Global Simulation Analysis of Industry-Level Trade Policy

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Abstract: In this paper, we outline a modeling strategy for the partial equilibrium analysis of global trade policy changes at the industry level. The framework employs national product differentiation, and allows for the simultaneous assessment of trade policy changes, at the industry level, on a global, regional, or national level. Results allow the assessment of importer and exporter effects related to tariff revenues, exporter (producer) surplus, and importer (consumer) surplus.

Keywords: partial equilibrium model, trade policy, simulation model, global markets

1. Introduction

In this paper, we outline a global simulation model (GSIM) for the analysis of global trade policy changes. The approach we develop is partial equilibrium, being industry focused but global in scope. By definition, partial equilibrium models do not take into account many of the factors emphasized in general equilibrium trade theory. This implies practical limitations to the approach developed here. It also implies some useful advantages. Because we focus on a very limited set of factors, the approach followed here allows for relatively rapid and transparent analysis of a wide range of commercial policy issues with a minimum of data and computational requirements. In our view, as long as the limitations of the partial equilibrium approach are kept in mind, useful insights can be drawn with regard to relatively complex, multi-country trade policy changes at the industry level. This includes interaction of multiple market access concessions across various trading partners, exporter gains, consumer surplus (importer) gains, and changes in tariff revenue.

This paper is organized as follows. Section 2 develops the mathematical structure of the simulation model. This includes calibration of relevant own- and cross-price elasticities, as well as global market clearing conditions. The relationship of model results to the concept of trade creation and diversion is also discussed. Section 3 then discusses a sample 4 region implementation of the model in Excel. This serves to illustrate calculation of producer and consumer surplus changes, tariff revenue changes, and the overall strategy for solving the model. An Excel file is meant to be distributed with this paper.

2. Basic relationships

To estimate the global impact of trade policy changes at a combined country and industry level, our solution strategy involves a partial-equilibrium representation of the multi-country global market. Within this context, we work with a linearized (percent-change) representation of import demand, combined with generic export-supply equations. This allows us to reduce a potentially large system of bilateral trade relationships to one of reduced-form global supply and demand. This reduced-form system, which only includes as many equations as there are exporters, is then solved for the set of world (exporter) prices.

A basic assumption is national product differentiation.[1] As developed here, this means that imports are imperfect substitutes for each other. The elasticity of substitution is held to be equal and constant across products from different sources. The elasticity of demand in aggregate is also constant. Finally, import supply is also characterized by constant (supply) elasticities.

[1] This can result, in an Ethier-Krugman type model, if product varieties are fixed. It may also be a result of national differences in product characteristics (like French vs. Australian wine).

2.1 Elasticities

A critical element of the modeling approach developed here is the underlying own- and cross-price demand elasticities. To arrive at these values, we start by assuming that, within each importing country *v*, import demand within product category *i* of goods from country *r* is a function of industry prices and total expenditure on the category:

(1) $$M_{(i,v),r} = f(P_{(i,v),r} \;, P_{(i,v),s\neq r} \;, y_{(i,v)})$$

where $y_{(i,v)}$ is total expenditure on imports of *i* in country *v*, $P_{(i,v),r}$ is the internal price for goods from region *r* within country *v*, and $P_{(i,v),s\neq r}$ is the price of other varieties. In demand theory, this results from the assumption of weakly separability. (To avoid confusion on the part of the reader or the authors, Table 1 summarizes our notation).

By differentiating equation (1), applying the Slutsky decomposition of partial demand, and taking advantage of the zero homogeneity property of Hicksian demand, we can then derive the following (See Francois and Hall 1997):

(2) $$N_{(i,v),(r,s)} = \theta_{(i,v),s} E_s + \eta_{(i,v),(r,y)} \left(\eta_{(i,v),(y,s)} - \theta_{(i,v),s} \right)$$

where $\theta_{(i,v),s}$ is and expenditure share, $\eta_{(i,v)(r,y)}$ is the industry expenditure elasticity of demand for product variety *r*, and $\eta_{(i,v)(y,s)}$ is the price *s* elasticity of industry expenditure. We can also derive a similar term for own-price demand elasticities.

