

Structural Estimation and the Border Puzzle

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June 2005

Abstract

Theory-consistent gravity equations are the focus of recent efforts to understand large international border effects. We propose an improved method for structurally consistent estimation of general equilibrium models of bilateral trade. Rather than reducing the general equilibrium through selective assumption and substitutions, we estimate the trade equilibrium in its extensive form. Direct estimation is preferable to current methods because it avoids biased structural inferences and properly accounts for relative income changes in counterfactual analysis. We use our method to revisit the claim that structural estimation solves the U.S.-Canadian border puzzle. We find this claim tenuous, as the proposed solution conflates the contribution of structural estimation with that of added U.S. data and an ad hoc assumption that U.S. and Canadian border costs are symmetric. We find little empirical support for the argument that the theory alone, as proposed, either reduces or explains a sizeable Canadian border effect.

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I. Introduction

One of the more interesting puzzles in the recent international trade literature is the unexpectedly large size of the estimated “border effect” in U.S.-Canada trade. Several papers, beginning with McCallum (1995), have demonstrated that cross-border trade between the U.S. and Canada is well below what should be expected, given intra-national trade volumes.¹ The border puzzle has potentially important consequences for trade policy, as it suggests the possibility that large, unmeasured trade costs substantially distort the geographic trade pattern, even in the case of two close neighbours like the U.S. and Canada. It also raises important methodological questions, because a consensus on the size of unmeasured trade costs requires agreed upon methods for translating missing trade into inferred trade costs.

Anderson and van Wincoop (2003) (henceforth AvW) make an important methodological contribution to this discussion. Echoing Bergstrand (1985), Hummels (2001), and Head and Meyer (2000), AvW argue that econometric estimates arising from OLS gravity models are biased because they ignore the role of relative prices (multilateral resistance, in AvW’s terminology) in determining the pattern of trade. AvW’s key methodological innovation relative to this earlier literature is to use their economic theory to calculate multilateral resistance terms directly, and to incorporate changes in multilateral resistance in their counterfactual analysis of borderless trade.²

While the methodological contribution of AvW (2003) is indeed important, the paper is perhaps better known for its claim to have provided a “solution” to the border

¹ See, for example, Helliwell(1996) , Helliwell and McCallum(1995), Anderson and Smith(1999), and Hillberry(1998)

² Eaton and Kortum (2002) conduct a similar exercise that uses a different economic model, and different data.

puzzle. In this paper, we dissect this claim. We find that AvW's pre-treatment of the U.S.-U.S. data significantly reduces estimated border effects. Changes in the relative sizes of U.S. and Canadian border effects arise primarily because AvW impose a common regression coefficient on the two data series. Even assuming a common coefficient, we find that AvW's failure to impose the full theoretic structure on their estimates biases border coefficients towards zero.

Our primary methodological contribution to the literature is to detail a method for estimating the full general equilibrium structure of the AvW model. Because their focus is on producing a "gravity"-like form for their estimation model, AvW collapse their multiple equation economic model into a two equation system. The coefficient restriction is imposed en route, and the role of the regression constant in the theory is obscured. Our method can replicate AvW's estimates, as well as highlight the impact of border cost asymmetries in counterfactual analysis when the full structure of the economic model is imposed in estimation. More importantly, our method improves on the AvW technique because we directly isolate key structural parameters, the representative consumer's taste for each region's variety. These must be held fixed in counterfactual analysis if the estimates are to be consistent with the proposed economic model.

We use our extensive form method to isolate the role of added theory in solving the border puzzle. To avoid conflating the effects of added theory with the inclusion of U.S. data, we estimate the structural model on Canadian data alone. Against an estimated border effect of 13.9 in the OLS model, we find structurally consistent estimates of the

Canadian border effect to be 12.8. These estimates suggest little empirical support for the claim that structurally consistent estimation solves the border puzzle.

The remainder of the paper proceeds as follows. Section II provides a summary of the AvW model, and a review of estimation strategies. Section III provides a brief review of the AvW data. Section IV provides results, and section V concludes.

II. Theory

AvW's full theoretic setup can be found in AvW (2003) or Feenstra (2004), and we give a brief review here. The model includes identical constant-elasticity-of-substitution (CES) regional preferences over geographically differentiated aggregate goods, iceberg trade costs, and trade separability. Trade separability allows us to focus on the trade equilibrium, abstracting the complications embedded in technologies, specialization, and industrial organization [AvW (2004) p.707]. We thus assume pure exchange in each region- i 's aggregate good, which has a fixed endowment, e_i^0 .

If t_{ij} is the iceberg trade cost factor and T_{ij} is the quantity shipped from i to j , the representative agent in region j maximizes,

$$U_j = \left[\sum_i \alpha_i^{(1-\sigma)/\sigma} \left(\frac{T_{ij}}{t_{ij}} \right)^{(\sigma-1)/\sigma} \right]^{\sigma/(\sigma-1)}, \quad (1)$$

subject to the budget constraint

$$Y_j = \sum_i FOB_i T_{ij}, \quad (2)$$

where FOB_i is the f.o.b. price of region- i output units. Y_j is nominal income, which is the product of the endowment quantity, e_j^0 , and the price of endowment units, FOB_j . The

α_i 's are taste parameters defining the representative consumer's preferences over outputs from different source regions. The substitution elasticity, σ , is take as exogenous in all of the analysis here and in AvW (2003).

