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The Determinants of Armington Taste Parameters in CGE Models, or Why You Love Canadian Vegetable Oil

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Abstract: We note that calibration parameters in a multi-country Computable General Equilibrium (CGE) trade model play a role similar to that of econometric residuals. In an assessment of these parameters, we find strong evidence that such CGE models understate the degree to which agents respond to differences in bilateral trade costs. In 33 of the 50 commodity groups we assess, modeled economic behavior explains less than 20% of the variation in bilateral trade. We use a least squares procedure to estimate the elasticities of substitution consistent with neutral preferences. Our estimates suggest that standard parameterizations substantially understate economic responses to relative trade costs.

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Even limited exposure to multi-country CGE models can lead one to conclude that these models rely too heavily on calibrated taste parameters to explain the pattern of trade. Often, the results of a policy experiment (such as a preferential trade arrangement) are highly dependent on *ex ante* calibration parameters that contain little economic content. Because calibrated taste parameters are to multi-country CGE trade models what residuals are to econometric models, the models' reliance on such parameters to explain trade flows is rather unsatisfying. Even more problematic is the unfortunate relationship documented below, that taste parameters are often correlated with variables (bilateral trade costs) in the structural model. In other words, representative agents are assumed to have a preference for imports that face low bilateral trade costs.

This paper expands on the interpretation of calibration parameters as conceptual equivalents to econometric residuals. We use this analysis to ask if the information contained in such residuals can be used to improve CGE modeling efforts. In particular, we ask if the models can be reparameterized so that 1) structural variables explain a larger part of the variation in the bilateral trade flows, and 2) the residuals (calibration parameters) are uncorrelated with structural model variables.

In applying the language of econometrics to a multi-country CGE model, we hope to accomplish at least two objectives. First, we want to systematically explore, and justify, a piece of conventional wisdom in the CGE literature, that time series econometric estimates of Armington elasticities, which are a typical input into such models, are too low. We believe that low estimated Armington elasticities are largely responsible for the models' excessive reliance on region-specific calibration parameters to explain the pattern of trade. Second, we recognize that CGE models are often seen as impenetrably dense to non-specialists. We hope that our exposition will explain calibration techniques in a language familiar to non-specialists - econometrics.

The paper is organized as follows. Section I. describes the calibration procedures and explains the issues. Section II. provides a discussion of the data. Section III. describes the analytical measures and reports results. Section IV. concludes.

Section I. Exposition

CGE modelers face an important conceptual difficulty, explaining bilateral trade patterns of the sort exhibited in Figure 1, which shows the 1995 value of imports of vegetable oil from Canada and Malaysia by 45 regions in the GTAP database.[1] As the graph shows, the United States is the only major purchaser of Canadian vegetable oil, while most other countries buy more Malaysian than Canadian vegetable oil. In fact, Malaysia exports 11.5 times as much vegetable oil as Canada, a ratio seen in the slope of the ray OW, which, when extended, passes through the global consumption point.

Most readers will conclude that the primary reason for Canadian vegetable oil's large share in U.S. imports is the size of relative trade and transportation costs. Presumably, lower tariffs and transport costs on imports from Canada induce U.S. buyers to substitute Canadian for Malaysian vegetable oil. Yet most CGE models, while including a role for relative trade costs, explain most of this buying pattern by asserting an exogenous U.S. preference for Canadian, relative to Malaysian, vegetable oil. While we believe that parsimony justifies a role for distinct national (that is, Armington) preferences in such models, we argue here that the role of such preferences is often

[1]The GTAP database is a common data source for multi-country CGE studies. We provide more details on the GTAP database in section 2.

highly exaggerated in common CGE practice. Because such preferences limit modeled responses to trade policy changes, such conceptual difficulties may explain a widely-held belief (both in academic and policymaking circles) that such models understate the effects of policy changes on the economy.

Our critique of CGE models is based on familiar concepts from econometrics - goodness of fit and orthogonal residuals. The Armington taste parameters in CGE models are like error terms in econometric models, in that they contain the unexplained variance in the dependent variable. Our results below show that these parameters exhibit characteristics that would be highly troubling in econometric residuals. First, the taste parameters explain a large portion of the cross-country variation in industry trade patterns. We take this as an indictment of the model's ability to explain bilateral trade patterns. Second, the taste parameters are correlated with other variables in the structural model, especially bilateral trade costs. We interpret this as evidence that standard parameterizations allow insufficient responses to trade costs.