(3) $$N_{(i,v)(r,r)} = -\sum_{s\neq r} \theta_{(i,v),s} E_s + \eta_{(i,v),(r,y)} \left(\eta_{(i,v),(y,r)} - \theta_{(i,v),r} \right)$$

Equations (2) and (3) can be further simplified with the additional assumption of homothetic preferences for expenditures which, along with the assumption of weak separability, is sufficient for two stage budgeting. This lets us define composite price and composite quantity indexes, and define aggregate expenditure with respect to these composite price and quantity indexes. Formally, to simplify equations (2) and (3), we note that homotheticity of preferences implies that income $\eta_{(i,v)(r,y)} = 1$, while from Francois and Hall (1997) we also have:

(4) $$\eta_{(i,v)(y,s)} = \theta_{(i,v),s} \left(1 + E_{M,v} \right)$$

where $E_{M,v}$ is the composite demand elasticity in importing region v. Making substitutions, we arrive at the following relationships:

(5) $$N_{(i,v),(r,s)} = \theta_{(i,v),s} (E_m + E_s)$$

(6) $$N_{(i,v),(r,r)} = \theta_{(i,v),r} E_m - \sum_{s \neq r} \theta_{(i,v),s} E_s = \theta_{(i,v),r} E_m - (1 - \theta_{(i,v),r}) E_s$$

2.2 Individual Demand and Supply Conditions

We also need to introduce some basic supply and demand relationships. Defining $P_{i,r}*$ as the export price received by exporter r on world markets, and $P_{(i,v),r}$ as the internal price for the same good, we can link the two prices as follows:

(7) $$P_{(i,v),r} = (1 + t_{(i,v),r}) P_{i,r}* = T_{(i,v),r} P_{i,r}*$$

In equation (7), $T = 1 + t$ is the power of the tariff (the proportional price markup achieved by the tariff *t*.) We will define export supply to world markets as being a function of the world price $P*$.

(8) $$X_{i,r} = f(P_{i,r}*)$$

Differentiating equations (1), (7) and (8) and manipulating the results, we can derive the following:

(9) $$\hat{P}_{(i,v),r} = \hat{P}_{i,r}* + \hat{T}_{(i,v),r}$$

(10) $$\hat{X}_{i,r} = E_{X(i,r)}\hat{P}_{i,r}*$$

(11) $$\hat{M}_{(i,v),r} = N_{(i,v),(r,r)}\hat{P}_{(i,v),r} + \sum_{s \neq r} N_{(i,v),(r,s)}\hat{P}_{(i,v),s}$$

where ^ denotes a proportional change, so that $\hat{x} = \frac{dx}{x}$.

2.3 Global equilibrium conditions

From the system of equations above, we make further substitutions to arrive at a workable model defined in terms of world prices. In particular we substitute equations (9), (5), and (6) into (11), and sum over import markets.

(12) $$\hat{M}_{i,r} = \sum_v \hat{M}_{(i,v),r} = \sum_v N_{(i,v),(r,r)} \hat{P}_{(i,v),r} + \sum_v \sum_{s \neq r} N_{(i,v),(r,s)} \hat{P}_{(i,v),s}$$
$$= \sum_v N_{(i,v),(r,r)} [P_r * + \hat{T}_{(i,v),r}] + \sum_v \sum_{s \neq r} N_{(i,v),(r,s)} [\hat{P}_s * + \hat{T}_{(i,v),s}]$$

We can then set equation (12) equal to the modified version of equation (10).