The solution to the representative consumer's problem generates the nominal trade equation as a function of preferences, prices, incomes, and the CES price index;

$$FOB_i T_{ij} = Y_j \left(\frac{\alpha_i FOB_i t_{ij}}{CPI_j} \right)^{1-\sigma} . \quad (3)$$

The price index, CPI_j , is the true-cost-of-living index, which equals the unit expenditure function. Using the market clearance condition, and defining nominal aggregate (world) income as $Y^w \equiv \sum_j Y_j$, AvW (2003) transform equation (3) into

$$FOB_i T_{ij} = \frac{Y_i Y_j}{Y^w} \left(\frac{t_{ij}}{\Pi_i CPI_j} \right)^{1-\sigma} , \quad (4)$$

where

$$\Pi_i = \left(\sum_j \frac{Y_j}{Y^w} \left(\frac{t_{ij}}{CPI_j} \right)^{1-\sigma} \right)^{1/1-\sigma} . \quad (5)$$

Under symmetric trade costs ($t_{ij} = t_{ji}$), AvW show that $\Pi_i = CPI_i$ is a valid restriction, resulting in their gravity equation

$$FOB_i T_{ij} = \frac{Y_i Y_j}{Y^w} \left(\frac{t_{ij}}{CPI_i CPI_j} \right)^{1-\sigma} . \quad (6)$$

AvW refer to the CPI terms as they appear in the equation (6) as multilateral resistance indexes because they depend on all of the bilateral resistance terms with the source and destination regions. Furthermore, AvW show that a single price index can be represented as a function of all of the price indexes, the income shares, and the trade cost factors;

$$CPI_j^{1-\sigma} = \sum_i \frac{Y_i}{Y^w} \left(\frac{t_{ij}}{CPI_i} \right)^{1-\sigma} . \quad (7)$$

Equations (6) and (7) form the foundation for AvW's estimating strategy. Given data on incomes and trade flows, (6) and (7) can be used simultaneously to choose the t_{ij} and CPI_i that minimize an econometric objective.

The system (6) and (7) is also the foundation for AvW's argument that the theory solves the border puzzle. Specifically, (6) shows that trade flows between a given pair depend on the trade costs on that pair relative to the average trade barriers faced by the source and destination regions (through the CPI terms). Considering that Canada is small relative to the US and that there is a (symmetric) border charge, the size-adjusted trade within Canada relative to the size-adjusted trade between Canada and the US is much greater than the size-adjusted trade within the US relative to size-adjusted trade between the US and Canada. This reasoning explains higher relative Canadian border effects due to higher provincial (relative to state) CPI .³ This analytical explanation of the border puzzle is dependent on the specific restrictions (symmetric trade costs) imposed in the reduction of the more general theory to the estimating system, (6) and (7).

At this point, we add one important note on the interpretation of multi-lateral resistance within the structural economic model. Consider that the trade flows measured by the original trade equation (3) equal trade flows measured using the general gravity equation (4), which does not impose symmetric trade costs. Solving for the constructed index Π_i as a function of the problem's primitives yields:

³ AvW reframe the border puzzle to be the larger relative Canadian border effect, rather than the larger-than-expected size of the average border effect. When relative border effects are the issue, the implied difference in CPI , which generates different intra-national trade volumes, can explain the puzzle.

$$\Pi_i = (\alpha_i FOB_i)^{-1} \left(\frac{Y_i}{Y^w} \right)^{1/(1-\sigma)}. \quad (8)$$

Equation (8) reveals that, under observed incomes and a given (but arbitrary) choice of endowment units (which determines the FOB_i directly from measured Y_i), an estimated set of Π_i directly implies an estimated set of α_i . The geographic distribution of preferences is simultaneously being estimated through the implied α_i . Isolating the α_i is critical for theory consistent analysis of the effects of border removal because trade resistance attributed to the distribution of preferences has a very different effect than trade resistance attributed to border costs.

AvW (2003, p175) include an important footnote to their derivation of the simultaneous system, represented here as (6) and (7). AvW explain that border asymmetries cannot be identified by their regression. Although they explicitly assume symmetric borders, there are an infinite number of asymmetric combinations that yield the exact same set of equilibrium trade flows. The estimated border barrier is an average of the barriers in both directions. What we feel AvW omitted is a recognition that the calculated border effects depend critically on the degree of assumed asymmetry. AvW present one set of results as their solution to the border puzzle, when a wide variety of border effects is, in fact, supported by their econometric estimates. The key point is that assumptions about the degree of border symmetry change the degree to which observed border resistance is attributed to the pattern of α_i .

Finalizing our summary of AvW's theory we show the specific form of trade costs in terms of the regression coefficients. The estimated trade costs, t_{ij} , are decomposed into distance and border components. The form of t_{ij} is stylized to fit

conveniently into the log form of (6) including a set of regression coefficients ($a1$, $a2$, and $a3$), which measure how trade reacts to distance and border frictions. Bilateral distances are observed as d_{ij} , and a set of dummy variables is constructed to identify when a shipment involves a border. Allowing for potential asymmetric borders we construct δ_{ij}^{US-CA} to be one unless i is a state and j is a province, and we construct δ_{ij}^{CA-US} to be one unless i is a province and j is a state. Trade costs take the form

$$t_{ij} = d_{ij}^{(a1/(1-\sigma))} \left[\text{EXP}(a2/(1-\sigma)) \right]^{1-\delta_{ij}^{US-CA}} \left[\text{EXP}(a3/(1-\sigma)) \right]^{1-\delta_{ij}^{CA-US}}. \quad (9)$$

Consistent with AvW's notation, $a1$ is a measure of the product of the distance elasticity and $(1-\sigma)$. The border coefficients ($a2$ and $a3$) are measures of the product of the log border costs, $\ln(b_{ij})$, and $(1-\sigma)$, where the border cost, b_{ij} , is one plus the tariff equivalent of the border barrier on shipments from i to j . AvW's model does not include $a3$ because symmetry in trade costs requires $a2 = a3$.