Graphical exposition

We are concerned with the determinants of the import bundle purchased by a representative consumer (or firm) in region j. Consider figure 2, which shows the relative purchases of imports from countries A and B. Let U_W represent an indifference curve for a world representative agent.[2] At the frictionless world relative price P_W , which is the ratio of f.o.b. prices of exports from regions A and B, the global representative agent would choose to consume at point W.

[2]Consumers are minimizing a unit expenditure function, firms a unit cost function.

The isoutility curve U_J is drawn as if consumers in region j had a preference, relative to the global representative agent, for varieties from region A. Because all consumers share the same elasticity of substitution, the curvature of U_J equals that of U_W. In the figure, a consumer in region j faces P_J, a different relative price than that faced by the global consumer at frictionless trade. Bilateral trade costs between regions A and j are assumed lower than between regions B and j, leading to a decrease in the relative price of goods from A. Consumer j would purchase J' at the frictionless prices the global agent faces, P_W. Relative price differences lead the region j consumer to substitute goods from A for goods from B, moving away from the bundle the global representative agent would choose at frictionless prices.

The point of this paper is that CGE models do not explain the whole difference between global and national consumption shares with relative price changes alone. Relative price changes are only responsible for the difference between consumption bundles J and J'. CGE models attribute to taste parameters the entire unexplained portion of the deviation from the world bundle (J' to W). We wish to quantify these models' reliance on calibration parameters, and to highlight the conceptual difficulties involved in interpreting them.

It is worth stressing that there is no economic theory underlying the choice of calibration parameters, they simply represent the taste/technology parameters necessary to make the model fit the data exactly. In that sense, the role of calibration parameters in CGE models is equivalent to that played by econometric residuals. They are the difference between a fitted value predicted by the model and an observed data point. Just as econometricians are interested in characteristics of econometric residuals, we believe

CGE modelers should be concerned with the characteristics of calibration parameters. In particular, we wish to know their role in predicting bilateral trade variation (in an R^2 sense), and whether they are correlated with observable trade costs.

Model

We propose a straightforward model with nested constant elasticity of substitution (CES) production and utility functions. Both consumers and firms first allocate funds over commodities, then over the domestic/import choice, and finally over sources of imports. We focus on the choice over imported varieties.

Let the utility that consumers earn from imported varieties of commodity k take the form

$$1)\ U_j^{k,M} = \left(\sum_i \left(a_{ij}^k q_i^k \right)^{1-s} \right)^{1/1-s}$$

where $U_j^{k,M}$ is the utility that the representative consumer in region j gets from imported varieties of commodity k, i indicates the source of the product, a_{ij}^k (the focus of our study) is a preference weight that region j consumers attach to region i's variety of commodity k, q_i^k is the quantity of region i's commodity k output consumed in region j, and σ^k is the elasticity of substitution among imported varieties of k.[3] This is the familiar Armington (1969) specification, and it is straightforward to solve this for equilibrium prices and quantities.

We define the value share of region i's exports in region j's expenditure on commodity k as

[3]Obviously in the context of imported intermediates, the "utility" function is interpreted as an aggregating CES activity or process, not necessarily a consumer utility schedule.

$$2)\quad q_{ij}^{k} = \frac{\left(p_i^k\left(1+t_{ij}^{k}\right)\right)q_{ij}^{k}}{\sum_i \left(p_i^k\left(1+t_{ij}^{k}\right)\right)q_{ij}^{k}}$$

where p_i^k is the fob price in region i, τ_{ij}^k is the price wedge (inclusive of export subsidies, tariffs and transportation costs) between the f.o.b price at i and the cif price at j, and q_{ij}^k is as before. Let $\bar{q}_{ij}^k$ be the initial (or benchmark) quantity of region j imports from region i.

