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GRAVITY, SCALE AND EXCHANGE RATES

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ABSTRACT

We develop a structural gravity model that introduces scale effects in bilateral trade. Scale effects and incomplete passthrough give two channels through which exchange rates have real effects on trade patterns. Estimates from Canadian provincial trade data identify these effects through their interaction with the US border. We find statistically and quantitatively significant economies of scale in cross-border trade in almost 2/3 of sectors. Real effects of exchange rate changes on trade are found for 12 of 19 goods sectors and none of 9 services sectors.

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1 Introduction

This paper develops and estimates a structural gravity model with novel trade scale effects due to cross-border trade technology with variable returns to scale. Economies of scale are statistically and economically significant in almost half of sectors analyzed. The second novelty of the paper is a role for exchange rate movements. Exchange rate movements might be expected to be absorbed by movement of the multilateral resistance terms of structural gravity, an expectation confirmed here for the special case of constant returns trade technology and complete exchange rate passthrough. But non-uniform scale or passthrough elasticities open channels through which exchange rates have real effects on trade patterns. The application to the trade of Canada's provinces identifies these effects through their interaction with the US border. Exchange rates have economically significant real effects in most goods trade sectors. In contrast, the hypothesis of no real effects cannot be rejected for services trade.

Scale effects in cross-border trade are inferred from differences between internal and external destination trade cost parameters such as the elasticity of trade with respect to distance. Allowance for scale parameters significantly modifies the usual gravity equation. Increasing returns to scale (IRS) trade technology is plausibly associated with division of labor in distribution or with lumpy infrastructure investment at the destination. Decreasing returns to scale (DRS) is plausibly associated with congestion at border crossing points. DRS is not found in our data, perhaps because little of Canada-US trade passes through seaports. Differences in scale parameters across external destinations open the channel for exchange rate changes to have real effects.

Incomplete passthrough of exchange rates to prices is the second channel through which exchange rates have real effects. Incomplete passthrough is very well documented, with passthrough elasticities estimated from internationally comparable price data over relatively short horizons. This paper seeks to infer a passthrough elasticity from panel trade data based on a model of incomplete passthrough over a period of two years. Either non-uniform passthrough or non-uniform scale elasticities induces real effects of exchange rates on trade flows in our version of the structural gravity model.

Structural gravity models in the previous literature have not previously dealt with exchange rate effects because they are (implicitly) absorbed in the importer- and exporter-time fixed effects that are required to control for multilateral resistance. As we show, this is justified because previous literature assumed constant returns trade technology and most researchers implicitly assumed complete passthrough obtained in the static gravity model setting. Canadian provincial production and trade panel data afford the opportunity to identify possible exchange rate real effects via their interaction with the international border, as opposed to being lost in the fixed effects that act on both internal and international trade. Nevertheless, with uniform passthrough or scale elasticities, our model implies that in principle all exchange rate changes are absorbed in multilateral resistance, hence in practice are absorbed by origin and destination region fixed effects.

The model is applied to the bilateral trade of Canada's provinces with the US in 19 goods and 9 services sectors over 1997-2007, a decade that features an 11% depreciation followed by a 45% appreciation of the Canadian/US exchange rate.[1] We concentrate on bilateral trade between US and Canada, ignoring relationships with the Rest of the World (ROW). We suppress ROW from our analysis for three reasons. First, the trade cost function we develop below is unlikely to plausibly approximate such a heterogeneous aggregate region. Second, aggregation may bias our inferences regarding exchange rate and scale effects of trade with such a large region. Third, introducing ROW data does not have any effect on our model of biliateral trade or its estimated results due to the separable fixed effects estimation structure that we use. Thus, we leave a world study for future research.

Significant scale economies in cross-border trade are found for 36 of 56 (64%) of destination-country/sectors. To give a simple idea of magnitude, for aggregate goods trade a 100% rise in imports lowers Canadian trade costs by 10.8% and lowers US trade costs by 5.4%. For

[1] In 1997 the exchange rate stood at 0.72, then it fell to 0.64 in 2003, and in 2007 it was at 0.93.

aggregate services imports of Canada the corresponding reduction is 8.2% while for the US the estimated elasticity is not significantly different from 0.

We define money neutrality as equivalent to exchange rate changes having no real effects on trade. The reduced form elasticity of trade with respect to the exchange rate is not directionally identified due to multicollinearity (as explained below), so a test of money neutrality involves both rejecting scale uniformity and uniformity of a combination of other coefficients. Our results reject money neutrality for 12 of 19 goods sectors and no service sectors.

Partial identification of the underlying parameters based on the structural model allows either inference of a common passthrough elasticity and scale parameters for given elasticity of substitution, or inference of an elasticity of substitution and scale elasticities given assumed passthrough elasticities.[2] Inferred trade elasticities for goods accord with estimates in the related literature. Inferred passthrough elasticities for goods mostly lie within the unit interval, with an overall average estimate close to 1. We provide evidence consistent with depreciation passthrough being larger than appreciation passthrough. Our trade elasticity and passthrough estimates for services are far less plausible than for goods because money neutrality cannot be rejected in the hypothesis test, hence the constructed coefficient estimators that rely on non-neutrality are only weakly identified.

The modeling innovations of this paper come with several caveats. Both the trade cost scale elasticity and the passthrough elasticity are black box parameters. The variation of our results across sectors suggests a big payoff to opening the boxes. For scale elasticities, the caveat applies especially to a few sectors where the results suggest a mis-specified trade cost equation. As for exchange rate passthrough elasticities, there is ample evidence that exchange rate passthrough is incomplete over horizons of several years (Goldberg and Knetter, 1997) but it is unlikely to be constant.[3] Following much of the literature, we do not model

[2] The trade elasticity has gained new popularity as the single most important trade parameter for welfare purposes (Arkolakis et al., 2011).

[3] Goldberg and Knetter conclude that "While the response varies by industry, a price response equal to one-half the exchange rate change would be near the middle of the distribution of estimated responses

incomplete exchange rate passthrough in this paper,[4] nor the exchange rate itself.

The real effects of exchange rates identified in this paper have further unmodeled consequences. A full general equilibrium approach to the real effects of exchange rates would embed the sectoral gravity models of this paper in a general equilibrium superstructure that accounts for both pricing behavior and the general equilibrium consequences of the changing trade costs implied by the scale and passthrough effects.

Section 2 sets out the theoretical foundation. Section 3 develops the econometric specification and describes the data. Section 4 presents the main results, quantitative implications, and robustness checks. Section 5 concludes. Supplemental Appendices A and B respectively describe the data and provide technical notes.

2 Theoretical Foundation

We review gravity based on the Armington-CES demand system due to Anderson (1979).[5] Then we add a treatment of trade costs with scale effects and incomplete exchange rate passthrough.

The structural gravity model (Anderson and van Wincoop, 2003) specifies that in each sector k the share of the world's trade in k that flows form origin i to destination j is given by

$$X_{ij}^k = Y^k s_i^k b_j^k \left(\frac{t_{ij}^k}{\Pi_i^k P_j^k} \right)^{1-\sigma_k}, \tag{1}$$

where, X_{ij}^k is the bilateral shipment, Y^k is the world shipment from all origins to all destinations, $s_i^k = Y_i^k / Y^k$ is the share of world shipments coming from origin i, $b_j^k = E_j^k / Y^k$ is the

for shipments to US" (p.3). We abstract from explaining high frequency trade movements (within a year) because these reflect random shocks and dynamic adjustment that have yet to be integrated with the gravity model. Differences in currency invoicing practices and length of contract terms affect high frequency price responses to exchange rate changes. It is possible that such differences across sectors may induce differing passthrough rates that persist in the medium run. In that case differing invoicing and contracting practices may help explain part of the differences in results we report across sectors.

[4]A search for evidence of pricing-to-market using our industry level data produced no informative results.

[5]Gravity models of trade flows have a variety of consistent theoretical foundations that lead to equivalent representations at the sectoral level. See Anderson (2011) for details.

share of world shipments going from all origins to destination k, and $s_i^k b_j^k$ is the predicted pattern of trade in a frictionless world economy. All shipments are assumed to be valued at destination prices. The term in brackets gives the effect of frictions that drive trade away from the predicted frictionless pattern $s_i^k b_j^k$. Outward multilateral resistance Π_i^k and inward multilateral resistance P_j^k, are implied by the market clearance and budget constraint systems that lead to (1):

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

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

Gravity equations are typically estimated using origin- and destination-time fixed effects to control for the shares and the unobserved multilateral resistances. The fixed effects also control for the sales and expenditure shares s_i^k, b_j^k. The total shipment Y^k is typically not believably observed, so it is controlled for with a fixed effect (constant term) and gravity is estimated as

$$X_{ij}^k = c x_i^k m_j^k (t_{ij}^k)^{1-\sigma_k} + \epsilon_{ij}^k \tag{4}$$

where c is the constant term controlling for Y^k and mean measurement error in the X_{ij}'s, x_i and m_j are exporter and importer fixed effects controlling for $s_i^k/(\Pi_i^k)^{1-\sigma_k}$ and $b_j^k/(P_k^k)^{1-\sigma_k}$, respectively, and ϵ_{ij}^k is an error term that we will take to be Poisson below. Because the full set of importer and exporter fixed effects is perfectly collinear with the constant vector, it is necessary (and harmless) to omit a base country so that $m_0^k x_0^k$ for some country 0 is factored into the constant term c, along with the scaling term Y^k and the mean measurement error in the trade flow data. The estimation of t_{ij}^k, the bilateral trade friction, is the main object of empirical gravity, with specification discussed below in Section 2.1 that introduces exchange rate effects.

The full effect of exchange rate changes alters the multilateral resistances as well as the bilateral trade costs. In a special case set out in the next section these changes completely offset the bilateral effects, leading to money neutrality.

2.1 Modeling Exchange Rate Effects on Trade

Most previous gravity literature has ignored exchange rates on the assumption that exchange rates were neutral (money neutrality) in a static trade model setting. Some previous empirical gravity models have inserted real exchange rates into gravity equations without a theoretical foundation.[6] Modern applied gravity models use origin and destination country fixed effects to control for multilateral resistance, controls which absorb any exchange rate effects.

Exchange rate changes have effects on trade only if they alter relative prices. In the gravity model this effectively means altering the cost of international relative to intra-national trade. Thus exchange rates with real effects are part of the border effect component of bilateral trade costs. Two potential channels for exchange rate action are developed here. The price channel directly turns exchange rate changes into relative price changes based on overwhelming evidence from a large empirical literature (e.g. Goldberg and Knetter, 1997) showing that internal prices move less than external ones in response to exchange rate changes. Comparing prices of identical traded goods, the literature establishes that exchange rate passthrough is less than complete. The second, scale channel passes exchange rate (or other cost) changes to cross-border trade volume changes to changes in international relative to intra-national trade cost.

Trade cost factor $(t_{ij}^k)^{1-\sigma_k}$ is typically specified to be a loglinear function of bilateral variables such as distance, contiguity and the presence or absence of a border between the buyer and seller. The theoretical and empirical innovation to t_{ij}^k developed here adds log-

[6] The standard practice in these studies is to include a real exchange rate variable in a traditional version of the empirical gravity model, with no country-time fixed effects to control for multilateral resistance and with country mass variables represented by GDP and population. See for example Griffoli (2006), Kim et al. (2003), and Martìnez-Zarzoso and Felicitas Nowak-Lehmann (2003). A prominent but tangentially related literature considers the effect of exchange rate *regimes* such as currency unions on bilateral trade patterns. See Baldwin (2006) for a review of the literature on the effects of exchange rate *regimes*.

linear volume and exchange rate passthrough terms.

Analyzing exchange rate passthrough channel first, the implied relative price change reflects the standard intuition that appreciation of the exchange rate acts like a tax on imports and a subsidy on exports, both relative to domestic transactions. The portion of the appreciation of the currency that is passed through is modeled with parametric passthrough elasticity ρ_j for some generic good from region i sold to region j.[7] The direct effect on expenditures in j on goods from i in the CES system is given by the exchange rate component of bilateral trade costs $(r_i/r_j)^{(1-\sigma)\rho_j}$, where r_i is the appreciation factor of the currency for region i with respect to some base period and similarly for r_j. Then r_i/r_j is the appreciation of the bilateral exchange rate of i with j, $(r_i/r_j)^{\rho_j}$ is the passthrough to price paid by j, and is recognized as a component of bilateral trade cost t_{ij}^k when i and j are separated by a border.

As for multilateral resistance being affected by $(r_i/r_j)^{(1-\sigma)\rho_j}$, all the steps leading to (1)-(3) continue to be valid even when exchange rates have real effects on total shipments Y_i^k and total expenditures E_j^k as well as on multilateral resistances due to system (2)-(3). All such effects are subsumed into the origin and destination country fixed effects that vary with time in the best practice estimation. Exchange rates have real effects in the gravity model only through shifting bilateral trade costs t_{ij}^k asymmetrically.[8]

The scale channel is due to the trade cost effect of changing international trade volume. Volume shipped from i to j is V_{ij}. We assume that for each bilateral link that crosses a border (denoted by an indicator variable $B_{ij} = 1$ when i and j are in separate countries and $B_{ij} = 0$ elsewhere) there are volume effects with elasticity $\phi_{ij} = \phi_j B_{ij}$ such that the per unit

[7] This constant elasticity form is standard in empirical trade analysis; see Feenstra (2004), Chapter 7 for example. We can allow for different elasticity parameters in different regions and at different times, but always as exogenous parameters.

[8] It is possible to account for the full general equilibrium indirect effects of exchange rate changes by embedding (2)-(3) in a general equilibrium superstructure that also determines the effects of exchange rate changes on $\{Y_i^k, E_j^k\}$. A full account is unnecessary for the purposes of this paper.

trade costs are given by

$$t_{ij} = \tau_{ij} \left(\frac{r_i}{r_j}\right)^{\rho_j} V_{ij}^{\phi_{ij}}. \tag{5}$$

where τ_{ij} is the standard bilateral iceberg trade cost factor, a (loglinear) function of the standard set of trade cost gravity variables (see below). The usual constant trade costs case is $\phi_j = 0$, the boundary scale parameter between DRS (IRS) with elasticity $\phi_j > (<)0$. It is important in thinking about trade costs to note that t_{ij} includes *all* costs between the factory gate and the end user, usually including costs directly incurred by the end user. Thus the scale effects pertain to both seller and buyer in principle. Specification (5) associates scale effects with the border crossing into the destination, plausibly linked to customs control.[9] The simple model (5) can be elaborated in various ways to fit better and to accommodate special characteristics of sectors, but for our present purposes of comparison across sectors it is advantageous to apply this model everywhere.