Estimation Methods:

Our empirical exploration of the impact of structural estimation on the border puzzle includes three different approaches to the data: an OLS gravity specification similar to McCallum (1995), AvW's non-linear estimation model, and extensive form estimation of the structural general equilibrium. We relate each of these approaches to the economic model proposed by AvW.

McCallum treats the gravity model as an empirical regularity, and not necessarily as the outcome of a theoretic model with firm micro-foundations. He estimates the following OLS regression

$$\ln(FOB_{i,T_{ij}}) = \beta_0 + \beta_1 \ln Y_i + \beta_2 \ln Y_j + \beta_3 \ln d_{ij} + \beta_4 HOME + \varepsilon_{ij}, \quad (10)$$

where the β are regression coefficients, and HOME is a dummy variable taking the value of one for intra-national (Canadian) flows, and zero for cross-border flows. In the context of the log-linear model, McCallum's estimated coefficient $\beta_4=3.09$ implies 20+ times more trade within Canada than across the U.S.-Canada border.

AvW discount these estimates because the *CPI* terms in (6) are absent from the model. If these terms are correlated with FOB_iT_{ij} , as AvW's theory suggests they should be, then McCallum's estimate of β_4 is biased.⁴ AvW show that (6) and (7) can be estimated as a system, with the *CPI* calculated simultaneously (taking as given that the theory is correct, and imposing symmetric border coefficients).

Calculating *CPI* terms is not the only additional structure AvW's impose, relative to the McCallum specification; they also restrict the income coefficients (β_1 and β_2) to 1. Rather than constraining these coefficients in estimation AvW simply construct a new variable that enters the left-hand side of their regressions:

$$z_{ij} = \ln \left(\frac{FOB_iT_{ij}}{Y_iY_j} \right). \quad (11)$$

AvW's estimation method minimizes the sum of squared deviations between observed z and fitted values \tilde{z} . Let the indexes s and t indicate the econometric sample, which is a subset of the set of potential bilateral pairs; $\{(s,t)|s \in I, t \in J\}$.⁵ From equations

⁴ It is important to understand that AvW have not offered any proof that McCallum's OLS model is misspecified, though they are sometimes understood that way. AvW have simply imposed their preferred structure on the estimation, and observed a different estimate for β_4 . This should not be seen as direct evidence contradicting the OLS specification. One of our purposes is to show that AvW's lower average border effect estimates are due, in large part, to innovations other than the added theory. That said, we are quite sympathetic to AvW's argument that structural estimation is preferable to OLS if one is specifically interested in inferring structural parameters like trade costs.

⁵ Following AvW, the full set of bilateral pairs is reduced by flows that do not have observations, flows that are observed to be zero, and any measured internal flows.

(6) and (9) we construct AvW's fitted values, \tilde{z}_{st} , as a function of the estimated parameters and the multilateral resistance indexes:

$$\tilde{z}_{st} = -\ln(a_0 Y^w) + a_1 \ln(d_{st}) + a_2 (1 - \delta_{st}^{US-CA}) (1 - \delta_{st}^{CA-US}) - \ln CPI_s^{1-\sigma} - \ln CPI_t^{1-\sigma} \quad (12)$$

AvW estimate the first term on the right hand side of (12) as a free intercept parameter k , where their theory suggests the restriction $k = -\ln(Y^w)$. We introduce the new parameter a_0 to measure the degree to which aggregate income is misrepresented in AvW's regression relative to the theoretic restriction $a_0 = 1$. Distances and the border dummies are observed, but the multilateral resistance terms are problematic because they depend on the estimated parameters. Using equations (7) and (9) these are given by

$$CPI_j^{1-\sigma} = \sum_i \left[\frac{Y_i}{Y^w CPI_i^{1-\sigma}} \text{EXP} \left(a_1 \ln(d_{ij}) + a_2 (1 - \delta_{ij}^{US-CA}) (1 - \delta_{ij}^{CA-US}) \right) \right] \quad (13)$$

AvW's estimation procedure involves minimizing the squared differences between z_{st} and \tilde{z}_{st} choosing values for the parameters a_0 , a_1 , a_2 , and the $CPI_j^{1-\sigma} \forall j$ subject to the J constraints indicated by (13). This is a relatively transparent non-linear programming problem that is easily solved with modern computational software.⁶

The AvW estimation procedure minimizes the sum of the squared deviations between observed and fitted flows, subject to constraints defined by the multi-lateral resistance terms. The economic model's equilibrium conditions are reduced, via substitution, to generate the estimation procedure. The relevant substitutions can only be accomplished under specific restrictions. Our non-linear programming technique allows us to generalize the system so we can examine AvW's restrictions. Rather than

⁶ We use GAMS software to solve the non-linear programs in this paper (www.gams.com).

eliminating structural parameters and behavioural equations through substitution, our non-linear program includes the full general-equilibrium system as a set of side constraints.⁷