The taste parameter α can be shown to be a function of the initial share, $\bar{q}$, and $\bar{q}$:[4]

$$3)\quad a_{ij}^{k} = \bar{q}_{ij}^{k}\left(\bar{q}_{ij}^{k}\right)^{s-1/s}$$

Because θ is directly observable, our work will focus on θ as a proxy for α.

We wish to better understand the determinants of variation in the initial benchmark level, $\bar{q}$, across bilateral trade pairs. In particular, we wish to know how well relative price changes explain variation in $\bar{q}$, for all remaining variation can be tied to variation in the underlying taste parameters, α. We observe a proxy for variation in α's by observing variation in $\hat{q}$'s, the bilateral import shares calculated, given frictionless trade.[5] Since the role of relative prices has been removed from $\hat{q}$, the difference between $\hat{q}$ and the world share at frictionless prices is the variation in the trade pattern not explained by the model. This difference is, in effect, a residual.

Our first task is to evaluate the model's ability to explain bilateral trade patterns without the help of residuals. We characterize the model's goodness of fit with a measure of fit (MOF), which is quite similar to an R^2 measure:

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[4] See Rutherford (1995) for details on the calibrated share approach to CGE models.

$$4)\ MOF^k = \frac{\sum_i \sum_j \left(\bar{q}_{ij}^{k} - \hat{q}_{ij}^{k}\right)^2}{\sum_i \sum_j \left(\bar{q}_{ij}^{k} - \hat{q}_{iW}^{k}\right)^2}.$$

The numerator of MOF shows the variation in $\bar{q}$ that is explained by the model. This value is represented in figure two by the distance between J and J'. The denominator, the distance from J to W, measures the total variation in $\bar{q}$. In a well-fitting model, relative price changes would lead J' to be quite near W ($\hat{q}_{ij}^{k}$ near $\hat{q}_{iW}^{k}$), implying a small role for residuals.

We are also concerned with analytical issues that arise when errors are correlated with residuals. In particular, we are concerned that current parameterizations might imply that α_{ij}^{k}'s are correlated with interregional trade costs τ_{ij}^{k}. We define the term ε_{ij}^{k} as the difference between national and global import shares at liberalized prices:

$$5)\ e_{ij}^{k} = \hat{q}_{ij}^{k} - \hat{q}_{iW}^{k}$$

We wish to know whether the residuals, ε_{ij}^{k}'s, are correlated with the τ_{ij}^{k}'s. Ideally we would like the model to fully represent buyers' responses to relative price differences.

Section II. Data

Prior to a discussion of the results, we provide a description of data and calibration inputs used in our work below. Our calculations require two primary inputs: 1) data on trade and relative trade costs, and 2) substitution parameters (σ^k's). We take

[5] We isolate a movement along the indifference curve using compensated demand functions calibrated to the benchmark (see appendix A).

these from a common source, the Global Trade Analysis Project (GTAP) database, version 4.[6]

The GTAP database is a common input into multi-country CGE models. The GTAP consortium collects trade and output data and data documenting input-output relationships from 45 regions (for lack of data, some regions are groupings of countries, like "rest of asia"). Because CGE models require that all model equations be jointly satisfied, the GTAP consortium "balances" the data to produces a fully consistent global account of trade and output.[7] Data collection and global balancing efforts would be costly to duplicate, so most multi-country models rely on the GTAP data set to document production, trade and input-output relationships. GTAP data are aggregated at a fairly high level, there are only 50 sectors in the model, only 45 of which are traded. The high level of aggregation is necessitated by cross-national differences in industry classification.

GTAP also collects data on bilateral trade frictions. *Ad valorem* tariff rates are typically calculated by dividing revenue collected by import values. GTAP imputes bilateral transportation costs from one of the only available data sources on such costs, U.S. trade data.[8] We use GTAP estimates of implied bilateral tariffs and transportation costs in our work below.

