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Gravity with Gravitas: A Solution to the Border Puzzle*

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INTRODUCTION

- AW show that estimated gravity equations in John McCallum's (1995) do not have a theoretical foundation.
- **Two important implications:**
  - First, estimation results are biased due to omitted variables
  - Second, one cannot conduct comparative statics exercises
- AW develop a method that consistently and efficiently estimates a theoretical gravity equation

Introduction…

- The "border puzzle" ---
  - John McCallum (1995) finds that the U.S.-Canadian border led to trade between Canadian provinces that is a factor 22 (2,200 percent) times trade between U.S. states and Canadian provinces.
- Using 1993 data, AW find that borders reduce trade between the United States and Canada by 44 percent, while reducing trade among other industrialized countries by 29 percent

I. The McCallum's Equation

- McCallum (1995) estimated the following equation:

$$\ln x_{ij} = \alpha_1 + \alpha_2 \ln y_i + \alpha_3 \ln y_j + \alpha_4 \ln d_{ij} + \alpha_5 \delta_{ij} + \varepsilon_{ij} \qquad (1)$$

δ_{ij} is a dummy variable equal to one for interprovincial trade and zero for state-province trade.

- McCallum estimated this equation using data for all 10 provinces and for 30 states that account for 90 percent of U.S.-Canada trade.

I. McCallum's…

- ***Table 1*** : (first three columns) AW uses McCallum's approach with similar data set for 1993
- Also reports results when estimating equation (1) from the U.S. perspective, (2) Pooling all data
- Final three columns--- the same results after imposing unitary coefficients on the GDP variables.

TABLE 1—MCCALLUM REGRESSIONS

Data	McCallum regressions			Unitary income elasticities		
	(i) CA–CA CA–US	(ii) US–US CA–US	(iii) US–US CA–CA CA–US	(iv) CA–CA CA–US	(v) US–US CA–US	(vi) US–US CA–CA CA–US
Independent variable						
ln y_i	1.22	1.13	1.13	1	1	1
	(0.04)	(0.03)	(0.03)			
ln y_j	0.98	0.98	0.97	1	1	1
	(0.03)	(0.02)	(0.02)			
ln d_{ij}	−1.35	−1.08	−1.11	−1.35	−1.09	−1.12
	(0.07)	(0.04)	(0.04)	(0.07)	(0.04)	(0.03)
Dummy–Canada	2.80		2.75	2.63		2.66
	(0.12)		(0.12)	(0.11)		(0.12)
Dummy–U.S.		0.41	0.40		0.49	0.48
		(0.05)	(0.05)		(0.06)	(0.06)
Border–Canada	16.4		15.7	13.8		14.2
	(2.0)		(1.9)	(1.6)		(1.6)
Border–U.S.		1.50	1.49		1.63	1.62
		(0.08)	(0.08)		(0.09)	(0.09)
$\bar{R}^2$	0.76	0.85	0.85	0.53	0.47	0.55
Remoteness variables added						
Border–Canada	16.3		15.6	14.7		15.0
	(2.0)		(1.9)	(1.7)		(1.8)
Border–U.S.		1.38	1.38		1.42	1.42
		(0.07)	(0.07)		(0.08)	(0.08)
$\bar{R}^2$	0.77	0.86	0.86	0.55	0.50	0.57

Notes: The table reports the results of estimating a McCallum gravity equation for the year 1993 for 30 U.S. states and 10 Canadian provinces. In all regressions the dependent variable is the log of exports from region i to region j. The independent variables are defined as follows: y_i and y_j are gross domestic production in regions i and j; d_{ij} is the distance between regions i and j; *Dummy–Canada* and *Dummy–U.S.* are dummy variables that are one when both regions are located in respectively Canada and the United States, and zero otherwise. The first three columns report results based on nonunitary income elasticities (as in the original McCallum regressions), while the last three columns assume unitary income elasticities. Results are reported for three different sets of data: (i) state–province and interprovincial trade, (ii) state–province and interstate trade, (iii) state–province, interprovincial, and interstate trade. The border coefficients *Border–U.S.* and *Border–Canada* are the exponentials of the coefficients on the respective dummy variables. The final three rows report the border coefficients and $\bar{R}^2$ when the remoteness indices (3) are added. Robust standard errors are in parentheses.