The AvW general equilibrium is conveniently represented by $4n$ conditions, where n is the number of regions. From utility maximization we set the consumer price indexes equal to the unit expenditure functions in each region:

$$CPI_j = \left(\sum_i (\alpha_i FOB_i t_{ij})^{1-\sigma} \right)^{1/(1-\sigma)}. \quad (14)$$

The next set of conditions require market clearance for the region-specific commodities:

$$e_i^0 - \sum_j \left(\frac{Y_j}{FOB_i} \left[\frac{\alpha_i t_{ij} FOB_i}{CPI_j} \right]^{1-\sigma} \right) = 0. \quad (15)$$

We might also specify market clearance in the composite commodity:

$$U_i CPI_i = Y_i, \quad (16)$$

although this condition is not necessary as the utility index follows recursively from the solution to the other equilibrium conditions.⁸ The final equilibrium condition is that income for each region equals the product of the endowment quantity and the f.o.b. price:

⁷ More generally the technique is considered a Mathematical Program with Equilibrium Constraints or MPEC. Because we can rule out corner solutions, however, the problem reverts to the special case of a non-linear program. MPECs are usually applied to simulation models when alternative policy instruments are balanced against one another to maximize a social welfare function, but conceptually one can use the same technique to find a set of calibration parameters that minimize an econometric objective. We use GAMS software to estimate the model and compute the counterfactual equilibrium. All programs are available on request.

⁸ Given the small size of the non-linear equation system in question it is not problematic to maintain equation (16) in the computational problem. We do not perform welfare analysis in this study, however, so one might ask why (16) is included at all. We include (16) because it is consistent with the generalized template for computing Arrow-Debreu equilibria advocated by Rutherford (1999), and Markusen (2002). In computation (14), (15), and (16) are variational inequalities with associated complementary slack variables (as in a Kuhn-Tucker condition). The variable associated with equation (16) is the *CPI*. So the condition reads, supply of the composite might exceed demand if the price of the composite is zero, and if the price of the composite is positive then supply must equal demand.

$$Y_i = FOB_i e_i^0. \quad (17)$$

Together, conditions (14) through (17) are a complete multi-region general equilibrium that can be solved numerically for relative prices, regional utility, and income levels.⁹ In the estimation procedure the system yields a unique solution under an explicit price and utility normalization. Benchmark income and f.o.b. prices are determined by choosing regional output units such that measured income equals the quantity endowment. From (17) this normalizes $FOB_i = 1, \forall i$ at the benchmark.

Additionally, one of the n CES distribution parameters must be pinned down to determine the utility normalization (the structural estimation only indicates relative tastes at the calibration point). For consistency with AvW's benchmark normalization our estimation adopts one of their reduced-form side constraints (the one for Alabama):

$$CPI_{Alabama}^{1-\sigma} = \sum_i \left(\frac{Y_i}{\sum_j Y_j} \left[\frac{t_{Alabama,i}}{CPI_i} \right] \right)^{1-\sigma}. \quad (18)$$

This is an arbitrary local normalization, however, and any other numeric specification of one of the benchmark CPI_i or α_i is equally valid.¹⁰

The general-equilibrium fitted (benchmark) trade flows are taken directly from (3). Using (11) to transform (3), returns \hat{z}_{ij} (which is comparable to AvW's fitted value \tilde{z}_{ij}):

$$\hat{z}_{ij} = -\ln(Y_i) + (1-\sigma) \left[\ln(\alpha_i) + \ln(t_{ij}) + \ln(FOB_i) - \ln(CPI_j) \right]. \quad (19)$$

⁹ With n regions, the general equilibrium includes $4n$ equations (14, 15, 16, and 17) and $4n$ unknowns (Y_i , U_i , CPI_i , FOB_i). Only relative prices are determined, however, so one of the market clearance conditions is removed (by Walras' law) and the associated price is assigned the duty of numeraire.

¹⁰ The particular normalization adopted replicates the absolute scale of AvW's reported multi-lateral resistance.

Using equation (9) we replace t_{ij} everywhere (in the general-equilibrium) with its definition in terms of the regression coefficients $a1$, $a2$ and $a3$.

To estimate the structural model we minimize the sum of squared deviations between the observed z_{st} and the fitted \hat{z}_{st} . The objective is given by

$$\sum_s \sum_t [z_{st} - \hat{z}_{st}]^2. \quad (20)$$

Our estimation procedure minimizes (20) subject to (14), (15), (16), (17) and (18) at the point of observed incomes (and $FOB_i = 1, \forall i$).¹¹ The regression coefficients ($a1$, $a2$ and $a3$), the calibrated taste parameters (α_i), and the benchmark levels of the equilibrium variables (CPI_i and U_i) are determined simultaneously in the solution. In this sense our procedure is both an estimation and calibration of the AvW model.¹² We term this procedure an extensive-form estimation of the proposed general equilibrium, because all equilibrium conditions are satisfied in the programming problem and all calibration parameters are directly estimated.

In order to show that our approach is consistent with AvW's reduced estimation model, we replicate their coefficient estimates within our extensive-form procedure. AvW's failure to maintain a structural interpretation of their intercept, however, indicates that $\hat{z}_{ij} \neq \tilde{z}_{ij}$ when $a0$ is not equal to one. We replace the fitted value \hat{z}_{ij} in the objective function (20) with \tilde{z}_{ij} and find AvW's coefficients in the solution to our extensive-form

¹¹ Of course, whenever we impose direct observations of variables on the system (observed incomes, for example) some of the equations become redundant. We do not remove the redundancy because the extensive-form representation allows us to seamlessly transition from estimation to theory-consistent general-equilibrium counterfactual experiments, in which the estimated parameters are fixed and the variables are free.