The GTAP consortium also reviews the econometric literature, providing "consensus" estimates of substitution elasticities for each commodity k. These too are

[6]More detailed descriptions of the GTAP model, data and consortium can be found in Hertel (1997).
[7]Balancing procedures typically minimize the squared deviations from reported data that are necessary to reconcile various data sources, such as sector output, consumption, and net trade.
[8]One might suspect that bilateral transportation costs imputed from U.S. trade data might understate the true costs of trade among developing nations. One explanation for the results we report below is that GTAP understates unobservable trade costs. Underestimated transportation costs are a good candidate for a non-random source of error in the model.

frequently used in multi-country CGE models, though modelers are free to use GTAP data while choosing their own elasticities. The choice of elasticities in most CGE models is heavily informed by the time series econometric literature, though a growing consensus of those who use time series estimates as inputs is that such estimates are too low, and so underestimate actual responses to trade policy changes.[9] We use these "consensus" estimates reported by GTAP as our initial inputs.

Section III. Results

In this section we document evidence consistent with our contention that CGE models rely too heavily on calibration parameters. The trade pattern is not well explained by the model, and the taste parameters are correlated with bilateral trade costs. In 33 of the 50 commodity groups, differences in relative trade costs explain less than 20 percent of the overall variation in bilateral trade shares. We also find positive correlation between ε_{ij}^{k}'s and τ_{ij}^{k}'s in every commodity. We find that doubling the value of σ used in the model improves the fit and reduces the correlation between ε and τ in most commodities.

We calculate MOF and a correlation between ε and τ for each commodity group using two different values of σ^k. Details of this calculation are reported in an appendix.[10] Our initial input are the values of σ taken from the GTAP database, which are reported in column 2 of table 1. To show the impact of raising σ, we calculate each of the measures,

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[9]Recent econometric evidence also points to larger estimates of σ^k. Gallaway, McDaniel and Rivera (2000) use co-integration techniques to estimate long-run Armington elasticities (3 to 5 for the domestic/import choice) that are larger than are common in the time series literature. Hummels (1999) finds even larger estimates (7 to 9 for the choice across importers) in cross-section data.

[10] Transport is a service used in fixed proportion to imports. Slight adjustments are made to the equations in the appendix to account for this treatment.

setting σ at twice the estimate proposed by GTAP. Commodities in table 1 are ranked by their MOF with the initial GTAP σ.

Columns 3 and 4 show MOF evaluated at two estimates of σ. In column 3, we use the GTAP estimate as an input. The results indicate a quite poor fit in most commodities - 33 of 50 sectors have a MOF of below .20, and 24 of 50 have a MOF below 0.1. Our hypothesis is that the GTAP estimates of σ are too low, so we double that estimate for each commodity, calculating MOF and reporting it in column 4. A comparison of MOF in columns 3 and 4 shows that it rises. We find that MOF rises in most cases. Far fewer commodities have the extremely poor fits estimated at the value of σ given by GTAP.

Raising the elasticity of substitution makes buyers more responsive to relative trade costs. The role of bilateral preferences for low-priced varieties, such as the apparent U.S. taste for Canadian vegetable oil, is reduced because the model now treats buyers as more responsive to relative trade costs.[11]

An interesting exception to our general finding of low measures of fit is the "Other Manufactures" (that is, "Manufactures nec") commodity group, which shows a MOF of 2.49.[12] A value of MOF >1 suggests that the full removal of trade and transport costs leads to greater variation in $\hat{q}$ than existed in the benchmark trade shares, $\bar{q}$. This

[11]In some sense, we are simply arguing that current parameterizations take insufficient account of substitution possibilities over the very long run. Presumably, an economy's taste and technology parameters reflect long-run substitution toward the varieties it can obtain most cheaply. We wish to treat that kind of substitution explicitly in σ, rather than leaving it to calibration parameters to explain.

[12]Such a measure appears curious, given that we have stressed the conceptual link between MOF and R2, which is usually limited by 1 in a regression context. The answer to this puzzle is that we are not estimating σ, but evaluating model fit at a given value of σ. Conceptually, this is equivalent to imposing a value of β in a linear regression, and calculating R^2. If the chosen β exceeds $\hat{b}$ the fitted values will

is possible if the elasticity of substitution is so large that the removal of bilateral trade costs induce importers to substitute away from a diversified bundle of imports and toward a bundle dominated by a few commodities.