Volume is given by $V_{ij} = X_{ij}/(\tau_{ij} r_i/r_j)$ where the deflator $t_{ij} r_i/r_j$ removes both the effect of exchange rate appreciation (that raises 'factory gate' prices p_i in terms of the numeraire currency used to convert trade flows to common value units) and the 'volume' used up in trade costs, thus specifying in (5) that trade cost is a function of volume *delivered*.[10] Use this deflation and the deterministic portion of the right hand side of (4) for X_{ij} and combine with (5) to solve for volume as a reduced form function of the exogenous variables:

$$V_{ij} = \left[x_i m_j \tau_{ij}^{-\sigma} (r_i/r_j)^{-1-\rho_j\sigma}\right]^{1/(1+\sigma\phi_{ij})}. \tag{6}$$

The constant elasticity specification is an important simplification allowing a simple reduced form solution.[11]

[9]The scale setup is robust to at least modest generalization of the bilateral volume effect modeled here, though it fits with the focus on Canadian trade with US. A plausible alternative is multilateral volume effects on trade costs. The technical appendix (Appendix B) available on request shows that this case retains the key properties from the bilateral model.

[10]Specifying (5) with volume defined at the origin, $X_{ij}/(r_i/r_j)$, differs unessentially for purposes below. Also, switching from assuming value is measured in the data based on origin currency prices to measurement based on destination currency prices makes no essential difference; the deflation is by $(r_i/r_j)^{\rho_j}$.

[11]The DRS case with parametric $\phi_j > 0$ can be derived as a good approximation to an underlying constant

Substituting (6) into (5) and simplifying,[12] the reduced-form bilateral trade cost function is

$$t_{ij} = \left[\tau_{ij}(x_i m_j)^{\phi_{ij}}(r_i/r_j)^{\rho_j-\phi_{ij}}\right]^{1/(1+\sigma\phi_{ij})}, \forall i,j. \quad (7)$$

Exchange rate movements r_i/r_j have effects potentially only on international trade costs in (7); domestic trade costs are insulated by $r_i/r_i \equiv 1$. In the empirical analysis, the real effects of exchange rate movements are identified at the border where $r_i \neq r_j$ in contrast to internal and interprovincial trade. The remainder of the (7) differs from the usual gravity specification in that (i) τ_{ij} is modified by being raised to a destination-specific power $1/(1+\sigma\phi_{ij})$ and (ii) there is a cost-changing scale term $(x_i m_j)^{\phi_{ij}/(1+\sigma\phi_{ij})}$. The stability condition for the plausible quantity-adjustment mechanism in the 'trade market' is $1+\sigma\phi_{ij} > 0$, i.e. IRS cannot be too strong. (Appendix B available on request presents the argument.)

The model is completed by substituting the reduced form trade cost function (7) into the deterministic part of the structural gravity equation (4)

$$X_{ij,t} = c^{(1+\phi_{ij})/(1+\sigma\phi_{ij})}(x_{i,t}m_{j,t})^{(1+\phi_{ij})/(1+\sigma\phi_{ij})}\tau_{ij}^{(1-\sigma)/(1+\sigma\phi_{ij})}(r_{i,t}/r_{j,t})^{(\rho_j-\phi_{ij})(1-\sigma)/(1+\sigma\phi_{ij})}. \quad (8)$$

The determinants of τ_{ij} comprise the usual list of geographic variables including a pure border effect, each entering (8) with a coefficient to be inferred that combines with the exponent of τ_{ij}, $(1-\sigma)/(1+\sigma\phi_{ij})$. The rightmost term in (8) is the exchange rate effect.

Equation (8) is the key mechanism explaining the link of exchange rates to trade in our paper. For $\rho_j - \phi_j \geq 0$, appreciation of the bilateral exchange rate increases trade costs t_{ij} and thus decreases the value of trade at delivered (user) prices X_{ij} or at origin ('factory gate') prices X_{ij}/t_{ij}. In contrast, for $\rho_j - \phi_j < 0$ appreciation decreases trade costs and thus

returns Cobb-Douglas technology with fixed capacity. Different elasticities could reflect different physical or regulatory environments in which the trade technology must operate. If capacity is adjustable in the short run, the model reverts to the standard case where the cost of entering j's market is uniform and subsumed into P_j, empirically controlled for with importer fixed effects.

[12] At the first step

$$t_{ij} = \tau_{ij}(r_i/r_j)^{\rho_j}\left[cx_i m_j \tau_{ij}^{-\sigma}(r_i/r_j)^{-1-\rho_j\sigma}\right]^{\phi_{ij}/(1+\phi_{ij}\sigma)}.$$

Collecting the exponents of r_i/r_j and τ_{ij} and simplifying yields equation (7) below.

increases the value of trade at delivered prices X_{ij} or at origin prices X_{ij}/t_{ij}. The intuition is that less of the iceberg melts: volume going through shipment falls by (6) and with $\rho_j < \phi_j$ the net effect is a reduction in loss due to shipping costs, resulting in a gain in both factory gate priced exports and user priced exports.[13]

The general effect of increasing returns to scale (IRS) is to amplify the effect of exchange rate depreciation on exports because the increase in trade volume induces a further fall in trade costs. A interesting implication of (8) is that strong IRS may result in more than complete effective passthrough $\rho_j - \phi_j > 1$. Similarly, the general effect of decreasing returns to scale (DRS) is to dampen the effect of exchange rate appreciation on exports because the decline in trade volume induces a compensating fall in trade costs. A novel and surprising implication of (8) is that with strong enough DRS (large ϕ_j), the fall in trade costs can more than compensate for the appreciation of exchange rates, $\rho_j - \phi_j < 0$. For different goods and services the sign of $\rho_j - \phi_j$ can differ, reflecting small or large congestion elasticity ($\phi_j > 0$ relative to the passthrough elasticity ρ_j, or a switch from DRS ($\phi_j > 0$) to scale economies IRS ($\phi_j < 0$).

This paper takes exchange-rate-passthrough induced changes in relative prices as exogenous, hence no reverse causality flows from trade to exchange rates. Exogeneity is a defensible assumption for sectoral bilateral trade flows in goods and services, where the bilateral trade in any sector has negligible impact on the aggregate current account and hence on exchange rates. Sensitivity experiments confirm the robustness of our main findings to endogeneity concerns. The experiments use lagged exchange rates and alternatively employ the average treatment effect methodology from Baier and Bergstrand (2007), who use it to successfully address trade policy endogeneity.[14]

[13] Whether the reduction in t_{ij} is a global efficiency gain or not depends on specifying what the trade cost represents. If there is s a change in dead weight loss associated with the change in t_{ij}, then a fall is an efficiency gain. For example, unpriced congestion results in inefficiently long delays because at the margin the shippers do not internalize the added delays they impose on others; hence an appreciation with $\rho_j < \phi_j$ reduces the inefficiency.

[14] The monopolistic competition literature suggests endogenous exchange rate passthrough due to Pricing to Market (PTM) by firms that rationally price discriminate. We do not address PTM in this paper based on industry level data. We failed to find meaningful evidence of PTM when using industry data along with

3 Econometric Specification

An important simplification preserves degrees of freedom. Let $R = \{CA, US\}$ denote the destination country. Impose common scale and passthrough parameters across all Canadian destination provinces: $\phi_{ij} = \phi_{iR} = \phi_R B_{ij}$.[15] The structural ER gravity specification for international trade becomes:

$$X_{ij,t} = c^{(1+\phi_R)/(1+\sigma\phi_R)}(x_{i,t}m_{j,t})^{(1+\phi_R)/(1+\sigma\phi_R)}\tau_{ij}^{(1-\sigma)/(1+\sigma\phi_R)}(r_{i,t}/r_{j,t})^{(\rho_R-\phi_R)(1-\sigma)/(1+\sigma\phi_R)}.$$

It is convenient to rewrite this restriction of (8) as

$$X_{ij,t} = \exp\left[k_R + \frac{1+\phi_R}{1+\sigma\phi_R}(\ln x_{i,t} + \ln m_{j,t}) + \frac{1-\sigma}{1+\sigma\phi_R}\ln\tau_{ij} + \frac{(\rho_R-\phi_R)(1-\sigma)}{1+\sigma\phi_R}\ln(r_{i,t}/r_{j,t})\right] \tag{9}$$

where $k_R = (1+\phi_R)/(1+\sigma\phi_R)\ln c$. For inter-provincial and internal trade of Canada and for internal trade of the US, the term ϕ_R disappears from (9) because the international trade indicator variable $B_{ij} = 0$. In subsequent steps below, switching off ϕ_R for internal and interprovincial trade is taken as implicit.

The right hand side of (9) comprises three parts: the fixed effects part (including the constant), the trade costs part exclusive of exchange rate effects and the exchange rate part. We develop the fixed effects part first, then the trade costs part and finally the exchange rate effects part.

3.1 Fixed Effects Specification

The fixed effects terms in (9) is $\frac{1+\phi_R}{1+\sigma\phi_R}\ln x_{i,t} + \frac{1+\phi_R}{1+\sigma\phi_R}\ln m_{j,t}$. The nonlinearity of each fixed effects term (in logs) is approximated by expanding a Taylor's Series about $\phi_R = 0$ and

strong symmetry assumptions about the unobserved distribution of firms. Essentially this is because the elasticity of the markup with respect to exchange rate variation is very small for finite but plausible firm share size. Appendix B is available on request for more discussion.

[15]For the US as a destination there is no state variation because our services data is available only for aggregate US origin and destination, and we impose the same aggregation on the goods data for comparability.

the average $\ln x_{i,t}$ and $\ln m_{j,t}$: for example, replacing the theoretically exact value $\ln x_{i,t}(1+\phi_R)/(1+\sigma\phi_R)$ with $\ln x_{i,t} + \ln \bar{x}[(1-\sigma)\phi_R)/(1+\sigma\phi_R)]$, where $\ln \bar{x} = \sum_{i,t} x_{i,t}/NT$ where N is the number of regions and T is the number of time periods.[16] The second term in the expansion is an international border effect.[17] Adding together the analogous expression for inward trade, the specification of the fixed effects is simplified to:

$$\frac{1+\phi_R}{1+\sigma\phi_R}(\ln x_{i,t} + \ln m_{j,t}) = \eta_{i,t} + \theta_{j,t} + \beta_{brdr} USA\_CAN. \tag{10}$$

Here, $\eta_{i,t}$ and $\theta_{j,t}$ are time-varying exporter and importer fixed effects, respectively. USA_CAN is a dummy variable equal to one for US exports to Canada. Evidently, $\beta_{brdr} = \beta_{usa,can} + \beta_{can,usa}$, where $\beta_{usa,can}$ and $\beta_{can,usa}$ are the directional border estimates for US exports to Canada and for US imports from Canada, respectively. Finally, we note that the origin and destination fixed effects in (10) will absorb completely the destination-specific constant term k_R in specification (9).

3.2 Trade Cost Specification

As a first step we proxy τ_{ij} with bilateral distance, contiguity and borders. The trade costs term from (9), $\frac{1-\sigma}{1+\sigma\phi_R}\ln\tau_{ij}$, becomes:

$$\begin{aligned}\frac{1-\sigma}{1+\sigma\phi_R}\ln\tau_{ij} \quad = \quad & \frac{\beta_1(1-\sigma)}{1+\sigma\phi_R}DIST_{ij} + \frac{\beta_2(1-\sigma)}{1+\sigma\phi_R}CONTIG_{ij} + \frac{\beta_3(1-\sigma)}{1+\sigma\phi_R}INTERNAL + \\ & \frac{\beta_4(1-\sigma)}{1+\sigma\phi_R}INTERNATIONAL\_CA\_US + \frac{\beta_5(1-\sigma)}{1+\sigma\phi_R}INTERNATIONAL\_US\_CA.\end{aligned} \tag{11}$$

[16]The approximation is a first order Taylor's series,

$$\frac{1+\phi_R}{1+\sigma\phi_R}\ln x_{i,t} \approx \ln\bar{x} + [\ln x_{i,t} - \ln\bar{x}] + \ln\bar{x}[(1+\phi_R)(1+\sigma\phi_R)-1] = \ln x_i + \ln\bar{x}(1-\sigma)\phi_R/(1+\sigma\phi_R).$$

[17]The expansion is simplified to time invariance by imposing a single mean $\ln\bar{x}$. In principle this can be relaxed to allow time varying means, $\ln\bar{x}_t$.

Here, $DIST_{ij}$ is the logarithm of bilateral distance between trading partners i and j, including internal distance in i.[18] $CONTIG_{ij}$ takes a value of one when a Canadian province neighbors a US state, and is set to zero otherwise. The contiguity variable is widely used in the literature on Canadian trade with the US. The motivation is that, all else equal, contiguous provinces and states would trade more with each other. The next three covariates in (11), $INTERNAL$, $INTERNATIONAL\_CA\_US$ and $INTERNATIONAL\_US\_CA$, capture the effects of borders relative to interprovincial trade. Here, $INTERNAL$ is a dummy variable that is equal to one for internal trade within any region, i.e. a province or a territory and US. $INTERNATIONAL\_CA\_US$ is equal to one for Canadian exports to US and $INTERNATIONAL\_US\_CA$ is equal to one for US exports to Canada, allowing for asymmetric border effects between the two countries. Importantly, all border variables in (11) will be absorbed in the specification of the fixed-effects interaction terms above. The remaining trade cost terms from specification (11) yield:

$$\frac{\beta_1(1-\sigma)}{1+\sigma\phi_R}DIST_{ij} + \frac{\beta_2(1-\sigma)}{1+\sigma\phi_R}CONTIG_{ij} \tag{12}$$

where for internal and interprovincial trade $\phi_R = 0$ and for international trade $\phi_R = \phi_R, R = usa, can$.

Expression (12) captures three important implications of our theory that deviate from standard gravity treatments. First, owing to destination-specific trade-volume effects (i.e. $\phi_{can} \neq \phi_{usa}$), the effects of international distance could differ across importers. Therefore, we split the international distance variable into its directional components $DIST\_CAN$ and $DIST\_USA$. Second, due to the fact that trade-volume effects are assumed not to obtain internally, the effects of internal distance within each region, $INTERNAL\_DIST$, should be different from the effects of international distance.[19] Third, we offer an additional structural motivation for the magnitudes and for the asymmetries in the effects of contiguity between

[18] The measure of this variable is from Anderson and Yotov (2010), who follow Mayer and Zignago (2006) to obtain population-weighted bilateral distances for Canada's trade. This procedure is consistent with respect to calculating both internal and bilateral distances.

[19] This lends support to the empirical findings from Anderson and Yotov (2012) who estimate different effects on internal and on international distance at the sectoral level for goods trade in the world.