¹² Calibration requires data on the elasticity of substitution between regional varieties. For comparability we simply follow AvW and adopt 5. AvW point out that different elasticity assumptions do not affect the regression coefficients, but do affect counterfactual analyses.

estimation. We also adopt AvW's non-linear program and, restricting a_0 to unity, find our central coefficients from the extensive-form estimation under symmetry. The two procedures are identical under a consistent set of assumptions about symmetry and the size of aggregate income in the objective function.¹³

Although the two procedures are consistent under specific restrictions, the novelty of our approach is in its generality and transparency. The procedure proposed by AvW cannot directly accommodate asymmetries nor does it directly reveal the estimated demand system (implied by the distribution of α_i). Furthermore, the reduction in the equilibrium conditions that AvW make to arrive at their non-linear program is specific to the form of their particular general equilibrium. The procedure that we propose has any number of applications beyond the specific model that we examine. We propose a general approach to non-linear structural estimation in which one carefully formulates a computable general equilibrium and then chooses calibration parameters that minimize a given econometric objective function.

III. Data

An important difference between the McCallum and AvW estimates is the inclusion of U.S.-U.S. shipment data in AvW's estimating sample. We are skeptical of the premise that these data can be usefully combined. The U.S. and Canadian series differ in the manner they are collected and in the activity they measure. AvW employ a

¹³A key component of estimation is the measurement of the second moments. To find the standard errors in the non-linear estimations, we generate an empirical distribution of the coefficients using 1000 bootstrap draws from the data. Rounding to two decimals, our bootstrap procedure reproduces the measured robust standard errors reported by AvW (these are asymptotically equivalent measures). Matching both the first and second moments from the AvW procedure gives us confidence that our extensive-form estimation is identical to AvW's estimation under their specific restrictions.

scalar correction to the US data, and pool the two data series.¹⁴ Imposing a common regression coefficient on the pooled data reduces the size of the implied Canadian border effect, relative to its US counterpart. This section offers a brief description of the data, and of AvW's pre-estimation adjustment. We show later that data treatment significantly affects conclusions about the border puzzle.

The Canadian data used by McCallum reflect a traditional understanding of trade activity; bilateral flows represent movements from province of manufacture to province of consumption (or substantial material transformation).¹⁵ AvW append an updated Canadian sample with Commodity Flow Survey (CFS) data on U.S. interstate shipments. CFS data were designed to measure freight activity; goods movements from manufacturer to wholesaler and from wholesaler to retailer are reported as 2 distinct shipments.

In an effort to account for the differences between the CFS and Canadian data, AvW employ a scalar correction to the U.S. data as a preliminary step in their analysis. They reduce all interstate flows by 48 percent, the share of wholesale shipments in total U.S. goods shipments. This calculation implicitly assumes that wholesale and non-wholesale shipments are equally sensitive to geographic trade frictions. Using shipment level CFS data, Hillberry and Hummels (2003) find that wholesale shipments travel shorter distances and are less likely than other shipments to cross state borders. This suggests that AvW may have overcorrected for the presence of wholesale shipments in

¹⁴ Proper inference might control for structural shifts across each sample. Unfortunately, the experimental treatment of interest is often perfectly correlated with one of these sample breaks. For example, cross-border data often comes from a different source than data on internal trade. This begs the important question of whether one is measuring economic phenomena or data collection phenomena with border dummies.

¹⁵ While conceptually more appealing, the Canadian data have an important shortcoming; they rely heavily on imputation from several different data sources.

inter-state flows (those CFS flows that are included in their sample). The potential overstatement of inter-state flows is important because a substantial portion of AvW's argument relies on the observation of substantial asymmetries in the Canadian relative to US border effects. AvW hypothesize that large countries experience smaller border effects than small countries. In this context, an exaggerated reduction in observed interstate trade directly works in favour of the maintained hypothesis.

IV. Estimation Results

AvW's claimed solution to the border puzzle rests on the conflation of four effects: the inclusion of selected theoretic restrictions derived from their economic model, the commingling of U.S. and Canadian data series, the imposition of a common regression coefficient in estimation, and the assumption of symmetric trade costs in counterfactual analysis. While AvW highlight the contribution of additional theory, we find considerable evidence that the other effects contribute significantly to AvW's findings. We also find that imposing the full structure on the estimates generates larger border coefficients than AvW report. In this section we attempt to disentangle these effects by reporting the results of a variety of econometric specifications and counterfactual analyses.

We begin with OLS estimates that highlight the relationship between the pooling of the data series and the coefficient restriction. We regress AvW's transformed trade flows, z_{st} , on logged distance and borders for two subsamples of the data. In column 1, where U.S.-U.S. flows are excluded from the sample (as in McCallum [1995]), the border coefficient is quite large, -2.63. In column 2, where U.S.-U.S. flows are included (and intra-Canadian flows excluded), the border coefficient is considerably smaller in absolute

magnitude, -0.49.¹⁶ Using the linear model to conduct counterfactual analysis, these estimates imply border effects of 13.9 for Canada and 1.63 for the U.S.¹⁷

AvW argue that the difference between the two countries' OLS border effects is likely due to cross country differences in multilateral resistance. They do not, however, separately assess the effects of their imposition of a single regression coefficient on the pooled sample. We estimate an OLS specification over the whole sample, imposing a common BORDER coefficient. This exercise isolates the effect of imposing symmetry on the pooled data, without conflating these with the effects of imposing AvW's estimation method.

