade barriers, due to the lack of data and research" (p. 6, PPF Report, 2013). "The lack of current research on best practices has meant that [...] policymakers have often had to rely on anecdotal evidence that is often misinformed, biased and dated. As a result, it has been difficult to clearly identify solutions or accurately evaluate the impact that policies are having on internal trade flows. It has also meant that developing evidence-based policy solutions to address these issues has been made significantly more difficult."

Our approach is in two steps. First, we apply gravity to estimate intra-regional, inter-regional, and international trade costs.[4] A key objective is to infer border barriers between regions, inevitably as a residual effect of lower inter-regional trade relative to intra-regional trade, all else equal. But the border barrier effect inferred in this way is necessarily relative to intra-regional friction effects and likely to be contaminated by other systematic residual effects as well as randomness. In the first step, Unexplained Trade Barriers (UTBs) are the difference between bilateral frictions inferred from pair fixed effects gravity regressions and those inferred from standard gravity variables (essentially, taking out inter-regional distance) regressions. To extract information from the UTBs, we structure the components of full bilateral trade costs with a Cobb-Douglas aggregator. The added structure permits a second stage decomposition of UTBs into the systematic effects of regional relative border barriers in both origin and destination, and a systematic residual component. This procedure solves the inference problem posed by identification of inter-regional border barriers in the presence of heterogeneous intra-regional trade costs and pure inter-regional costs associated with distance and contiguity.

The first stage procedure infers bilateral trade costs from the pair fixed effects and gravity variables specifications of structural gravity regressions. The bilateral fixed effects specification combines with importer-time and exporter-time fixed effects.[5] The standard gravity specification replaces pair fixed effects with standard bilaterally varying variables (e.g. distance and contiguity) along with importer-time and exporter-time fixed effects and a set of fixed effects for intra-regional trade. The difference between the estimated pair fixed effect and the fitted bilateral effect of standard gravity variables is the Unexplained Trade Barrier.[6]

[4]Consistent with our empirical focus on Canada, the reader should think of 'intra-regional' trade costs as 'intra-provincial' trade barriers. 'Inter-regional' trade costs should be thought of as 'inter-provincial' trade barriers. Finally, 'international' trade costs are the costs between Canada's provinces and foreign countries as well as among the foreign countries themselves.

[5]Previous literature (including our own) has used the somewhat suspect concept of internal distance or a single dummy variable for intra-national trade to proxy for internal frictions, imposing a uniform distance elasticity to provide sufficient degrees of freedom. Regionally varying internal trade fixed effects gain adequate degrees of freedom by judicious use of panel structure.

[6]Our Unexplained Trade Barrier indexes are related to the analysis from two contemporary papers. Caliendo et al (2016) isolate the effects of distance vs. "other" trade costs that apply to US inter-state

The second stage procedure is based on a regression of the estimated bilateral fixed effects on the volume effects of the fitted bilateral gravity variables. With no internal border barriers, the theory predicts that UTBs should be random and small, hence the naive regression of inferred pair fixed effects on the combined fitted effects of bilateral distance and contiguity should have slope equal to 1 and a very good fit. Instead, UTBs implied by the naive regression are systematic and large. Applying the restrictions of the Cobb-Douglas trade cost aggregator and of structural gravity, the fixed effects for intra-regional trade have explanatory power in the appropriate second stage regression. Moreover, the restrictions applied to the appropriate second stage regression permit the systematic component of UTBs to be decomposed into a relative border barrier effect and a systematic residual effect.

The assay uses a dataset of Canadian provincial trade flows in 19 goods and 9 service sectors from 1997-2007. The empirical focus is on Canada due to this country's heterogeneous geographical and economic structure, significant policy interest in understanding intra-national trade barriers, and availability of detailed and carefully constructed data.[7] The discussion of results focuses on estimates from aggregate manufacturing bilateral trade for simplicity. The results are qualitatively similar to those for the 19 goods and 9 services sectors briefly discussed.[8] Estimates are quite precise. Analysis of residuals and sensitivity

trade. Our paper differs from Caliendo et al (2016) methodologically, because we use estimation methods while they rely on ratio methods. In addition, our main focus is on the decomposition of international vs. inter-regional vs. intra-regional trade costs. In another recent paper Egger and Nigai (2016) find that the pair fixed effects from structural gravity estimations carry additional information about *international* trade costs that is not captured by standard gravity covariates. We expand their analysis to demonstrate that intra-national trade costs are also subject to significant "unexplained" barriers to trade. "Unexplained" here applies Head and Mayer's (2013a) cosmological metaphor: gravity trade costs are *dark*. This paper moves the darkness one step by identifying systematic effects of border costs relative to internal costs, but shadow covers what these costs may be.

[7] The main advantage of our dataset is that it covers intra-provincial, inter-provincial, and international trade flows for each of Canada's provinces and territories. Statistics Canada has made every effort to ensure consistency between the three types of trade flows, cf. Genereux and Langen (2002). The paucity of research on intra-national trade costs is partly due to deficient data. To our knowledge, except for Canada, data on bilateral shipments within nations does not record true origin-destination trade. In particular, the widely used US Commodity Flow Survey does not control for entrepôt trade.

[8] The sectoral estimates are essential for informing policy reform, and as an input to investigate the relationship between border barriers and institutional and infrastructure variables, or for general equilibrium comparative statics. Details are available on request. Sectoral disaggregation is generally important because previous work (Anderson and Yotov (2010)) has shown that estimates of trade costs from aggregate data are biased downward, a concern especially acute for estimating intra-national trade costs.

experiments support our baseline specification.

The most important "takeaway" from our paper, is that the relative border barrier effect component of UTBs is large and substantially heterogeneous across Canada's provinces. The relative border barrier is the ratio of the border friction to intra-provincial friction for each province. The large variation of relative border barriers is explained by provincial variation in economic and geographic size. Yukon has the largest relative border effect because its population is concentrated in Whitehorse (its capital) while the second largest relative border effect is for geographically compact Prince Edward Island. Ontario, followed by British Columbia and Alberta have the lowest relative border barrier effects partly reflecting high internal frictions due to dispersed intra-provincial trade as well as their highly developed trade networks. The wide heterogeneity of intra-regional trade frictions across Canada's provinces suggests that the common approach in the trade literature that treats regions (provinces and/or countries) as point masses is *substantially* at odds with reasonable inference from the data.

A second "takeaway" is that systematic residual Unexplained Trade Barriers induce significant systematic distortions of interprovincial trade. The more remote and smaller regions (e.g. Yukon, Prince Edward Island, and the Northwest Territories) are subject to the largest systematic residual UTBs. The effects of border barriers are measured relative to a national average, so economically developed and central regions (e.g. Ontario, Alberta, and British Columbia) enjoy relative stimuli to trade from UTBs.[9] At one extreme, Prince Edward Island's exports to Yukon are reduced 43% by their 2002 UTB in manufacturing. At the other extreme, Ontario's exports to British Columbia are raised 30% by their UTB. The details of variation across provinces and provincial pairs may indicate where policy intervention is needed most and where policy intervention will be most efficient. Disentangling internal from border cost variation is an important but difficult task for future work. We expect

[9]The provincial border barriers are inferred as deviations around a Canada-wide mean, so low border barrier provinces tend to enjoy relative stimulus due to the UTB. Due to collinearity we are unable to measure the level of border barriers, only the variation.

the magnitude and heterogeneity of UTBs will be even larger in a cross-country study with international data.

To support aggregation of trade barriers we develop and apply a new bilateral trade cost index, Constructed Trade Bias (CTB).[10] CTB measures the general equilibrium effects of trade barriers as the ratio of predicted to frictionless trade, allowing straightforward aggregation from bilateral trade to any combination of trade partners. CTBs for each province's inter-provincial trade (aggregating each province's exports to all others) are all greater than one, the familiar result of 'excess' inter-provincial trade. But CTBs for intra-provincial trade (Constructed Home Bias, CHB) are greater still, evidence for the importance of inter-provincial trade barriers. The ratio of CHB to CTB for Canadian provincial partners ranges from 2 for Ontario upward to 8.3 for Quebec and is vastly greater for the smaller and more remote provinces. We also apply CTBs to measure the evolution of intra-national trade bias faced by Canada's provinces. Since the direct trade costs are estimated as constant, CTB changes are due to the changes in provincial outputs and expenditures. Falling CHBs are the rule, Canada's provinces are becoming more integrated with both the world and with each other over the period from 1997 to 2007. Moreover, the ratio of inter- to intra-regional CTB rises for all but Yukon: intra-national integration is rising faster than international. Finally, we use the percentage changes in CTBs to simulate a counterfactual removal of all inter-provincial UTBs at given sales and expenditures (corresponding to the Modular Trade Impact by Head and Mayer (2014)). The effects of removal for each province's trade with its Canadian partners vary between 10% up or down, with some bilateral effects considerably larger in absolute value.

Our paper is related to a small but vibrant and fast-growing literature concerned with the proper measurement of intra-national trade costs and their implications for various economic outcomes. Ramondo *et al.* (2016) demonstrate that the standard findings that larger countries should be richer than smaller countries (from the macro literature) and that real

[10] CTB is a generalization of the Constructed Home Bias (CHB) index of Anderson and Yotov (2010) to a family of bias indexes that can be aggregated to and decomposed across various dimensions.

income per capita increases too steeply with country size (from the trade literature), disappear when intra-national trade costs are taken into account. Donaldson (2016) extends a multi-country and multi-sector Ricardian model of trade to accommodate intra-national trade costs and examines the implications of the railroad network in India for productivity and welfare. Cosar and Demir (2016) and Cosar and Fajgelbaum (2016) study the implications of enhanced transportation infrastructure and internal geography by recognizing that international trade flows must pass through gateway locations, e.g. seaports and airports. Our main contribution to this literature is that we propose new methods and capitalize on a unique data set in order to simultaneously identify international vs. inter-regional vs. intra-regional trade costs, and to decompose them into geographical components and unexplained trade barriers. We find that inter-regional and intra-regional trade costs are quite heterogeneous, thus reinforcing the main arguments from the aforementioned papers that allowing for variation in intra-national trade costs has important implications for regional policy and for general equilibrium comparative statics.

Inference of border frictions from trade flows using gravity models feature in a prominent literature mostly focused on international borders, but studies in this vein (e.g., Eaton and Kortum (2002)) usually suppress variation in distribution costs internal to the origin and destination areas of observation (regions or countries). The previous literature using gravity to infer internal trade frictions from trade flows[11] has mainly adopted two methods of estimating internal trade barriers: using the gravity model with a *uniform* effect of intra-regional relative to inter-regional trade costs or using proxies for inter-regional trade borders.[12] We

[11]For the United States see Wolf (2000), Hillberry and Hummels (2003), Millimet and Osang (2007), Head and Mayer (2002, 2010), Coughlin and Novy (2012), Yilmazkuday (2012)); for the European Union see Nitsch (2000), Chen (2004), and Head and Mayer (2000, 2010); for Canada see Tombe and Winter (2014) and Albrecht and Tombe (2016); for OECD countries see Wei (1996); for China see Young (2000), Naughton (2003), Poncet (2003, 2005), Holz (2009), Hering and Poncet (2010); for Spain see Llano and Requena (2010); for France see Combes et al. (2005); for Brazil see Fally et al. (2010); and for Germany see Lameli et al. (2013) and Nitsch and Wolf (2013).

[12]Hillberry and Hummels (2008) is a notable exception that shows that manufacturing shipments between establishments within the same zip-code are three times larger than between establishments in different zip codes in the U.S. While, our data do not allow such a fine treatment of international trade costs, we complement Hillberry and Hummels (2008) by offering a unified framework to treat intra-regional, inter-regional, and international trade costs.

generalize this treatment to allow for *non-uniform intra-regional trade costs*, in addition to non-uniform inter-regional, and non-uniform international barriers. Non-uniformity of intra-regional border frictions is both consequential and substantial, as we show. We are not aware of existing comparable estimates at the intra-regional level, however, our inter-provincial estimates are smaller as compared to estimates from previous studies. One possible explanation for this result is that we are able to separate intra-regional from inter-regional trade costs. Another reason could be the specifics of our sample. The provincial border barrier variation we find has potential implications for regional policy. International border barriers are not our focus, but our estimation utilizes international as well as inter-regional trade flows. Thus, it relates somewhat to the literature on the international border barrier to Canada's trade: e.g., McCallum (1995), Anderson and van Wincoop (2003). Our methods should be applicable widely to inference of intra-national trade costs and UTBs in multi-country and multi-regional studies. The methods can also be applied to quantify barriers to immigration and FDI, about which we know much less than about trade costs.

A more distantly related literature infers trade costs from price differences (e.g., Engel and Rogers (1996)) at a highly disaggregated level. As with trade flows, distance and borders account well for price differences. Price comparisons often imply large intra-national price gaps in developing countries (Atkin and Donaldson (2013)); much less so in developed countries. The price comparison method is informative but it is limited in coverage due to the difficulty of matching prices for truly comparable items across locations. Inference from trade flows provides complementary evidence on trade costs for these reasons. Finally, apart from gravity, a number of case studies have also examined the economic costs of internal trade barriers in Canada. Grady and Macmillan (2007) provide a descriptive overview of the academic and non-academic literature on barriers to internal trade in Canada and also evaluate the economic costs brought about these impediments to trade. Beaulieu et al. (2003) describe in great detail the various trade policies and reforms initiated by the Canadian government to liberalize inter-provincial trade. We see a combination of our "top-down" estimation methods with the "bottom-up" approach in the case studies as a fruitful direction for future research.

The remainder of the paper is organized as follows. Section 2 sets out the theoretical foundation and introduces Constructed Trade Bias indexes. Section 3 describes our data and presents the econometric specification and identification strategy. Section 4 presents our main findings and sensitivity experiments. Section 5 summarizes and discusses sectoral estimates. Section 6 concludes. Detailed supplementary appendixes with data description and sectoral and sensitivity estimates are available upon request.