Canadian provinces and US states. Following the existing literature, we allow for asymmetric contiguity effects by splitting $CONTIG$ in two directional components $CONTIG\_PR\_ST$, for provincial exports, and $CONTIG\_ST\_PR$, for provincial imports. In addition, our theory implies that trade-volume effects can strengthen or weaken the effects of contiguity and can make the symmetries in these effects more or less pronounced. With these considerations in mind expression (12) for the effect of trade costs apart from pure border effects and exchange rates becomes:

$$\frac{1-\sigma}{1+\sigma\phi_R}\ln\tau_{ij} = \gamma_1(1-\sigma)INTERNAL\_DIST + \frac{\gamma_1(1-\sigma)}{(1+\sigma\phi_{can})}DIST\_CAN + \frac{\gamma_1(1-\sigma)}{(1+\sigma\phi_{usa})}DIST\_USA + \frac{\gamma_2(1-\sigma)}{(1+\sigma\phi_{usa})}CONTIG\_PR\_ST + \frac{\gamma_3(1-\sigma)}{(1+\sigma\phi_{can})}CONTIG\_ST\_PR. \quad (13)$$

3.3 Exchange Rate Effects Specification

Finally, we turn to modeling the exchange rate effect on log trade, $\frac{(\rho_R-\phi_R)(1-\sigma)}{1+\sigma\phi_R}\ln(r_{i,t}/r_{j,t})$. Given the regions in our sample, we define:

$$\frac{(\rho_R-\phi_R)(1-\sigma)}{1+\sigma\phi_R}\ln(r_{i,t}/r_{j,t}) = \frac{(\rho_{usa}-\phi_{usa})(1-\sigma)}{1+\sigma\phi_{usa}}CAN\_USA\times r_{can,t} - \frac{(\rho_{can}-\phi_{can})(1-\sigma)}{1+\sigma\phi_{can}}USA\_CAN\times r_{can,t}. \quad (14)$$

Here, $r_{can,t}$ is defined as Canadian dollars per US dollar at time t relative to the same ratio in the base year, 1997. Thus, a fall (an increase) in $r_{can,t}$ depicts an appreciation (a depreciation) of the Canadian dollar. This implies $\frac{(\rho_{usa}-\phi_{usa})(1-\sigma)}{1+\sigma\phi_{usa}} > 0$, i.e. a depreciation of the Canadian dollar should lead to increase in Canadian exports to US. Similarly, we would expect $-\frac{(\rho_{can}-\phi_{can})(1-\sigma)}{1+\sigma\phi_{can}} < 0$ i.e. a depreciation of the Canadian dollar should be associated with a fall in Canadian imports from US. CAN_USA and USA_CAN are indicator variables for Canadian exports (to US) and for Canadian imports (from US), respectively.

The interactive fixed effect structure of (14) implies that the estimates of the exchange rate effects in each direction are deviations from the corresponding directional border estimates for CA-US trade. To describe the relationship in terms of estimated coefficients, rewrite (14) as:

$$\frac{(\rho_R - \phi_R)(1-\sigma)}{1+\sigma\phi_R}\ln(r_{i,t}/r_{j,t}) \quad = \quad \beta_{er\_exp} ER\_CA\_EXP + \beta_{er\_imp} ER\_CA\_IMP. \qquad (15)$$

Here, $ER\_CA\_EXP = CAN\_USA \times r_{can,t}$ and $ER\_CA\_IMP = USA\_CAN \times r_{can,t}$. $\beta_{er\_exp} = \frac{(\rho_{usa}-\phi_{usa})(1-\sigma)}{1+\sigma\phi_{usa}} - \beta_{can,usa}$ measures the ER effects on Canadian exports relative to the corresponding directional border effect, $\beta_{can,usa}$, which is defined above. Similarly, $\beta_{er\_imp} = -\frac{(\rho_{can}-\phi_{can})(1-\sigma)}{1+\sigma\phi_{can}} - \beta_{usa,can}$ measures the relative ER effects on Canadian imports.

Due to perfect collinearity between the two exchange rate terms in (15) and the time-varying directional fixed effects in (10), we cannot separately identify the two ER effects when using the full set of origin and destination fixed effect (less one due to keeping the constant term). Instead of dropping another origin-destination fixed effect, we choose to drop the ER term for Canadian imports from the US. The interpretation of the fixed effects is that the dropped term is subtracted from the 'true' fixed effect, and the estimate of the ER effect on Canadian exports to the US includes the ER term for Canadian imports. (15) as it is estimated becomes:

$$\frac{(\rho_R - \phi_R)(1-\sigma)}{1+\sigma\phi_R}\ln(r_{i,t}/r_{j,t}) \quad = \quad \beta_{er} ER\_CA\_EXP, \qquad (16)$$

where, making use of the definitions of the directional ER estimates,

$$\beta_{er} = \beta_{er\_exp} + \beta_{er\_imp} = \left(\frac{(\rho_{usa}-\phi_{usa})(1-\sigma)}{1+\sigma\phi_{usa}} - \beta_{can,usa}\right) + \left(-\frac{(\rho_{can}-\phi_{can})(1-\sigma)}{1+\sigma\phi_{can}} - \beta_{usa,can}\right) \quad (17)$$

(17) is an important relationship between the relative border and the relative ER estimates, used in the empirical section to recover some of the structural parameters in our model.[20]

Substitute (10), (13) and (16) into the deterministic gravity equation (9), to obtain the

[20]To build intuition and trust in the structural use of collinearity in (17), in the empirical analysis (see Table 2) we show that estimating the two coefficients β_{er_exp} and β_{er_imp} through the expedient of dropping another origin country or province fixed effect yields a sum equal to the estimate of β_{er} as described above. The same alternative regression demonstrates that $\beta_{brdr} = \beta_{us,ca} + \beta_{ca,us}$.

following econometric specification (for a generic sector) that incorporates exchange rates, in addition to the standard set of gravity covariates:

$$X_{ij,t} = e^{\alpha_0+\alpha_1 INTERNAL\_DIST+\alpha_2 DIST\_CAN+\alpha_3 DIST\_USA+\alpha_4 CONTIG\_PR\_ST} * e^{\alpha_5 CONTIG\_ST\_PR+\beta_{brdr} USA\_CAN+\beta_{er} ER\_CA\_EXP+\theta_{j,t}+\eta_{i,t}}. \quad (18)$$

Here, $\alpha_1 = \gamma_1(1-\sigma)$, $\alpha_2 = \frac{\gamma_1(1-\sigma)}{(1+\sigma\phi_{can})}$, and $\alpha_3 = \frac{\gamma_1(1-\sigma)}{(1+\sigma\phi_{usa})}$ capture the effects of distance on trade. We expect the estimates of these coefficients to be negative and the estimate of the effect of internal distance, α_1, to be smaller in absolute value than the effects of international distance, α_2 and α_3. $\alpha_4 = \frac{\gamma_2(1-\sigma)}{(1+\sigma\phi_{usa})}$ and $\alpha_5 = \frac{\gamma_3(1-\sigma)}{(1+\sigma\phi_{can})}$ capture the effects of contiguity between a province and a state. We expect the estimates of these coefficients to be positive and we can test whether scale effects contribute to directional asymmetries, if any.

A statistically significant difference in the magnitudes of the estimates of α_2 and α_3 rejects the hypothesis of scale neutrality, a component of money neutrality. The model also implies a direct test of whether exchange rates are neutral on not. Rearranging (17) and using $\beta_{brdr} = \beta_{usa,can} + \beta_{can,usa}$

$$\beta_{er} + \beta_{brdr} = \frac{(\rho_{usa} - \phi_{usa})(1-\sigma)}{1+\sigma\phi_{usa}} - \frac{(\rho_{can} - \phi_{can})(1-\sigma)}{1+\sigma\phi_{can}}.$$

The hypothesis of net money neutrality is rejected when the estimated $\hat{\beta}_{er} + \hat{\beta}_{brdr}$ differs significantly from zero. If the scale neutrality hypothesis $\hat{\alpha}_3 - \hat{\alpha}_2 = 0$ is also rejected then the implication of the preceding equation is that passthrough uniformity cannot be rejected. In this case full money neutrality cannot be rejected because the right hand side is equal to zero if $\rho_{usa} = \rho_{can}$ and $\phi_{usa} = \phi_{can}$, which the theory shows implies money neutrality.

Money neutrality in the sense of this paper applies to *distribution* of goods within a sector — exchange rates have no real effects on the pattern of trade within sectors. Full general equilibrium neutrality requires that all sectors have money neutrality in this sense.

Departures from neutrality in any sector imply relative price changes between sectors that shift sales and expenditure shares. These real effects on the economy are controlled for in the sectoral gravity equations with origin and destination time fixed effects.

3.4 Data

A notable feature of this project is that we compile a comprehensive data set that covers most of Canada's economy at the sectoral level for a total of 28 industries including agriculture, fuels, 17 manufacturing sectors, and 9 service categories for the period 1997-2007.[21] The choice of the 1997-2007 period is due to coverage limitations of our services data set. In order to estimate gravity, we use industry-level data on bilateral trade flows and output for each trading partner (including all Canadian provinces and territories and US), all measured in current ('00,000) Canadian dollars, as well as other variables which we describe below.

Trade flows data. Statistics Canada's Table 386-0002 is the original data source for intra-provincial and interprovincial trade flows for both goods and services.[22] Data on shipments between Canadian provinces and the United States are from the Trade Data Online web interface of Industry Canada, which provides access to Canadian and US trade data by

[21]The sector selection was based on (but is not completely identical to) the S-level of aggregation as classified in the Statistics Canada's Hierarchical Structure of the I-O Commodity Classification (Revised: November 3, 2010). The 28 sector categories include (Abbreviated labeling in parentheses): Agriculture (AGRIC); Mineral Fuels (FUELS); Food (FOOD); Leather, Rubber and Plastic Products (LETHR); Textile Products (TXTLE); Hosiery, Clothing and Accessories (APPRL); Lumber and Wood Products (WOOD); Furniture, Mattresses and Lamps (FRNTR); Wood Pulp, Paper and Paper Products (PAPER); Printing and Publishing (PRNTG); Primary Metal Products (METL1); Fabricated Metal Products (METL2); Machinery (MCHNS); Motor Vehicles, Transportation Equipment and Parts (VHCLS); Electrical, Electronic, and Communications Products (ELCTR); Non-metallic Mineral Products (MNRLS); Petroleum and Coal Products (PETRL); Chemicals, Pharmaceutical, and Chemical Products (CHMCL); Miscellaneous Manufactured Products (MISCL); Transportation and Storage Services, including transportation margins (TRNSP); Communication Services (CMNCN); Wholesale Services, including Wholesale Margins (WHLSL); Finance, Insurance and Real Estate services (FNNCE); Professional, Scientific, Technical, Computer, Administrative, Support, and Related Services (BUSNS); Education Services (EDCTN); Health Care and Social Assistance Services (HELTH); Accommodation Services and Meals (ACMDN); and, Miscellaneous Services (OTHER). Finally, we sometimes aggregate all goods (GOODS) and all services (SRVCS). The few commodities missing from the complete S-level I-O Commodity Classification spectrum are Forestry Products, Fish, Metal Ores, and Tobacco and Beverages. Reliable bilateral trade data ware not available for those products. Detailed description of each of the sector categories in our sample are presented in Appendix A.

[22]The actual services data used here (including trade, output and expenditures) is from Anderson et al. (2011). Please see their data section and data appendix for further details.

product classified according to NAICS; the NAICS sectors were then matched or aggregated to the S-level. Internal trade for US are obtained as the difference between output and total exports.

Output data. Provincial output, defined here as the value of production plus shipments out of the inventories of producers, wholesalers and retailers is from Statistics Canada's Table 386-0002. All zero values and blank cells in the output data are treated as missing information and interpolated accordingly. Output data for the United States come from several sources. Manufacturing data are from the UNIDO Industrial Statistics database, which reports industry-level output data at the 3- and 4-digit level of ISIC code. Output for Agriculture and Mineral Fuels, 1997-2003, is from Anderson and Yotov (2012). The original sources of these data are the United Nations Food and Agriculture Organization (FAOSTAT) web page, which provides data on agricultural output, and the Energy Information Administration, which provides official energy statistics on the value of fuel production (including oil, natural gas, and coal). Finally, services output data are from Anderson et al. (2011). The US Bureau of Economic Analysis is the original source for US service production data.

Other variables. We use the bilateral distances data from Anderson and Yotov (2010), who follow Mayer and Zignago (2006) to obtain population-weighted bilateral distances. This procedure is consistent with respect to calculating both internal and bilateral distances. See Anderson and Yotov (2010) for more details. Exchange rates data are from the Federal Reserve Bank of Saint Louis' web site at http://research.stlouisfed.org/fred2/categories/15. Finally, we construct a series of border and regional dummy variables, which are described in the text.

4 Estimation Results and Analysis

We estimate (18) with the Poisson pseudo-maximum-likelihood (PPML) estimator. Santos-Silva and Tenreyro (2006) propose PPML to simultaneously address the prominent presence of zeroes and of heteroskedasticity in bilateral trade flows data. We use 2-year lags rather than a simple panel because Cheng and Wall (2005) note that "[f]ixed-effects estimations are sometimes criticized when applied to data pooled over consecutive years on the grounds that dependent and independent variables cannot fully adjust in a single year's time."(p.8).[23]

Tables 1a-1c report results from estimating (18) for each sector in the Canadian economy. The first column of Table 1a presents estimates for all goods and the remaining columns of Tables 1a and 1b present estimates for 19 goods sectors. Similarly, the first column of Table 1c presents aggregate estimation results for all service sectors, and the remaining columns in the table report estimates for 9 service sectors. Table 2 reports results of dropping alternative dummy variables from the overall goods trade regression of Table 1a. The results illustrate the collinearity structure of the data that is used to interpret results. Coefficient estimates from Tables 1a-1c are used with theoretically based identifying restrictions to recover scale parameters and to infer substitution and passthrough elasticities. Results are reported in Tables 3a-3c. Finally, sensitivity experiments are offered in Table 4.

4.1 Gravity Estimates

Overall, the PPML estimates from Tables 1a-1c give the usual good fit of gravity for both disaggregated goods and services. The coefficient estimates of each of the gravity covariates are discussed in the order in which they appear in econometric specification (18).

Internal Distance. Distance is a significant impediment to internal trade, just as it is for international trade. All the estimates of the effects of internal distance on trade are statistically significant at any level and for each sector in our sample.

Variation of the effects of internal distance over sectors is mostly intuitive. For example, the largest estimates among the goods sectors are for Agriculture, Printing and Minerals, while the largest estimates among the services categories are for Health services and Other services, which includes the subcategories of beauty and personal care, funeral, child care,

[23]Olivero and Yotov (2012) confirm the relevance of this issue by experimenting with various lags in a dynamic gravity setup.

household, automobile repairs to recreation, all strongly locally biased because of their personalized nature. Comparison between the aggregate distance elasticities for goods (see column 1 of Table 1a) and for services (see column 1 of Table 1c) reveals that the latter are, on average, larger in magnitude: services are on average more localized. Finally, we note that our estimates of the effects of internal distance are not sensitive to the exclusion of US, as the single largest region in the sample.