The results are reported in column (3). The BORDER coefficient (-0.71) is, in effect, a weighted average of the coefficients in columns (1) and (2). Pooling the data and imposing a common coefficient generates a much smaller BORDER coefficient than is observed in the Canadian data alone. These estimates imply an OLS border effect of only 2.03 in the pooled data; McCallum would have calculated substantially smaller border effects if he had used AvW's data and imposed a common border coefficient.

The final three rows of Table 1 shows that the symmetry restriction generates systematic errors: in column (3), fitted intra-Canadian flows are too small, and fitted U.S.-U.S. flows are too large. Subsequent estimates reveal that the contribution of AvW's theory is to reduce (but not eliminate) the size of these systematic errors. The

¹⁶ These regressions mimic the regressions AvW report in their Table 1 under their restricted case of unitary income coefficients. We do not need to restrict the coefficients because we immediately adopt AvW's transformed dependent variable, z_{ij} . We also immediately adopt the form of the dummy that AvW use in their non-linear regressions so our OLS border coefficients are negative.

¹⁷ In the log-linear model, border effects are calculated as the inverse log of the BORDER coefficient. The OLS estimates are subject of course, to AvW's critique that the log-linear model is mis-specified and that the OLS counterfactual analysis does not fully account for trade diversion associated with national border costs. We report these merely to provide a benchmark estimate against which to show that the AvW theory, isolated from data treatment issues, does little to solve the border puzzle.

theory-consistent border effect estimates we report in the subsequent section are *larger* than the estimates in the linear model.

The estimates in columns (1)-(3) are subject to AvW's critique that they do not properly control for multilateral resistance. Feenstra (2004) and Hummels (2001) have argued that this concern can be dealt with effectively by including origin and destination fixed effects.¹⁸ Column (4) estimates the fixed effects regression with a common border coefficient, replicating the results reported in Feenstra.¹⁹ Feenstra uses these estimates to calculate a theory-consistent *average* border effect of $e^{1.55} = 4.7$, an increase over the OLS estimate with a common coefficient.

In order to isolate the effects of AvW's pre-adjustment of U.S.-U.S. data on their estimates, we re-estimate the fixed effects regression, using the raw CFS data to measure U.S.-U.S. flows. The results are reported in column (5). The estimated BORDER coefficient is significantly larger in absolute magnitude²⁰ In our view, it is difficult to justify pooling across these two data series. Our point here is simply to emphasize that, even if pooling is deemed appropriate, AvW's scalar adjustment to the data is not innocuous, and significantly reduces the magnitude of the estimated border coefficient.

Returning to the sample with scaled U.S.-U.S. data , we report the results from our non-linear extensive-form estimation in Table 2.²¹ The first column reports the

¹⁸ The fixed effects should remove the confounding effect of spatial variation in aggregate price levels, without affecting the coefficient estimates on geographic frictions.

¹⁹ The estimated errors for each sub-sample are zero in the fixed effects specification because the fixed effects absorb any systematic differences in bilateral flows..

²⁰ Experimenting with different scaling procedures generates intermediate values of the BORDER coefficient that are (roughly) proportional to the scaling.

²¹ We also performed non-linear extensive-form estimation on samples that excluded the US-US flows and that used the raw CFS data under alternative symmetry assumptions. The full results from these regressions are available on request. The pattern is as expected: AvW's correction decrease measured border coefficients. The border coefficient under the full theory and symmetry when the US-US flows are

results from our replication of AvW. The border coefficients a_2 and a_3 are constrained to be equal, and a_0 is allowed to deviate from its theory-consistent value. Our estimates of the distance and border coefficients match AvW's.

One might find the estimate of a_0 , which is statistically different from one, as definitive evidence against the structural model in this application. Alternatively, one might take the theory seriously and restrict the value of a_0 to one. AvW do neither, and, from a structural perspective, their estimated distance and border coefficients are biased toward zero. Essentially, if one allows "right-hand-side" aggregate income to be 3.55 times larger than it is observed to be, much of the observed missing trade is absorbed in the intercept. This artificially reduces the burden on the trade-cost coefficients to reduce interregional trade relative to income (because GDP consumed within a region is not included in the sample).

The structural bias in the fitted flows is evident in our calculation of the mean errors on the sub-samples. On average the predicted values implied by AvW's specification are 144% to 121% percent higher than measured z_{st} , depending on the subsample. The calculated mean errors are large because we evaluate them using the theory consistent fitted \hat{z} . AvW report substantially smaller mean errors on the \tilde{z} , which in their case cannot be consistent with the proposed general equilibrium at observed income levels. Our method is preferable because in a consistent general-equilibrium comparative-statics experiment that relies on a set of estimated distance and border elasticities, one must start with a benchmark consistent with \hat{z} (regardless of the

excluded is 2.28 with a standard error of 0.34, and the border coefficient under the full theory and symmetry when the raw US-US flows are used is 2.50 with a standard error of 0.08.

estimated a_0). Again we point out that a_0 has no place in the theory, as proposed, and cannot be inserted into the general equilibrium without violating an adding-up condition.