Perhaps it should not be surprising that "Manufactures nec" is the category in which σ^k is too high. Given its catchall nature, one might expect far different national production bundles in this category. So, a priori, one might expect it to have a lower Armington elasticity than other manufacturing categories. Since the GTAP estimate σ=5.6, is in line with the manufacturing elasticities in general, it likely overstates the substitutability of national production bundles in the "Manufacturers nec" commodity. One of the lessons we take from this exercise is national bundles of goods in the "Manufactures nec" category are less substitutable than are goods from other categories in manufacturing sector.

Columns 5 and 6 of table 3 report the Pearson correlation coefficient between the residuals, ε_{ij}^k, and the tariff revenue collected on each bilateral pair. We note that a systematic positive correlation exists at the GTAP estimates of σ, and that it declines as sigma increases. Given the non-linear nature of our problem, and the strong distributional assumptions imposed in the correlation, we do not dwell on these results.

Finally, we estimate an optimal value of σ, the value that sets MOF = 1. Under this condition, the variance of the modeled trade shares equals the variance of the observed trade shares. In this sense, we believe that the σ's chosen by this procedure neutralize the importance of preferences as explanators of the trade pattern.

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exhibit more variation than the observed data, producing an R^2>1. We take MOF >1 as evidence that the value of σ is particularly inappropriate, and in this context, too large.

The results of this exercise are reported in table 2, and compared to the original σ used in the GTAP database. In most cases, our estimated σ exceeds the GTAP value considerably. Notable exceptions are “Construction” and “Manufactures nec”, the commodities that had MOF>1 using the initial GTAP estimates.

An alternative explanation for CGE models reliance on calibration is the obvious caveat that much is going on in the world that does not appear in the model. In particular, one might expect unobservable costs (non-tariff barriers and distance related costs not associated with transportation) or mismeasured costs (transportation costs may be an issue of special importance in the GTAP data) to explain some portion of the variation in bilateral trade shares that is unexplained by the model. To the extent that unobserved costs are correlated with observed costs, we might expect them to explain a portion of the variation in import shares not explained by the model. In that sense, the results reported below are upper bounds, for they treat the data as comprehensive.

While the inclusion of data on unobserved costs could reduce the degree of error we find in existing parameterizations, it need not negate our point. Rather, it presses the need for better data that would allow CGE models to fit the data with some degree of confidence. Our contention, that multi-country CGE models rely too heavily on calibration parameters that are not well explained by the model, still stands.

Section IV. Conclusion

We postulate that calibration parameters in CGE models are similar in function to econometric residuals. Therefore, we ask what information might be contained in the calibration parameters. In particular, we test a lesson learned from experience with these models, that existing parameterizations do not explain the bilateral trade pattern very well. Our issue is not with the Armington structure, *per se*, but with the models' reliance on trading-pair-wise calibration parameters.

We calculate a measure of fit that is similar in kind to an R^2 measure in econometrics. We find that "consensus" parameterizations perform quite poorly by our measure of fit. It appears as if agents are insufficiently responsive to relative price differences across sources of imports. In most of the 50 commodities we assess, the model explains well under 20 percent of the variation in the bilateral trade pattern.

We reparameterize the model so as to neutralize the role of taste parameters in explaining trade. We find that the elasticity of substitution necessary to neutralize preferences is generally quite high. Under the assumption that included data measures trade costs correctly, agents in CGE models are insufficiently responsive to relative interregional trade costs.

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Figure 1.