International Distance. Most of the estimates on the international distance variables are significant at any level of statistical significance. Notable exceptions, where the estimates of the effects of international distance are not statistically significant, are some resource sectors such as Fuels, Petroleum and Coal Products and Wood Products.

More novel and important, we find significant asymmetries in the effects of international distance between Canada's exports and Canada's imports. Our estimates suggest that distance is a larger impediment to trade for Canadian imports of both goods and services. See Panels B of Tables 1a-1c , where we obtain statistically significant differences between the effects of distance on Canadian imports and exports for fourteen of the nineteen goods sectors in our sample and for seven of the nine services sectors.

These findings lend support to our theoretical predictions for destination-specific distance effects. Specifically, based on the structural definitions of the distance coefficients ($\alpha_1 = \gamma_1(1-\sigma)$, $\alpha_2 = \frac{\gamma_1(1-\sigma)}{(1+\sigma\phi_{can})}$, $\alpha_3 = \frac{\gamma_1(1-\sigma)}{(1+\sigma\phi_{usa})}$), the estimates on $DIST\_CAN$ and $DIST\_USA$ suggest an IRS relationship between trade volume and trade costs ($\phi_R < 0$, $R \in \{CA, USA\}$), which is more pronounced for Canada's imports, $\phi_{can} < \phi_{usa}$. See Tables 3a-3c below for details.

This implication should be treated cautiously, because it is sensitive to imprecisely estimated distance elasticities from Canada's provinces to the single US market in contrast to the more precisely estimated distance elasticities for Canada's imports. The greater imprecision for the US destination is due to less variation in the bilateral distance data. Service trade data limitations required aggregating trade to the US destination. As a result, only 3 of 9 service sectors and 12 of 19 goods sectors have significant distance elasticities for export to the US. The only two sectors for which we obtain negative and significant estimates on $DIST\_USA$ are Transportation and Accommodation.[24] Aggregation bias is not a glaring issue because all bilateral distance variables are consistently aggregated by construction as population weighted aggregates of city-pair distances.

Panels B of Tables 1a-1c also report statistically significant differences between the effects of internal and international distance, $\alpha_1 - \alpha_2$ and $\alpha_1 - \alpha_3$. We obtain statistically and economically smaller effects of internal distance as compared to the effects of distance on Canadian imports, $\alpha_1 - \alpha_2$, for fifteen of the nineteen goods sectors and for eight of the nine services categories. The findings from comparing the effects of internal distance and the effects of distance on Canadian exports to US are mixed. We find that the effects of internal distance are smaller for eight of the nineteen goods sectors and for none of the nine services sectors. We also estimate smaller effects of distance on CA exports for four goods and four services sectors. Usually, these results are driven by an insignificant estimate of the effects of distance on CA exports to US.

The much smaller (in absolute value) estimates on internal distance in most cases suggest that the scale effects introduced in Section 2 are indeed operational. The results suggest an IRS relationship ($\phi_R < 0$, $R \in \{CA, USA\}$) between trade volume and trade costs, confirmed in Tables 3a-3c discussed in Section 4.2 below. Notable exceptions are Fuels, Petroleum and Coal Products and Wood Products, where the estimates of the effects of international distance are not only smaller in magnitude but also not statistically significant. The specific modes of transportation in these sectors in cases where pipelines are used may be a natural explanation, but the finding also suggests that the cost function is too crude to accurately represent the reality.

[24]The estimate on $DIST\_USA$ for Health services is positive and statistically significant, while the corresponding estimate in the opposite direction (on $DIST\_CAN$ for Health) is the largest of all negative distance estimates. Both findings indicate that the trade cost function for Health is mis-specified, especially the positive distance elasticity that violates the stability condition. For purposes of this study it is useful to maintain a single specification of the trade cost function but a serious treatment of gravity for health services trade should alter the specification.

Contiguity. Most of the contiguity estimates from Tables 1a-1c are positive and statistically significant in each direction of Canadian trade. We also find evidence for directional asymmetries in the effects of contiguity. In the case of goods trade, contiguity raises Canada's imports but not its exports on average, evidenced by the aggregate goods estimates from column (1) of Table 1a. There is a large, positive and statistically significant estimate on $CONTIG\_ST\_PR$, capturing contiguity effects on Canada's imports, but a statistically insignificant estimate on $CONTIG\_PR\_ST$ for contiguity effects on Canada's exports. Exactly the opposite is true for services trade, where we obtain a positive and statistically significant estimate on $CONTIG\_PR\_ST$ for Canadian services exports but an insignificant estimate on $CONTIG\_ST\_PR$. See column (1) of Table 1c. In the next section, we analyze the contribution of trade-volume effects for the magnitudes of the contiguity estimates and for the directional asymmetries between them.

International Borders. The novelty of generalizing the trade cost function to have distance and contiguity responses that potentially vary by destination has parallel potential consequences for the border effect coefficient estimates. In terms of the structural model, an additional term $(\ln \bar{x} + \ln \bar{m})(1-\sigma)\phi_R/(1+\sigma\phi_R)$ appears in the destination R border coefficient. This structure explains the large magnitude and varying signs of the border estimates on $\eta_{usa,can}$ from Tables 1a-1c as compared to those of Anderson and van Wincoop (2003). The estimates imply that Canadian imports from US, all else equal, are disproportionately larger as compared to Canadian exports to US in all but five goods sectors. In those sectors, the trade balance border estimate for Food is not statistically significant and, not surprisingly, the sectors in which Canada's exports to US dominate Canada's imports from US are Agriculture, Fuels, Wood, and Petroleum and Coal Products. The picture is quite different for services, where most of the sectoral border estimates of β_{brdr} are not statistically significant, which translates into an insignificant estimate for aggregate services trade as reported in column (1) of Table 1c. The four significant services border estimates on $\eta_{usa,can}$ are all negative, which suggests larger Canadian exports in Communication, Education, Health and

Other services, all else equal.

It is useful for interpreting results to demonstrate that the estimates of β_{brdr} from Tables 1a-1c capture the border effects on Canadian imports from US plus the border effects on Canadian exports to US. In particular, Table 2 demonstrates empirically that $\beta_{brdr} = \beta_{usa,can} + \beta_{can,usa}$. In column (1) of Table 2, we reproduce our main gravity results for aggregate goods trade from the first column of 1a.[25] In column (2), we include a dummy variable for Canada's exports to US, $\eta_{can,usa}$, in addition to the border dummy for Canada's imports from the main specification, $\eta_{usa,can}$. In order to estimate both directional border coefficients $\beta_{usa,can}$ and $\beta_{can,usa}$, we drop one of the exporter, time-varying fixed effects. Then, at the bottom panel of Table 2, we show that the sum of the directional border estimates from column (2) is exactly equal to the relative border estimate from column (1), i.e. $\beta_{brdr} = \beta_{usa,can} + \beta_{can,usa}$. Finally, in column (3), we reproduce the experiment after omitting a different exporter-time fixed effect. As expected, the directional border estimates from columns (2) and (3) are different, however, their sum is the same and, once again, equal to the relative border estimate from column (1).

Exchange Rates. There is wide variability in the relative ER effects across sectors. For some industries, such as Agriculture, Wood, Minerals and Health services, we obtain large, positive and significant estimates on ER_CA_EXP, which suggest that the ER effects on Canadian exports dominate the corresponding effects on Canadian imports. For other categories, such as Apparel, Raw Metals, Chemical Products and Finance Services, the ER effects on imports are stronger. In the next section, we demonstrate how the estimates of the ER effects can be used in combination with other gravity estimates to recover the elasticities of substitution for each sector in our sample.

We conclude by demonstrating that the estimates of β_{er} from Tables 1a-1c are estimates of the exchange rates effects on Canadian exports relative to Canadian imports that also net out border effects. The relative ER estimates from column (1) of Table 2 are taken

[25] For brevity, we only report the estimates of the border effects and the exchange rates effects.

from column 1 of Table 1a. Compare these in Table 2 to the sum of the directional ER estimates from columns (4) and (5). The latter are obtained simultaneously in each column at the expense of one dropped exporter-time fixed effect. The comparison reveals that $\beta_{er} = \beta_{er\_imp} + \beta_{er\_exp}$, regardless of the choice of omitted fixed effect.

4.2 Inferred Structure

A key question of this paper is whether exchange rates have real effects in gravity models, which the theory shows boils down to non-uniformity of scale elasticities or passthrough elasticities. Structural parameters can be inferred from the coefficient estimates of Tables 1a-1c combined with identifying restrictions.

Theoretical restrictions of the model partially identify the structural parameters. Identification is completed with assumed parameter values for either the elasticity of substitution or of exchange rate passthrough along with the gravity estimates from Tables 1a-1c.

$$\hat{\alpha}_1 = \gamma_1(1-\sigma) \tag{19}$$

$$\hat{\alpha}_2 = \frac{\gamma_1(1-\sigma)}{(1+\sigma\phi_{can})} \tag{20}$$

$$\hat{\alpha}_3 = \frac{\gamma_1(1-\sigma)}{(1+\sigma\phi_{usa})} \tag{21}$$

$$\hat{\beta}_{er} + \hat{\beta}_{brdr} = \frac{(\rho_{usa}-\phi_{usa})(1-\sigma)}{1+\sigma\phi_{usa}} - \frac{(\rho_{can}-\phi_{can})(1-\sigma)}{1+\sigma\phi_{can}}, \tag{22}$$

where (22) is based on (17) and utilizes the relationship between the directional border estimates, $\hat{\beta}_{brdr} = \hat{\beta}_{usa,can} + \hat{\beta}_{can,usa}$. For a common passthrough elasticity $\bar{\rho}$, solve system (19)-(22) for the implied relationship between $\bar{\rho}$ and σ as

$$\bar{\rho} = \frac{(\hat{\beta}_{er} + \hat{\beta}_{brdr})\hat{\alpha}_1}{(1-\sigma)(\hat{\alpha}_3 - \hat{\alpha}_2)} - \frac{1}{\sigma}. \tag{23}$$

First we obtain estimates of the trade cost scale parameters for Canada and the US from

(19)-(21) assuming a substitution elasticity σ. Second, we use (23) and assume complete passthrough, $\rho = 1$, to obtain estimates of the elasticity of substitution for each sector. Finally, we solve for the average (across countries) passthrough elasticity $\bar{\rho}$ assuming an elasticity of substitution. The inferred passthrough and scale elasticities yield country specific net elasticities of price with respect to exchange rates $\bar{\rho} - \phi_R$.

Scale Elasticities. The scale parameters are solved from (19)-(21) as:

$$\phi_{can} = \frac{\alpha_1 - \alpha_2}{\sigma \alpha_2} \quad and \quad \phi_{usa} = \frac{\alpha_1 - \alpha_3}{\sigma \alpha_3} \tag{24}$$

Substituting the estimates $\hat{\alpha}_i; i - 1, 2, 3$ from Tables 1a-1c into (24) and setting $\sigma = 7$ yields the trade-volume parameter estimates of ϕ_{can} and ϕ_{usa} reported in panel A of Tables 3a-3c, where we also report the difference $\phi_{can} - \phi_{usa}$ along with standard errors.[26]

The majority of the scale parameters are small in magnitude but statistically significantly less than zero in 36 of the 56 destination-country/sector cases. In Health services for Canada's exports to the US the statistically significant estimate of ϕ_{usa} is suspicious because it results from the positive elasticity of distance to the US $\hat{\alpha}_3$. We interpret this result (which violates the stability condition) as implying a mis-specified trade cost function that does not appropriately control for trade in health services. (This finding and the generally imprecise estimation of $\hat{\alpha}_3$ hamper our attempt to identify $\bar{\rho}$ and σ for services, as presented below.) On average for all goods Column (1) of Table 3a reports that a 10% rise in trade volume will lower trade costs to Canada by 1.1% and to the US by 0.5%. In most goods sectors $\phi_{can} < \phi_{usa}$, scale economies are more pronounced for Canadian imports (i.e., US exports to Canada). A rationale is that the larger US market comes closer to exhausting division of labor economies of scale. The insignificant scale parameters for Fuels are due to its presumptively mis-specified trade cost equation.

Scale Elasticity and Contiguity. Scale elasticities contribute to the asymmetries in con-

[26] $\sigma = 7$ is in the middle of the distribution of elasticity of substitution parameters from recent related trade studies.

tiguity parameter estimates. To 'remove' the scale effects, we multiply the estimates of $CONTIG\_PR\_ST$ and $CONTIG\_ST\_PR$ by $(1 + \sigma\phi_{can})$ and by $(1 + \sigma\phi_{can})$, respectively. Results are presented in Panels B of Tables 3a-3c, where we also report the original estimates on $CONTIG\_PR\_ST$ and $CONTIG\_ST\_PR$.

Three properties stand out. First, the majority of contiguity effects are smaller after the 'removal' the trade volume effects; trade-volume effects contribute to mostly larger contiguity estimates in each direction of Canadian trade. Second, the differences between the contiguity estimates after trade-volume effects are accounted for are reduced; i.e., trade-volume effects increase the difference between the effects of directional contiguity. Third, many of the contiguity estimates remain positive and significant even after removing volume effects, and exhibit directional symmetries.

Trade Elasticities. To obtain the elasticity of substitution estimate we assume complete exchange rate passthrough in each direction of trade between Canada and US, i.e. $\bar{\rho} = \rho_{can} = \rho_{usa} = 1$. In that case, equation (23) is rearranged as a quadratic equation to be solved for the elasticity of substitution:

$$\sigma^2 + \frac{\hat{\alpha}_1(\hat{\beta}_{er} + \hat{\beta}_{brdr})}{\hat{\alpha}_3 - \hat{\alpha}_2}\sigma - 1 = 0. \tag{25}$$

(25) solves for a unique estimate of σ after eliminating one root by imposing the standard theoretical restriction $1 - \sigma < 0$.

Sectoral estimates of the trade elasticities of substitution obtained from equation (25) are reported in Panels C of Tables 3a-3c. Overall, we view the estimates of σ as encouraging for the goods sectors in our sample. Sixteen of the nineteen possible estimates of the elasticity of substitution for goods are positive and greater than one, as suggested by theory. Eleven of these estimates are statistically significant. The estimate of $\sigma = 6.62$ (std.err. 1.866) for aggregate goods is in the middle of the distribution of estimates from related studies, which vary in the range between 2 and 10,[27] and almost all of the other significant elasticity

[27] See Eaton and Kortum, 2002, Anderson and van Wincoop, 2003, Broda et al. 2006, and Arkolakis et

estimates are within this range too. The three sectors for which we obtain estimates of σ that are smaller than one (and not statistically significant) are Agriculture, Fuels and Wood. This is not surprising because these are three of the four sectors for which we did not estimate significant scale effects (see Panels A of Tables 3a and 3b), and our identification of σ requires active scale effects.[28]

The elasticities of substitution for services trade are much less convincing. The underlying difficulty is imprecise estimates of α_3, the distance elasticity for Canadian exports to the US. The requirement $\hat{\alpha}_3 - \hat{\alpha}_2 \neq 0$ in (23) arises mechanically for the equation to be defined, but the deeper economic implication is that significant scale elasticity difference is needed for identification because uniform ρ is assumed in deriving (23). With uniform scale elasticities money is neutral and neither σ nor ρ can be identified from gravity. Despite this, we report σ values in panel C of Table 3c. All of the elasticities are positive, but only five of the nine sectoral estimates are statistically significant, and only two of those are greater than one. The five significant sectoral estimates of σ are for the sectors where we obtain significant estimates of $\hat{\alpha}_3 - \hat{\alpha}_2$. See Panel D of Table 3c.