2 Theoretical Foundation

A review of structural gravity theory (Anderson and van Wincoop, 2003, 2004) sets the stage for extensions. Next, we model bilateral trade costs as a combination of intra-regional, inter-regional, and international costs, developing implications for comparative statics and econometric identification. Then, we define Constructed Trade Bias (CTB), the generator of a family of Constructed Bias indexes with two novel ones useful for understanding intra-national trade. Finally, consistent aggregation of bilateral trade costs is developed.

The structural gravity model assumes identical preferences or technology across countries for national varieties of goods or services differentiated by place of origin for every good or service category k, represented by a globally common Constant Elasticity of Substitution (CES) sub-utility or production function. The demand system derived from cost minimizing behavior yields a system of final or intermediate demands represented by equation (1) below. Use of the market clearing condition for each origin region's shipments and each destination region's budget constraint yields equations (2) and (3) below:

$$\frac{X_{ij}^k}{E_j^k Y_i^k / Y^k} = \left(\frac{t_{ij}^k}{P_j^k \Pi_i^k}\right)^{1-\sigma_k} \tag{1}$$

$$(\Pi_i^k)^{1-\sigma_k} = \sum_j \left(\frac{t_{ij}^k}{P_j^k}\right)^{1-\sigma_k} \frac{E_j^k}{Y^k} \tag{2}$$

$$(P_j^k)^{1-\sigma_k} = \sum_i \left(\frac{t_{ij}^k}{\Pi_i^k}\right)^{1-\sigma_k} \frac{Y_i^k}{Y^k}. \tag{3}$$

The left hand side of (1) is size-adjusted trade, the actual distribution of goods and services relative to a frictionless benchmark distribution given the aggregate sales and aggregate expenditures at each origin and destination respectively. X_{ij}^k denotes the value of shipments at destination prices from region of origin i to region of destination j in goods or services of class k; E_j^k denotes the expenditure at destination j on goods or services in k from all origins; and Y_i^k denotes the sales of goods or services k at destination prices from i to all destinations. Y^k is the total output, at delivered prices, of goods or services k. On the right hand side of (1), $t_{ij}^k \geq 1$ denotes the variable trade cost factor on shipments of goods or services from i to j in class k, and σ_k is the elasticity of substitution across goods or services of class k. P_j^k is the inward multilateral resistance (IMR), and also the CES price index of the demand system. Π_i^k is the outward multilateral resistance (OMR), which from (2) aggregates i's outward trade costs relative to destination price indexes. Multilateral resistance is a general distributional equilibrium concept, since $\{\Pi_i^k, P_j^k\}$ solve equations (2)-(3) for given $\{Y_i^k, E_j^k\}$.

The right hand side of (1) comprises two parts, the distortion to size-adjusted trade induced by trade costs $(t_{ij}^k/\Pi_i^k P_j^k)^{1-\sigma_k}$ directly with t_{ij}^k and indirectly with $\Pi_i^k P_j^k$. Anderson and Yotov (2010) note that P_j^k and Π_i^k are respectively the buyers' and sellers' overall incidence of trade costs to their counter-parties worldwide. Incidence here means just what it does in the first course in economics: the proportion of the trade cost factor t_{ij}^k paid by the buyer and seller respectively. The difference is that purchase and sales are aggregated across bilateral links, such that conceptually it is as if each seller's global sales travel to a hypothetical world market with equilibrium world price equal to 1. The seller receives $1/\Pi_i^k$, hence pays incidence factor Π_i^k. Each buyer makes purchases from all origins on the world market, paying incidence P_j^k to bring them to destination j. These overall incidence measures further imply bilateral incidence: t_{ij}^k/P_j^k is seller i's incidence of trade costs on sales to destination j for good k, and t_{ij}^k/Π_i^k is buyer j's incidence of trade costs on purchase from origin i for good k. $t_{ij}^k/\Pi_i^k P_j^k$ is interpreted as either bilateral buyer's incidence, $(t_{ij}^k/\Pi_i^k)/P_j^k$ relative to overall buyers' incidence, or bilateral sellers' incidence $(t_{ij}^k/P_j^k)/\Pi_i^k$ relative to overall sellers' incidence.

Structural gravity theory in the Armington CES setup offers no explanation of the Y_i^ks and E_j^ks; it is a theory about bilateral distribution given these variables. The alternative structural gravity foundation for (1)-(3) of Eaton and Kortum (2002) is in contrast about bilateral distribution given the equilibrium location of production driven by random Ricardian productivity draws from a Frechet distribution.[13] Estimation of (1) under either foundation faces identical issues. The endogeneity of Y_i^k and E_j^k is controlled for with size-adjusted trade as the dependent variable and origin and destination fixed effects to control for multilateral resistance. In the application below, i and j refer to Canadian provinces, the US, and a Rest of World (ROW) aggregate.

For simplicity in presenting results we focus mainly on estimates for a single aggregate manufacturing sector and, therefore, we also suppress the sectoral subscript k in this section. The inference of trade costs from aggregate manufacturing has the disadvantage of a potential bias from composition effects within manufacturing (see Anderson and van Wincoop (2004) for analysis). We offer theoretically-consistent aggregation procedures in Section 2.3. The significance of the aggregation bias across Canada's provinces is illustrated empirically in Section 4.3, and the aggregation bias across sectors is discussed in Section 5 by comparison

[13]See Anderson (2011) and Costinot and Rodriguez-Clare (2014) for more discussion of the alternative theoretical foundations of structural gravity. Larch and Yotov (2016) re-derive the Eaton and Kortum (2002) model with the multilateral resistance terms from Anderson and van Wincoop (2003) in order to clearly emphasize the similarities and the differences between the supply-side gravity foundation and the demand-side gravity model.

of some aggregate results to results from the disaggregated study of 28 goods and services sectors.[14]

2.1 Full Bilateral Cost Model

The regional composition of full bilateral costs has usually been submerged in the gravity literature. The implicit justification of this practice is that origin and destination region fixed effects absorb any effects of local distribution frictions on full inter-regional trade frictions, hence bilateral costs modeled as iceberg log linear functions of geographic proxies reflect the pure inter-regional or international frictions of primary interest. In contrast, intra-national costs are consequential for comparative statics and regional policy analysis. In particular, regional border barriers are a key concern of this paper. Moreover, the implicit justification turns out to be valid only under restrictions revealed by a formal treatment.

Full inter-regional trade costs are modeled as a degree one homogeneous, increasing, and concave function $t_{ij} = g(r_{ij}, r_{ii}, r_{jj})$ of three components, the resource costs $(r_{hl},\ \forall h, l)$ of delivering one unit of distribution activity within the origin, destination and transit between them respectively.[15] (In the Ricardian case $r_{ij} = w_i a_{ij}$ where w_i is the wage and a_{ij} is the unit labor requirement in activity ij.) Homogeneity of degree one is consistent with iceberg trade costs with no indivisibilities.[16] Concavity is implied by cost-minimizing behavior. The base case is the Cobb-Douglas specification:

$$t_{ij} = r_{ij}^{\rho_1} r_{ii}^{\rho_2} r_{jj}^{\rho_3},$$

where $\rho_1 + \rho_2 + \rho_3 = 1$. For $i = j$, the specification implies $t_{ii} = r_{ii}$.

Border barriers are a component of r_{ij}, $b_{ij}^{1-\delta_{ij}}$ generally, where δ_{ij} is the Kronecker delta.

[14] Aggregation bias of the *cet. par.* trade cost is due to composition variation due to location of activity responding to trade costs. Yi (2010) among others emphasizes this force and calculates a general equilibrium response of trade to trade costs that differs from the partial equilibrium effect estimated from gravity equation (1). Calculating the general equilibrium response requires embedding the gravity modules of each sector in an upper level general equilibrium model, in Yi's (2010) case the Ricardian Eaton-Kortum model.

[15] The sectoral subscript k is suppressed in this section for expositional simplicity.

[16] Indivisibilities are treated by Helpman, Melitz and Rubinstein (2008), who include fixed export cost component. Their identification strategy to distinguish variable from fixed cost uses common religion to determine fixed but not variable cost, controversial in any case but unavailable for Canada's provinces.

Our methods identify systematic regional variation of border effects $b_i \geq 1$. Directional variation takes the form of $b_{ij} = b_i^{\zeta_O} b_j^{\zeta_D}$. (Bilaterally and directionally varying border effects, if any, are residuals in the second stage regression of estimated pair fixed effects on their gravity variables counterparts.) Thus $r_{ij} = \bar{r}_{ij}(b_i^{\zeta_O} b_j^{\zeta_D})^{1-\delta_{ij}}$ and the full cost is

$$t_{ij} = \left(\bar{r}_{ij}(b_i^{\zeta_O} b_j^{\zeta_D})^{1-\delta_{ij}}\right)^{\rho_1} r_{ii}^{\rho_2} r_{jj}^{\rho_3}. \tag{4}$$

The Cobb-Douglas restriction implies a useful theoretical property: system (1)-(3) is invariant to intra-regional trade costs. Invariance follows because $r_{ii}^{\rho_2}$, $r_{jj}^{\rho_3}$ form part of the composite multilateral resistances $r_{ii}^{-\rho_2}\Pi_i$, $r_{jj}^{-\rho_3}P_j$ that solve (2)-(3), hence the composite multilateral resistances are invariant to the level of intra-regional trade costs. In the econometric specification of bilateral trade costs below, the composite multilateral resistance terms are controlled for with origin and destination fixed effects and the bilateral cost identified is the pure inter-regional cost. Comparative static effects of intra-regional trade costs in the Cobb-Douglas case are confined to upper level inter-sectoral allocation due to invariance of (2)-(3) for given Es and Ys.

Internal cost variation induces trade cost asymmetry unless $\zeta_O = \zeta_D$. Estimates below indicate $\zeta_O \neq \zeta_D$. Asymmetry also arises if $\bar{r}_{ij} \neq \bar{r}_{ji}$, the case focused on by Waugh (2010). In our notation, Waugh (2010) assumes $r_{ii} = r_{jj} = 1$, introduces asymmetry to $t_{ij} = r_{ij} b_i$ with exporter-specific b_i and symmetric r_{ij}. Variation in b_i is used to explain asymmetry in trade patterns between high income and developing countries. Our focus on Canadian provincial trade reveals no significant effects of allowing for asymmetric $\bar{r}_{ij}$ in robustness checks reported below. Under the Cobb-Douglas invariance property, our allowance for internal cost variation makes no difference, hence (4) differs from Waugh's specification in allowing for destination border effect variation.

Invariance to internal cost variation is violated by general cost function specifications $g(\cdot)$. For example, in the translog case $\ln(t_{ij}/\Pi_i P_j)$ decomposes into the Cobb-Douglas invariance term analyzed above plus a second order effect term that contains the intra-regional trade cost. Non-invariance implies that intra-regional trade cost changes affect all bilateral trade patterns by changing all the multilateral resistances. Evidence below is weakly consistent with rejecting non-invariance.

2.2 Constructed Trade Bias

Constructed Trade Bias is defined as the ratio of the econometrically predicted trade flow $\widehat{X}_{ij}^k$ to the hypothetical frictionless trade flow between origin i and destination j for goods or services of class k. Rearranging the econometrically estimated version of equation (1), Constructed Trade Bias is given by:

$$CTB_{ij}^k \equiv \frac{\hat{X}_{ij}^k}{Y_i^k E_j^k / Y^k} = \left(\frac{\widehat{(t_{ij}^k)^{1-\sigma_k}}}{\widehat{(\Pi_i^k)^{1-\sigma_k}} \widehat{(P_i^k)^{1-\sigma_k}}} \right). \tag{5}$$

In the hypothetical frictionless equilibrium $CTB_{ij}^k = 1$, i's share of total expenditure by each destination j, X_{ij}^k/E_j^k, is equal to Y_i^k/Y^k, i's share of world shipments in each sector k. This would be the pattern in a completely homogenized world. "Frictionless" and "trade costs" are used here for simplicity and clarity, but the model can also reflect local differences in tastes that shift demand just as trade costs do, suggesting "resistance" rather than costs. The second equation in (5) gives the structural gravity interpretation of CTB, the $1 - \sigma_k$ power transform of the ratio of predicted bilateral trade costs to the product of outward multilateral resistance at i and the inward multilateral resistance at j. (CTB_{ij}^k when $i = j$ is the Constructed Home Bias of Anderson and Yotov, 2010).

Four properties of CTB are appealing. First, CTB is independent of the normalization needed to solve system (2)-(3) for the multilateral resistances.[17] Therefore, it is comparable across sectors and time as well as across provinces and countries. Second, CTB is independent of the elasticity of substitution σ_k, because it is constructed using the inferred (estimated) volume effects of the $1 - \sigma_k$ power transforms of the t_{ij}^k's, the Π^k's and the P^k's.[18] Third,

[17]Note that (2)-(3) solves for $\{\Pi_i^k, P_j^k\}$ only up to a scalar. If $\{\Pi_i^0, P_j^0\}$ is a solution then so is $\{\lambda\Pi_i^0, P_j^0/\lambda\}$.

[18]We refer the reader to Arkolakis et al. (2012), Costinot and Rodriguez-Clare (2014), and Head and Mayer (2014) for detailed and insightful discussions regarding the role and measurement of σ in the trade literature.

CTBs can be consistently aggregated across sets of partners and/or sectors to index volume effects within or across sectors at the region or country level.[19] Fourth, CTB infers central tendency out of the random errors that beset notoriously mis-measured bilateral trade flow data. Specifically, the ratio of observed bilateral trade to hypothetical frictionless trade is an observation of CTB while our estimated CTB is its conditional expectation.[20]

2.3 Consistent Aggregation

Aggregation of volume concepts such as CTBs and trade cost concepts such as multilateral resistance and t_{ij}^k or t_{ij}^k/t_{ii}^k is useful for many purposes. Aggregation procedures are set out here for CTBs that are consistent with maintaining a constant aggregate volume of trade given the theoretical model. (Similar procedures generate consistent aggregation of multilateral resistances. Volume consistent trade cost aggregation can be done following Anderson and Neary (2005), pp. 177-183.) Aggregation over regions is the focus, but similar principles apply to consistent aggregates over sectors.