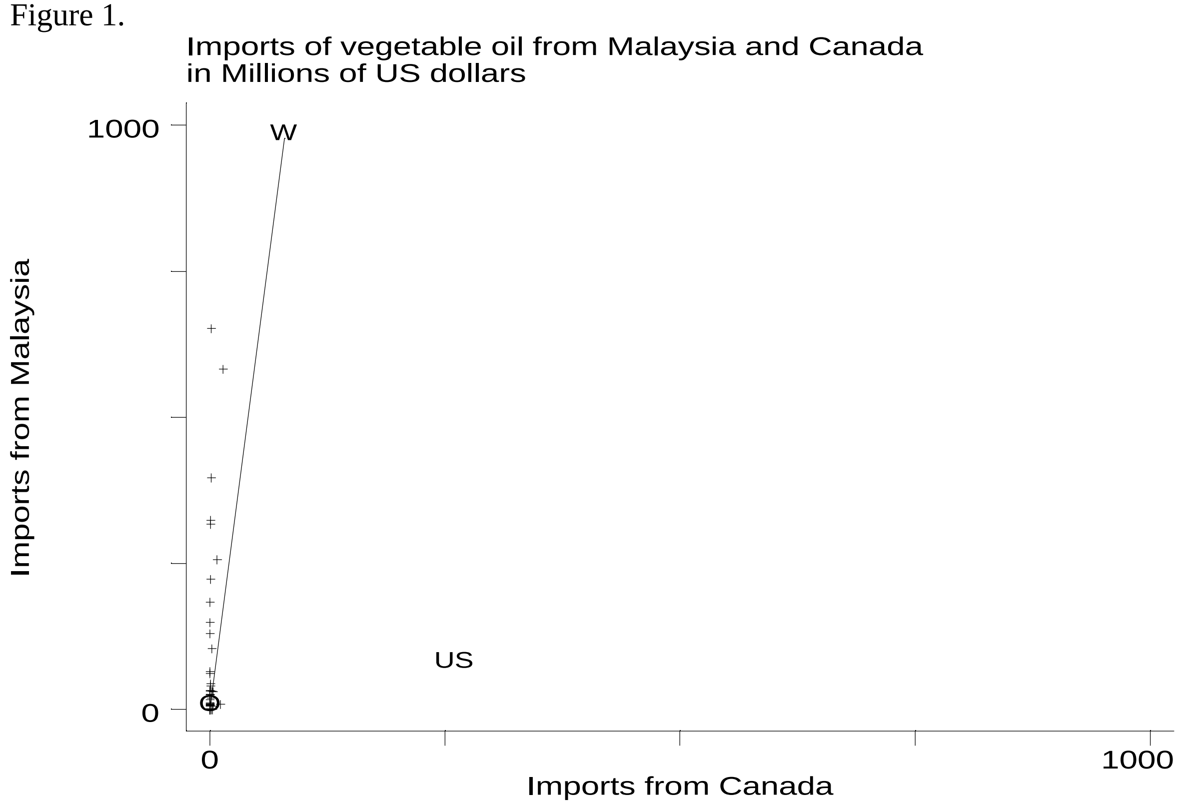
Imports of vegetable oil from Malaysia and Canada
in Millions of US dollars
Imports from Malaysia
1000
0
W
US
0
1000
Imports from Canada

Figure 2.

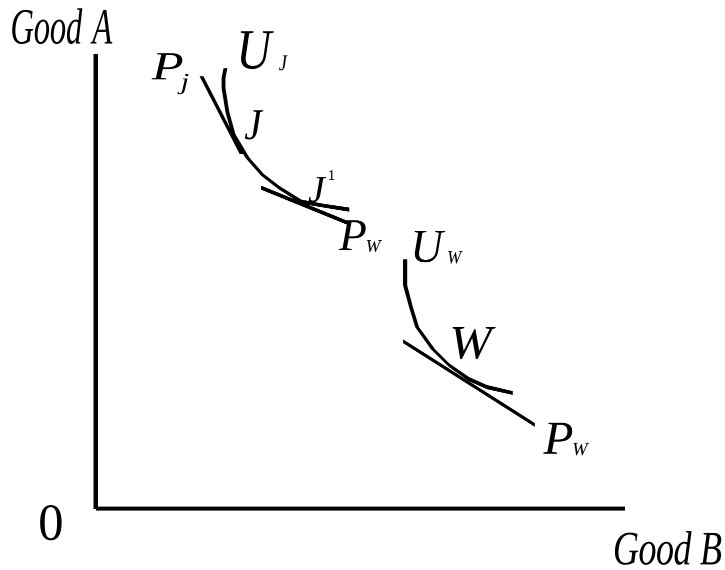

Table 1. Summary statistics by GTAP sector[1]