Exchange Rate Passthrough. Representative exchange rate passthrough elasticities $\bar{\rho}$ for aggregate goods and aggregate services are displayed in Figures 1 and 2 for varying common elasticities of substitution. For goods, in Figure 1, $\bar{\rho}$ is typically decreasing in σ.[29] By construction the solution to (23) for each sectoral value of σ reported in Panel C of Tables 3a-3c is always $\rho = 1$. Figure 1 uses values of sigma between 4 and 12, representative of the estimates of σ from the existing literature. The results suggest that for reasonable values of σ, the implied passthrough elasticity $\bar{\rho}$ is in the unit interval. As a benchmark result, for aggregate goods trade and $\sigma = 7$, $\bar{\rho} = 0.932$ and the implied net passthrough elasticity $\bar{\rho} - \phi_R$ is 0.986 for the US and 1.04 for Canada.

al., 2011.

[28]The fourth sector for which we do not obtain significant trade-volume estimates is Petroleum and Coal Products. The corresponding elasticity estimate for this sector is greater than one, but not statistically significant.

[29]$d\bar{\rho}/d\sigma < 0$ for $(\hat{\beta}_{er} + \hat{\beta}_{brdr})\hat{\alpha}_1/[(1-\sigma)(\hat{\alpha}_3 - \hat{\alpha}_2)] < 0$, which obtains for most sectors.

The structural approach to estimating $\bar{\rho}$ is much less successful with services due to the identification issue discussed in connection with solving (23) for σ given ρ. Mechanically, following the procedure of equation (23) with the coefficient point estimates of the services gravity coefficients produces the results displayed in Figure 2. These are quite implausible but explained by $\bar{\rho}$ being unidentified under the theoretical implications of our model.

The test of money neutrality has two components, scale neutrality ($\phi_{can} - \phi_{usa} = 0$) and net neutrality ($\hat{\beta}_{er} + \hat{\beta}_{brdr} = 0$), reported in Panel D of Tables 3a-3c. For 13 of 19 goods sectors, scale neutrality and net neutrality are rejected. The coincidence of the two rejections, implying rejection of money neutrality, obtains for 12 of the 19. For services, in contrast, scale neutrality and net neutrality are rejected in 4 of 9 sectors. The only sector for which both are rejected is Health, a test statistic that is based on an almost surely mis-specified trade cost function evidenced by a positive distance elasticity for Canada's exports to the US. We conclude that money neutrality can be rejected for a majority of goods sectors but not for services sectors.

4.3 Sensitivity Experiments

This section introduces two alternative specifications to address potential endogeneity concerns. A third specification allows for time-varying exchange rate effects. For brevity we present only the representative results for aggregate goods and services, reported in columns (1)-(5) and in columns (6)-(10) of Table 4 respectively. We report the base case results for goods in column (1) of Table 4 (from column 1 of Table 1a), and in column (6) we report the main estimates for services (from column 1 of Table 1c). The top panel of Table 4, labeled 'A. Gravity Estimates,' presents the gravity estimates from our experiments and in the bottom panel, labeled 'B. Parameter Inferences,' we recover the volume parameters and the elasticity of substitution.

Begin with goods. Two alternative specifications test for potential endogeneity with respect to exchange rates. First, in column (2) of Table 4, we use lagged exchange rate values to eliminate any simultaneity between trade and exchange rates. Overall, the results from column (2) are not statistically different from the main findings from column (1). Three properties stand out. (i) The estimates of the standard gravity variables in columns (1) and (2) are virtually identical. This suggests that the ER effects are orthogonal to the effects of distance, border and contiguity. We exploit this property in the next experiment. (ii) The estimate of the relative ER effect is still not statistically significant, as it was in the main results. (iii) We do not find any statistically significant effects on the structural parameters in our model, which are reported in Panel B. Comparison between the numbers in columns (6)-(7) reveals that these results are confirmed for services as well.

The second alternative specification applies the methods of Baier and Bergstrand (2007), who convincingly account for endogeneity of free trade agreements in a similar, structural gravity setting by including the full set of country-pair fixed effects in addition to the directional (exporter and imported) fixed effects. The intuition is that the bilateral fixed effects can successfully absorb the correlation between the trade policy variable and the unobservable error term in the gravity model in order to eliminate endogeneity. Applied to our setting, Baier and Bergstrand's methodology translates into the following econometric specification:

$$X_{ij,t} \quad = \quad exp[\tilde{\alpha}_0 + \tilde{\beta}_{er} ER\_CA\_EXP + \psi_{ij} + \eta_{i,t} + \theta_{j,t}] + \tilde{u}_{ij,t}, \tag{26}$$

where ψ_{ij} is the full set of bilateral fixed effects for any two trading partners in our sample, and all other variables are defined as before. All time-invariant standard gravity covariates (such as distance for example) will be absorbed by the bilateral fixed effects. To obtain estimates of the standard gravity variables, which are needed to recover the structural parameters in our model, we apply a two-stage procedure similar to the one from Anderson and Yotov (2011). In particular, first we estimate (26) to obtain the ER effects after addressing endogeneity, then we restrict the ER estimates in a constrained second-stage optimization, where the bilateral fixed effects are replaced with the standard set of gravity variables.

Orthogonality between the ER effects and the standard gravity covariates validates this approach.

Results are reported in column (3) of Table 4. There are no statistically significant differences from estimates in column (1). In particular, (i) the standard gravity estimates are identical; (ii) the ER estimates are not statistically significant; and (iii) the structural parameters from columns (1) and (3) in panel B are not statistically different from each other. The estimates for services from column (6) and column (8) are identical as well.

In the last experiment, exchange rate effects can vary over time due to splitting the data in two periods: before and after 2002. Choosing 2002 to allow for time-varying ER effects has two advantages in addition to being the mid-year in our sample. First, the Canadian dollar depreciated steadily during the period 1997-2002 , while it appreciated steadily between 2002 and 2007. These patterns provide an opportunity to look for asymmetric trade responses to ER changes. Second, splitting the time series at 2002 can pick up any changes in trade due to changes in border security after the 9/11 events.

Pre-2002 and post-2002 estimates for goods are reported in columns (4) and (5) of Table 4, respectively. Similar estimates of the standard gravity covariates obtain in the two periods. There are also two important differences between the estimates in columns (4) and (5). First, we obtain a large positive and statistically significant estimate on ER_CA_EXP for the period before 2002, but a negative and significant estimate on ER_CA_EXP for the period after 2002. Based on the definition of $\tilde{\beta}_{er}$, as a relative effect capturing the response of Canadian exports to US relative to Canadian imports from US, our estimates imply that when the CA dollar was depreciating, in the pre-2002 period, Canadian exports responded much more than Canadian imports. The trade response was asymmetric in the post-2002 period too, when the CA dollar was steadily appreciating. This time however, the response of Canadian imports was stronger than the response of Canadian exports. Hence, the negative estimates of $\tilde{\beta}_{er}$ for the post-2002 period. The implication of these results is that the response of Canadian trade to exchange rate fluctuations is directionally asymmetric. Our findings also support the hypothesis that the passthrough of depreciation is stronger than the passthrough of appreciation, taking the scale elasticity as constant. Thus our results are consistent with those of Delatte and Lopez-Villavicencio (2012) based on price comparison data.

The second difference between columns (4) and (5) is between the estimates of the structural parameters. There is an insignificant estimate of ϕ_{usa} in the post-2002 period (column 8), although the estimate lies within 2 standard deviations of the pre-2002 estimate. The mechanical reason for the significance test result is that the standard error doubles in the post-2002 period. Interpreting this weak evidence as indicating a fall in the scale elasticity (in absolute value), the result is consistent with a thickening of the US border after 9/11. It should be emphasized that scale effect inference is identified independently of exchange rate effects so it is not subject to passthrough asymmetry.

For services there are no significant differences between the pre-2002 and post-2002 estimates. This finding underlines the conclusion drawn from the main results that the scale and passthrough channels are weakly identified in the services data, and splitting the data does not help. The results are reported in columns (9) and (10) of Table 4.

The sensitivity experiments support the base findings from Sections 4.1 and 4.2. The main addition is evidence of differences in the response of goods trade flows to exchange rate appreciations as opposed to depreciation.

5 Conclusion

We develop a structural model that can identify the effects of exchange rates in the structural gravity model. Exchange rate influence moves through two channels, a volume scale effect in trade costs and incomplete exchange rate passthrough. Non-uniformity of either passthrough or scale induces relative price effects of exchange rate changes. Our application to the trade of Canadian provinces with the US suggests that these channels are active.

Our theory and results suggest that gravity modeling should allow for variable returns to scale trade technology. This significant departure from constant returns points toward a richer model that includes infrastructure detail as a determinant of bilateral trade. Application to more disaggregated trade data would permit direct measures of trade volume to be used to directly identify scale elasticities, increasing the precision of estimation. Disaggregation would also permit examination of more detailed analysis of scale effects, such as allowing for multiple points of entry in borders, multiple modes of transport and infrastructure details.

Another novel implication of the extended trade cost function developed here is that trade-volume effects can be used in combination with an exogenously given exchange rate passthrough elasticity to recover estimates of the trade elasticity of substitution. Our results suggest that this is a promising method of identifying substitution elasticities.

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Table 1a: Sectoral PPML Panel Gravity Estimates, 1997-2007

	(1) GOODS	(2) AGRIC	(3) FUELS	(4) FOOD	(5) LETHR	(6) TXTLE	(7) APPRL	(8) WOOD	(9) FRNTR	(10) PAPER
A. Gravity Estimates										
INTERNAL_DIST	-0.728	-1.194	-0.839	-0.621	-0.679	-0.469	-0.558	-0.816	-0.667	-0.663
	(0.038)**	(0.040)**	(0.239)**	(0.030)**	(0.036)**	(0.034)**	(0.034)**	(0.037)**	(0.041)**	(0.029)**
DIST_USA_CAN	-2.994	-1.344	-0.010	-2.529	-3.479	-2.847	-2.477	-0.837	-3.885	-2.773
	(0.307)**	(0.518)**	(1.342)	(0.409)**	(0.306)**	(0.280)**	(0.382)**	(0.709)	(0.514)**	(0.372)**
DIST_CAN_USA	-1.166	-0.996	2.832	-0.116	-2.077	-1.877	-1.216	-0.331	-1.147	-0.193
	(0.277)**	(0.361)**	(2.644)	(0.228)	(0.257)**	(0.422)**	(0.437)**	(0.270)	(0.243)**	(0.233)
CONTIG_PR_ST	0.280	0.703	1.965	-0.387	-1.184	0.016	2.510	0.923	1.085	0.476
	(0.301)	(0.412)+	(0.925)*	(0.289)	(0.245)**	(0.282)	(0.437)**	(0.276)**	(0.310)**	(0.203)*
CONTIG_ST_PR	1.467	4.121	-0.121	2.482	2.826	3.246	3.976	4.818	2.984	2.839
	(0.292)**	(0.450)**	(1.043)	(0.418)**	(0.323)**	(0.295)**	(0.369)**	(0.745)**	(0.460)**	(0.537)**
ER_CA	0.018	3.514	0.987	-0.664	0.235	-0.726	-1.451	1.764	0.207	-0.060
	(0.228)	(0.797)**	(1.066)	(0.292)*	(0.153)	(0.395)+	(0.531)**	(0.282)**	(0.350)	(0.143)
BRDR_USA_CAN	16.216	-10.399	-39.555	4.285	26.688	21.837	9.760	-12.892	20.125	6.644
	(2.153)**	(4.431)*	(20.199)+	(3.400)	(2.559)**	(3.622)**	(4.466)*	(5.803)*	(3.840)**	(2.987)*
_cons	-1.465	-5.659	-24.356	-5.025	-2.291	-8.545	-6.347	-3.944	-5.134	-6.029
	(1.122)	(0.610)**	.	(0.997)**	(1.071)*	(1.044)**	(1.529)**	(0.820)**	(1.432)**	(1.513)**
N	1014	835	435	964	888	812	705	931	789	865
ll	-2836.314	-667.641	-682.285	-1033.760	-509.447	-316.743	-268.199	-588.349	-358.937	-614.923
B. Scale Effects Specification Tests										
$\alpha_1 - \alpha_2$	2.266	0.150	-0.830	1.909	2.800	2.378	1.919	0.021	3.218	2.111
	(0.300)**	(0.516)	(1.465)	(0.404)**	(0.303)**	(0.287)**	(0.378)**	(0.701)	(0.502)**	(0.371)**
$\alpha_1 - \alpha_3$	0.438	-0.198	-3.672	-0.505	1.398	1.407	0.658	-0.485	0.479	-0.469
	(0.281)	(0.361)	(2.497)	(0.234)*	(0.246)**	(0.412)**	(0.419)	(0.246)*	(0.242)*	(0.230)*
$\alpha_2 - \alpha_3$	-1.829	-0.347	-2.842	-2.414	-1.402	-0.970	-1.261	-0.506	-2.738	-2.580
	(0.500)**	(0.710)	(3.213)	(0.509)**	(0.439)*	(0.530)+	(0.546)*	(0.730)	(0.603)**	(0.484)**

This table reports PPML gravity estimates of the effects of exchange rate fluctuations on Canadian goods trade. Column (1) includes estimates for aggregate goods and the numbers in the next nine columns are for individual sectors. All estimates are obtained with time-varying, directional (importer and exporter) fixed effects and the years included in our sample are 1997, 1999, 2001, 2003, 2005 and 2007. The dependent variable is nominal exports. Standard errors in parentheses. + $p < 0.10$, * $p < .05$, ** $p < .01$. See text for more details.

