Approximating International Linkages in a National CGE Model*

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Abstract

This paper assesses the trade-offs of incorporating a reduced form representation of international trade in a national computable general equilibrium model setting. We compare the efficacy of a reduced form representation of a large open economy model using estimated elasticities derived from the GTAPinGAMS package with a model with the rest of world explicitly denominated. We then apply the reduced form framework to U.S. EPA's SAGE model, a large scale intertemporal CGE model of the United States economy. We explore implications of the reduced form framework by comparing modeled impacts to those produced by a version of SAGE modeled as a small open economy. Particular attention is paid to how the reduced form approach to modeling international trade linkages interacts with other salient features of the more complicated modeling framework.

*The views expressed in this research are of the authors and not those of the U.S Environmental Protection Agency. All errors are our own.

1 Introduction

The computable general equilibrium (CGE) modeling community frequently confronts the issue of dimensionality. The trade-offs involved in modeling multiple regions, sectors, time periods, households, etc. can be numerous, but typically boil down to issues of computational tractability, parameter uncertainty, and model maintenance. One example of this broader class of issues is representing international trade linkages in models that provide extensive detail on single country economies without explicit representation of the rest of world. Single country models often circumvent these issues by assuming that they are small open economies, or price takers on the world market. This may be a reasonable assumption in many cases, but when the modeled country is large enough, it can assume away potentially large terms of trade impacts particularly when modeling policy scenarios for trade exposed sectors.

To capture rest of world interactions in a single country model, a modeler has two choices, barring building a world economy model from scratch: (1) link the single country model to an existing international model like GTAP, or (2) build in reduced form mechanisms to capture trade responses without explicitly capturing the physical process of trade. Both of these approaches have relative advantages and disadvantages. In the first case, the model would capture the full richness of the international framework. However, this also requires the single country model to conform with the larger international framework, both in terms of import and export quantities and prices and may require additional information on subnational trade if the single country model has multiple sub-regions. Furthermore, if the single country model incorporates complicated dynamics (like intertemporal dynamic optimization), the international model like GTAP would have to be altered and therefore maintaining both frameworks would pose relatively large burdens. Conversely, in the second case, while a reduced form approach may potentially limit the ability to properly capture terms of trade impacts, it could significantly simplify the representation of the rest of world and reduce the burdens of maintenance and parameter uncertainty accompanying the first option.

In this paper, we assess this trade-off. We adopt the reduced form framework from Yuan et al. (2019) and parameterize it with import supply and export demand price elasticities derived from the GTAPinGAMS package (Lanz and Rutherford, 2016). The core GTAPinGAMS model is used to trace out export demand curves for U.S. exports and import supply curves for imports coming into the U.S. implied by the default calibration of the static model. The curvature in changes to prices and quantities is used to fit isoelastic functions to estimate implied export demand and import supply elasticitities for a representative set of sectors that are either directly or indirectly impacted by environmental regulations in the United States.

We use these set of elasticities to parameterize a version of the core, static GTAPinGAMS model that includes the reduced form large open economy mechanism. Using this modeling environment, we can directly test how well the reduced form framework captures trade related impacts that: (1) would have otherwise been missed given a small open economy assumption that assumes a fixed price of foreign exchange and, (2) can be modeled explicitly using the comprehensive multi-country GTAP database. We construct three versions of the GTAPinGAMS model that are otherwise identical except for their representation of trade: (1) a model that explicitly characterizes the rest of world (ROW) along with the United States; (2) a model that includes just the US economy but with the reduced form large open economy mechanisms that allows changes in the US to impact world prices; and (3) a model that assumes the US is a small open economy. We compare these three frameworks by simulating the trade and welfare impacts for a suite of representative environmental regulations modeled as sector specific productivity shocks. In this framework, we model the simplified representation of an environmental regulation by assuming additional inputs for compliance are required to produce the same level of output.