(13) $$\hat{M}_{i,r} = \hat{X}_{i,r} \Rightarrow \quad E_{X(i,r)} \hat{P}_{i,r} * = \sum_v N_{(i,v),(r,r)} \hat{P}_{(i,v),r} + \sum_v \sum_{s \neq r} N_{(i,v),(r,s)} \hat{P}_{(i,v),s}$$
$$= \sum_v N_{(i,v),(r,r)} [P_r * + \hat{T}_{(i,v),r}] + \sum_v \sum_{s \neq r} N_{(i,v),(r,s)} [\hat{P}_s * + \hat{T}_{(i,v),s}]$$

Once we solve this system for world prices, we can then use equations (11) to backsolve for export quantities, and equations (12) to solve for import quantities. From there, calculations of revenue effects are also straightforward. These can be combined with partial equilibrium measures of the change in producer (i.e. exporter) surplus ΔPS and net consumer (i.e. importer net of tariff revenue changes) surplus $\Delta CS_{i,v}$ as a crude measure of welfare effects. Our measure of producer surplus is shown in Figure 1 as the area of trapezoid *hsnz*, and approximates the change in the area between the export supply curve and the price line. Formally, this is represented by equation (14) below.

[Figure 1 about here]

(14) $$\Delta PS_{(i,r)} = R^0{}_{(i,r)} \cdot \hat{P}_{i,r} * + \tfrac{1}{2} \cdot R^0{}_{(i,r)} \cdot \hat{P}_{i,r} * \cdot \hat{X}_{i,r}$$
$$= \left(R^0{}_{(i,r)} \cdot \hat{P}_{i,r} * \right) \cdot \left(1 + \frac{E_{X,(i,r)} \cdot \hat{P}_{i,r} *}{2} \right)$$

In equation (14), $R^{0}_{(i,r)}$ represents benchmark export revenues, either bilateral or in total, valued at world prices.

The change in consumer surplus is also represented in Figure 1, as the area of trapezoid *abcd*. It is defined as the change in the area between the demand curve and the composite good price, as perceived by consumers. This is formalized in equation (15).

(15)
$$\Delta CS_{(i,v)} = \left(\sum_{r} R^{0}{}_{(i,v),r} \cdot T^{0}{}_{(i,v),r} \right) \cdot \left(\tfrac{1}{2} E_{M,(i,v)} \hat{P}_{(i,v)}{}^{2} \cdot sign(\hat{P}_{(i,v)}) - \hat{P}_{(i,v)} \right)$$
$$where\ \hat{P}_{(i,v)} = \sum_{r} \theta_{(i,v),r} \hat{P}_{r} * + \hat{T}_{(i,v),r}$$

In equation (15), consumer surplus is measured with respect to the composite import demand curve, with $P_{(i,v)}$ representing the price for composite imports, and $R^{0}_{(i,r)} \cdot T^{0}{}_{(i,v),r}$ representing expenditure at internal prices. (To derive the relative change in composite good prices, we define quantities so that the initial composite price is unity). To make an approximation of welfare changes, we can combine the change in producer surplus, consumer surplus, and import tariff revenues.

2.4 TRADE CREATION AND DIVERSION

Within the system developed above, in the case of a small country it is relatively easy to link our functional relationships to a representation of trade creation and trade diversion. In particular, assume that world prices are fixed, so that price changes are simply driven by tariff changes. In this case, we have:

(16) $$\hat{M}_{(i,v),r} = N_{(i,v),(r,r)}\hat{P}_{(i,v),r} + \sum_{s \neq r} N_{(i,v),(r,s)}\hat{P}_{(i,v),s}$$
$$= N_{(i,v),(r,r)}\hat{T}_{(i,v),r} + \sum_{s \neq r} N_{(i,v),(r,s)}\hat{T}_{(i,v),s}$$

Where we can further decompose equation (16) into a trade creation and trade diversion effect:

(17) Trade Creation: $$TC_{(i,v),r} = M_{(i,v),r} \times [N_{(i,v),(r,r)}\hat{T}_{(i,v),r}]$$

(18) Trade Diversion: $$TD_{(i,v),r} = M_{(i,v),r} \times \sum_{s \neq r} N_{(i,v),(r,s)}\hat{T}_{(i,v),s}$$

In equations (17) and (18), we have defined trade creation as trade generated by own tariff reductions, and trade diversion as trade changes generated by changes in tariffs on imports from third countries. Trade creation and diversion are really just a special case of the cross-price and own-price effects that make up import demand in equation (12) and equation (13).