I. McCallum's…

Four conclusions (*Table 1*):

- First, we confirm a very large border coefficient for Canada.
- Second, the U.S. border coefficient is much smaller.
- Third, these border coefficients are very similar when pooling all the data.
- Finally, Similar border coefficients when unitary income coefficients are imposed.

I. McCallum's…

- The bottom of the table reports results when remoteness variables are added
- Very little effect of adding remoteness indices on the border coefficient estimates and very little addition on the adjusted R^2

II. AW's Gravity Model

- The first building block ---each region is specialized in production of only one good. The supply of each good is fixed
- The second building block --- identical, homothetic preferences, a CES utility function.
- Trade barriers are symmetric $t_{ij} = t_{ji}$

II. AW's Gravity Model…

- AW derives the theoretical Gravity equation :

$$x_{ij} = \frac{y_i y_j}{y^W}\left(\frac{t_{ij}}{P_i P_j}\right)^{(1-\sigma)} \qquad (13)$$

- The equilibrium Price Indices are defined as :

$$P_j^{1-\sigma} = \sum_i P_i^{(\sigma-1)} \theta_i t_{ij}^{(1-\sigma)} \qquad \forall j \qquad (12)$$

II. AW's Gravity Model…

- $\{P_i\}$: "multilateral resistance" variables as they depend on all bilateral resistances $\{t_{ij}\}$
- A rise in trade barriers with all trading partners will raise the index.
- The gravity equation tells us that bilateral trade, after controlling for size, depends on the bilateral trade barrier between i and j, relative to the product of their multilateral resistance indices.

II. AW's Gravity Model…three implications

- Trade barriers reduce size-adjusted trade between large countries more than between small countries.
- Trade barriers raise size-adjusted trade within small countries more than within large countries.
- Trade barriers raise the ratio of size-adjusted trade within country 1 relative to size-adjusted trade between countries 1 and 2 by more the smaller is country 1 and the larger is country 2.

II. AW's Gravity Model…

- As the final step AW assumes --- t_{ij} is a log-linear function of observables, bilateral distance d_{ij}, and whether there is an international border between i and j:

$$t_{ij} = b_{ij} d_{ij}^{\rho} \qquad (18)$$

- $b_{ij} = 1$ if region i and j are located in the same country. Otherwise b_{ij} is equal to one plus the tariff equivalent

II. AW's Gravity Model…

- Compare the theoretical Gravity Model and the one used in empirical literature:--
- The theory implies that---

$$\ln x_{ij} = k + \ln y_i + \ln y_j + (1-\sigma)\rho \ln d_{ij} + (1-\sigma)\ln b_{ij} - (1-\sigma)\ln P_i - (1-\sigma)\ln P_j \qquad (19)$$

- The McCallum's model is ---

$$\ln x_{ij} = \alpha_1 + \alpha_2 \ln y_i + \alpha_3 \ln y_j + \alpha_4 \ln d_{ij} + \alpha_5 \delta_{ij} + \varepsilon_{ij} \qquad (1)$$

II. AW's Gravity Model…

- The key difference is the two price index terms.
- The omitted multilateral resistance variables

$$P_j = f\left(t_{ij}(d_{ij}, b_{ij})\right)$$

Since the multilateral resistance terms are therefore correlated with d_{ij} and b_{ij}, they create omitted variable bias when the coefficient of the distance and border variables is interpreted as ---

$$(1-\sigma)\rho \;\; and \;\; (1-\sigma)\ln b_{ij}$$

III. Estimation

- Two-country model --US and Canada
- A multi-country model--- US, Canada and other industrialized countries
- Latter – more realistic