The aggregate (export) trade volume from origin i to some subset of destinations $C(i) = \{j \in C, j \neq i\}$ is

$$\sum_{j \in C(i)} X_{ij} = \sum_{j \in C(i)} \frac{Y_i^k E_j^k}{Y^k} \left(\frac{t_{ij}^k}{\Pi_i^k P_j^k} \right)^{1-\sigma_k}. \tag{6}$$

$C(i)$ excludes internal trade, and can also exclude other bilateral trade depending on what is defined to be contained in C. In the present application, C designates within country C (Canada), so it excludes international trade, thus $C(i)$ is the set of inter-provincial partners of province i. Constructed Trade Bias for i's export trade to $C(i)$ is given by the ratio of the theoretical aggregate volume given above to the frictionless benchmark aggregate export

[19]Other CTB aggregates have been defined and reported in Anderson and Yotov (2010) and Anderson, Milot and Yotov (2014).

[20]It should also be noted that a CTB equivalent index can be constructed directly from the data as $X_{ij}^k/(Y_i^k E_j^k/Y^k)$. Thus, complementing the ratio trade cost indexes from the existing literature, e.g. the tetrads index of Head and Mayer (2000). Importantly, the tetrads index identifies bilateral trade costs exclusive of the multilateral resistances, while CTB is a general equilibrium index that is inclusive of the MRs.

volume $Y_i^k E_{C(i)}^k / Y^k$ where $E_{C(i)}^k \equiv \sum_{j \in C(i)} E_j^k$. Using equation (5), the ratio is equal to

$$CTB_{C(i)}^k = \sum_{j \in C(i)} \frac{E_j^k}{E_{C(i)}^k} CTB_{ij}^k. \tag{7}$$

The aggregate CTB for set C (Canada's overall CTB for inter-provincial trade) is given by

$$CTB_C^k = \sum_{i \in C} \frac{E_{C(i)}^k}{E_C^k} CTB_{C(i)}^k = \sum_{i \in C} \sum_{j \in C(i)} \frac{E_j^k}{E_C^k} CTB_{ij}^k, \tag{8}$$

where $E_C^k = \sum_i E_{C(i)}^k$.[21]

The $CTB_{C(i)}^k$ concept is illustrated by Canadian province i's inter-provincial exports, but can be applied to any arbitrary set of regions' inter-regional exports or, *mutatis mutandis*, to imports rather than exports.[22] For example, the concept can usefully be applied to aggregate trade within multilateral preferential trade arrangements as well as to trade within the European Union.

3 Empirical Foundation

This section details the econometric specification and procedures used to infer the volume displacement and trade cost indexes describing inter-provincial trade in Canada. An extension of now standard gravity methods that exploits the panel nature of the data permits measurement of potential unobservable barriers at provincial borders — Unexplained Trade Barriers (UTBs). The section closes with a brief description of our data, supplemented by a detailed Data Appendix.

3.1 Pair Fixed Effects Estimator

The pair fixed effects econometric approach estimates Constructed Trade Biases for each pair of regions and each year in the sample directly (except where necessary the sectoral

[21]The Constructed Foreign Bias (CFB) and the Constructed Domestic Bias (CDB) indexes of Anderson et al. (2014) are focused on aggregation across destinations to measure outward resistance to trade.

[22]In the import case, the expenditure share weights are replaced by sales share weights.

index k is suppressed):

$$\frac{X_{ij,t}Y_t}{Y_{i,t}E_{j,t}} = \exp[\alpha'\mathbf{T}_{ij,t} + \gamma_{ij} + \eta_{i,t} + \theta_{j,t}] + \epsilon_{ij,t}. \tag{9}$$

The dependent variable is size-adjusted trade. Hence the CTB is the predicted value from (9). On the right hand side $\epsilon_{ij,t}$ is the error term.[23] The last two terms under the exponentiation operator account for the multilateral resistances. $\eta_{i,t}$ denotes the set of time-varying source-country dummies that control for the unobservable outward multilateral resistances and any other time-varying source country factors, and $\theta_{j,t}$ encompasses the time-varying destination country dummy variables that account for the inward multilateral resistances and any other time-varying destination country factors.[24] The first two terms under the exponentiation operator of (9) account for bilateral trade costs, which are decomposed into time-dependent and time-invariant components:

$$\left(t_{ij,t}^{FE}\right)^{1-\sigma} = \exp[\alpha'\mathbf{T}_{ij,t} + \gamma_{ij}]. \tag{10}$$

Here, $t_{ij,t}^{FE}$ denotes bilateral trade costs between regions i and j at time t, and the superscript FE captures the fact that we use the full set of pair-fixed effects, γ_{ij}, to account for the time invariant portion of trade costs. In addition to absorbing the vector of time-invariant covariates that are used standardly in the gravity literature (e.g. distance), the pair-fixed effects will control for any other time-invariant trade costs components that are unobservable to researchers and to policy makers.[25]

[23]Equation (9) will be estimated with the Poisson Pseudo-Maximum Likelihood (PPML) method of Santos Silva and Tenreyro (2006), who note that the error term does not need to follow Poisson distribution.

[24]With size adjusted trade as dependent variable, equation (9) resembles the original Anderson and van Wincoop (2003) gravity specification. Thus, in principle, it can be estimated with an iterative non-linear method as a joint system with the definitions of the multilateral resistances from Equations (2) and (3). However, we favor the specification with directional fixed effects for two reasons. First, as noted above, in addition to the multilateral resistances, the exporter-time and the importer-time fixed effects would also account for any other unobserved region-specific characteristics that may affect trade, omission of which may bias our estimates of bilateral trade costs, which are the focus of this study. Second, the fixed-effects estimator is less computationally intensive and has become the standard for estimating gravity.

[25]Using bilateral fixed effects in the gravity equation is not new. For example, Baier and Bergstrand (2007) use pair fixed-effects to successfully account for potential endogeneity of FTAs. However, to the best

The first term in (10), $\mathbf{T}_{ij,t}$, is a vector of time-varying gravity variables intended to capture changes in bilateral trade costs over time. The changes are restricted to sensibly pick up suspected effects.[26] The evolution of internal trade costs in Canada is captured by two time-varying covariates. $INTRAPR\_T_{ij,t} = INTRAPR_{ij} \times T_t$ is the interaction between a dummy variable for intra-provincial trade $INTRAPR_{ij}$ and a time trend T_t.[27] The estimated coefficient of $INTRAPR\_T_{ij,t}$ would capture any changes in intra-provincial trade costs over the period of investigation. Similarly, $INTERPR\_T_{ij,t} = INTERPR_{ij} \times T_t$ is the interaction of $INTERPR_{ij}$, a dummy variable for inter-provincial trade with a time trend, and its estimated coefficient has a similar interpretation. By construction, the estimated coefficients of $INTERPR\_T_{ij,t}$ and $INTRAPR\_T_{ij,t}$ should be interpreted as deviations of internal (intra-provincial or inter-provincial) Canadian trade costs from the changes in international trade costs over time. With these restrictions, specification (9) becomes:

$$\frac{X_{ij,t}Y_t}{Y_{i,t}E_{j,t}} = \exp[\alpha_1 INTERPR\_T_{ij,t} + \alpha_2 INTRAPR\_T_{ij,t} + \gamma_{ij} + \eta_{i,t} + \theta_{j,t}] + \epsilon_{ij,t}. \quad (11)$$

The full set of pair-fixed effects in (11) implies perfect collinearity of regressors, so restrictions are required in order to estimate (11).[28] Our solution is to drop internal trade

of our knowledge, this paper and Egger and Nigai (2016) are the only papers to use bilateral pair fixed effects to measure bilateral trade costs and to study the difference between the trade costs from the fixed effects specification and the trade costs from a standard specification with gravity variables. Egger and Nigai (2016) measure international trade costs, while our focus is on intra-national trade costs and their decomposition in inter-regional vs. intra-regional components.

[26] The usual components of $\mathbf{T}_{ij,t}$, when the gravity model is applied to international trade data, control for tariffs, for the presence of free trade agreements (FTAs), monetary unions (MUs), World Trade Organization (WTO) membership, etc. Given the specifics of our sample, we cannot include any of these variables. Therefore, we rely on time-varying indicator variables to pick up any unobservable time-varying effects.

[27] Note that, even though $INTRAPR_{ij}$ takes a value of one only for intra-provincial trade, this variable has a subscript i, j because it is defined across all observations, including inter-provincial and international trade.

[28] The sum of the dummy variable vectors corresponding to the hypothetical full set of γ_{ij}s, denoted Γ_{ij}s is equal to the sum of dummy variable vectors corresponding to the full set of province dummies, either as exporter or importer. Another collinearity problem, which is standard in gravity estimations, arises because the sum of the province/territory dummy variable vectors corresponding to origin and destination regions respectively are equal to each other in each period. This problem is solved by dropping one province as a destination in each year, meaning that the remaining province origin and destination coefficients for that period are interpreted as relative to the coefficient of the dropped province. To use a constant term, the same province is also dropped once as an origin. Finally, we note that identification of the symmetric pair fixed effects in our main specification is obtained from two sources including the time dimension and the fact

fixed effects. The restriction we impose scales the time-invariant bilateral trade costs so that origin and destination border-crossing frictions are suppressed. (Internal trade costs at origin and destination are absorbed by multilateral resistance in any specification.) The theoretical full trade cost (4) is reduced to its pure inter-regional cost component by this treatment: $\gamma_{ij} = (1-\sigma)\rho_1 \ln \bar{r}_{ij}$ in our structural interpretation. The estimated bilateral fixed effects for inter-provincial trade volume are thus understood as:

$$(\tau_{ij}^{FE})^{1-\sigma} = \exp(\gamma_{ij}) = \exp[(1-\sigma)\rho_1 \ln \bar{r}_{ij}] \tag{12}$$

We further restrict the pair fixed effects to symmetry: $\gamma_{ij} = \gamma_{ji}$; $\forall i, j \in CA$.[29] Symmetry is imposed for comparability with the necessarily symmetric gravity variables specification below. In contrast we do not impose any restrictions on trade costs between the Canadian regions, the U.S. and the rest of the world. This helps control for complications and biases associated with measuring trade costs among these aggregate regions.[30]

3.2 Gravity Variables Estimator

The gravity counterpart to the full pair fixed effect Γ_{ij} equation (10) is:

$$\left(t_{ij,t}^{GRAV}\right)^{1-\sigma} = \exp[\alpha' \mathbf{T}_{ij,t} + (1-\delta_{ij})\beta' \mathbf{GRAV}_{ij} + \delta_{ij}\psi_{ii}]. \tag{13}$$

Here, $\mathbf{GRAV}_{ij}$ is a vector of time-invariant covariates that replace the vector of pair-fixed effects γ_{ij} from specification (10) for $i \neq j$ and δ_{ij} is the Kronecker delta. The explanatory variables in $\mathbf{GRAV}_{ij}$ include the logarithm of bilateral distance between partners i and j, and a contiguity indicator for whether or not the two trading regions share a common border.[31] The gravity variables regression continues to use a pair fixed effect for provincial

that we have directional trade flows.

[29]In the robustness analysis, which are presented in the Supplementary Appendix, we allow for asymmetry of the pairwise fixed effects.

[30]In the Supplementary Appendix, we demonstrate that our internal trade costs estimates are robust to the exclusion of the U.S. and the rest of the world from our sample.

[31]Our gravity specification does not include two covariates that are usually used in the international trade literature, the indicators for common language and for colonial relationships. Exclusion of these

flows to or from the US and the ROW (Rest of the World). For inter-provincial trade flows, remembering that internal trade costs are absorbed into multilateral resistance, $t_{ij,t}^{GRAV}$ is interpreted in terms of theoretical specification (4) as:

$$t_{ij,t}^{GRAV} = (\bar{r}_{ij} b_i^{\zeta_O} b_j^{\zeta_D})^{\rho_1} \tag{14}$$

The full set of intra-provincial fixed effects ψ_{ii} are estimated in specification (13). ψ_{ii} is the volume effect of *relative* border frictions, meaning relative to intra-regional friction. Moreover, this relative border (or home bias) effect is measured relative to *all* bilateral trade after controlling for distance and contiguity, hence it is implicitly normalized by an economy-wide average border effect.[32] The structural interpretation of the intra-provincial fixed effect (up to its normalization) is based on specification (4) econometrically implemented with a fixed effect for intra-regional trade. Thus

$$\psi_{ii} = \ln \left(\frac{\bar{b}_i / r_{ii}}{\bar{b} / \bar{r}} \right)^{(\sigma-1)\rho_1}, \tag{15}$$

where r_{ii} denotes the true intra-provincial trade cost and $\bar{b}_i$ is the provincial border cost b_i plus the national average effect of provincial border effects facing exporter province i. Using

variables is because of our focus on intra-regional trade within the same country. The only significant variation in colonial relationships is identical with linguistic variation and restricted to a Quebec effect. Thus the potential effects of linguistic and colonial heritage differences between Quebec and the rest of the Canadian provinces and territories are controlled by the directional QC fixed effects in the econometric model. The large magnitudes of the UTB indexes that we estimate below point to significant unexplained trade barriers for trade within Canada. We speculate that these can be attributed to a variety of factors including communication, institutional, and political reasons, along with specific bilateral policies that may impede trade. Studying the determinants of the UTBs that we identify here is an important policy question that we leave for future work.

[32]This combined effect arises because the indicator variable for i's internal trade measures internal relative to inter-provincial trade, all else equal. Specification (13) is constructed without regional border indicator variables due to collinearity. In principle, the ψ_{ii} estimates can be regressed on various potential determinants of domestic trade costs. We defer this investigation to future work. Using internal log distance measures for the 12 provinces plotted against the estimated ψ_{ii}s reveals a positive slope, suggesting important variation as is intuitive. But the data is too weak to use believably to decompose sources of variation in ψ_{ii}. Indeed, even this positive distance elasticity emerges only after excluding outliers YT and PE, which are relatively compact and small in population.

the log of (4) and noting that r_{ij} is controlled for by distance, etc,

$$\rho_1 \ln \bar{b}_i = \rho_1 \left[\zeta_O \ln b_i + (1/N) \sum_{j \neq i} \zeta_D \ln b_j \right]$$

where N is the number of partner provinces (11).