Table 1b: Sectoral PPML Panel Gravity Estimates, 1997-2007

	(1) PRNTG	(2) METL1	(3) METL2	(4) MCHNS	(5) VHCLS	(6) ELCTR	(7) MNRLS	(8) PETRL	(9) CHMCL	(10) MISCL
A. Gravity Estimates										
INTERNAL_DIST	-1.022	-0.741	-0.794	-0.757	-0.747	-0.434	-1.037	-1.016	-0.585	-0.686
	(0.032)**	(0.065)**	(0.030)**	(0.048)**	(0.030)**	(0.033)**	(0.038)**	(0.056)**	(0.039)**	(0.040)**
DIST_USA_CAN	-4.804	-2.508	-2.960	-2.616	-4.412	-2.873	-3.289	-0.297	-3.293	-4.215
	(0.524)**	(0.268)**	(0.286)**	(0.252)**	(0.213)**	(0.203)**	(0.411)**	(0.696)	(0.295)**	(0.301)**
DIST_CAN_USA	-0.243	-0.644	-1.757	-2.364	-2.491	-0.985	-1.470	-0.919	-1.145	-1.072
	(0.466)	(0.480)	(0.205)**	(0.286)**	(0.201)**	(0.181)**	(0.354)**	(0.653)	(0.295)**	(0.298)**
CONTIG_PR_ST	2.488	2.628	0.321	0.619	1.343	1.071	1.843	0.292	1.350	0.766
	(0.578)**	(0.613)**	(0.281)	(0.256)*	(0.210)**	(0.330)**	(0.402)**	(0.919)	(0.377)**	(0.512)
CONTIG_ST_PR	2.709	2.425	1.852	2.161	0.348	1.556	3.104	-0.023	2.508	2.414
	(0.458)**	(0.418)**	(0.403)**	(0.266)**	(0.262)	(0.270)**	(0.463)**	(0.592)	(0.583)**	(0.290)**
ER_CA	0.245	-2.113	0.551	0.502	0.171	-0.591	2.689	0.249	-0.970	-0.481
	(0.199)	(0.264)**	(0.286)+	(0.498)	(0.265)	(0.215)**	(0.306)**	(0.671)	(0.261)**	(0.250)+
BRDR_USA_CAN	11.521	7.377	17.286	21.647	37.050	18.545	9.422	-10.141	18.527	22.910
	(5.015)*	(3.719)*	(2.041)**	(1.827)**	(1.562)**	(2.119)**	(3.501)**	(4.815)*	(2.666)**	(2.720)**
_cons	0.312	-6.786	-1.296	-3.051	-2.026	-7.782	0.282	-1.215	-5.612	-3.650
	(0.700)	(1.564)**	(0.946)	(0.856)**	(1.089)+	(1.107)**	(0.188)	(0.990)	(1.332)**	(1.159)**
N	911	821	943	903	891	866	837	805	911	887
ll	-464.607	-642.499	-613.867	-612.272	-735.230	-543.901	-395.034	-911.532	-745.889	-431.996
B. Scale Effects Specification Tests										
$\alpha_1 - \alpha_2$	3.783	1.767	2.166	1.859	3.665	2.440	2.252	-0.719	2.708	3.528
	(0.516)**	(0.274)**	(0.278)**	(0.257)**	(0.202)**	(0.195)**	(0.401)**	(0.672)	(0.289)**	(0.286)**
$\alpha_1 - \alpha_3$	-0.778	-0.097	0.963	1.608	1.744	0.551	0.433	-0.097	0.560	0.386
	(0.470)+	(0.455)	(0.207)**	(0.274)**	(0.202)**	(0.178)*	(0.359)	(0.676)	(0.299)+	(0.308)
$\alpha_2 - \alpha_3$	-4.561	-1.864	-1.203	-0.251	-1.921	-1.889	-1.819	0.622	-2.147	-3.142
	(0.758)**	(0.596)*	(0.413)*	(0.468)	(0.351)**	(0.270)**	(0.626)*	(1.201)	(0.472)**	(0.482)**

This table reports PPML gravity estimates of the effects of exchange rate fluctuations on Canadian goods trade. Column (1) includes estimates for aggregate goods and the numbers in the next nine columns are for individual sectors. All estimates are obtained with time-varying, directional (importer and exporter) fixed effects and the years included in our sample are 1997, 1999, 2001, 2003, 2005 and 2007. The dependent variable is nominal exports. Standard errors in parentheses. + $p < 0.10$, * $p < .05$, ** $p < .01$. See text for more details.

Table 1c: Sectoral PPML Panel Gravity Estimates, 1997-2007

	(1) SRVCS	(2) TRNSP	(3) CMNCN	(4) WHLSL	(5) FNNCE	(6) BUSNS	(7) EDCTN	(8) HELTH	(9) ACMDN	(10) OTHER
A. Gravity Estimates										
INTERNAL_DIST	-1.162	-0.944	-1.044	-0.911	-1.372	-1.143	-1.764	-2.745	-1.336	-1.382
	(0.055)**	(0.043)**	(0.059)**	(0.039)**	(0.095)**	(0.054)**	(0.087)**	(0.099)**	(0.041)**	(0.066)**
DIST_USA_CAN	-2.712	-1.563	-1.733	-2.300	-4.382	-3.287	-2.840	-6.028	-0.895	-2.520
	(0.520)**	(0.404)**	(0.523)**	(0.375)**	(0.780)**	(0.514)**	(1.013)**	(0.766)**	(0.437)*	(0.650)**
DIST_CAN_USA	-0.478	-1.341	-0.365	-0.427	0.123	-0.350	-0.191	2.061	-1.779	-0.137
	(0.527)	(0.401)**	(0.483)	(0.334)	(0.692)	(0.471)	(1.015)	(0.862)*	(0.438)**	(0.660)
CONTIG_PR_ST	0.954	0.598	0.352	-0.006	1.442	1.124	0.700	1.181	0.249	1.282
	(0.405)*	(0.356)+	(0.374)	(0.348)	(0.532)**	(0.363)**	(0.692)	(0.733)	(0.352)	(0.476)**
CONTIG_ST_PR	0.247	0.777	0.145	-0.077	-0.464	-0.000	-0.086	-0.889	1.079	0.549
	(0.357)	(0.354)*	(0.370)	(0.399)	(0.511)	(0.400)	(0.681)	(0.639)	(0.383)**	(0.432)
ER_CA	-0.061	0.321	-0.790	0.125	-0.869	0.767	-0.250	1.649	-0.281	-0.150
	(0.181)	(0.150)*	(0.362)*	(0.312)	(0.235)**	(0.451)+	(0.379)	(0.218)**	(0.263)	(0.603)
BRDR_USA_CAN	-0.481	0.569	-6.569	-3.816	4.745	3.439	-8.673	-17.570	-4.215	-6.362
	(2.450)	(2.292)	(2.200)**	(2.382)	(3.082)	(2.735)	(3.827)*	(4.578)**	(3.317)	(3.180)*
_cons	-1.382	-4.619	-4.944	-5.498	-1.729	-3.550	-3.693	2.522	-3.066	-2.213
	(0.514)**	(0.624)**	(0.832)**	(0.789)**	(0.529)**	(0.638)**	(0.342)**	(0.354)**	(0.276)**	(0.354)**
N	1014	1014	1014	1014	1014	1014	1014	1014	1014	1014
ll	-92.985	-32.892	-23.798	-29.082	-45.775	-39.825	-10.902	-22.185	-22.313	-27.220
B. Scale Effects Specification Tests										
$\alpha_1 - \alpha_2$	1.550	0.620	0.689	1.389	3.010	2.144	1.076	3.284	-0.440	1.139
	(0.506)*	(0.411)	(0.503)	(0.366)**	(0.711)**	(0.508)**	(1.013)	(0.731)**	(0.434)	(0.620)+
$\alpha_1 - \alpha_3$	-0.684	0.398	-0.680	-0.483	-1.495	-0.793	-1.573	-4.805	0.444	-1.245
	(0.541)	(0.391)	(0.502)	(0.342)	(0.761)*	(0.478)+	(1.020)	(0.899)**	(0.434)	(0.690)+
$\alpha_2 - \alpha_3$	-2.234	-0.222	-1.369	-1.873	-4.505	-2.937	-2.649	-8.089	0.884	-2.384
	(0.998)*	(0.746)	(0.970)	(0.636)*	(1.418)*	(0.917)*	(1.968)	(1.525)**	(0.754)	(1.241)+

This table reports PPML gravity estimates of the effects of exchange rate fluctuations on Canadian services trade. Column (1) includes estimates for aggregate services and the numbers in the next nine columns are for individual sectors. All estimates are obtained with time-varying, directional (importer and exporter) fixed effects and the years included in our sample are 1997, 1999, 2001, 2003, 2005 and 2007. The dependent variable is nominal exports. Standard errors in parentheses. + $p < 0.10$, * $p < .05$, ** $p < .01$. See text for more details.

Table 2: Border and Exchange Rates Collinearity Analysis

	(1) Main	(2) BRDR1	(3) BRDR2	(4) ER1	(5) ER2
β_{brdr}	16.216			16.216	16.216
	(2.153)**			(2.153)**	(2.153)**
$\beta_{usa,can}$		23.567	17.189		
		(2.584)**	(2.450)**		
$\beta_{can,usa}$		-7.351	-0.973		
		(2.489)**	(2.277)		
β_{er}	0.018	0.018	0.018		
	(0.228)	(0.228)	(0.228)		
β_{er_exp}				-9.466	-0.955
				(3.266)**	(2.331)
β_{er_imp}				9.484	0.973
				(3.211)**	(2.277)
N	1014	1014	1014	1014	1014
ll	-2836.314	-2836.314	-2836.314	-2836.314	-2836.314
$\beta_{er\_imp} + \beta_{er\_exp}$				0.018	0.018
				(0.228)	(0.228)
$\beta_{can,usa} + \beta_{usa,can}$		16.216	16.216		
		(2.153)**	(2.153)**		

This table reveals correlation relationships between the border variables and the exchange rate variables, respectively. Estimates of the rest of the gravity variables are omitted for brevity. Standard errors in parentheses. + $p < 0.10$, * $p < .05$, ** $p < .01$.

Table 3a: Parameter Inferences from Sectoral Canadian Trade, 1997-2007

	(1) GOODS	(2) AGRIC	(3) FUELS	(4) FOOD	(5) LETHR	(6) TXTLE	(7) APPRL	(8) WOOD	(9) FRNTR	(10) PAPER
A. Scale Parameters ($\sigma = 7$)										
ϕ_{can}	-0.108	-0.016	12.323	-0.108	-0.115	-0.119	-0.111	-0.004	-0.118	-0.109
	(0.004)**	(0.049)	(1740.377)	(0.006)**	(0.003)**	(0.003)**	(0.005)**	(0.117)	(0.003)**	(0.005)**
ϕ_{usa}	-0.054	0.028	-0.185	0.624	-0.096	-0.107	-0.077	0.209	-0.060	0.347
	(0.022)*	(0.062)	(0.048)**	(1.522)	(0.005)**	(0.008)**	(0.022)**	(0.276)	(0.018)**	(0.587)
$\phi_{can} - \phi_{usa}$	-0.054	-0.044	12.509	-0.732	-0.019	-0.012	-0.033	-0.213	-0.059	-0.456
	(0.023)*	(0.089)	(1740.391)	(1.523)	(0.007)*	(0.008)	(0.023)	(0.293)	(0.019)*	(0.589)
B. Contiguity Estimates										
$CONTIG\_PR\_ST$	0.280	0.703	1.965	-0.387	-1.184	0.016	2.510	0.923	1.085	0.476
	(0.301)	(0.412)+	(0.925)*	(0.289)	(0.245)**	(0.282)	(0.437)**	(0.276)**	(0.310)**	(0.203)*
$CONTIG\_PR\_ST(1 + \sigma\phi_{usa})$	0.175	0.843	-0.583	-2.080	-0.387	0.004	1.152	2.274	0.632	1.631
	(0.216)	(0.689)	(0.443)	(3.665)	(0.080)**	(0.071)	(0.528)*	(2.152)	(0.267)*	(2.426)
$CONTIG\_ST\_PR$	1.467	4.121	-0.121	2.482	2.826	3.246	3.976	4.818	2.984	2.839
	(0.292)**	(0.450)**	(1.043)	(0.418)**	(0.323)**	(0.295)**	(0.369)**	(0.745)**	(0.460)**	(0.537)**
$CONTIG\_ST\_PR(1 + \sigma\phi_{can})$	0.357	3.662	-10.524	0.609	0.551	0.535	0.896	4.698	0.513	0.678
	(0.098)**	(1.727)*	(1404.042)	(0.187)*	(0.104)**	(0.107)**	(0.211)**	(4.531)	(0.137)**	(0.193)**
C. Elasticity of Substitution ($\rho_{can} = \rho_{usa} = 1$)										
σ	6.615	0.042	0.087	1.569	13.110	10.310	3.931	0.056	5.149	2.155
	(1.866)**	(0.098)	(0.100)	(0.544)*	(4.142)*	(6.629)	(2.654)	(0.104)	(0.895)**	(0.576)**
D. Money Neutrality Tests										
$\alpha_3 - \alpha_2$	1.829	0.347	2.842	2.414	1.402	0.970	1.261	0.506	2.738	2.580
	(0.500)**	(0.710)	(3.213)	(0.509)**	(0.439)*	(0.530)+	(0.546)*	(0.730)	(0.603)**	(0.484)**
$\beta_{er} + \beta_{brdr}$	16.234	-6.885	-38.568	3.621	26.924	21.111	8.309	-11.129	20.332	6.584
	(2.327)**	(4.201)	(20.320)+	(3.295)	(2.640)**	(3.660)**	(4.578)+	(5.986)+	(3.974)**	(3.020)*

This table reports quantitative implications based on our theory. In panel A, we recover scale parameters for Canada and for US. Panel B, offers quantitative implications for the effects of contiguity on trade between Canadian provinces and US states. In panel C, we obtain estimates of the elasticity of substitution. Finally, in panel D, we report tests for money neutrality. See text for further details. Standard errors, constructed with the Delta method, are reported in in parentheses. + $p < 0.10$, * $p < .05$, ** $p < .01$.