We correct the structural bias in AvW's coefficients in column 2 by restricting the value of a_0 to unity. The coefficients in column 2 are the true non-linear structural estimates for AvW's two-country model under the maintained assumption of a common BORDER coefficient. Imposing consistency on the constant term increases the absolute magnitude of both the distance and border coefficients. Although the specification in column 2 significantly reduces the structural bias, notice that the calculated average errors on the sub-samples are all negative. This indicates that the best-fit regression, subject to imposing the full theory, overstates trade flows – especially for the intra-national sub-samples.

We use the regression that restricts the intercept to its theory consistent value as a point of departure for exploring the implications of potentially asymmetric border charges. In our explicitly structural framework, asymmetric border charges can be expressed as differences in the regression coefficients a_2 and a_3 . Columns 3 and 4 of Table 3 show the results of respectively constraining the charge on U.S.-to-Canada shipments (a_2) and Canada-to-U.S. shipments (a_3) to zero. As AvW point out (in footnote 11 of their paper, p. 175, 2003), the structural model cannot identify asymmetries; the degree of asymmetry must be assumed.²² The only element determined in the regression is average border resistance, and in each of the regressions shown in columns (2), (3), and (4) the fitted trade flows are identical. What AvW do not show is

²² AvW explain that the theory they propose cannot distinguish, empirically, symmetric border barriers from asymmetric barriers that generate the same average barrier. We use this property to show the importance of potential asymmetries on measured multi-lateral resistance. We must use the strategy of adopting the theory consistent \hat{z} in the objective in order to look at asymmetric trade costs, because $\tilde{z} \neq \hat{z}$ if there are asymmetric border charges (even if a_0 is restricted to one).

the dramatic impact these potential asymmetries have on measured multi-lateral resistance. Calculating average multi-lateral resistance using AvW's method (see the footnote to their Table 3, p. 183, 2003), we find that the ratios of average Canadian-to-U.S. multi-lateral resistance range from 0.56 to 22.5 in our experiments.²³ Depending on the degree of asymmetry assumed almost any ratio of the Canadian-to-U.S. multi-lateral resistance can be obtained.

The final column of Table 2 reports estimates of the structural model with U.S.-U.S. data excluded (assuming border cost symmetry). This exercise is AvW's sensitivity analysis, except that we impose the theory consistent constant.²⁴ The border coefficient in these estimates is considerably larger than in the entire sample, and lies well outside the 95% confidence interval in the pooled-sample estimates.

We further explore the implications of border charge asymmetries and interstate data treatments by examining the full general-equilibrium border effects implied by the non-linear estimations. We conduct counterfactual analysis of border removal in a manner consistent with the structural model; the values of the calibration parameters are locked at their point estimates and the border costs are set to zero.²⁵ The non-linear

²³ AvW (2004) distinguish between "inward" and "outward" multi-lateral resistance. The figures we report here are inward multi-lateral resistance, calculated from the estimated CPI_i , which is the appropriate indicator of the trade costs in our view. We interpret outward multilateral resistance, indicated by the Π_i , as an indicator of the implied preference for region- i output, relative to the income distribution, [see equation (8)] rather than an index of trade costs. Border asymmetries indicate different balances across inward and outward resistance (and different comparative statics solutions) so we feel it is best to report and summarize the α_i directly. Analysis of the implied α_i from each of our regressions is available on request.

²⁴ AvW find no significant effect of removing U.S.-U.S. data on the border coefficient, but this is because their regression constant shifts when the subsample is removed. AvW's claimed solution to the border puzzle posits that the theory explains differences in the intensity of intra-Canadian and intra-U.S. trade flows. In that context a shifting regression constant is evidence against the claim.

²⁵ In addition, a numeraire must be chosen for consistent aggregation across nominal trade flows, of the differentiated commodities, at solutions away from the benchmark. We arbitrarily chose f.o.b. output from

system (14) through (17) is then solved numerically to reveal the new equilibrium. Nominal trade flows are directly recovered by evaluating (3) at the new equilibrium. This general-equilibrium technique is preferable to the calculations of borderless trade performed by A-vW.²⁶ The border effect for each country is calculated using the following:

$$BorderEffect = \left(\frac{BB_{intranational} / NB_{intranational}}{BB_{international} / NB_{international}} \right), \quad (21)$$

where *BB* indicates nominal trade volumes in the border-barrier benchmark and *NB* indicates nominal trade volumes in the no-border-barrier counterfactual. Our general equilibrium border effect estimates are reported in rows 8 and 9 of Table 2.

The Canadian border effect of 13.9 reported in Table 1 is the appropriate benchmark against which to judge a claim that theory has solved the border puzzle. A-vW report a border effect of 10.5 for Canada when the regression constant is freed and the reduced model is used for counterfactual analysis. The general-equilibrium equivalents to these estimates are reported in Table 2 as 8.3. Applying both structure and symmetry reduces the Canadian border effect further to 7.6, reported in column (2). Estimates in columns (3) and (4) show that theory-consistent border effects hinge critically on the degree of assumed border cost asymmetry.

A more appropriate comparison with the 13.9 OLS border effect compares estimations over equivalent samples -- the sub-sample that does not include the U.S.

Alabama as the unit of measure. This numeraire choice does not affect our reported border effects, because this “ratio of ratios” nets out relative price changes.