3. Implementation – an example

A 4x4 sample implementation of the model developed above is available as an Excel file. The data input section is illustrated in Figure 2, which highlights the basic data requirements. These include trade flows (valued at a common set of world prices), trade policy wedges, and relevant demand, supply, and substitution elasticities. The same types of data (with greater matrix dimensionality) are also required for larger applications. Note that while elasticities are symmetric for the present example, this is not necessary. On the basis of input data, other key parameters (as defined in equations

(5) and (6) above) are calculated for cross-price and own-price effects. These are shown in Figure 3.

[Figure 2 about here]

[Figure 3 about here]

The Excel solver is then used to solve the excess demand conditions specified in equation (13) above for equilibrium prices in the counterfactual. This involves specifying one of the R excess demand functions for exports as the objective function, with the other excess demand functions then specified as constraints. The same approach can be specified for version of the model with higher dimensionality. (For more on the use of the Excel solver for solving computational models, see Francois and Hall 1997, and Devarajan et al 1997). The core solution values, involving prices and excess demands, are shown in Figure 4.

[Figure 4 about here]

On the basis of equilibrium price values, other changes in the system can be calculated as well. These include, of course, producer and consumer surplus measures (equations 14 and 15), changes in tariff revenues, trade quantities, and trade values. These are illustrated in Figures 5 and 6. The experiment results, while based on synthetic data, still illustrate the types of effects captured in the model. We have modeled an experiment where two regions, the United States and European Union, introduce reciprocal tariff cuts (as might happen from a free trade agreement). The two regions gain, on net, from the tariff reductions. One of the outside regions, Japan, loses as its relative market access conditions erode in both markets. The fourth region, ROW, actually gains. This is primarily because Japanese exports, diverted from the European Union and United States, enter the ROW at reduced prices. This yields gains in consumer surplus and tariff revenue.

[Figure 5 about here]

[Figure 6 about here]

References

Devarajan, S., D.S. Go, J.D. Lewis, S. Robinson, and P. Sinko, "Simple General Equilibrium Modeling," in J.F. Francois and K. Reinert, eds., *Applied Methods for Trade Policy Analysis: A Handbook*, Cambridge University Press: Cambridge, 1997.

Francois, J.F. and H.K. Hall, "Partial Equilibrium Modeling," in J.F. Francois and K. Reinert, eds., Applied *Methods for Trade Policy Analysis*: A Handbook, Cambridge University Press: Cambridge, 1997.

Table 1
Notation

	<u>INDEXES</u>
r,s	exporting regions
v,w	importing regions
i	industry designation
	<u>VARIABLES</u>
M:	imports (quantity)
X:	exports (quantity)
$E_{m,(i,v)}$:	aggregate import demand elasticity Defined for aggregate imports $M_{(i,v)}$ and composite price $P_{(i,v)}$ $= \frac{\partial M_{(i,v)}}{\partial P_{(i,v)}} \cdot \frac{P_{(i,v)}}{M_{(i,v)}}$
$E_{x,(i,r)}$:	elasticity of export supply $= \frac{\partial X_{(i,r)}}{\partial P_{(i,r)}^*} \frac{P_{(i,r)}^*}{X_{(i,r)}}$
E_s:	elasticity of substitution
$N_{(i,v),(r,r)}$:	own price demand elasticity
$N_{(i,v),(r,s)}$:	cross-price elasticity
$T_{(i,v),r}$:	The power of the tariff, T=(1+t)
$\theta_{(i,v),r}$:	demand expenditure share (at internal prices) $\theta_{(i,v),r} = M_{(i,v),r}T_{(i,v),r} / \sum_s M_{(i,v),s}T_{(i,v),s}$
$\phi_{(i,v),r}$:	export quantity shares $\phi_{(i,v),r} = M_{(i,v),r} / \sum_w M_{(i,w),r}$