Table 3b: Parameter Inferences from Sectoral Canadian Trade, 1997-2007

	(1) PRNTG	(2) METL1	(3) METL2	(4) MCHNS	(5) VHCLS	(6) ELCTR	(7) MNRLS	(8) PETRL	(9) CHMCL	(10) MISCL
A. Scale Parameters ($\sigma = 7$)										
ϕ_{can}	-0.112	-0.101	-0.105	-0.102	-0.119	-0.121	-0.098	0.346	-0.117	-0.120
	(0.003)**	(0.006)**	(0.004)**	(0.005)**	(0.001)**	(0.002)**	(0.005)**	(1.134)	(0.003)**	(0.002)**
ϕ_{usa}	0.457	0.021	-0.078	-0.097	-0.100	-0.080	-0.042	0.015	-0.070	-0.051
	(1.152)	(0.117)	(0.008)**	(0.005)**	(0.004)**	(0.012)**	(0.025)+	(0.116)	(0.020)**	(0.027)+
$\phi_{can} - \phi_{usa}$	-0.570	-0.122	-0.026	-0.004	-0.019	-0.041	-0.056	0.331	-0.048	-0.068
	(1.153)	(0.119)	(0.010)*	(0.008)	(0.004)**	(0.012)**	(0.027)*	(1.206)	(0.020)*	(0.027)*
B. Contiguity Estimates										
$CONTIG\_PR\_ST$	2.488	2.628	0.321	0.619	1.343	1.071	1.843	0.292	1.350	0.766
	(0.578)**	(0.613)**	(0.281)	(0.256)*	(0.210)**	(0.330)**	(0.402)**	(0.919)	(0.377)**	(0.512)
$CONTIG\_PR\_ST(1+\sigma\phi_{usa})$	10.451	3.023	0.145	0.198	0.403	0.472	1.301	0.323	0.690	0.490
	(21.610)	(2.580)	(0.136)	(0.095)*	(0.089)**	(0.197)*	(0.532)*	(1.132)	(0.326)*	(0.409)
$CONTIG\_ST\_PR$	2.709	2.425	1.852	2.161	0.348	1.556	3.104	-0.023	2.508	2.414
	(0.458)**	(0.418)**	(0.403)**	(0.266)**	(0.262)	(0.270)**	(0.463)**	(0.592)	(0.583)**	(0.290)**
$CONTIG\_ST\_PR(1+\sigma\phi_{can})$	0.576	0.716	0.497	0.625	0.059	0.235	0.979	-0.077	0.446	0.393
	(0.153)**	(0.194)**	(0.139)**	(0.135)**	(0.046)	(0.052)**	(0.239)**	(1.895)	(0.123)**	(0.067)**
C. Elasticity of Substitution ($\rho_{can} = \rho_{usa} = 1$)										
σ	2.972	2.494	11.857	66.656	14.547	4.355	7.048	16.210	4.986	5.096
	(1.039)*	(1.664)	(3.748)*	(125.425)	(2.661)**	(0.740)**	(2.785)*	(32.324)	(1.251)**	(0.915)**
D. Money Neutrality Tests										
$\alpha_3 - \alpha_2$	4.561	1.864	1.203	0.251	1.921	1.889	1.819	-0.622	2.147	3.142
	(0.758)**	(0.596)*	(0.413)*	(0.468)	(0.351)**	(0.270)**	(0.626)*	(1.201)	(0.472)**	(0.482)**
$\beta_{er} + \beta_{brdr}$	11.766	5.264	17.837	22.149	37.221	17.953	12.111	-9.892	17.557	22.429
	(4.951)*	(3.655)	(2.122)**	(1.986)**	(1.577)**	(2.051)**	(3.401)**	(4.826)*	(2.784)**	(2.750)**

This table reports quantitative implications based on our theory. In panel A, we recover scale parameters for Canada and for US. Panel B, offers quantitative implications for the effects of contiguity on trade between Canadian provinces and US states. In panel C, we obtain estimates of the elasticity of substitution. Finally, in panel D, we report tests for money neutrality. See text for further details. Standard errors, constructed with the Delta method, are reported in in parentheses. + $p < 0.10$, * $p < .05$, ** $p < .01$.

Table 3c: Parameter Inferences from Sectoral Canadian Trade, 1997-2007

	(1) SRVCS	(2) TRNSP	(3) CMNCN	(4) WHLSL	(5) FNNCE	(6) BUSNS	(7) EDCTN	(8) HELTH	(9) ACMDN	(10) OTHER
A. Scale Parameters ($\sigma = 7$)										
ϕ_{can}	-0.082	-0.057	-0.057	-0.086	-0.098	-0.093	-0.054	-0.078	0.070	-0.065
	(0.011)**	(0.023)*	(0.025)*	(0.009)**	(0.006)**	(0.008)**	(0.032)+	(0.008)**	(0.103)	(0.019)**
ϕ_{usa}	0.204	-0.042	0.266	0.162	-1.743	0.324	1.174	-0.333	-0.036	1.300
	(0.387)	(0.029)	(0.548)	(0.240)	(8.956)	(0.631)	(6.987)	(0.078)**	(0.026)	(6.984)
$\phi_{can} - \phi_{usa}$	-0.286	-0.014	-0.323	-0.248	1.645	-0.417	-1.228	0.255	0.106	-1.364
	(0.396)	(0.048)	(0.569)	(0.245)	(8.961)	(0.636)	(7.015)	(0.083)*	(0.119)	(6.999)
B. Contiguity Estimates										
$CONTIG\_PR\_ST$	0.954	0.598	0.352	-0.006	1.442	1.124	0.700	1.181	0.249	1.282
	(0.405)*	(0.356)+	(0.374)	(0.348)	(0.532)**	(0.363)**	(0.692)	(0.733)	(0.352)	(0.476)**
$CONTIG\_PR\_ST(1+\sigma\phi_{usa})$	2.320	0.421	1.007	-0.012	-16.153	3.672	6.458	-1.573	0.187	12.950
	(3.462)	(0.346)	(2.315)	(0.736)	(85.603)	(5.990)	(40.083)	(0.554)*	(0.302)	(67.009)
$CONTIG\_ST\_PR$	0.247	0.777	0.145	-0.077	-0.464	-0.000	-0.086	-0.889	1.079	0.549
	(0.357)	(0.354)*	(0.370)	(0.399)	(0.511)	(0.400)	(0.681)	(0.639)	(0.383)**	(0.432)
$CONTIG\_ST\_PR(1+\sigma\phi_{can})$	0.106	0.469	0.087	-0.031	-0.145	-0.000	-0.054	-0.405	1.609	0.301
	(0.170)	(0.319)	(0.245)	(0.155)	(0.144)	(0.139)	(0.406)	(0.256)	(1.285)	(0.303)
C. Elasticity of Substitution ($\rho_{can} = \rho_{usa} = 1$)										
σ	0.869	4.034	0.173	0.446	1.752	2.111	0.164	0.179	6.936	0.249
	(0.552)	(14.808)	(0.123)	(0.230)+	(0.749)*	(0.950)*	(0.134)	(0.050)**	(7.553)	(0.146)+
D. Money Neutrality Tests										
$\alpha_3 - \alpha_2$	2.234	0.222	1.369	1.873	4.505	2.937	2.649	8.089	-0.884	2.384
	(0.998)*	(0.746)	(0.970)	(0.636)*	(1.418)*	(0.917)*	(1.968)	(1.525)**	(0.754)	(1.241)+
$\beta_{er} + \beta_{brdr}$	-0.541	0.890	-7.359	-3.691	3.876	4.206	-8.923	-15.921	-4.496	-6.512
	(2.477)	(2.331)	(2.061)**	(2.439)	(3.070)	(2.842)	(3.910)*	(4.555)**	(3.394)	(3.310)*

This table reports quantitative implications based on our theory. In panel A, we recover scale parameters for Canada and for US. Panel B, offers quantitative implications for the effects of contiguity on trade between Canadian provinces and US states. In panel C, we obtain estimates of the elasticity of substitution. Finally, in panel D, we report tests for money neutrality. See text for further details. Standard errors, constructed with the Delta method, are reported in in parentheses. + $p < 0.10$, * $p < .05$, ** $p < .01$.

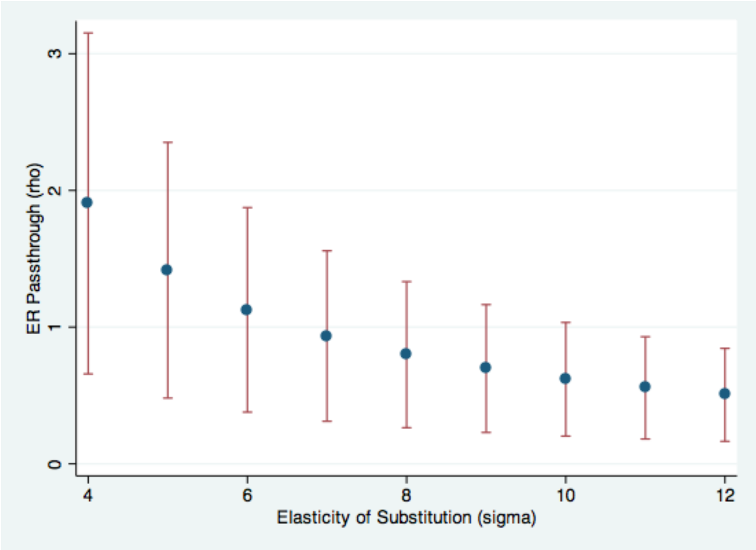

Figure 1: Exchange Rate Passthrough: Goods

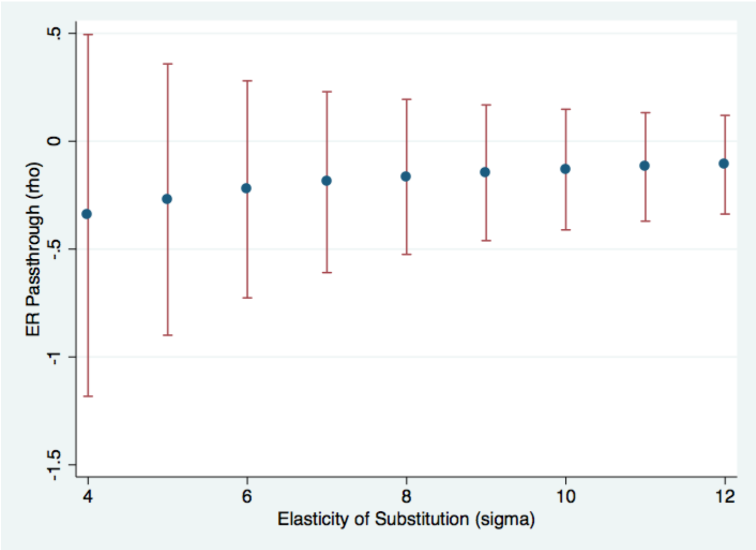

Figure 2: Exchange Rate Passthrough: Services

Table 4: Exchange Rates and Canadian Trade: Sensitivity Experiments

	GOODS					SERVICES				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Main	Lagged	Pair FEs	pre-2002	post-2002	Main	Lagged	Pair FEs	pre-2002	post-2002
A. Gravity Estimates										
INTERNAL_DIST	-0.728	-0.728	-0.728	-0.717	-0.736	-1.162	-1.162	-1.162	-1.167	-1.158
	(0.038)**	(0.038)**	(0.038)**	(0.036)**	(0.040)**	(0.055)**	(0.055)**	(0.055)**	(0.054)**	(0.055)**
DIST_USA_CAN	-2.994	-2.994	-2.994	-3.177	-2.821	-2.712	-2.712	-2.712	-2.864	-2.598
	(0.307)**	(0.307)**	(0.307)**	(0.280)**	(0.326)**	(0.520)**	(0.520)**	(0.520)**	(0.520)**	(0.520)**
DIST_CAN_USA	-1.166	-1.167	-1.166	-1.349	-1.040	-0.478	-0.478	-0.478	-0.507	-0.455
	(0.277)**	(0.277)**	(0.277)**	(0.258)**	(0.293)**	(0.527)	(0.527)	(0.527)	(0.525)	(0.530)
CONTIG_PR_ST	0.280	0.280	0.280	0.371	0.245	0.954	0.954	0.954	0.928	0.974
	(0.301)	(0.300)	(0.301)	(0.265)	(0.318)	(0.405)*	(0.405)*	(0.405)*	(0.402)*	(0.408)*
CONTIG_ST_PR	1.467	1.466	1.467	1.234	1.689	0.247	0.248	0.248	0.264	0.235
	(0.292)**	(0.292)**	(0.292)**	(0.275)**	(0.341)**	(0.357)	(0.357)	(0.357)	(0.358)	(0.357)
ER_CA_EXP	0.018	-0.110	0.066	1.458	-0.594	-0.061	-0.015	-0.042	0.074	-0.007
	(0.228)	(0.157)	(0.217)	(0.292)**	(0.213)**	(0.181)	(0.130)	(0.187)	(0.300)	(0.187)
usa_can	16.216	16.399	16.235	17.583	14.328	-0.481	-0.519	-0.540	0.628	-1.480
	(2.153)**	(2.173)**	(2.335)**	(2.351)**	(2.391)**	(2.450)	(2.451)	(2.476)	(2.522)	(2.478)
_cons	-1.465	-1.468	-1.532	-1.752	-1.477	-1.382	-1.382	-1.340	-1.701	-1.409
	(1.122)	(1.122)	(1.126)	(1.023)+	(1.139)	(0.514)**	(0.514)**	(0.514)**	(0.506)**	(0.524)**
N	1014	1014	1014	507	507	1014	1014	1014	507	507
B. Parameter Inferences										
ϕ_{can}	-0.108	-0.108	-0.108	-0.111	-0.106	-0.082	-0.082	-0.082	-0.085	-0.079
	(0.004)**	(0.004)**	(0.004)**	(0.003)**	(0.004)**	(0.011)**	(0.011)**	(0.011)**	(0.010)**	(0.012)**
ϕ_{usa}	-0.054	-0.054	-0.054	-0.067	-0.042	0.204	0.204	0.204	0.186	0.221
	(0.022)*	(0.022)*	(0.022)*	(0.015)**	(0.029)	(0.387)	(0.387)	(0.387)	(0.344)	(0.427)
σ	6.615	6.641	6.615	7.597	5.843	0.869	0.871	0.869	1.189	0.676
	(1.866)**	(1.869)**	(1.866)**	(1.964)**	(1.832)*	(0.552)	(0.551)	(0.552)	(0.721)+	(0.429)

This table reports sensitivity experiments for aggregate Goods, in the left panel, and for aggregate Services, in the right panel. Panel A of the table reports PPML gravity estimates and Panel B reports quantitative implications. Columns (1) and (5) reproduce the findings for aggregate goods and services, respectively, from the first columns of Tables 1a and 1c. The estimates in columns (2) and (6) are obtained with lagged exchange rate variables. Bilateral fixed effects are used to obtain the ER estimates in in columns (3) and (7). Finally, in the last two columns of each panel, we allow for time-varying ER effects for the periods pre-2002 and post-2002, respectively. Standard errors in parentheses. + $p < 0.10$, * $p < .05$, ** $p < .01$. See text for further details.