A. Two-Country Model

- Two-country model $b_{ij} = b^{1-\delta_{ij}}$, where *b-1* represents the tariff-equivalent US- Canada border barrier and δ_{ij} is the same dummy variable

$$\ln z_{ij} \equiv \ln \frac{x_{ij}}{y_i y_j} = k + a_1 \ln d_{ij} + a_2 (1 - \delta_{ij}) - \ln P_i^{1-\sigma} - \ln P_j^{1-\sigma} + \varepsilon_{ij} \qquad (20)$$

- We estimate a stochastic form of (13):

$$where \;\; a_1 = (1-\sigma)\rho \;\; and \;\; a_2 = (1-\sigma)\ln b$$

A. Two-Country Model…

- Observables in the model ---distances, borders, and income shares
- The gravity equation to be estimated :

$$\ln \mathbf{z} = h(\mathbf{d}, \delta, \theta; k, a_1, a_2) + \varepsilon \qquad (22)$$

- AW estimates (22) with nonlinear least squares, minimizing the sum of squared errors

A. Two-Country Model…

- Estimator is unbiased if ε is uncorrelated with the derivatives of h with respect to

  $\mathbf{d}$, δ , and θ

- Alternative approach--- replace multilateral resistance terms with country-specific dummies

B. Multi-country Model

- 61 regions : 30 states, the rest of the US, 10 provinces, and 20 other countries (ROW)
- The border barriers b_{ij} may differ for U.S.-Canada trade, US-ROW trade, Canada-ROW trade, and ROW-ROW trade.

B. Multi-country Model…

- Three additional parameters :

$$(1-\sigma)\ln b_{US,ROW}, (1-\sigma)\ln b_{CA,ROW} \text{ and } (1-\sigma)\ln b_{ROW,ROW}$$

- Three constraints

$$\sum_{j \in ROW} (\varepsilon_{US,j} + \varepsilon_{j,US}) = 0$$

$$\sum_{j \in ROW} (\varepsilon_{CA,j} + \varepsilon_{j,CA}) = 0$$

$$\sum_{i,j \in ROW} \sum_{i \neq j} \varepsilon_{i,j} = 0$$

IV. Results

- Estimates of the theoretical gravity equation
- Impact of national borders on trade flows
- McCallum border parameters

Similar U.S.-Canada border barrier in both the two-country model and the multi-country model Table 2

A. Parameter Estimates

- Multi-country model : Border barrier estimates are similar across country pairs.
- Barrier between the US and Canada slightly lower than between the other 20 industrialized countries
- A bit higher than the others is between Canada and the ROW countries.

TABLE 2—ESTIMATION RESULTS

		Two-country model	Multicountry model
Parameters	$(1-\sigma)\rho$	−0.79	−0.82
		(0.03)	(0.03)
	$(1-\sigma)\ln b_{US,CA}$	−1.65	−1.59
		(0.08)	(0.08)
	$(1-\sigma)\ln b_{US,ROW}$		−1.68
			(0.07)
	$(1-\sigma)\ln b_{CA,ROW}$		−2.31
			(0.08)
	$(1-\sigma)\ln b_{ROW,ROW}$		−1.66
			(0.06)
Average error terms:	US–US	0.06	0.06
	CA–CA	−0.17	−0.02
	US–CA	−0.05	−0.04

Notes: The table reports parameter estimates from the two-country model and the multicountry model. Robust standard errors are in parentheses. The table also reports average error terms for interstate, interprovincial, and state–province trade.

B. The Impact of the Border on Bilateral Trade

- General-equilibrium comparative statics ---the ratio of trade flows with border barriers to that under the borderless trade
- ***Table 3*** reports the average transform of multilateral resistance $P^{\sigma-1}$ for regions in each of sets of countries
- Border barriers to lead to a larger increase of multilateral resistance in small countries than in large countries.

B. The Impact of the Border on Bilateral Trade…

- $P^{\sigma-1}$ rises by a factor of 1.12 percent for U.S. states, while it rises by a factor 2.44 for Canadian provinces.
- The number is intermediate for ROW countries, whose size is also intermediate.
- The Canadian border creates a barrier between provinces and most of its potential trading partners, while states face no border barriers with the rest of the large U.S. economy.