Figure 1
Producer and Consumer Surplus Measures

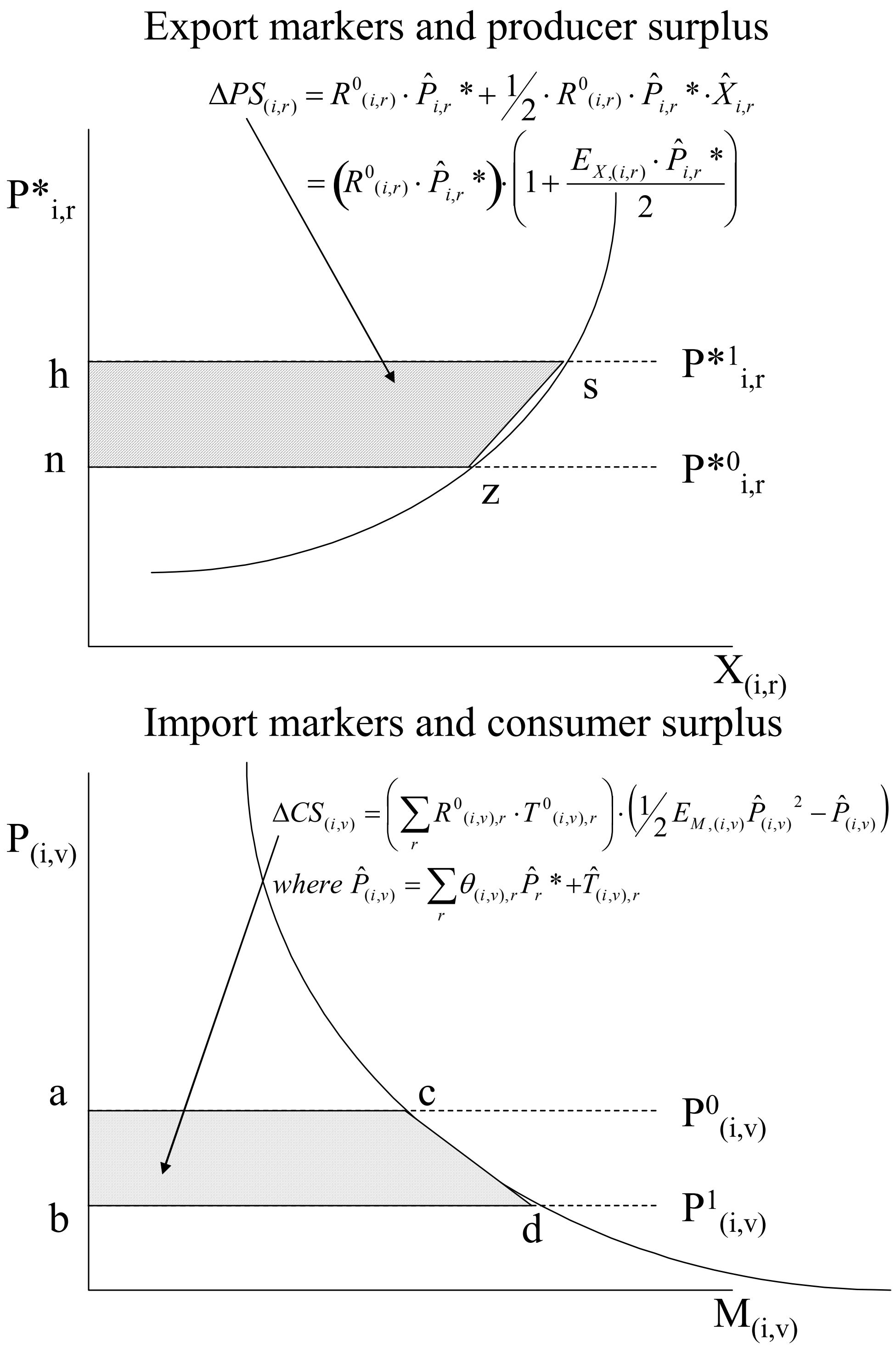

Figure 2
Excel 4x4 implementation of GSIM -- model inputs

	A	B	C	D	E	F	G	H	I
1									
2		SECTOR: cat's pajamas		**INPUTS**					
3									
4				trade at world prices:					
5					destination				Totals
6					USA	JAPAN	EU	ROW	
7			origin	USA	0	50	200	300	550
8				JAPAN	500	0	150	200	850
9				EU	300	100	200	200	800
10				ROW	50	100	110	20	280
11				Totals	850	250	660	720	
12				initial import tariffs					
13					destination				
14					USA	JAPAN	EU	ROW	
15			origin	USA	1	1.2	1.4	1.2	
16				JAPAN	1.3	1	1.4	1.2	
17				EU	1.3	1.2	1	1.2	
18				ROW	1.3	1.2	1.4	1.2	
19									
20				final import tariffs					
21					destination				
22					USA	JAPAN	EU	ROW	
23			origin	USA	1	1.2	1	1.2	
24				JAPAN	1.3	1	1.4	1.2	
25				EU	1	1.2	1	1.2	
26				ROW	1.3	1.2	1.4	1.2	
27									
28				Elasticities:					
29					USA	JAPAN	EU	ROW	
30			Em	Import Demand	-1.25	-1.25	-1.25	-1.25	
31			Ex	Export Supply	1.5	1.5	1.5	1.5	
32			Es	Substitution	5	5	5	5	

Figure 3
Excel 4x4 implementation of GSIM -- Calibrated values

	A	B	C	D	E	F	G	H	I
34				***Calibrated values***					
35									