3.3 Unexplained Trade Barriers

The theoretical interpretation of the pair fixed effects and gravity variables estimators implies that the relationship between them is (using equations (12) and (14)):

$$\gamma_{ij} = (1-\sigma)\rho_1[\ln t_{ij}^{GRAV} - \zeta_O \ln b_i - \zeta_D \ln b_j].$$

The difference (in logarithms) between the pair fixed effect estimator and the gravity variables estimator is defined as the Unexplained Trade Barrier:

$$\ln UTB_{ij} = \ln \left(\hat{\tau}_{ij}^{FE}\right)^{1-\sigma} - \ln \left(\hat{t}_{ij}^{GRAV}\right)^{1-\sigma} + u_{ij}. \tag{16}$$

where, u_{ij} is a residual. u_{ij} is random in the absence of border barriers ($b_i = 1 = b_j$) and subject to the Cobb-Douglas cost structure (4). With border barriers, u_{ij} has a systematic component. Procedures implemented in Section 4.2 use estimated $\hat{\psi}_{ii}$s and the Cobb-Douglas cost structure to control for border barriers. The coefficients ζ_O, ζ_D are identified from a second stage regression. Although $\psi_{ii} = (1-\sigma)\ln r_{ii}$ in the absence of border barriers, the Cobb-Douglas cost structure and the resulting invariance property of gravity implies that the residual u_{ij} has no systematic component. (The effect of r_{ii}, r_{jj} on cross-border gravity frictions is absorbed in the multilateral resistances.) At a minimum, analysis of variance based on (16) gives a measure of how well the standard parsimonious gravity treatment of trade costs performs.[33]

[33] Henderson and Millimet (2008) examine the consistency of the assumptions needed for an empirical implementation of the gravity equation using parametric and non-parametric models. Our empirical specification is a hybrid of parametric and non-parametric approaches that allows for heterogeneity of intra- and

Systematic UTBs can alternatively be controlled for with origin and destination fixed effects in a second stage regression of the pair fixed effects estimates on the gravity variables estimates. The results below support the robustness of our preferred UTB estimator that makes use of the information in estimates of ψ_{ii}. ψ_{ii} is interpreted as $(1-\sigma)(\ln r_{ii} - \rho_1 \ln \bar{b}_i)$. The internal cost component $\ln r_{ii}$ of ψ_{ii} is in theory incidental to both the pair fixed effect estimator and the gravity variables estimator, so its effect on their variation is expected to be zero. The provincial border barrier component of ψ_{ii} is $\ln \bar{b}_i$ which varies directly with b_i and an average of border barriers over all provincial partners. Treating ψ_{ii} as an instrument to be used with suspicion we estimate a second stage regression (19) below of the pair fixed effects estimates on the gravity variables estimates and estimates of ψ_{ii}, ψ_{jj}.

3.4 Data

This research capitalizes on significant efforts of the Canadian government and Statistics Canada, in particular, to construct a detailed, comprehensive, and internally consistent dataset that covers intra-provincial, inter-provincial, and international trade flows for each of Canada's provinces and territories at the sectoral level over the period 1997-2007.[34] As noted in Genereux and Langen (2002), the objectives of the Canadian government to construct such data were channeled under the Project to Improve Provincial Economic Statistics (PIPES): "Three fundamental developments [under PIPES] contributed to strengthen considerably the interprovincial and international trade flows from 1997 onwards. The three areas are: (i) The various surveys that collect data on provincial trade are more comprehensive and robust from 1997 onwards than in previous years; (ii) Trade information is analyzed, reconciled and integrated in a detailed set of official provincial/territorial Input-Output (IO) tables from 1997 onwards; Furthermore, the survey information that buttresses these provin-

inter-regional border effects.

[34] Our dataset covers most of Canada's economy at the sectoral level for a total of 28 industries including agriculture, 17 manufacturing sectors, aggregate manufacturing, and 9 service categories for the period 1997-2007. We aggregate the Northwest Territories and Nunavut in one unit, even though they are separate since April 1st, 1999. Thus, our sample consists of a total of 14 regions including 12 Canadian provinces and territories, US, and the rest of the world. All value data employed in our analysis are measured in current ('00,000) Canadian dollars.

cial IO tables has also been expanded and/or strengthened considerably, contributing not only to the overall quality of the provincial IO tables but also to the overall quality of the provincial trade flows program; (iii) Finally, trade flow information is reconciled with other System of National Accounts relevant variables such as the provincial/ territorial Gross Domestic Product Expenditures-based and its components and the provincial/territorial Gross Domestic Product by Industry, thus improving overall data consistency." (p.6, Genereux and Langen, 2002).

As a result of the efforts of the Canadian government, we took advantage of a rare opportunity to work with a database with the following unique and appealing features. First, and most important, our data include consistent production, expenditure and trade data including inter-provincial, intra-provincial and international trade flows between Canada's provinces and territories and the U.S. and the rest of the world (ROW), defined as an aggregate region that includes all countries other than Canada and the U.S.[35] In addition, every effort has been made by the developers of the dataset to ensure that the missing and zero values in the data are indeed missing or zeros, respectively.[36] Finally, we complemented the Statistics Canada's trade, production, and expenditure data with variables that measure bilateral distance and whether two regions share a common border. A detailed description of our dataset and sources as well as summary statistics are included in a supplementary Data Appendix.

While Statistics Canada has made every effort to ensure completeness and internal con-

[35]We also use activity data (trade, production, and expenditure) for the U.S. and for ROW. In the robustness analysis, we demonstrate that our results are robust to dropping U.S. and ROW from our sample.

[36]In the sensitivity analysis, we experiment by replacing all missing values with zeros. We find no qualitative differences and the quantitative changes that we observe are intuitive. There are several explanations for the robustness of our results to such experiments. First, our data are relatively aggregated and there are not many zero and/or missing values. For example, in the Total Manufacturing data that we employ for our main analysis, we have a total of only 62 zero trade values and 38 missing trade values. Second, the vast majority of missing values are for remote provinces and territories, whose share in economic activity is relatively small. For example, YT is the region with the least non-zero and non-missing trade flows both on the importer and on the exporter side. Specifically, trade flows are missing for the entire period for YT-MB and YT-NB, zero trade flows are found in all years for YT-NL and YT-PE, and we only observe one-way trade flows for SK-YT and NS-YT. In the sensitivity experiments, we demonstrate the our results are also robust to the removal of YT and NT, which is another region with significant number of zero and/or missing trade flows in our sample.

sistency of their trade, production, and expenditure data, which usually come from different primary sources, there are some data caveats that should be kept in mind when interpreting our results. For example, the primary source of data for interprovincial trade flows of manufactured goods is the Canadian Annual Survey of Manufacturers (ASM), which is collected at the establishment level and, as such, comes with some limitations. For instance, the ASM does not collect destination information for small manufacturing establishments, which account for close to 8% of all Canadian manufacturing shipments and vary by province. Instead, in the ASM, these shipments are recorded as purchased by consumers within the province of the establishment. While, it is reasonable to assume that *most* of the shipments of the small firms are indeed local, it is unrealistic to assume that *all* shipments are local. This implies that, by construction, our sample may overstate the importance of intra-provincial trade. Some other issues with the ASM are that geographic distribution is only reported on the total value of shipments at the establishment level and not by commodity and also that sometimes the destination of shipments identified in ASM are not necessarily the final destination of the shipments. The former is not a concern for our analysis due to the relatively high level of aggregation, and, in order to alleviate the latter issue related to the destination of shipments, Statistics Canada utilized the Wholesale Trade Commodity Survey by Origin and Destination, which provides information on origin of purchases and destination of sales of wholesalers. Despite such limitations, we view the dataset employed here as a significant improvement beyond any existing data and we are not aware of any other comparable dataset that may enable us to address the research questions of interest in this study. For a detailed description of the challenges, advantages, and caveats with the construction of the Canadian intra-provincial, interprovincial, and international trade data, we refer the reader to Genereux and Langen (2002).

4 Estimation Results

We estimate the pair fixed effects specification (11) and the gravity variables specification (17) below with PPML, generating bootstrapped standard errors using resampling with replacement. First we report the inter-provincial volume effects of trade costs from the pair fixed effects and gravity variables models. Then, we report on the UTBs and their systematic component. The CTBs implied by the pair fixed effects model come next. These include the effect of UTBs directly and indirectly and summarize the overall bilateral impact of frictions within Canada. The difference between pair fixed effects CTBs and gravity variables CTBs isolates the direct plus indirect effect of UTBs on interprovincial trade. Credibility checks conclude, with analysis of residuals and sensitivity to variations of model specification.

4.1 Intra-provincial and Inter-provincial Trade Costs

Results from pair fixed effects specification (11) are reported in column (1) of Table 1 for Total Manufacturing trade of Canada's provinces, 1997-2007.[37] Coefficient estimates on $INTERPR\_T$ and $INTRAPR\_T$ indicate no significant intertermporal change on trade with international partners, so static results are presented.[38] The estimates of the inter-provincial fixed effects $\hat{\gamma}_{ij}$ of specification (11) are reported in Panel A of Table 2. The first column in Table 2 lists each region as an exporter, while the label of each column stands for each region as an importer.[39] The last column of Table 2, labeled CA, reports aggregate inter-provincial log volume reduction estimates for each province, obtained using the consistent aggregation procedure from Section 2.2. The diagonal elements are all zeros,

[37]The main estimates use the Poisson pseudo-maximum-likelihood (PPML) estimator advocated by Santos Silva and Tenreyro (2006 and 2011). OLS results are reported in the sensitivity analysis. We refer the reader to Head and Mayer (2014) for an insightful discussion on the use of alternative gravity estimators. A summary of our sectoral findings is included in Section 5. Detailed sectoral estimates are included in the Supplementary Appendix.

[38]Specifically, the economically small and statistically insignificant estimates on $INTERPR\_T$ and $INTRAPR\_T$ suggest that there has not been any significant change in the inter-provincial and intra-provincial bilateral trade frictions during the period of investigation.

[39]The order of the Canadian provinces and territories in our tables follows the preamble of the Agreement on Internal Trade. Specifically: Newfoundland and Labrador, Nova Scotia, Prince Edward Island, New Brunswick, Quebec, Ontario, Manitoba, Saskatchewan, Alberta, British Columbia, the Northwest Territories and Yukon.

reflecting the fact that the intra-provincial fixed effects are used as a reference group. In addition, due to our symmetry assumption, we only report the inter-provincial γ_{ij}'s above the diagonal. The latter should be interpreted relative to the geometric mean of the omitted intra-provincial fixed effects, as explained above. The off-diagonal $\hat{\gamma}_{ij}$'s of Table 2 are all negative, large in absolute value, and statistically significant. The estimates are quite precise but to avoid clutter, the standard errors are suppressed. The estimates vary widely across provincial partners for each origin and by origin for each destination.

The estimated inter-provincial fixed effects are presented as percentage trade volume effects in Panel B of Table 2. All off-diagonal elements in Panel B of Table 2 are less than 100: after controlling for origin and destination province-specific characteristics, inter-provincial trade is significantly smaller than intra-provincial trade. The vast majority of the volume effect estimates are considerably small (smaller than 10 percent even), implying that trade between provinces is much lower than trade within provinces. For example, the estimate of 9.49 for pair NL-NS implies that trade between these two provinces is only about 10 percent of the average internal trade for these regions, all else equal, while the estimate of 0.02 for pair NL-YT suggests that inter-provincial trade between these regions is about 0.02 percent of their average intra-provincial trade. Panel B also reveals significant heterogeneity in the percentage volume reductions across different pairs. Aggregating each province's volume reductions across its partners, column CA reveals that YT, NT and NL are the regions with the largest deflection of inter-provincial into intra-provincial trade, while ON, AB, and QC are the regions with the smallest corresponding deflection. The bottom right element of Panel B summarizes that overall inter-provincial manufacturing trade in Canada is about 5.2 percent of the intra-provincial trade.

The gravity variables trade cost estimator replaces the province-pair fixed effects from specification (11) with observable geographic trade cost proxies, bilateral distance and contiguity. We continue to use flexible, directional pair-fixed effects to model international trade costs, hence for these observations the specification remains (11).[40] Recent gravity studies decompose distance effects into intervals. Eaton and Kortum (2002), for instance, use aggregate world data and split the effects of distance into four intervals.[41] Following these studies, we split distance in four intervals, which correspond to the four quantiles of our distance variable. In addition, we define $CONTIG\_PR\_PR_{ij}$ as an indicator variable that takes the value of one when two provinces or territories share a common border, and it is equal to zero otherwise.[42]

Substituting the trade cost proxies into specification (13) delivers the estimating equation for observations inside Canada:

$$\begin{aligned}\frac{X_{ij,t}Y_t}{Y_{i,t}E_{j,t}} &= \exp[(1-\delta_{ij})(\sum_{m=1}^{4}\beta_m^k DISTANCE\_m_{ij} + \beta_{contig}CONTIG\_PR\_PR + INTERPR\_T_{ij,t})] \times \\ &\quad \exp[(INTRAPR\_T_{ij,t} + \psi_{ii}\delta_{ij} + \eta_{i,t}^G + \theta_{j,t}^G] + \epsilon_{ij,t}^G, \qquad (17)\end{aligned}$$

where δ_{ij} is the Kronecker delta, $DISTANCE\_1$ corresponds to the smallest quartile and $DISTANCE\_4$ corresponds to the largest quartile. All distance variables are standardly expressed in logarithmic form.

Estimation of (17) obtains province-specific estimates of intra-provincial trade costs ($\hat{\psi}_{ii}$) along with inter-provincial and international trade costs. This is a notable distinction from the existing literature, which is mostly focused on international trade costs and treats countries as identical point masses. Our estimates of the intra-provincial fixed effects below demonstrate that this standard assumption in the literature is clearly rejected by the data, even for regions within the same country. Estimates of all intra-provincial fixed effects can

[40] In principle, we can use the same gravity variables to model international trade costs. The flexible specification has two advantages. First, there is evidence of significant asymmetries in the trade barriers between Canada and the US. Second, more importantly, we use the pair fixed effects structure in order to stay consistent with the fixed effects gravity specification from the previous section. As we demonstrate below, this will enable us to construct consistent estimates of unexplained provincial trade barriers in Canada.