Description	GTAP σ_0	MOF σ_0	MOF 2 x σ_0	Pearson correlation σ_0	Pearson correlation 2 x σ_0
Construction	3.8	3.04	8.8	-0.06	-0.21
Manufactures nec	5.6	2.28	8.35	0.28	0.21
Dairy products	4.4	0.89	2.22	0.06	-0.04
Processed rice	4.4	0.6	1.02	0.19	0.17
Beverages and tobacco products	6.2	0.46	1.52	0.14	-0.01
Motor vehicles and parts	10.4	0.37	3.53	0.27	-0.04
Bovine cattle, sheep and goats, horses	5.6	0.34	0.59	0.14	0.11
Transport equipment nec	10.4	0.32	1.33	0.28	0.12
Bovine cattle, sheep, goat, and horse meat products	4.4	0.3	0.56	0.14	0.12
Plant-based fibers	4.4	0.28	2.67	0.16	-0.08
Sugar	4.4	0.28	0.76	0.23	0.16
Minerals nec	5.6	0.25	1.51	0.24	0.1
Meat products nec	4.4	0.23	1.04	0.18	0.05
Animal products nec	5.6	0.18	0.7	0.31	0.21
Cereal grains nec	4.4	0.18	0.52	0.14	0.07
Paddy Rice	4.4	0.18	0.48	0.2	0.19
Wearing apparel	8.8	0.16	1	0.2	0.06
Oil seeds	4.4	0.16	0.97	0.09	-0.02
Leather products	8.8	0.16	0.74	0.08	-0.04
Fishing	5.6	0.12	0.87	0.22	0.1
Crops nec	4.4	0.12	0.57	0.22	0.18
Mineral products nec	5.6	0.11	0.48	0.21	0.14
Forestry	5.6	0.1	0.5	0.22	0.19
Sugar cane, sugar beet	4.4	0.09	0.18	0.3	0.28
Vegetable oil	4.4	0.08	0.33	0.38	0.36
Wheat	4.4	0.07	0.39	0.09	0.07
Coal	5.6	0.07	0.3	0.2	0.19
Oil	5.6	0.06	0.52	0.09	-0.06
Electronic equipment	5.6	0.06	0.37	0.27	0.22
Vegetables, fruit, nuts	4.4	0.06	0.3	0.15	0.06
Food products nec	4.4	0.05	0.33	0.21	0.11
Wood products	5.6	0.05	0.23	0.29	0.25
Textiles	4.4	0.04	0.17	0.34	0.3
Metal products	5.6	0.03	0.17	0.31	0.27
Metals nec	5.6	0.03	0.11	0.28	0.27
Financial, business and recreational services	3.8	0.02	0.2	0.17	0.16
Petroleum, coal products	3.8	0.02	0.17	0.43	0.37
Trade, transport	3.8	0.02	0.15	0.31	0.3
Machinery and equipment nec	5.6	0.02	0.13	0.35	0.31
Ferrous metals	5.6	0.02	0.09	0.27	0.23
Chemical, rubber, plastic products	3.8	0.01	0.14	0.24	0.19
Gas	5.6	0.01	0.08	0.31	0.3
Paper products, publishing	3.6	0.01	0.04	0.35	0.34
Wool, silk worm cocoons	4.4	0.01	0.01	0.08	0.08
Public administration and defense, education, health	3.8	0	0.03	0.21	0.19
Electricity	5.6	0	0.01	0.06	0.06

[1]Four sectors (Raw milk, Gas manufacture and distribution, Water, and Dwellings) excluded for lack of trade data