Multilateral resistance rises much more for provinces (in Small countries) than for states (in Large countries).

TABLE 3—AVERAGE OF $P^{1-\sigma}$

	US	Canada	ROW
Two-country model			
With border barrier (BB)	0.77	2.45	
	(0.03)	(0.12)	
Borderless trade (NB)	0.75	1.18	
	(0.03)	(0.01)	
Ratio (BB/NB)	1.02	2.08	
	(0.00)	(0.08)	
Multicountry model			
With border barrier (BB)	1.55	4.67	2.97
	(0.01)	(0.09)	(0.07)
Borderless trade (NB)	1.39	1.91	1.54
	(0.00)	(0.04)	(0.01)
Ratio (BB/NB)	1.12	2.44	1.93
	(0.01)	(0.09)	(0.06)

Notes: The table reports the average of $P_i^{\sigma-1}$, where the average is defined as the exponential of the average logarithm. For the United States the average is taken over the 30 states in the sample, for Canada over the 10 provinces, and for ROW over the other 20 industrialized countries.

B. The Impact of the Border on Bilateral Trade…

- ***Table 4*** reports the impact of border barriers on bilateral trade flows among and within each of the three sets of regions (US, CA, ROW).
- AW breaks down the impact of border barriers on trade into ---
  - the impact of the bilateral border barrier, and
  - the impact of border barriers on multilateral resistance of regions in both sets

TABLE 4—IMPACT OF BORDER BARRIERS ON BILATERAL TRADE

	US–US	CA–CA	US–CA	US–ROW	CA–ROW	ROW–ROW
Two-country model						
Ratio BB/NB	1.05	4.31	0.41			
	(0.01)	(0.34)	(0.02)			
Due to bilateral resistance	1.0	1.0	0.19			
	(0.0)	(0.0)	(0.01)			
Due to multilateral resistance	1.05	4.31	2.13			
	(0.01)	(0.34)	(0.09)			
Multicountry model						
Ratio BB/NB	1.25	5.96	0.56	0.40	0.46	0.71
	(0.02)	(0.42)	(0.03)	(0.01)	(0.01)	(0.02)
Due to bilateral resistance	1.0	1.0	0.20	0.19	0.10	0.19
	(0.0)	(0.0)	(0.02)	(0.01)	(0.01)	(0.01)
Due to multilateral resistance	1.25	5.96	2.72	2.15	4.70	3.71
	(0.02)	(0.42)	(0.12)	(0.09)	(0.31)	(0.25)

Notes: The table reports the ratio of trade with the estimated border barriers (BB) to that under borderless trade (NB). This ratio is broken down into the impact of border barriers on trade through bilateral resistance ($t_{ij}^{1-\sigma}$) and through multilateral resistance ($P_i^{\sigma-1}P_j^{\sigma-1}$).

B. The Impact of the Border on Bilateral Trade…

- *Implication 2* of the theory– Strongly confirmed in ***Table 4***.
  - The table reports a spectacular factor 6 increase in interprovincial trade due to borders, while interstate trade rises by only a factor of 1.25
- Borders reduce trade between US and Canada to a fraction 0.56 of that under borderless trade. Trade among ROW countries is reduced to a fraction of 0.71.
- The bilateral border barrier itself implies an 80-percent drop in trade between states and provinces, but increased multilateral resistance, particularly for provinces, raises state-province trade by a factor 2.72.

C. Intranational Trade Relative to International Trade

- Large McCallum border parameter for Canada is due to a combination of (i) the relative small size of the Canadian economy and (ii) omitted variables bias.
- *Implication 3* --Trade barriers raise the ratio of size-adjusted trade within country 1 relative to size-adjusted trade between countries 1 and 2 by more the smaller is country 1 and the larger is country 2.