36		Notation definitions		Import shares at internal prices					
37					destination				
38					USA	JAPAN	EU	ROW	
39				USA	0.00000	0.20000	0.33175	0.41667	
40			origin	JAPAN	0.58824	0.00000	0.24882	0.27778	
41				EU	0.35294	0.40000	0.23697	0.27778	
42				ROW	0.05882	0.40000	0.18246	0.02778	
43				SUM	1	1	1	1	
44									
45		Notation definitions		Export shares at world prices					
46					destination				
47					USA	JAPAN	EU	ROW	SUM
48				USA	0.0000	0.0909	0.3636	0.5455	1
49			origin	JAPAN	0.5882	0.0000	0.1765	0.2353	1
50				EU	0.3750	0.1250	0.2500	0.2500	1
51				ROW	0.1786	0.3571	0.3929	0.0714	1
52									
53									
54			N(i,v),(r,r)	Own price elasticities					
55		Equation (6)			destination				
56					USA	JAPAN	EU	ROW	
57				USA	-5.0000	-4.2500	-3.7559	-3.4375	
58			origin	JAPAN	-2.7941	-5.0000	-4.0669	-3.9583	
59				EU	-3.6765	-3.5000	-4.1114	-3.9583	
60				ROW	-4.7794	-3.5000	-4.3158	-4.8958	
61									
62			N(i,v),(r,s)	Cross price elasticities					
63		Equation (5)			destination				
64					USA	JAPAN	EU	ROW	
65				USA	0.0000	0.7500	1.2441	1.5625	
66			origin	JAPAN	2.2059	0.0000	0.9331	1.0417	
67				EU	1.3235	1.5000	0.8886	1.0417	
68				ROW	0.2206	1.5000	0.6842	0.1042	