[41] They find that the estimate of the distance coefficient for shorter distances is larger (in absolute value) than for longer distances. Anderson and Yotov (2010) find a non-monotonic (inverted u-shape) relationship between distance and disaggregated goods trade flows in the world.

[42] When applied to international trade flows, the gravity model consistently delivers positive and significant estimates on $CONTIG\_PR\_PR_{ij}$ suggesting that, all else equal, countries that share a common border trade more with each other.

be obtained even in the presence of province fixed effects because the latter apply equally to inter-provincial and intra-provincial trade, while the former are switched on only for intra-provincial trade. It should also be noted, however, that estimation of the full set of intra-regional, inter-regional and international trade costs requires estimation of both equation (11), where we proxy for trade costs with a rich set of bilateral fixed effects, and equation (17), where we proxy for trade costs with the standard gravity variables used in the literature.

Inter-provincial trade costs. Estimation results from specification (17) are reported in column (2) of Table 1. As expected, distance impedes inter-provincial trade: all of the four distance estimates are sizable, negative, and statistically significant. Overall, the estimates of the effects of distance on inter-provincial trade in Canada across different distance intervals are similar, with some variation. The smallest estimate (in absolute value) is for the smallest distance interval ($DISTANCE\_1$), and the largest estimate is for the largest interval ($DISTANCE\_4$), but there is some evidence of non-monotonicity, since the estimate on ($DISTANCE\_3$) is smaller than the estimate on ($DISTANCE\_2$).

The coefficient estimate of $CONTIG\_PR\_PR_{ij}$ is positive but statistically insignificant and very small in magnitude, $\beta_{contig} = 0.055$ (std.err. 0.041). The small and economically insignificant estimate on $CONTIG\_PR\_PR_{ij}$ contrasts with the large, positive and statistically significant estimates from the international gravity literature. A possible explanation for the difference between our contiguity estimates and the corresponding numbers form the literature is that we are estimating the effects of contiguity between regions within the same country and not between different countries. We are not aware of existing comparable estimates.[43]

Provincial relative border costs. Column (2) of Table 1 also reports estimates of the volume effects of the log of provincial relative border costs. *Relative* border cost means

[43]Despite the insignificant result, contiguity may matter, but differently for trade between the large contiguous provinces and their partners, such as ON and QC, than it does for trade between small and remote contiguous provinces such as NT and YT. This differential contiguity hypothesis could in principle be tested by introducing individual indicator variables for each possible pair of contiguous provinces in our sample. We choose not to do this since it essentially introduces 15 bilateral fixed effects and obviates the difference between pairwise fixed effects and the gravity variables estimator.

relative to internal friction, the ratio of border friction to the internal friction. Recall from (15) that the volume effect in levels corresponds to the theoretical concept

$$\left(\frac{\bar{b}_i/r_{ii}}{\bar{b}/\bar{r}}\right)^{(\sigma-1)\rho_1}.$$

The variation in column (2) has meaning but the level of the ψ_{ii} estimates is relative to an implicit normalization represented by the denominator above. The rightmost column of Table 3 reports relative volume effects of relative border frictions normalized by a national average. The average of the estimates of column (2) of Table 1 is subtracted from the values in column (2) and the result is exponentiated and reported in the rightmost column of Table 3. (The remaining columns are explained in Section 4.2 below.) A visual representation of the ψ_{ii} estimates is in the heat map of Figure 1.

The large heterogeneity across the estimates of the ψ_{ii}'s across provinces makes intuitive sense because it is inversely related to the economic and geographic size of the provinces after controlling for distance and contiguity in inter-provincial trade. The largest value for relative border effects in the rightmost column of Table 3 is for Yukon Territory, 3 times the national average, followed by Prince Edward Island at 1.65 and Northwest Territories at 1.2. The smallest values for Ontario, British Columbia and Alberta is 0.36 times the national average. Relatively large home bias (less negative ψ_{ii}) is associated with high border barriers or low internal cost. The former is associated with small investments in pair-specific relationships that may be typical of small destination markets. The latter is associated with geographic dispersion that raises intra-regional cost.

The extreme values in Table 1 illustrate the roles of economic and geographic size. YTs population of about 33,000 is 75% concentrated in Whitehorse, the capital. PE, with next largest value of ψ_{ii} has almost 5 times YT's population, little more than a fifth in Charlottetown, the capital. Most of the remainder is dispersed in sizable towns around the compact island. NT with the third highest ψ_{ii} has population over 20% larger than YT, less than half of which is located in Yellowknife, the capital. More significantly, NT has the highest GDP per capita in Canada due to natural resources. At the other extreme, ON has the lowest value of ψ_{ii}, followed closely by AB and BC. A final implication of the results is that statistically significant heterogeneity of the ψ_{ii}s among the lower tier of more populous provinces with good infrastructure suggests the variation of internal border barriers b_i.

The relative performance of the gravity variables and pairwise fixed effects estimator is reported in row AIC of Table 1. The Akaike Information Criterion (AIC) gives a rough comparison of these non-nested specifications.[44] The difference between AIC for the bilateral fixed effects specification and AIC for the gravity specification is 1.82, less than the threshold of 2 that the usual rule of thumb suggests, which provides 'substantial' support for the gravity specification relative to the bilateral fixed effects specification (Burnham and Anderson (2002)). This finding suggests that distance alone is a powerful predictor of bilateral trade costs within Canada, since contiguity effects are insignificant. Nevertheless, a systematic pattern in the difference between fixed effects and gravity variables estimators emerges from a second stage regression.

4.2 UTB Estimates

UTB estimates are defined as the difference between the pair fixed effects $\hat{\gamma}_{ij}$ and the deflated gravity variables estimates:

$$\ln UTB_{ij} \equiv \hat{\gamma}_{ij} - \ln(\hat{t}_{ij}^{GRAV})^{1-\sigma}. \tag{18}$$

The difference on the left hand side of (18) should be random under the Cobb-Douglas (neutrality) assumption if there are no border barriers. Systematic UTBs are analyzed and decomposed by making use of the Cobb-Douglas structure.

First, rearrange (18) as $\hat{\gamma}_{ij} = \ln(\hat{t}_{ij}^{GRAV})^{1-\sigma} + \ln UTB_{ij}$. Next, allow for the systematic influence of relative border barriers in origin and destination provinces on the pair fixed

[44] AIC is theoretically founded for maximum likelihood estimators, so its use for PPML estimators is a rough guide only.

effects $\hat{\gamma}_{ij}$ in the econometric specification:

$$\hat{\gamma}_{ij} = \omega_0 + \omega_1 \ln \left(\hat{t}_{ij}^{GRAV}\right)^{1-\sigma} + \omega_2 \, \hat{\psi}_{ii}^{GRAV} + \omega_3 \, \hat{\psi}_{jj}^{GRAV} + \nu_{ij}, \quad \forall i \neq j. \tag{19}$$

With no border barriers under the Cobb-Douglas cost assumption, $\ln UTB_{ij}$ is random and the plot of $\hat{\gamma}_{ij}$ against $\ln(\hat{t}_{ij}^{GRAV})^{1-\sigma}$ should be clustered around the 45 degree line. That is, with no border barriers, the Cobb-Douglas version of the theory predicts $\omega_1 = 1$ and $\omega_0 = \omega_2 = \omega_3 = 0$. That is because in the no border barriers case ψ_{ii} reflects only variation of intra-regional trade costs r_{ii}, by equation (15), and this has no influence on γ_{ij} under the Cobb-Douglas assumption. Non-uniform border effects are indicated by significant coefficients on the estimated $\hat{\psi}_{ii}$ in (19). If, furthermore, there is no correlation of internal costs r_{ii} with border frictions b_i, the systematic difference in (18) is equal to the border frictions only (up to a normalization), so

$$\hat{\gamma}_{ij} = \ln \left(\hat{t}_{ij}^{GRAV}\right)^{1-\sigma} - [\hat{\zeta}_O \hat{\psi}_{ii} + \hat{\zeta}_D \hat{\psi}_{jj}]$$

where $\hat{\zeta}_O = \hat{\omega}_2$ and $\hat{\zeta}_D = \hat{\omega}_3$. This is because both the fixed effect bilateral estimates and the gravity variables bilateral estimates are invariant to internal costs – the former by construction and the latter because r_{ii} and r_{jj} are absorbed by the multilateral resistances. The list of assumptions suggests that they are overly restrictive. In particular correlation between r_{ii} and b_i is plausible. For these reasons we proceed to look for systematic UTBs from the agnostic approach (19) with unrestricted coefficients.

$\hat{\gamma}_{ij}$s are the estimated pair fixed effects from specification (11), the mean of the bootstrapped coefficient estimates. On the right hand side of (19), the $\ln(\hat{t}_{ij}^{GRAV})^{1-\sigma}$s are the bilateral gravity variables log volume effects and $\hat{\psi}_{ii}$, $\hat{\psi}_{jj}$ are intra-provincial fixed effects, all estimated from gravity variables specification (13), again calculated as the mean values of the bootstrapped estimates. Due to the independent draws of the resampled residuals in the two first stage gravity estimators, the error term ν_{ij} in (19) is plausibly independent of the regressors. (19) is estimated using OLS with bootstrapping by resampling the ν_{ij}s with replacement.

Applying the Cobb-Douglas cost structure to the estimated equation (19), the Cobb-Douglas weights, ζ_O and ζ_D are estimated from the results of (19) as $\hat{\omega}_2/(\hat{\omega}_2+\hat{\omega}_3)=\hat{\zeta}_O$ and $\hat{\omega}_3/(\hat{\omega}_2+\hat{\omega}_3)=\hat{\zeta}_D$. Evidence presented at the end of this section is consistent with the Cobb-Douglas restriction. $\hat{\zeta}_O$ and $\hat{\zeta}_D$ are used with the estimates of $\hat{\psi}_{ii}$ and $\hat{\psi}_{jj}$ to construct the normalized relative border effects in Table 3.

The theory suggests that the systematic relative border effects $\hat{\zeta}_O\hat{\psi}_{ii}+\hat{\zeta}_D\hat{\psi}_{jj}$ (normalized and reported in exponentiated form in Table 3) should be removed from the UTB in (18) along with the predicted effect of the gravity variables (with unit elasticity). This procedure yields estimates of systematic residual Unexplained Trade Barriers, denoted UTB^*. Systematic residual UTBs in log form are calculated as the difference between $\hat{\gamma}_{ij}$ and $\ln\left(\hat{t}_{ij}^{GRAV}\right)^{1-\sigma}-[\hat{\zeta}_O\hat{\psi}_{ii}+\hat{\zeta}_D\hat{\psi}_{jj}]$. Thus

$$\ln\widehat{UTB}^*_{ij}=\hat{\omega}_0+(\hat{\omega}_1-1)\ln\left(\hat{t}_{ij}^{GRAV}\right)^{1-\sigma}+[\hat{\omega}_2+\hat{\omega}_2/(\hat{\omega}_2+\hat{\omega}_3)]\,\hat{\psi}_{ii}+[\hat{\omega}_3+\hat{\omega}_3/(\hat{\omega}_2+\hat{\omega}_3)]\,\hat{\psi}_{jj} \quad (20)$$

By construction, $\ln\widehat{UTB}_{ij}=\ln\widehat{UTB}^*_{ij}-[\zeta_O\hat{\psi}_{ii}+\zeta_D\hat{\psi}_{jj}]$. Including the random component, $\ln UTB_{ij}=\ln\widehat{UTB}_{ij}+\hat{\nu}_{ij}$.

Turning to inferences from estimation of (19), homogeneity implies $\omega_0=0$, $\omega_1+\omega_2+\omega_3=0$. The Cobb-Douglas specification implies $\omega_2+\omega_3+1=0$. Estimates of (19) permit tests of these restrictions. Rejection of the null hypothesis indicates the presence of systematic UTBs, calculated using (20). An initial benchmark estimates (19) subject to $\omega_2=\omega_3=0$. The results reported in column (1) of Table 4 reveal that the coefficient estimate on $\ln\left(\hat{t}_{ij}^{GRAV}\right)$ is not significantly different from 1; the $R^2=.48$; and the estimate of the constant term is statistically significant and very large.

Column (2) of Table 4 presents estimates of (19) with unrestricted ωs. (i) $R^2=.94$, a substantial increase; (ii) $\hat{\omega}_1$ is closer to 1 and not statistically different from 1; (iii) $\hat{\omega}_2$ and $\hat{\omega}_3$ are each greater in absolute value than $-1/2$ and their sum is statistically smaller than -1, all at the 1% level of confidence; (iv) $\hat{\omega}_0$ is smaller in absolute value, but statistically and quantitatively significantly less than 0; (v) $\hat{\omega}_1 + \hat{\omega}_2 + \hat{\omega}_3 < 0$. Result (i) implies that intra-national relative trade cost variation picked up by volume effect $\hat{\psi}_{ii}$ contributes significantly to the variation of bilateral fixed effects, doubling the variation explained by distance.

Results (i) and (ii) together indicate that intra-national cost variation is almost uncorrelated with bilateral distance. Result (iii) implies that intra-national trade costs are correlated with an unobserved variable affecting inter-regional trade costs that is not neutralized by origin and destination fixed effects. Results (iv) and (v) imply that homogeneity of degree zero is rejected: the chi-squared test for the combined restrictions $\omega_0 = 0,\ \omega_1+\omega_2+\omega_3 = 0$ is rejected (p-value of 0.0001). Given the Cobb-Douglas structure, the hypothesis tests in (iii)-(v) are consistent with the presence of systematic residual UTBs measured using equation (20).

Column (3) of Table 4 reports estimates of (19) subject to the constraint $\omega_2 + \omega_3 = -1$. The results imply that, subject to the constraint, the values of $\omega_1 = 1$ and $\omega_0 = 0$ cannot be rejected. The homogeneity hypothesis in the constrained model is not rejected: the chi-squared test for the combined restrictions $\omega_0 = 0,\ \omega_1 + \omega_2 + \omega_3 = 0$ has a p-value of 0.1754. The constrained $-\hat{\omega}_2$ and $-\hat{\omega}_3$ values are pushed slightly toward 1/2 compared to the $\hat{\omega}_2/(\hat{\omega}_2 + \hat{\omega}_3)$ and $\hat{\omega}_3/(\hat{\omega}_2 + \hat{\omega}_3)$ values.