C. Intra-national Trade Relative to International Trade…

- The impact of border barriers on intranational relative to international trade in the first row of ***Table 5***.
- **The multi-country model --**
  - National Borders lead to trade between provinces a factor 10.7 larger than between states and provinces
  - Border Barriers raise trade between states by only a factor 2.24 relative to trade between states and provinces
- This is exactly as anticipated by *Implication 3* of the theory

C. Intranational Trade Relative to International Trade…

- The other part of the explanation is the result of omitted variables bias in two distinct senses: estimation and computation.
  - Estimation bias --- Omitted variables bias
  - Computation bias---Erroneous comparative statics
- To analyze the ***Omitted variables bias--*** Write theoretical model :

$$\ln x_{ij} = k + \ln y_i + \ln y_j + \rho(1-\sigma)\ln d_{ij} + R_{ij} + \varepsilon_{ij} \qquad (24)$$

where $R_{ij} = (1-\sigma)\ln b_{ij} - (1-\sigma)\ln P_i - (1-\sigma)\ln P_j$

- McCallum estimated (24), but replaced R_{ij} with a dummy variable that is 1 for interprovincial trade and 0 for state-province trade

C. Intranational Trade Relative to International Trade…

- In the absence of the multilateral resistance terms this would yield unbiased estimates of

$$(1-\sigma)\rho \; and \; (1-\sigma)\ln b.$$

- Omitted multilateral resistance terms

$P_j = f\left(t_{ij}(d_{ij}, b_{ij})\right)$ → McCallum's regression not unbiased $(1-\sigma)\rho$ *or* $(1-\sigma)\ln b$

- ***Computation bias***-- Assume that McCallum had correctly estimated the parameter $(1-\sigma)\rho$ multiplying bilateral distance

TABLE 5—IMPACT BORDER ON INTRANATIONAL TRADE RELATIVE TO INTERNATIONAL TRADE

	Two-country model		Multicountry model	
	Canada	US	Canada	US
Theoretically consistent estimate	10.5	2.56	10.7	2.24
	(1.16)	(0.13)	(1.06)	(0.12)
McCallum parameter implied by theory	16.5	1.64	14.8	1.63
	(1.63)	(0.09)	(1.32)	(0.10)

Notes: The first row of the table reports the theoretically consistent estimate of the impact of border barriers on intranational trade relative to international trade for both Canada and the United States. The second row reports the McCallum border parameter implied by the model, which provides a biased estimate of the impact of borders on the ratio of intranational to international trade.

C. Intranational Trade Relative to International Trade…

- The much higher Canadian multilateral resistance term, $P_{CA}^{\sigma-1}$, than the U.S. multilateral resistance term, $P_{US}^{\sigma-1}$, blows up the border effect for Canada, while dampening it with the same factor for the United States.
- A comparison of rows 1 and 2 of ***Table 5*** shows that McCallum's measure for Canada overstates our consistent estimate of the impact of borders on intranational trade relative to international trade.
- Reason-- the multilateral resistance terms in (25) and (26) are replaced by the ratio of multilateral resistance with border barriers relative to that without border barriers;

V. Sensitivity Analysis

- ***Table 6*** reports the results from a variety of sensitivity analysis.
  - Key variables of interest-- the impact of borders on trade, and the McCallum border parameter
- Column (i) ---results from base reg. ($\sigma = 5$)
- Column (ii) --- a higher $\sigma = 10$
  - Negligible difference in results. The same is the case when we lower σ to 2 or raise it 20 (not reported)

The insensitivity to σ is encouraging --- as there is little agreement about the precise magnitude of this parameter