Figure 3
Excel 4x4 implementation of GSIM – Core solution values

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
70				**MODEL SOLUTIONS**										
71														
72				MARKET CLEARING CONDITIONS							CROSS-PRICE EFFECTS ON DEMAND			
73				Relative price changes										
74					benchmark prices	new prices	change in supply	change in demand	Excess Demand					
75		Equation (13)	origin	USA	0.0000	0.0783	0.1175	0.1175	0.0000		-0.3168	0.0424	0.0000	0.0136
76				JAPAN	0.0000	-0.0308	-0.0461	-0.0461	0.0000		-0.2490	0.1012	-0.2294	0.1680
77				EU	0.0000	0.0455	0.0683	0.0683	0.0000		-0.0716	0.0329	-0.2985	0.0885
78				ROW	0.0000	-0.0172	-0.0259	-0.0259	0.0000		-0.3130	0.1270	-0.2463	0.1378
79														

Figure 4
Excel 4x4 implementation of GSIM – Other solution values

	A	B	C	D	E	F	G	H
80				**OTHER RESULTS**				
81				**trade values and quantities**				
82				trade quantities: percent change				
83					destination			
84					USA	JAPAN	EU	ROW
85			origin	USA	0.0	-29.0	77.9	-25.6
86				JAPAN	-16.3	0.0	-10.4	29.0
87				EU	60.9	-12.7	-48.6	-9.2
88				ROW	-23.1	18.7	-17.2	22.2
89								
90				Trade at world prices: new values				
91					destination			
92					USA	JAPAN	EU	ROW
93			origin	USA	0.0	38.3	383.7	240.8
94				JAPAN	405.6	0.0	130.2	250.0
95				EU	504.8	91.3	107.5	189.9
96				ROW	37.8	116.7	89.5	24.0
97								
98				Trade at world prices: change in values				
99					destination			
100					USA	JAPAN	EU	ROW
101			origin	USA	0.0	-11.7	183.7	-59.2
102				JAPAN	-94.4	0.0	-19.8	50.0
103				EU	204.8	-8.7	-92.5	-10.1
104				ROW	-12.2	16.7	-20.5	4.0
105								
106				Proportional change in internal prices				
107					destination			
108					USA	JAPAN	EU	ROW
109			origin	USA	0.1	0.1	-0.2	0.1
110				JAPAN	0.0	0.0	0.0	0.0
111				EU	-0.2	0.0	0.0	0.0
112				ROW	0.0	0.0	0.0	0.0
113				Composite price	-0.1	0.0	-0.1	0.0
114								
115				**Tariff revenue and consumer surplus**				
116					destination			
117					USA	JAPAN	EU	ROW
118				Tariff revenue	-98.2	3.7	-50.9	15.2
119				Consumer surplus	102.8	8.0	67.4	30.6
120								
121				**Total welfare effects**				
122					A	B	C	D=A+B
123					Producer surplus	Consumer surplus	Tariff revenue	Net welfare effect
124			country	USA	45.6	102.8	-98.2	50.2
125				JAPAN	-24.1	8.0	3.7	-12.5
126				EU	36.4	67.4	-50.9	52.9
127				ROW	-4.8	30.6	15.2	41.0

Figure 5
Excel 4x4 implementation of GSIM – Results summary

	Exports			
	Old Export Values	New Export Values		
USA	550.00	662.73		
JAPAN	850.00	785.85		
EU	800.00	893.57		
ROW	280.00	268.05		
	2480.00	2610.21		
	Imports			
	Old Import Values	New Import Values		
USA	850.00	948.21		
JAPAN	250.00	246.28		
EU	660.00	710.94		
ROW	720.00	704.78		
	2480.00	2610.21		
	Net Effects			
	A	B	C	D=A+B+C
	Producer surplus	Consumer surplus	Tariff revenue	Net effect
USA	45.60	102.82	-98.21	50.21
JAPAN	-24.13	7.96	3.72	-12.45
EU	36.43	67.41	-50.94	52.90
ROW	-4.83	30.62	15.22	41.01