We then assess how well the reduced form approach extrapolates to an existing large-scale CGE model of the United States economy. In this work, we use the SAGE (SAGE is an Applied General Equilibrium) model (Marten et al., 2020). SAGE is a dynamic CGE model with perfect foresight that features multiple sub-regions, sectors and households. We isolate the effect of the reduced form large open economy specification by comparing modeled impacts to those produced by a version of SAGE modeled as a small open economy. Particular attention is paid to how the reduced form approach to modeling international trade linkages interacts with other salient features of the more complicated modeling framework. Furthermore, we also evaluate the implications of extrapolating elasticities generated from a static modeling environment to a dynamic framework.

The remainder of the paper is organized as follows. In section 2, we give an overview of how we've modified the GTAPinGAMS package (including sectoral and regional aggregation schemes), the estimation framework for import and export price elasticities and illustrative results comparing the three versions of the model outlined above. In section 3, we present an overview of the SAGE model that will be updated prior to the conference.

2 GTAPinGAMS

The GTAPinGAMS framework is discussed at length in Lanz and Rutherford (2016). Similar to the authors, we also use GTAP v9 data for this paper. For the purposes of this paper and outside of the bilateral trade framework, we only modify the sectoral and regional aggregation of the core model to cleanly map estimated elasticities back to the SAGE framework. Table 1 provides a description of the sectoral and regional aggregation assumed in this paper.

Table 1: Sector and Region Aggregation

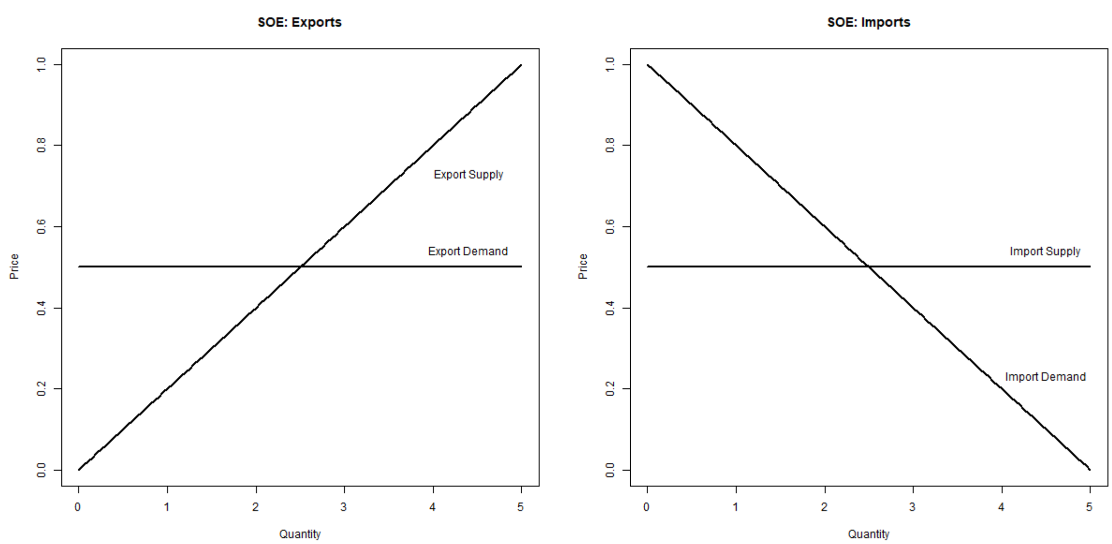
Type	*Set Index*	*Description*
Sectors/ Commodities	agf	Agriculture, forestry, fishing and hunting
	cru	Crude oil
	col	Coal mining
	min	Metal ore and nonmetalic mineral mining
	ele	Electric power
	gas	Natural gas
	wsu	Water, sewage, and other utilities
	con	Construction
	fbm	Food and beverage manufacturing
	wpm	Wood product manufacturing
	ref	Petroleum refineries
	chm	Chemical manufacturing
	cem	Cement manufacturing
	pmm	Primary metal manufacturing
	fmm	Fabricated metal product manufacturing
	cpu	Electronics and technology manufacturing
	tem	Transportation equipment manufacturing
	bom	Other manufacturing
	trn	Transportation
	ttn	Truck transportation
	srv	Services
	hlt	Healthcare services
Regions	usa	United States
	row	Rest of World