Appendix (not for publication)

Appendix A: Sector description

Goods. *Agricultural products*: unmilled wheat; corn, barley, oats and other grains, excluding imputed feed; live animals; other agricultural products (unprocessed milk, eggs, honey, vegetables, seeds, tobacco and wool). *Mineral Fuels*: crude oil; natural gas, excluding liquified. *Food products*: meat, fish and dairy products (including processed milk); fruit and vegetable products; feeds; flour; breakfast cereal; sugar; cocoa; coffee, tea etc. *Leather, rubber and plastic products*: tires; other rubber products; plastic pipes; other plastics; footwear; gloves; handbags; other leather products. *Textile products*: yarns and fibres; fabrics; ropes, tents and threads; other textile products. *Hosiery, clothing and accessories*: hosiery; knitted clothing; furs; custom tailoring; other clothing. *Lumber and wood products*: lumber and timber; plywood and veneer; wood chips; prefabricated buildings; wood containers; caskets and coffins; other wood products. *Furniture*: household furniture; office furniture; mattresses; lamps; furniture parts; other furniture. *Wood pulp, paper and paper products*: wood pulp; newsprint; tissue; wrapping paper; paperboard; coated paper and paper products; paper bags; stationery; other paper products. *Printing and publishing*: newspapers; magazines; books; business forms; advertising; miscellaneous printing components. *Primary metal products*: ferro-alloys; iron and steel ingots; steel castings; bars and rods; flat iron and steel; railway construction materials; oil and gas pipe; other pipes and tubes; primary forms of aluminum copper, nickel, carbon, lead zinc etc.; precious metals excluding gold; scrap and waste; other primary metal products. *Fabricated metal products*: boilers; tanks; plates; iron and steel structural materials; metal doors and windows; stampings; containers; wire and cable; chains; utensils; wire products; hardware; machine tools; furnaces; cooking equipment; iron and steel forgings; valves; plumbing fixtures; gas and water meters; firearms; other fabricated metal equipment. *Machinery*: agricultural machinery; bearings; pumps; conveyors; elevators; fans; furnaces; industry-specific machinery for construction, oil and gas, logging metal working and other industries; power hand tools; refrigeration and air-conditioning equipment; scales; vending machines; computers; miscellaneous machinery. *Motor vehicles and other transportation equipment*: automobiles; trucks; buses; mobile homes; trailers; specialized vehicles; motor vehicle engines and parts; motor vehicle electric equipment; aircraft and engines; locomotives and railway stock; ships and boats; snowmobiles. *Electrical, electronic and communication products*: appliances; household equipment; household furnaces; household refrigerators and freezers; household cooking equipment; TVs, VCRs etc.; telephone and related equipment; broadcasting equipment; electric motors; transformers; batteries; wiring materials; lighting fixtures; other electric equipment. *Non-metallic mineral products*: cement; concrete products; lime; brick; gypsum; stone; asbestos; glass; abrasive products. *Petroleum and coal products*: gasoline; diesel; fuel oils; tar and pitch; naptha; asphalt; other petroleum products. Chemicals, pharmaceuticals and chemical products: industrial chemicals; hydrocarbons; organic acids; fertilizers; pharmaceuticals; soaps, detergents and other cleaning products; explosives; paints; ammunition; insecticides; inks; other chemical products. *Miscellaneous manufactured products*: scientific and lab equipment; measuring and other scientific instruments; clocks and watches; photographic equipment; pearls and precious stones; toys and games; shades and blinds; recordings; musical instruments; miscellaneous end-use consumer products.

Services. *Transportation and Storage Services*: Air, water and rail passenger and freight transportation; Bus (including school), ambulance and truck transportation; Urban transit and taxi transportation; Pipeline transportation of natural gas and oil; Grain and other storage; Warehousing. *Communication Services:* Radio, television broadcasting; Cable programming; Telephone and telecommunication; Postal and courier. *Finance, insurance and real estate services:* Paid charges to financial institutions; commissions and investment banking; Mutual funds, Other securities and royalties; Real estate commissions; Life and non-life insurance; Pension funds; Paid residential and non-residential rent and lodging.*Professional Services*: Architect, engineering, scientific, accounting, legal, advertising and other professional services; software, computer lease, data processing and other information services; Investigation and security services; Other administrative and personal services. *Education Services*: Elementary, Secondary, College and University fees and tuition. Other education fees. *Health care and Social assistance Services*: Private hospital, private residential care and other health and social services; Child care outside the home; Laboratory, physician and dental services; Other health practitioner services. *Accommodation Services and Meals*: Hotel, motel and other accommodation; Meals outside the home; Board paid. *Wholesale Services*: Wholesale trade and wholesaling margins. *Miscellaneous Services*: Beauty and other personal care services; Funeral services; Child care in the home; Private household services; Photographic, laundry and dry cleaning, services to building and dwellings; Automotive and other repair and maintenance; Rental of office, machinery, equipment, automobile and truck; Trade union and other membership organization dues and political parties contribution; Motion picture production, exhibition and distribution; Lottery, gambling and other recreation services.

Appendix B: Technical Notes

This appendix provides technical notes on multilateral scale elasticities and our model of Pricing to Market with industry data. It closes with a derivation of the stability condition for the model with increasing returns trade technology.

5.1 Bilateral vs. Multilateral Scale Models

It is useful to gain perspective by reviewing the bilateral scale trade costs model of the text before proceeding to the multilateral case.

The gravity equation with exporter and importer fixed effects is given by

$$X_{ij} = x_i m_j t_{ij}^{1-\sigma}. \tag{27}$$

Let the trade cost be given by

$$t_{ij} = \tau_{ij} \left(\frac{r_i}{r_j}\right)^{\rho_j} V_{ij}^{\phi_j}. \tag{28}$$

where τ_{ij} denotes a log-linear function of the standard set of trade cost gravity variables augmented by passthrough of bilateral exchange rate change r_i/r_j at passthrough elasticity ρ_j, and where volume shipped from i to j is V_{ij}. Congestion effects are a natural interpretation of $\phi_j > 0$, representing the crowding of fixed capacity ports and border entry points while division of labor is a natural interpretation of IRS. The scale effect applies to bilateral volume.

Volume is given by

$$V_{ij} = X_{ij}/(t_{ij} r_i/r_j) \tag{29}$$

where the deflator removes the effect of exchange rate appreciation (that raises 'factory gate' prices p_i^k), and also removes the volume lost in transit, so that the volume relevant to the congestion is measured at destination size.

Use (27) in (29) and substitute the result into (28) to solve for the reduced form trade cost function repeated from (7):

$$t_{ij} = \left[\tau_{ij}(x_i m_j)^{\phi}(r_i/r_j)^{\rho_j-\sigma_j}\right]^{1/(1+\sigma\phi_j)}.$$

The key implication is that when congestion is important enough, $\phi_j > \rho_j$, the effect of an appreciation of i's bilateral exchange rate is to *lower* trade costs from i to j.

It is alternatively natural to think that congestion affects all exporters simultaneously, as when ships must wait to enter a port irrespective of their nationality. Or, division of labor may naturally apply to all the exporters to a given market when they access various intermediaries. Reality combines aspects of the bilateral and multilateral extremes. The pure multilateral case, while more complex than the pure bilateral case, still remains manageably simple. More important, the qualitative properties of the effect of an appreciation of exporter i's exchange rate on the value of bilateral trade from i to destination j remain the same: sufficiently important congestion implies that an appreciation of i's exchange rate will lower trade costs from i to j.

Let the trade cost function be given by

$$t_{ij} = \tau_{ij}\left(\frac{r_i}{r_j}\right)^{\rho_j}\left(\sum_{k\neq j} V_{kj}\right)^{\phi_j}. \tag{30}$$

Now all exporters crowd the shipments to j. Again we can solve for a reduced from trade cost that eliminates the endogenous volume.

Substitute (27) into (29) and substitute the result into (30). This yields, after simplification,

$$t_{ij} = \tau_{ij}\left(\frac{r_i}{r_j}\right)^{\rho_j}\left[\sum_{k\neq j} t_{kj}^{-\sigma}(r_k/r_j)^{-1}x_k m_j\right]^{\phi_j}. \tag{31}$$

We can simplify (31) by taking advantage of a relationship between exporter trade costs into destination j that is implied by (27):

$$\frac{t_{kj}}{t_{ij}} = \frac{\tau_{kj}}{\tau_{ij}}\left(\frac{r_i}{r_j}\right)^{\rho_j} \tag{32}$$

Multiply both sides of (32) by t_{ij} and substitute the result into (31). Simplify further to obtain:

$$t_{ij} = \tau_{ij}\tau_{-j}^{-\sigma\phi_j/(1+\sigma\phi_j)}\left(\frac{r_i}{r_j}\right)^{\rho_j/(1+\sigma\phi_j)}\left(\frac{r_i}{r_{-j}}\right)^{-\phi_j(1+\sigma\rho_j)/(1+\sigma\phi_j)}(x_{-j}m_j)^{\phi_j/(1+\sigma\phi_j)}, \tag{33}$$

where:

$$x_{-j} \equiv \sum_{k\neq j} x_k,$$

$$\tau_{-j}^{-\sigma} = \sum_{k\neq j}\tau_{kj}^{-\sigma}x_k/x_{-j},$$

$$r_{-j} = \left[\sum_{k\neq j}\frac{\tau_{kj}^{-\sigma}x_k}{\sum_{k\neq j}\tau_{kj}^{-\sigma}x_k}r_k^{1+\sigma\rho_k}\right]^{1/(1+\sigma\rho_j)}.$$

τ_{-j} is a CES index of bilateral trade costs into j facing all exporters except j where the weights are the exporter fixed effects. r_{-j} is a CES index of exchange rates excluding j's. The weights are $(\tau_{kj}/\tau_{-j})^{-\sigma}x_k/x_{-j}$, exporter fixed effect weights adjusted for the volume shifting effects of variation in τ_{kj} relative to its average τ_{-j}.

Interpreting (33), consider first the special case of $\phi_j \to 0 \Rightarrow t_{ij} \to \tau_{ij}(r_i/r_j)^{\rho_j}$. Reverting to iceberg trade costs, exchange rate passthrough acts like a tax on exports. Once volume effects on trade costs are active, the remainder of (33) applies. The rightmost term is a scale of activity effect. The two middle terms in relative exchange rates act intuitively: a rise in the bilateral exchange rate raises trade costs (it acts like an export tax) while a rise in the cross-rate r_i/r_{-j} lowers trade costs because the reduction in volume from i reduces congestion, conferring a cost reduction to all exporters to j. Moving leftward, the direct bilateral trade costs τ_{ij} are offset by the index of direct costs from all exporters into j, τ_{-j}.

Note that (33) retains the property that t_{ij} is decreasing in r_i if $\phi_j > \rho_j$, $\partial t_{ij}/\partial r_i > 0$, just as in the bilateral scale case. While cumbersome, (33) remains tractable in the simple way it brings in all third party effects as they affect the bilateral trade cost from i to j through scale effects.

5.2 Pricing to Market

There is ample evidence in the literature that firms sell identical goods to different markets at prices that differ by more than the trade cost differentials between them. This could be due to unobserved trade costs but also could reflect pricing to market by monopolistically competitive firms.

The standard monopoly pricing theory implies that profit maximizing firms mark up prices relative to costs using the inverse (demand) elasticity formula. Exchange rate changes shift the relative costs of serving various markets and can potentially change markups because the new equilibrium has changed elasticities of demand facing the firms in the various markets. With small numbers of monopolistic firms, pricing to market does produce effects that vary by market.

The firm's markup is derived from the profit maximizing condition that marginal revenue should be equal to marginal cost in each market. This yields the condition that the ratio of price to marginal cost should be equal to

$$1/(1 + 1/\epsilon) \tag{34}$$

where ϵ is the elasticity of demand facing the firm.

The CES demand system is the rationale for the structural gravity model. For CES demand the formula for the elasticity of demand facing firm h based in country i, selling in market j in some generic sector with superscript suppressed for clarity is given by:

$$\epsilon_{ih} = -\sigma(1 - s^j_{ih}) \tag{35}$$

where σ is the parametric elasticity of substitution among varieties, common to all markets, s^j_{ih} is the share of firm h from country i in total sales in market j, including sales of other firms based in i and all the firms not based in i.

A standard case in the monopolistic competition literature simplifies to the small firms case of $s^j_{ih} \to 0$. Applying specification (35) to markup formula (34) in this case yields $\sigma/(\sigma - 1)$, implying constant markups.

In contrast, more usefully for investigating pricing to market, with finite market shares in (35), elasticities of demand do vary across markets and thus so do markups. Substituting from (35) into (34) and simplifying for the general case yields markup formula

$$\frac{1 - s^j_{ih}}{1 - s^j_{ih} - 1/\sigma}. \tag{36}$$

In this situation, when costs change, as with an exchange rate change, the equilibrium shares of the firms will change and the markups given by (36) move in response. The markup is increasing the the share,[30] while the share presumably decreases with appreciation of i's exchange rate, hence *markups fall with appreciation.*

For many markets, this action of exchange rates on markups will be small (see the preceding footnote). With large values of σ, the markup factor given by (36) will be close to 1 no matter what the value of s^j_{ih}. A standard range of elasticities for goods markets is 6 to 10, implying small response of markups to exchange rates. (Services trade is too little explored to predict a range of elasticities, but these may be lower.) Also, when firm's shares

[30]The elasticity of the markup in (36) with respect to the share is

$$\frac{s_{ih}/\sigma}{(1 - s^j_{ih} - 1/\sigma)(1 - s_{ih})}.$$

are small, the markups are confined close to $\sigma/(\sigma-1)$ and won't have much movement in the data.

In the absence of firm level trade data the market shares are not observable and we could not draw inferences from aggregate data about changing markups based on the structure of (36). We attempted pretending that there was a monopoly middleman in each market who marked up according (36) replacing s_{ih}^j with the observable bilateral market share of all firms in i selling to j, $s_i^j = \sum_h s_{ih}^j$. Since markups are based on perceived elasticities we assumed that the middleman used lagged shares to calculate an elasticity of demand. This version of our model was unable to gain any traction on the data.

5.3 Stability with Increasing Returns

With increasing returns to scale, the supply of trade services function slopes downward. Stable equilibrium arises when the supply of trade services function cuts the demand function from below under the plausible dynamic adjustment assumption that quantity supplied adjusts toward quantity demanded. Consider the standard quantity adjustment analysis in $(\ln t_{ij}, \ln X_{ij})$ space with the familiar Marshallian scissors diagram (not drawn).

On the demand side, taking logs of the CES expenditure function (27) and suppressing irrelevant terms, the buyers' willingness to pay for trade services is given by

$$\ln t_{ij} = \frac{1}{1-\sigma} \ln X_{ij}. \tag{37}$$

On the supply side, taking logs of (28), suppressing irrelevant terms and using $\ln V_{ij} = \ln X_{ij} - \ln t_{ij}$ yields the cost of services supplied as

$$\ln t_{ij} = \frac{1}{1+\phi_j} \ln \tau_{ij} + \frac{\phi_j}{1+\phi_j} \ln X_{ij}. \tag{38}$$

The equilibrium defined by the intersection of (37) and (38) is locally stable under the quantity adjustment assumption if $0 > \phi_j/(1+\phi_j) > 1/(1-\sigma)$. Simplifying the rightmost inequality yields the stability condition $1 + \sigma\phi_j > 0$. QED.

With the constant elasticity structure imposed on supply and demand, the existence of a stable interior equilibrium depends on the vertical intercept of (37) lying above the vertical intercept of (38). Taking account of the suppressed constant term in (37) that includes the positive frictionless value of trade and the positive value of $\ln \Pi_i P_j$, the condition is ordinarily met, though a high enough constant term (suppressed) in (38) can violate it. (Technically, zero bilateral trade flows would result from the condition not being met. There are not many zeroes in our data, but the proportion rises with disaggregation.)