The constrained model comes close in practice to the simple homogeneous Cobb-Douglas model. Nevertheless, columns (2) and (3) taken together imply non-random residuals of the constrained regression, with important information. The UTBs generated by the estimated version of (20) using the coefficients in column (3) of Table 4 are given by (21) below. Standard errors are reported in parentheses.

$$\ln \widehat{UTB}^*_{ij} = \underset{(0.283)}{-1.059} - \underset{(0.035)}{0.035} \ln(\hat{t}^{GRAV}_{ij})^{1-\sigma} - \underset{(0.022)}{0.1122}\hat{\psi}_{ii} - \underset{(0.023)}{0.1149}\hat{\psi}_{jj} + \hat{\nu}_{ij}. \tag{21}$$

Equation (21) includes the adjustment term $z_{ij} = (\hat{\omega}_1 - 1)\ln(\hat{t}^{GRAV}_{ij})^{1-\sigma}$ due to the slight under-prediction of the gravity trade cost coefficient. The importance of variation in relative home bias ψ_{ii} and z_{ij} in explaining $\ln \widehat{UTB}^*_{ij}$ is described by standardized (beta) coefficients of 0.583 (z_{ij}), -0.491 ($\hat{\psi}_{ii}$) and -0.534 ($\hat{\psi}_{jj}$). Idiosyncratic border effects ν_{ij} have relatively small influence, because the residual ($\hat{\nu}_{ij}$) variance is 6.6% of the variance of $\hat{\gamma}^{FE}_{ij}$ based on the unconstrained regression (19).

The systematic provincial border barrier effects in residual UTB (21) are inherently non-discriminatory, though producing systematic effects. Discriminatory border effects, if any, are part of the error term ν_{ij}. In principle, groups of regions could form samples to pick up systematic discriminatory effects through different $\hat{\omega}_k$ coefficients. With only 12 Canadian provinces this suggested technique has too few degrees of freedom to be useful. The discriminatory implications of the residuals ν_{ij} of (20) may be informative in some cases where added information can be brought to bear on discriminatory provincial border effects.

Table 5 reports expected (fitted) systematic residual UTBs in levels, $E[\widehat{UTB}^*_{ij}]$, the systematic portion of equation (21). (Compare with Table 3 and recall that $\ln UTB_{ij} = \ln UTB^*_{ij} - [\zeta_O \hat{\psi}_{ii} + \zeta_D \hat{\psi}_{jj}]$. Thus the full UTB in levels, up to a scalar, is the ratio of the value in Table 5 to the value in Table 3.) There are some residual UTBs that are greater than one and some that are less than one. For instance, YT, NT and PE exhibit a large number of UTBs that are smaller than one, while most of the UTBs for AB, BC and ON are greater than one. At one extreme, the UTB estimate of 0.57 for PE exports to YT that we report in Table 5 suggests that PE exports to YT are reduced 43% by their 2002 UTB in manufacturing. At the other extreme, our estimate of 1.3 for ON exports to BC suggests that exports from ON to BC are raised 30% by their UTB. In general, we find that relatively large (arithmetic) estimated intra-provincial volume effects $\hat{\psi}_{ii}$ for small and remote provinces and relatively small (arithmetic) $\hat{\psi}_{ii}$ for large and central provinces have non-neutral effects, diverting inter-provincial trade positively on some bilateral links and negatively on others. The pattern is consistent with the interpretation of the measured UTBs as based on deviations from the mean log border barriers of partners. These patterns and the variation across provinces and provincial pairs may indicate where policy intervention has larger payoffs. Beaulieu et al.

(2003) offer ample anecdotal evidence for the existence of significant inter-provincial barriers to trade within Canada including home-biased government procurement, province-specific occupational licenses, etc. We believe that some of these barriers are definitely captured by our UTB indexes and we view a formal study that connects our indexes with detailed data on inter-provincial barriers as a valuable direction for future work.

The interpretation here of systematic UTBs is tentative for two reasons. First, omitted bilateral effects could be components of the error term in (21) and hence (20).[45] Second, specification (21) assumes a Cobb-Douglas cost function. But the results of estimating (20) could be indicative of non-CD cost structure for costs other than UTBs, with no UTBs. This implies omitted variables in the test based on equation (21).

The translog is natural to use as the alternative nesting the Cobb-Douglas. The translog adds 6 second order parameters to be estimated (using symmetry and the number of permutations of 3 activities: one for Origin, one for Destination, and one for the pure inter-regional).[46] The first order parameters are constrained to sum to one as in the Cobb-Douglas case; the second order parameters are constrained to sum to zero. For the Canadian case, with 12 provinces, the data are rather sparse ($12 \times 11 = 136$ observations of inter-regional fixed effects under symmetry) to believably estimate so many parameters. On datasets with more observations, the translog gains traction. But collinearity is a well-known issue. A translog counterpart to (19) is

$$\hat{\gamma}_{ij} = \omega_0 + \omega_1 \ln(\hat{t}_{ij}^{GRAV})^{1-\sigma} + \omega_2 \hat{\psi}_{ii} + \omega_3 \hat{\psi}_{jj} + \omega_4 \hat{\psi}_{ii}^2 + \omega_5 \hat{\psi}_{jj}^2 + \omega_6 \hat{\psi}_{ii} \hat{\psi}_{jj} + \nu_{ij}. \tag{22}$$

Theory implies $\omega_2 + \omega_3 = -1$ and $(\omega_4, \omega_5) < 0$ and $\omega_4 + \omega_5 + \omega_6 = 0$.

[45] If the set of gravity variables in (17) is incomplete, $\hat{\tau}_{ij}^{UTB}$ will be biased. In other words, more information might be extracted with more details about the types of bilateral relationships (i.e., infrastructure details) between the provinces in our sample. This point is especially relevant at the sectoral level. In addition, it is possible that the gravity variables that we use already proxy for institutional and policy measures intended to promote inter-provincial trade. For example, contiguous provinces are more likely to cooperate with each other. As an example of close cooperation between contiguous provinces consider Alberta and British Columbia, partners in the Trade, Investment and Labour Mobility Agreement (TILMA) in 2007. Due to data limitations, we cannot study the effects of TILMA here.

[46] Special case restrictions can reduce this number.

Column (4) of Table 4 reports the results from the translog specification in equation (22). None of the new terms is statistically different from zero and joint test cannot reject the hypothesis that $\omega_4 + \omega_5 + \omega_6 = 0$. The p-value for the corresponding chi-squared test is 0.4908. (We also cannot reject the hypotheses that $\omega_1 = 1$, $\omega_0 = 0$, $\omega_2 = -1/2$, $\omega_3 = -1/2$, and $\omega_2 + \omega_3 = -1$.) In sum, our findings do not reject the CD functional form, while the multicollinearity of the translog form blows up the standard errors. The significant changes in the estimates of the CD terms (compare columns 2 and 4) point to potential caveats in the assumption of CD to identify UTBs. If non-CD cost functions obtain, accurate comparative statics (e.g. the effect of an intra-regional improvement on bilateral costs) need to use them. This is an important task for future research.

Equation (19) and its structural interpretation invite suspicion that an alternative origin and destination effects mechanism may be at work. A natural atheoretic "smell" test replaces ψ_{ii} and ψ_{jj} with the time-averaged estimates of origin and destination fixed effects $\hat{\eta}_i^G$ and $\hat{\theta}_j^G$. The results are reported in column (5) of Table 4. The coefficient of $\ln(\hat{t}_{ij}^{GRAV})^{1-\sigma}$ is insignificantly different from its value in column (2) and R^2 rises only slightly compared to column (2). The closeness of the coefficient estimates and goodness of fit suggests that the restrictions of theory are plausible.

4.3 CTB Estimates

Constructed Trade Bias estimates capture the direct and indirect volume effects of trade costs, by equation (5). As discussed in Section 2.2, one of the most important properties of the CTB indexes is that they are invariant to normalization. Thus CTBs can be compared across sectors and over time. Based on the fitted pair-fixed effects gravity specification (11), CTB (for a generic sector) is generated by:

$$\widehat{CTB}_{ij,t} = \exp[\hat{\alpha}_1 INTERPR\_T_{ij,t} + \hat{\alpha}_2 INTRAPR\_T_{ij,t} + \hat{\gamma}_{ij} + \hat{\eta}_{i,t} + \hat{\theta}_{j,t}] \tag{23}$$

CTB estimates for manufacturing within and between provinces for 2002, the mid-year in our sample, are reported in Panel A of Table 6. In the absence of trade frictions, all elements of the CTB table would be equal to 1. The rightmost column reports that all provinces trade more with their provincial partners in Canada than they would in a frictionless world, ranging from 2.3 to 14.2 times as much. This reflects the international border barrier that deflects trade into domestic destinations, a familiar result.

Next, consider deflection from both foreign and inter-provincial trade into intra-provincial trade. The principal diagonal elements of Table 6 (Constructed Home Bias, $CTB_{ii} = CHB_i$) in Table 6, Panel A, are massive. For example, CHB for Ontario at 19.8 is the smallest among the provinces and territories, meaning that Ontario trades about 20 times more internally than it would have traded in a frictionless world at given sales and expenditures patterns. More developed and central provinces exhibit smaller Constructed Home Bias than relatively distant and less developed regions like YT, NT, and PE. This is due to the strong tendency for larger regions to have lower multilateral resistances because they naturally do more trade with themselves (Anderson and van Wincoop (2003); Anderson and Yotov (2010) for a formal argument).

Turn next to Table 6's information on intra-national trade cost variation. Comparing Ontario's CHB of 19.8 with its CTB for trade with other Canadian provinces of 10.1, the implication is that interprovincial trade barriers due to distance and provincial borders double Ontario's trade with itself. For other provinces the same calculation implies much larger effects of interprovincial barriers (e.g. Quebec at 8.3=65.6/7.9 and vastly larger for the smallest provinces). These conditional general equilibrium results imply that intra-national trade cost variation has very large effects. Variation in the pattern of direct bilateral trade costs faced by regions plays a role (see column (2) of Table 1), but the size-multilateral-resistance link dramatically increases the CTB variation.

The importance of intra-national trade cost variation is more dramatically driven home by the off-diagonal variation of bilateral CTBs. The off-diagonal elements in Panel A are generally larger than 1 but smaller than the intra-provincial bias for all regions. For example AB and BC have Constructed Home Bias 4 to 6 times larger than their bilateral CTBs. International borders deflect foreign trade into domestic trade, but the direct plus indirect effects lead to a much greater deflection into local trade. The off-diagonal estimates in Panel A of Table 6 also reveal that more developed provinces demonstrate larger inter-provincial biases as exporters than as importers. In contrast, less developed and more remote regions, such as YT, PE, and NT, tend to have larger inter-provincial biases as importers than as exporters.[47]

Panel B of Table 6 reports percentage differences between CTBs from the pairwise fixed effects estimator and the gravity variables estimator. These are the conditional general equilibrium comparative static effects of removal of UTBs on CTBs, comprising the direct effects of Table 5 and the indirect effects via changes in multilateral resistance, all at given Y_is and E_js.[48] The diagonal elements in Panel B impose intra-regional UTBs = 1 by construction, hence the difference between the two CTBs is due to the difference in the multilateral resistances (the origin and destination fixed effects differ in the two estimations).[49] These effects are small. In contrast, the off-diagonal elements are sizable and vary in sign. The influence of UTBs here combines the systematic effects from Table 5 with the idiosyncratic effects ν_{ij}. Each province's average across its partners is given by the rightmost column, ranging around 10% in absolute value.

The idiosyncratic bilateral effects are large in some cases, notably the exports of NL to YT. The extreme reductions reported for the smallest remote provinces, YT and NT, are substantially due to composition effects due to estimation from aggregate manufacturing. YT and NT differ greatly in manufacturing composition from ON, for example, and this difference shows up in the ν_{ij} and in principle biases all other estimates in the model. Moreover, the

[47] Notably, the only three CTB indexes that we obtain that are lower than or equal one are for exports from NT to ON, and for exports from YT to QC and ON.

[48] The conditional general equilibrium effect is called Modular Trade Impact by Head and Mayer (2014). Full general equilibrium requires a model of supply (such as the endowments model) and determination of the equilibrium sellers' prices.

[49] The interpretation is $(CTB_{ii}^{FE} - CTB_{ii}^{GRAV})/CTB_{ii}^{GRAV} = \left((\Pi_i^{FE} P_i^{FE})/(\Pi_i^{GRAV} P_i^{GRAV} 0)\right)^{\sigma-1} - 1$.

difference is partly due to the effect of trade costs on location (Yi, 2010). Analogous measures for disaggregated trade reduce the magnitude by a factor of 4 or more. The same composition effects help explain the very small values of direct effects $\hat{\gamma}_{ij}$ found in Panel B of Table 2. Our focus on the aggregate manufacturing results is for expositional ease despite these issues. For purposes of extracting more information from UTBs by relating them to qualitative measures of regulatory and other barriers it is necessary to use the disaggregated gravity results that we report only briefly.