Table 2. Optimal values of σ

Description	optimal σ	GTAP σ
Gas	40.1	5.6

Ferrous metals	29.36	5.6
Paper products, publishing	27.96	3.6
Metals nec	27.59	5.6
Bovine cattle, sheep and goats, horses	27.49	5.6
Public administration and defense, education, health	26.06	3.8
Coal	24.21	5.6
Metal products	23.81	5.6
Machinery and equipment nec	22.38	5.6
Paddy Rice	21.57	4.4
Wood products	21.31	5.6
Leather products	20.32	8.8
Textiles	19.89	4.4
Chemical, rubber, plastic products	19.77	3.8
Transport equipment nec	18.08	10.4
Vegetables, fruit, nuts	18.01	4.4
Forestry	17.78	5.6
Wearing apparel	17.61	8.8
Vegetable oil	16.79	4.4
Mineral products nec	16.54	5.6
Electronic equipment	15.92	5.6
Bovine cattle, sheep, goat, and horse meat products	15.59	4.4
Oil	14.99	5.6
Trade, transport	14.97	3.8
Wheat	14.23	4.4
Cereal grains nec	13.92	4.4
Petroleum, coal products	13.84	3.8
Motor vehicles and parts	13.74	10.4
Food products nec	13.52	4.4
Animal products nec	13.45	5.6
Fishing	11.86	5.6
Crops nec	11.71	4.4
Sugar	11.17	4.4
Financial, business and recreational services	10.22	3.8
Minerals nec	9.33	5.6
Oil seeds	8.92	4.4
Meat products nec	8.65	4.4
Processed rice	8.31	4.4
Plant-based fibers	6.22	4.4
Manufactures nec	4.22	5.6
Construction	2.81	3.8
Sugar cane, sugar beet	d	4.4
Wool products	d	4.4
Dairy products	d	4.4
Beverages and tobacco products	d	6.2
Electricity	d	5.6

d – no solution.

Appendix A.

To find the value of MOF at varying levels of σ we compute a complementarity problem, which includes the constant elasticity behavioral reactions.[13] This system accommodates alternative experiments that decompose the trade costs into transport and tax margins as well as solving for the optimal sigma. We define the problem as a system of complementary slack conditions such that inequality constraints are associated with positive variable. First, calibration to the observed trade pattern implies the unit expenditure function for each destination region j,

$$c_j \geq \left[\sum_i \left(\bar{q}_{ij} \left(g_{ij}(1+tm_{ij})(1+tx_{ij}) p_{ij} / \bar{p}_{ij} + (1-g_{ij})(1+tm_{ij}) p^t / \bar{p}^t_{ij} \right)\right)^{1-s} \right]^{1/1-s} \perp c_j \geq 0 \text{; (A1)}$$

and the compensated import demand functions are,

$$M_{ij} \geq \bar{M}_{ij} \left[\frac{c_j}{g_{ij}(1+tm_{ij})(1+tx_{ij}) p_{ij} / \bar{p}_{ij} + (1-g_{ij})(1+tm_{ij}) p^t / \bar{p}^t_{ij}} \right]^s \perp M_{ij} \geq 0 \text{.} \qquad \text{(A2)}$$

The fob prices (for the commodity p_{ij} and transport services p^t) and trade taxes are exogenously controlled. Reference prices ($\bar{p}_{ij}$ and $\bar{p}^t_{ij}$) are constant. Adopting a structure that assumes a fixed proportion of transport service -- g_{ij} is the benchmark value share of the commodity in the overall import purchase. To compute the compensated response from an elimination of all trade frictions, p^t and the tax parameters are set to zero. The value shares are defined by:

$$q_{ij} \geq \frac{(1+tm_{ij})(1+tx_{ij}) p_{ij} M_{ij} + (1+tm_{ij}) p^t T_{ij}}{\sum_i \left((1+tm_{ij})(1+tx_{ij}) p_{ij} M_{ij} + (1+tm_{ij}) p^t T_{ij}\right)} \perp q_{ij} \geq 0 \text{, (A3)}$$

[13] The behavioral functions are similar to the GAMS equations presented by Rutherford and S.V. Paltsev (2000), in a full general equilibrium representation of the GTAP data. For a discussion of complementarity problems see Rutherford (1995), "Extensions of GAMS for Complementarity Problems Arising in Applied Economics", Journal of Economics Dynamics and Control, 1299-1324)).

where T_{ij} is the demand for transport services (proportional to imports). The conditions A1, A2 and A3 are sufficient for computing $\hat{q}_{ij}$ and the MOF for a given sigma. To find the sigma that is consistent with neutral tastes (MOF=1), s is freed up as an endogenous variable and the following condition is added to the system:

$$\frac{\sum_i \sum_j \left(\bar{q}_{ij} - \hat{q}_{ij}\right)^2}{\sum_i \sum_j \left(\bar{q}_{ij} - \hat{q}_{iW}\right)^2} \geq 1 \perp s_{ij} \geq 1 \quad . \quad \text{(A4)}$$

This is analogous to minimizing the square of one minus MOF subject to A1,A2,A3, but the complemenarity formulation has numeric advantages.