TABLE 6—SENSITIVITY ANALYSIS

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
Two-country model									
Trade (BB/NB)									
US–US	1.05	1.05	1.05	1.05	1.04	1.04	1.03	1.05	
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	
CA–CA	4.31	4.26	4.31	4.41	3.92	3.82	4.37	3.76	
	(0.34)	(0.34)	(0.30)	(0.39)	(0.53)	(0.29)	(0.38)	(0.23)	
US–CA	0.41	0.41	0.41	0.41	0.50	0.50	0.54	0.43	
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	
McCallum parameter									
US	1.64	1.64	1.58	1.70	1.37	1.03	1.05	1.33	
	(0.09)	(0.09)	(0.08)	(0.09)	(0.11)	(0.05)	(0.06)	(0.07)	
CA	16.5	16.5	17.1	16.1	12.2	15.4	14.9	16.4	
	(1.63)	(1.63)	(1.64)	(1.65)	(1.93)	(1.50)	(1.63)	(1.56)	
Multicountry model									
Trade (BB/NB)									
US–US	1.25	1.26	1.21	1.29	1.22	1.19	1.18		1.14
	(0.02)	(0.02)	(0.02)	(0.02)	(0.04)	(0.02)	(0.02)		(0.02)
CA–CA	5.96	5.93	5.90	6.21	5.07	5.03	5.21		4.44
	(0.42)	(0.42)	(0.37)	(0.49)	(0.66)	(0.36)	(0.40)		(0.39)
US–CA	0.56	0.56	0.54	0.57	0.63	0.62	0.63		0.51
	(0.03)	(0.03)	(0.03)	(0.03)	(0.05)	(0.03)	(0.03)		(0.03)
ROW–ROW	0.71	0.70	0.71	0.72	0.83	0.50	0.87		0.76
	(0.02)	(0.02)	(0.02)	(0.02)	(0.06)	(0.02)	(0.04)		(0.04)
McCallum parameter									
US	1.63	1.63	1.56	1.69	1.38	1.13	1.19		1.56
	(0.10)	(0.10)	(0.09)	(0.11)	(0.12)	(0.06)	(0.08)		(0.09)
CA	14.8	14.8	15.3	14.5	11.1	13.6	12.9		12.4
	(1.32)	(1.32)	(1.34)	(1.33)	(1.57)	(1.37)	(1.29)		(1.25)

Notes: The table reports sensitivity analysis with regards to the ratio of trade with border barriers to trade without border barriers and with regards to the McCallum border parameters implied by the model. Column (i) repeats results from the benchmark regression. Column (ii) assumes $\sigma = 10$ (in the benchmark $\sigma = 5$). Columns (iii) and (iv) report results when respectively doubling and halving distances internal to regions and countries. Column (v) reports results based on a regression that does not use interstate data. Columns (vi) and (vii) report results when income y is replaced by $x^{\alpha}y$ with x respectively income y and per capita income y/N. x^{α} represents the fraction spent on tradables in a region or country. Column (viii) reports for the two-country case results based on fixed-effects estimation. The final column reports for the multicountry case results when minimizing the sum of all squared error terms, including those involving ROW countries.

V. Sensitivity Analysis…

- Columns (iii) and (iv) --- double and halve the measure of distance internal to states, provinces, and the other industrialized countries
  - Doubling or halving internal distances has very little effect on our results
- Column (v) --- no data on interstate trade (to ensure consistency with McCallum)
  - The results, somewhat different from those based on the benchmark regression, but qualitatively identical
- Columns (vi) and (vii) report results when allowing for non-unitary income elasticities.
  - The results --- while they change somewhat from the base regression, are still qualitatively the same.

V. Sensitivity Analysis…

- Column (viii) ---Fixed-effects estimation, feasible only in the two-country model
  - Very little effect on the trade results. The border parameter $(1-\sigma)\ln b$ does not change much, the distance parameter $(1-\sigma)\rho$ drops from -0.79 in the structural model to -1.25
- Last column -- estimates parameters by minimizing the sum of all squared residuals (including the ROW-ROW, US-ROW, and CA-ROW residuals)

The results reported in Table 6, the impact of borders on trade and the McCallum parameters, remain quite close to those under the benchmark regression

VI. Conclusion

- Overall, the results from benchmark regression are robust to a wide range of sensitivity analysis.
- Commonly estimated gravity equations generally have a very good fit to the data– but not theoretically grounded
  - Leads to biased estimation, incorrect comparative statics analysis, and generally a lack of understanding of what is driving the results.
- AW developed a method -- to consistently and efficiently estimate the theoretical gravity equation.
  - Applied the method to solve the border puzzle.

Thank you !