Percentage changes in CTBs over time in Manufacturing from 1997 to 2007 are reported in Table 7. In the absence of evidence for change in bilateral trade costs, the changes are due to changes over time in the importer and exporter fixed effects.[50] The flexible pair fixed effects specification (9) is used here because it controls for UTBs.[51] CHBs (intra-provincial CTBs) have decreased for all provinces save BC and NB, with increases of 2% and 4.2%, respectively. Thus, most provinces are becoming more integrated with the world. The fall in CHBs is largest for the remote regions YT (79%) and NT (62%). Second, the changes in inter-provincial CTBs off the diagonal are mixed, but with some consistent patterns. More remote regions experience a fall in the CTBs for exports, exemplified by decreases for NT and for YT with any other region in our sample. CTB changes at the province level are summarized in the last column in Table 7, where we report consistently aggregated

[50]The importance of this channel, the effect of changing patterns of sales and expenditure on multilateral resistances, is emphasized in Anderson and Yotov (2010). While CTB change over time may also reflect changes in bilateral trade costs $t_{ij,t}$, the estimates of the two time-varying components in specification (23) ($\widehat{INTERPR\_T}_{ij,t}$ and $\widehat{INTRAPR\_T}_{ij,t}$) reveal no evidence of such changes. We also looked for omitted time-varying trade cost factors in the estimated error terms from specification (23):

$$\widehat{\epsilon}_{ij,t} = \frac{x_{ij,t} Y_t}{Y_{i,t} E_{j,t}} - \widehat{CTB}_{ij,t}. \tag{24}$$

. We saw no obvious evidence of systematic changes in trade costs amidst the noise in $\hat{\epsilon}_{ij,t}$. We caution that movement of the CTB estimates over time is subject to reliability of ROW data used to construct the value of world output for each sector.

[51]The gravity variables estimator is subject to spurious movement of the importer-time and exporter-time fixed effects due to the omitted systematic variation in the UTBs. The systematic portion of UTBs identified above has to be correlated with the importer-time and exporter-time FEs, inducing bias in those estimates. In contrast our estimate of the distance elasticity seems to be unbiased based on the results of estimating equation (19).

provincial numbers. Subtracting the diagonal terms gives the percentage change in inter-provincial to local trade. All provinces except YT (-4.8%) experience a rise in relative integration by this measure; Canada's provinces have become more integrated. NT, ON and MB are provinces that experience lower CTBs for their exports to most provinces and territories, but their fall in CHBs ($CTB_{ii}s$) implies a rise in relative inter-provincial trade. All the inter-temporal variation is due to changes in the provincial output and expenditure shares acting on multilateral resistances. As discussed earlier, there is little evidence of time variation in the bilateral trade costs.

4.4 Partial vs. General Equilibrium Home Bias

The intra-national home bias for province i is the ratio of its predicted to theoretical frictionless trade within Canada, $i \in C(i)$, a measure incorporating the direct plus indirect effects of trade costs on multilateral resistances:

$$CTB_{C(i)} = \sum_{j \in C(i)} \frac{E_j}{E_{C(i)}} CTB_{ij}. \tag{25}$$

The partial equilibrium effect of estimated relative provincial home bias on is exports to its Canadian partners is given by $\exp(\psi_{ii}) = [t_{ii}/\bar{b}(i)]^{1-\sigma}$, while the general equilibrium effect is given by (25). Variation of ψ_{ii} across provinces has substantial effects that affect $CTB_{C(i)}$s non-uniformly. This point is illustrated by estimating (17) alternately with $\psi_{ii} = 0$ and $\psi_{ii} \neq 0$, then calculating the $CTB_{C(i)}$ under each specification.

Table 8 presents the results. Column (1) reports $CTB_{C(i)}$ constructed with $\hat{\psi}_{ii} = 0$ and Column (2) reports $CTB_{C(i)}$ with $\hat{\psi}_{ii} \neq 0$, as in column (2) of Table 1. The correlation between values in the two columns is only 0.67. CTBs obtained with $\psi_{ii} \neq 0$ are mostly larger than their counterparts in column (1). The differences are smaller for the smaller, more remote provinces (e.g. YT, NT, and PE). In contrast, for ON, AB, and BC the dispersion of relative intra-provincial trade costs reduces their CTBs. The difference between columns (1) and (2) of Table 8 is not driven by the direct effect of ψ_{ii} on CTBs alone. This is evidenced by a correlation of 0.38 between the CTB difference from Table 8 and $\hat{\psi}_{ii}$ (differenced from 0) from Table 1.

4.5 Credibility Checks

The credibility of the pair fixed effects results that yield UTBs is buttressed by analysis of the residuals and sensitivity to variations of the model specification. Residuals are defined in equation (24) as the difference between the actual data and the fitted CTBs for the pair fixed effect specification (9). Residuals are primarily due to measurement error in the trade, output and expenditure data, but may also indicate time-varying trade costs or a specification error. Systematic sign switches of residuals over time could vitiate our use of panel structure to identify UTBs. Systematic under- or over- predictions for pairs could indicate departure from the iceberg (log-linearity of) trade costs assumed in (9). The residuals data reveal very few instances where the residuals for a given pair are steadily positive or negative up to a given year and then switch signs until the end of the period, suggesting that the model does not omit a systematically important time-varying explanatory variable.[52] The examination of residuals combines with the finding of no significant time-varying effects captured by $INTERPR\_T_{ij,t}$ and $INTRAPR\_T_{ij,t}$ from specification (11) to suggests that internal trade costs in Canada were stable between 1997 and 2007. Systematic under- or over-predictions across years occur for only 18 of the 144 possible pairs of provinces and territories in our sample.[53] The scarcity of such examples indicates randomness rather than non-iceberg trade costs.

A full cross section display of initial (before resampling) residuals for 2002 is expressed in percentage terms for comparability in Table 9. Note first that the residuals are mostly not systematically signed: each row and column contains positive and negative elements.

[52] The dataset of residuals is available by request.

[53] For example, on average, the largest (as percent) over-predictions of our model are for 'exports' from NT to MB and from NT to SK, and the largest under-prediction is for shipments from YT to BC. In most cases, the model over-predicts or under-predicts either the exports or the imports for a given province/territory from another province or territory. In a few instances there are systematic differences in each direction for a given pair. For instance, the model over-predicts shipments from AB to BC but under-predicts shipments from BC to AB.

This is consistent with the process generating the ϵ realizations being a zero mean random generator. Second, in terms of distribution across provinces and across provincial pairs, the biggest discrepancies between the data and the model predictions (based on the dispersion of the residuals) are for YT and NT, followed by NL and PE. In contrast, the model performs best for QC, followed by AB, BC and ON. Thus, the model performs best for the big provinces and worst for the smallest provinces. Note that this is so even after the rich system of fixed effects controls for time-varying province-specific effects (both as importer and exporter) and for time-invariant bilateral effects. This pattern is explained by less efficient estimators for YT and NT (due to lack of data for these territories), or it may reflect meaningless randomness. It certainly implies some heteroskedasticity not controlled for in our econometric specification.

We perform six robustness checks with variations of the model, described in detail in a Supplementary Appendix available by request. Our findings are robust to all six variations. First, we allow for asymmetric bilateral fixed effects in equation (9). Differences are small, hence symmetry is consistent with the data.[54] Second, OLS estimation of the log-linearized gravity equation yields very similar results to the PPML estimation. Third, suspicious of the role played by large rest-of-the-world (ROW) aggregate and US regions, we exclude them consecutively from our sample. The estimates of inter-provincial trade costs are unaffected.[55] Fourth, we replace all missing trade values in the data with zeros. The CTB indexes, the inter-provincial trade costs and the tariff equivalents remain qualitatively unchanged with only minor quantitative changes. Fifth, we drop YT and NT, which are the regions with the most missing and/or zero trade flow values in our sample. The results remain unchanged. Our explanation is that these regions are relatively small as compared to the rest of the

[54]The CTBs obtained with symmetric and asymmetric trade costs are indeed similar in levels, but we do obtain some significant percentage differences, especially for small CTBs. For example, the pair BC-NB has an estimated average CTB of 3.5 with symmetric trade costs and an estimated average CTB of 6.02 with asymmetry. Trade cost asymmetries should be significantly more pronounced in international trade data than in inter-regional trade data. Modeling of asymmetric international trade costs is an important direction for future research.

[55]The reason for insensitivity is that we use the most flexible fixed effects specification to account for trade costs with US and ROW.

Canadian provinces. Finally, we employ only data for the years 1997, 1999, 2001, 2003, 2005, and 2007.[56] There are no significant differences between the set of estimates with two-year lags and the main estimates.

5 Sectoral Estimates

The pairwise fixed effects and gravity estimates that we obtain for each of the 28 sectors in our sample are generally consistent with the findings for 'Total Manufacturing'.[57] Across all sectors and all exporter-importer pairs, the inter-provincial trade costs are greater than the corresponding intra-provincial indexes. 'Health', 'Education', and 'Finance' are the sectors with the largest costs, whereas 'Leather, Rubber, Plastic' and 'Hosiery and Clothing' are the sectors with the smallest costs. Highly localized consumption is a natural explanation for these results. The UTB sectoral border tax equivalents, consistently aggregated across all provinces, range from 86.3% for 'Health' to -12.6% for 'Agriculture'. We find some positive and some negative UTBs both across sectors for a given region and across regions for a given sector. Overall, the results suggest that provinces/territories face inter-provincial trade costs beyond those associated with bilateral distance and contiguity.

Generally, the CTB indexes for the disaggregated sectors are consistent with the 'Total Manufacturing' findings. Constructed Home Bias ($CHB_i = CTB_{ii}$) is large and varies considerably by province i, largest for the small remote ones. Looking at CHB consistently aggregated over provinces across sectors for 2002, the largest values are for 'Agriculture', 'Hosiery and Clothing', and 'Health'. The ratios of inter-provincial to intra-provincial CTBs (CTB_{ij}/CTB_{ii}) for each sector are significantly less than one. Overall CTB_{ij}/CTB_{ii} is lower for services sectors than for goods sectors. Among the services categories, the lowest values are for 'Health' and 'Finance', while 'Furniture', 'Textile Products, 'Wood, Pulp, Paper' exhibit the highest CTB_{ij}/CTB_{ii} values. Over time, the average greater integration of

[56] Cheng and Wall (2005) argue against the use of fixed effects with "... data pooled over consecutive years on the grounds that dependent and independent variables cannot fully adjust in a single year's time."(p.8).

[57] A detailed analysis of the sectoral results is reported in the Supplementary Appendix available by request.

Canada's provinces with each other and the world in both goods and services conceals some declines. All effects are due to changing location of sales and expenditure; we find no evidence of changing trade costs over time in any sector. 'Leather, Rubber, and Plastic', 'Hosiery and Clothing', and 'Fabricated Metal' are among the sectors with the steadiest CTB decline (trade is falling further below its frictionless benchmark). In contrast, consistent with the overall picture of rising integration, 'Wholesale', 'Education', and 'Health' generally exhibit increases in inter-provincial CTBs over time.

6 Conclusion

A structural gravity econometric method is developed and applied to flexibly estimate bilateral intra-national trade costs from inter- and intra-regional trade flows. A key step is specifying a bilateral trade cost function that aggregates internal, border and pure inter-regional costs. Application to the bilateral trade of Canada's provinces reveals that provincial trade is differentially affected by variation in relative border frictions that depress the trade of small remote provinces and favor trade of large central provinces. We call these Unexplained Trade Barriers to suggest there is much to be learned from attempting to explain the variation in inter- and intra-regional trade costs and border barriers using detailed information on regulatory differences and intra-national infrastructure.

Our findings for the Canadian provinces and territories surely hold much more widely. Even larger differences in intra-national trade costs are likely to be obtained in an international study at the cross-country level. There are two implications for future research. First, the standard approach in the trade literature that treats regions (e.g. provinces and/or countries) as point masses is *substantially* at variance with reasonable inference from the data. Allowing for the variation has important implications for regional policy and general equilibrium comparative statics. Second non-uniform border barriers within countries induce significant systematic distortions of inter-regional trade. We expect that the magnitude and heterogeneity of UTBs will be even larger in a cross-country study with international data.

The flexible fixed effects treatment of trade costs can also be applied to quantify barriers to immigration and FDI, about which we know much less than about trade costs.

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Table 1: PPML Panel Gravity, Total Manufacturing, 1997-2007

	(1) Pair Fixed Effects	(2) Gravity Variables
INTERPR_T	-0.001	-0.000
	(0.097)	(0.132)
INTRAPR_T	-0.025	-0.023
	(0.097)	(0.132)
DISTANCE_1		-0.777
		(0.042)**
DISTANCE_2		-0.876
		(0.038)**
DISTANCE_3		-0.844
		(0.035)**
DISTANCE_4		-0.897
		(0.033)**
CONTIG_PR_PR		0.055
		(0.041)
$\psi_{AB,AB}$		-3.732
		(0.296)**
$\psi_{BC,BC}$		-3.619
		(0.317)**
$\psi_{MB,MB}$		-3.385
		(0.304)**
$\psi_{NB,NB}$		-2.565
		(0.257)**
$\psi_{NL,NL}$		-2.552
		(0.316)**
$\psi_{NS,NS}$		-2.681
		(0.245)**
$\psi_{NT,NT}$		-1.046
		(0.313)**
$\psi_{ON,ON}$		-3.969
		(0.340)**
$\psi_{PE,PE}$		-0.891
		(0.221)**
$\psi_{QC,QC}$		-2.972
		(0.322)**
$\psi_{SK,SK}$		-2.368
		(0.299)**
$\psi_{YT,YT}$		0.839
		(0.293)**
CONST	11.207	10.349
	(1.068)**	(1.482)**
N	2052	2052
AIC	6.38	8.20

Notes: This table reports PPML panel gravity estimates for Total Manufacturing, 1997-2007. The estimates in column (1) are obtained from the fixed effects specification (11). The estimates in column (2) are obtained from specification (17), where the bilateral fixed effects are replaced with gravity variables. Standard errors are clustered by pair and are in parentheses. + $p < 0.10$, * $p < .05$, ** $p < .01$. See text for more details.