²⁶ As Feenstra (2004, p.160, footnote 12) points out, AvW’s method treats regional incomes as unaffected by changes in the border charge. These nominal income changes are in fact substantial, and actually work in favour of reducing Canadian border effects. Canadian relative income increases substantially in the counterfactual and this acts to support inter-provincial trade relative to imports from the US.

interstate trade data.²⁷ Consistent structural estimation on the sub-sample reduces the Canadian border effect from 13.9 to 12.8. In other words, the contribution of the theoretical model, rigorously applied, generates a mere 8 percent reduction in the Canadian border effect, assuming border cost symmetry.

V. Conclusion

AvW argue that the inclusion of theoretic structure in estimation and counterfactual analysis solves the border puzzle posed by McCallum. We suggest a number of important qualifications to this claim. As a transparent comparison with McCallum, we show that AvW's adoption of a common border coefficient substantially reduces the estimated Canadian border effect. This effect is magnified by AvW's pre-estimation treatment of U.S. interstate flow data. We note that the AvW procedure does not account for an important adding up constraint implicit in their economic model, and show that imposing this additional bit of the theory raises the border coefficient even further. We estimate the structural model on the Canadian sample alone, and show that theory-consistent border effects are only marginally smaller than estimates from the OLS model.

Our work makes a methodological contribution to the structural estimation literature, detailing a procedure for fitting a general equilibrium model to bilateral trade data. While we focus here on the AvW model, our approach can be applied more broadly to many general equilibrium trade models. In the context of the specific application, our approach improves on the AvW procedure because 1) it allows us to consider border cost symmetry, and 2) it isolates structural parameters that are necessary for theory-consistent

²⁷ The full regression results from the sub-sample estimations are available on request.

counterfactual analysis. We show that AvW's claim that multilateral resistance is necessarily larger in Canada hinges on the symmetric border cost restriction.

Overall, the indication from our non-linear estimates and general equilibrium simulations is that the estimated coefficients and measured border effects are sensitive to potential asymmetries and the treatment of the added U.S.-U.S. data. Our alternative treatments generate border effects within the range of the OLS estimate, and we find little empirical support for the argument that the theory alone, as proposed, either reduces or explains a sizeable Canadian border effect.

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Table 1. OLS estimates

	(1)	(2)	(3)	(4)	(5)
<i>Constant</i>	-15.47 (0.10)	-17.60 (0.02)	-17.38 (0.04)		
$\ln(d_{ij})$	-1.35 (0.07)	-1.09 (0.04)	-1.06 (0.04)	-1.25 (0.04)	-1.25 (0.04)
<i>BORDER</i>	-2.63 (0.11)	-0.49 (0.06)	-0.71 (0.06)	-1.55 (0.07)	-1.88 (0.07)
R^2	0.53	0.47	0.42	0.66	0.71
N	679	1421	1511	1511	1511
AvW-adjusted US data?	Yes	Yes	Yes	Yes	No
Fixed effects	No	No	No	Yes	Yes
Sample	US-US excluded	CA-CA excluded	Full sample	Full sample	Full Sample
OLS border effect	13.9	1.63	2.03	4.71	6.55
Mean error on sub-samples of the data					
CA-CA flows	0.00		1.95	0.00	0.00
US-CA; CA-US	0.00	0.00	0.00	0.00	0.00
US-US		0.00	-0.21	0.00	0.00

The dependent variable is z_{ij} . Huber-White robust standard errors in parentheses. All coefficient estimates are significant at the 1% level. OLS border effect calculated as $\exp(-\text{BORDER})$. In columns 4 and 5, this estimate can be interpreted as a theory-consistent estimate of the *average* U.S. and Canadian border effect; see Feenstra (2004).

Table 2. Structural estimation of the AvW model

	AvW Replication: ($a2=a3$)	True structural estimation: ($a0=1$)	No border charge on Canadian Imports: ($a2=0$)	No border charge on Canadian Exports: ($a3=0$)	Structural estimation excluding U.S.-U.S. data
	(1)	(2)	(3)	(4)	(5)
$a0$ = (multiple on aggregate income)	3.55 (0.13)	1	1	1	1
$a1$ = $(1-\sigma)\rho$	-0.79 (0.03)	-1.44 (0.02)	-1.44 (0.02)	-1.44 (0.02)	-1.26 (0.15)
$a2$ = $(1-\sigma) \ln b_{US-CA}$	-1.65 (0.08)	-1.85 (0.09)	0	-3.69 (0.18)	-2.28 (0.34)
$a3$ = $(1-\sigma) \ln b_{CA-US}$	-1.65 (0.08)	-1.85 (0.09)	-3.69 (0.18)	0	-2.28 (0.34)
N	1511	1511	1511	1511	679
Sum of Squared Residuals	1699.74	2262.84	2262.84	2262.84	1525.08
Ratio of Average <i>MLR</i> : (CA/US)	3.17	3.55	0.56	22.50	3.60
Theory consistent border effects					
Canada	8.3	7.6	5.9	9.9	12.8
U.S.	3.1	4.9	6.4	3.7	6.9
Mean errors on sub-samples of the data					
CA-CA	-1.44	-0.58	-0.58	-0.58	-0.99
CA-US, US-CA	-1.32	-0.05	-0.05	-0.05	-0.04
US-US	-1.21	-0.27	-0.27	-0.27	

Bootstrap standard errors. All unrestricted coefficients significant at the 1% level. Theory consistent border effects calculated by solving the general equilibrium system for the removal of border costs, and calculating a ratio of ratios: intra-national border impeded trade/no border trade divided by international border-impeded trade/no border trade. Counterfactual analysis assumes an elasticity of substitution of 5.