Table 2: PPML with Pair Fixed Effects, Total Manufacturing, 2002

	NL	NS	PE	NB	QC	ON	MB	SK	AB	BC	NT	YT	CA
A. Pair Fixed Effects Estimates, γ_{ij}													
NL	0	-2.35	-3.21	-2.68	-3.4	-3.46	-4.31	-4.98	-4.53	-4.57	-5.9*	-8.4	-4.19
NS		0	-2.33	-1.67	-2.79	-2.68	-3.75	-4.34	-3.76	-3.88	-4.37*	-7.27*	-3.42
PE			0	-2.2	-3.37	-3.75	-4.56	-5.17	-5.04	-4.88	-6.66*	-7.94	-4.36
NB				0	-2.32	-2.34	-3.9	-4.26	-3.98	-4.2	-5.53*	-6.84	-3.42
QC					0	-1.52	-2.69	-3.33	-2.85	-3.09	-4.65	-6.46	-2.94
ON						0	-2.66	-2.85	-2.22	-2.67	-5.05	-6.05	-2.84
MB							0	-1.75	-1.9	-2.81	-4.84	-6.16	-3.1
SK								0	-1.67	-2.8	-5.61	-7.12*	-3.4
AB									0	-1.75	-4.2	-5.5	-2.89
BC										0	-4.67	-4.81	-3.21
NT											0	-5.9	-4.83
YT												0	-6.05
CA													-3.72
B. Volume Effects, $\exp(\hat{\gamma}_{ij}) \times 100$													
NL	1	9.49	4.04	6.88	3.33	3.14	1.34	.68	1.07	1.03	.27*	.02	2.5
NS		1	9.76	18.75	6.15	6.84	2.36	1.3	2.33	2.07	1.27*	.07*	4.86
PE			1	11.08	3.45	2.36	1.05	.57	.65	.76	.13*	.04	2.45
NB				1	9.84	9.65	2.02	1.42	1.86	1.49	.39*	.11	5.87
QC					1	21.84	6.81	3.57	5.79	4.54	.95	.16	8.69
ON						1	6.97	5.81	10.82	6.93	.64	.24	9.19
MB							1	17.36	14.93	6.01	.79	.21	6.68
SK								1	18.87	6.08	.37	.08*	6.33
AB									1	17.38	1.5	.41	8.78
BC										1	.93	.81	6.07
NT											1	.28	.87
YT												1	.32
CA													5.2

Notes: This table presents estimates based on specification (11), where trade costs are controlled for with bilateral fixed effects. Panel A reports estimates of the bilateral fixed effects γ_{ij} obtained with a panel PPML estimator. All estimates are highly statistically significant. Standard errors (clustered by pair) are omitted for brevity. Panel B reports the corresponding volume effects. "*" is used to denote that only one-way trade flows are used to obtain the corresponding estimate. See text for more details.

Table 3: Relative Border Effects in Manufacturing, 2002

	NS	PE	NB	QC	ON	MB	SK	AB	BC	NT	YT	CA
NL	.86	2.1	.91	.74	.45	.605	1	.505	.535	1.96	4.98	.65
NS		1.97	.85	.695	.42	.565	.94	.475	.505	1.84	4.76	.69
PE			2.08	1.7	1.03	1.38	2.3	1.16	1.23	4.45	11.425	1.65
NB				.735	.445	.6	.995	.505	.535	1.94	4.945	.7
QC					.365	.49	.81	.41	.435	1.57	4.035	.45
ON						.3	.495	.25	.26	.955	2.455	.36
MB							.66	.33	.35	1.28	3.28	.42
SK								.555	.585	2.125	5.56	.63
AB									.3	1.075	2.76	.36
BC										1.135	2.925	.36
NT											10.575	1.21
YT												3.04

Notes: This table reports estimates of the volume effects of the relative provincial border frictions normalized by a national average. See text for more details.

Table 4: Neutrality Tests and Alternatives, CA Manufacturing, 2002

	(1) BENCHMARK	(2) TEST	(3) CONSTRAINT	(4) TRANSLOG	(5) PROVINCE FEs
$\ln(\hat{t}_{ij}^{GRAV})^{1-\sigma}$	1.141	0.965	0.997	0.959	0.925
	(0.106)**	(0.036)**	(0.035)**	(0.039)**	(0.042)**
$\hat{\psi}_{ii}$		-0.607	-0.487	-0.473	
		(0.030)**	(0.023)**	(0.188)*	
$\hat{\psi}_{jj}$		-0.621	-0.513	-0.545	
		(0.033)**	(0.023)**	(0.186)**	
$\hat{\psi}_{ii}^2$				0.003	
				(0.022)	
$\hat{\psi}_{jj}^2$				-0.009	
				(0.020)	
$\hat{\psi}_{ii} \times \hat{\psi}_{jj}$				0.035	
				(0.033)	
CONST	4.259	-1.059	-0.077	-0.710	4.222
	(0.728)**	(0.272)**	(0.231)	(0.722)	(0.365)**
N	126	126	126	126	126
R^2	0.475	0.938		0.939	0.951

Notes: This table reports results from the invariance test and alternatives based on specification (19). Column (1) regressors include only bilateral trade cost effects $\ln\left(\hat{t}_{ij}^{GRAV}\right)$. Column (2) adds as regressors intra-regional volume effects $\hat{\psi}_{ii}$ and $\hat{\psi}_{jj}$. Column (3) restricts the sum of the coefficients on $\hat{\psi}_{ii}$ and $\hat{\psi}_{jj}$ to equal -1. Column (4) tests the translog specification by including the squared terms of $ln\left(\hat{t}_{ii}^{GRAV}\right)$ and $\ln\left(\hat{t}_{jj}^{GRAV}\right)$ and their interaction. Column (5) replaces $\hat{\psi}_{ii}$ and $\hat{\psi}_{jj}$ with $\hat{\eta}_i^G$ and $\hat{\theta}_j^G$. Coefficient estimates are omitted for brevity, since they have no theoretical interpretation. Bootstrapped standard errors in parentheses. See text for more details. + $p < 0.10$, * $p < .05$, ** $p < .01$

Table 5: UTB Levels, Total Manufacturing, 2002

	NS	PE	NB	QC	ON	MB	SK	AB	BC	NT	YT	CA
NL	.94	.765	.93	1.01	1.14	1.075	.98	1.145	1.135	.82	.685	1
NS		.745	.91	.98	1.145	1.085	.97	1.16	1.15	.84	.69	1
PE			.74	.8	.935	.885	.79	.945	.935	.68	.57	.8
NB				.96	1.095	1.07	.96	1.14	1.13	.82	.685	1
QC					1.12	1.12	1	1.17	1.18	.865	.715	1.1
ON						1.245	1.12	1.31	1.3	.965	.805	1.2
MB							.985	1.175	1.2	.9	.725	1.2
SK								1.025	1.035	.8	.65	1
AB									1.19	.925	.755	1.2
BC										.925	.735	1.2
NT											.55	.9
YT												.7

Notes: This table reports the UTBs in levels constructed based on equation (21). See text for more details.

Table 6: CTB^{FE} Indexes, Total Manufacturing, 2002

	NL	NS	PE	NB	QC	ON	MB	SK	AB	BC	NT	YT	CA
A. CTB Levels, 2002													
NL	1141	44.3	72	30.2	4.8	2	3.8	2.9	2.8	2.8	23.1	3.9	4.1
NS	178	579.7	248.5	117.5	12.7	6.1	9.5	7.8	8.7	8.1	153	17.1	11.4
PE	149.7	128.5	4371.1	137.1	14.1	4.2	8.3	6.7	4.7	5.9	30.6	17.3	11.5
NB	104.3	100.9	227.7	440	16.5	7	6.6	6.8	5.6	4.7	38.5	21.3	11.3
QC	22.7	14.9	31.9	22.5	65.6	7.1	10	7.8	7.9	6.5	41.9	13.9	7.9
ON	15	11.6	15.3	15.4	11.5	19.8	7.1	8.8	10.3	6.9	19.7	14.8	10.1
MB	18.1	11.3	19.2	9.1	10.1	4.5	251.6	74.7	40	16.9	68.6	37.5	11.5
SK	12.2	8.2	13.8	8.4	7	4.9	66.2	493.5	66.7	22.6	42	18.9	14.2
AB	11.2	8.7	9.2	6.5	6.7	5.4	33.5	63	181	38	101.4	56.1	11.4
BC	7.2	5.2	7.2	3.5	3.5	2.3	9	13.6	24.2	127.2	42.1	74.7	5.2
NT					3.2	.9	5.1	3.5	9	5.9	16927.4	109.1	2.7
YT					1	.7			4.9	10.3	106.9	68851.5	2.3
B. $(CTB^{FE} - CTB^{GRAV})/CTB^{FE}$													
NL	.2	24.9	21.3	12.1	20.4	-7.8	-80.9	-26.2	-26.9	3.1	-82.2	-256.2	0
NS	3	-.7	-19.3	-15.3	-60.7	12.3	-42.3	-37	22.7	36.7	53	-44.6	8.7
PE	10.1	-5.5	.1	14.2	-13	2.6	-26.2	-22.2	-9	32.8	-84.4	-10	7.1
NB	-2.2	-3.9	12.7	.3	-25.3	-29.1	-61.9	-20.5	8	17.3	-42.4	12.6	8.8
QC	2.2	-53.1	-21.6	-32.4	-.3	-43.5	41.7	29.8	35.4	61.7	21.9	18.2	6.2
ON	-8.7	31.5	14	-11.9	-17.8	.8	-7.6	43	43.5	37.5	-69	16.7	8.9
MB	-50.3	8.3	8.2	-15.7	60.6	11.3	-.3	20.3	9.1	35.3	-10	-42.3	9.3
SK	3.3	18.6	18	20.5	56.2	56.7	26.5	-.1	23.3	-4.9	-58.1	-104.9	11.8
AB	-20.3	43.2	9.5	25	50.1	46.9	-3.8	5.1	.2	-31.3	6.3	-11.8	9.4
BC	-13	42.8	31.3	17	63.6	27.7	9.1	-59.7	-61.5	.9	-25.3	32.9	3
NT					-11.6	-194.3	-132.5	-262	-73.4	-88.4	0	23.6	-6.2
YT					-30.7	-62.1			-131.3	-12.9	14.6	0	-10.9

Notes: This table presents estimates of the Constructed Trade Bias index, as defined in specification (23). Panel A reports CTBs in levels for 2002. Panel B reports percentage differences between the CTB indexes constructed using the fixed effects method (11), and the standard gravity variables approach, (17). See text for more details.

Table 7: CTB Percentage Changes, Total Manufacturing, 1997-2007

	NL	NS	PE	NB	QC	ON	MB	SK	AB	BC	NT	YT	CA
NL	-3.7	15.4	-7	6.4	15	23.8	17	-4.3	5.1	11.4	2.2	104.2	14.3
NS	15.8	-12.8	-11.3	1.5	9.6	18	11.6	-8.8	.2	6.1	-2.6	94.7	7
PE	45.6	38.3	-11.6	27.6	37.8	48.3	40.3	14.7	26	33.5	22.5	144.8	32.7
NB	50.2	42.6	15	4.2	42.1	52.9	44.6	18.2	29.9	37.6	26.3	152.4	42.6
QC	26.2	19.9	-3.4	10.5	-5.4	28.5	21.5	-.6	9.1	15.6	6.1	112.1	22.4
ON	1.1	-4	-22.6	-11.5	-4.4	-18.4	-2.7	-20.4	-12.6	-7.4	-15	69.9	-7.8
MB	2	-3.2	-21.9	-10.7	-3.5	3.8	-22.2	-19.7	-11.8	-6.6	-14.3	71.3	-.8
SK	49.4	41.9	14.4	30.9	41.4	52.2	43.9	-6.7	29.2	37	25.7	151.2	53.4
AB	9.7	4.2	-16	-3.9	3.8	11.8	5.7	-13.6	-24.8	.6	-7.7	84.4	5.8
BC	40.4	33.4	7.5	23	32.9	43	35.3	10.6	21.4	2	18.1	136	43.7
NT					-45.4	-41.2	-44.4	-54.5	-50.1	-47.1	-61.5	-3	-41.3
YT					-85.1	-84			-86.4	-85.6	-86.8	-79.1	-83.8

Notes: This table reports CTB percentage changes over the period 1997-2007.

Table 8: Intra-provincial costs and CTBs

	(1)	(2)
	$CTB_{C(i)}$ ($\gamma_{ii} = 0$)	$CTB_{C(i)}$ ($\gamma_{ii} \neq 0$)
NL	9	11.6
NS	17.8	22.5
PE	19.1	20.5
NB	15.1	19.4
QC	18.2	19.6
ON	31.1	15.1
MB	12.5	16.4
SK	16.6	19.1
AB	28.6	23.9
BC	19.9	16.9
NT	28.1	30.9
YT	32.7	32.6

Notes: This table reports CTBs which are constructed without intra-provincial trade costs (column 1) and with intra-provincial trade costs (column 2).

Table 9: Gravity Residuals as Percent of CTB, Total Manufacturing, 2002

	NL	NS	PE	NB	QC	ON	MB	SK	AB	BC	NT	YT	CA
NL	-1.5	130.3	-13.5	-65.7	-20.9	-45.2	-55.2	10.6	-36.3	-77	-18.5	1.5	-9.8
NS	16	-2.5	15	-1.1	1.6	8.4	-18.8	61.4	10.4	-44.8	-39.2	52.6	2.6
PE	-14	-26.1	.1	1.9	-4.4	38.4	84.6	-43.4	7.9	-48.6	46	183.3	0
NB	8.1	-10.2	-11.5	4.3	43.9	-53.4	-29.5	-45	-42.3	-43.6	-.1	71.1	-13.3
QC	.7	-1.6	15.9	-32.4	.8	14.2	14.6	12.3	8.7	-4.4	-7.7	7.5	8.9
ON	3.8	-6.6	-20.2	16.6	-.4	.7	-31.3	17.9	1	-2.5	-15.1	29.4	0
MB	-20.9	3.7	3.5	21.2	-16.4	35	-4.7	-.2	.2	-8.4	11.9	15.9	3.5
SK	36.7	24	-30.8	16.7	-11.2	8.1	17.4	-1.8	-2.8	14	-6	-25.3	4.2
AB	-2	-7.3	-21.8	6.2	-14.1	-12.1	7.1	8.4	-.8	-19.8	-13.6	34.3	-10.5
BC	15.7	-2.4	22.8	13.8	-3	9.4	27.7	31	21.3	-3.7	-24.1	-.3	13.5
NT					-68.7	-3.6	-100	-55.6	-18.7	12.9	.7	-100	-25.9
YT					-51.6	-47.9			23.5	204	-41.5	0	78.3

Notes: This table reports estimates of the Gravity Residuals as a percentage of the CTB index for 2002. See text for more details.

Figure 1: Intra-provincial Trade Costs