The representative sectors in Table 1 have a greater degree of disaggregation in the manufacturing and energy sectors of the economy that are more regularly impacted by environmental regulation. Note that the mapping to SAGE sectors is imperfect, as GTAP does not have plastic and rubber manufacturing separately disaggregated in its default sectoring scheme. Finally, we aggregate the rest of world to be a single region as we are most interested in aggregated trade impacts with the United States.

2.1 The Reduced Form Approach

In single country CGE models, it is common to employ the small open economy assumption. Figure 1 describes a simplified representation of this assumption where the modeled country supplies exports and demands imports from the world market with a perfectly elastic export demand and import supply curve. Given this assumption, the modeled country cannot influence world prices.

Figure 1: Small Open Economy Assumptions



When the modeled country is large enough, however, this may not be an appropriate assumption. To circumvent this issue in the USREP (U.S. Regional Energy Policy) model, Yuan et al. (2019) relaxes this assumption by introducing some curvature in the flat portions of Figure 1 using fixed factors calibrated to exogenous price elasticities. Note that this specification is not meant to explicitly capture the physical process of trade, but rather approximate price and quantity impacts in the modeled country if the rest of world were included in the model. We adopt a similar representation of a large open economy in this paper. The remainder of this sub-section presents a derivation of the reduced form approach in calibrated share form (Rutherford, 2002). In what follows, we assume that symbols with a "0" are data parameters and those without are variables in the model.

In a typical input output table, we would know the value of imports coming into a country for a given commodity. Using this information, the supply of imports from the rest of the world is characterized by a Cobb-Douglas production function, defined as

$$m_i = m0_i \left(\frac{fim_i}{fim0_i}\right)^{cs\_loe\_m_i} \left(\frac{m\_fx_i}{(m0_i - fim0_i)}\right)^{(1-cs\_loe\_m_i)} \tag{1}$$

where m_i is the supply of imports from the rest of world into the United States for commodity i, $m0_i$ the associated data parameter, fim_i be the fixed factor input to import supply and m_fx_i is foreign imports less the fixed factor. cs_m_i is the calibrated cost share based on exogenous price elasticities for import supply. The fixed factor data value, $fim0_i$, is calculated based on cs_m_i and $m0_i$.

Similarly, the international demand for exports (xd_fx_i) is also characterized by a Cobb-Douglas production function combining exports from the U.S. market (x_i) and exports from the rest of world agent treated as a fixed factor (fix_i), defined as

$$xd\_fx_i = (x0_i + fix0_i) \left(\frac{fix_i}{fix0_i}\right)^{cs\_loe\_x_i} \left(\frac{x_i}{x0_i}\right)^{(1-cs\_loe\_x_i)} \tag{2}$$

where $cs\_loe\_x_i$ is the calibrated cost share based on exogenous price elasticities for export demand. Note that when $cs\_loe\_m_i = 0$ and $cs\_loe\_x_i = 0$, the model is translated into a small open economy. We use a Cobb-Douglas function without loss of generality to pin down calibrated cost shares and fixed factors based on exogenous price elasticities.

The large open economy assumption is operationalized by calibrating the fixed factors in the above equations so that model behavior is consistent with exogenous price elasticities. Using a fixed factor formulation with a Cobb-Douglas function that assigns the elasticity of substitution equal to 1, we can solve for the cost shares (exponents in the above), and calculate the value of the fixed factors as our two unknowns. Costs shares are solved for as,

$$cs\_loe\_x_i = \frac{1}{|\epsilon_i^x|} \tag{3}$$

and

$$cs\_loe\_m_i = \frac{1}{1+\epsilon_i^m} \tag{4}$$

where ϵ_i^x is the price elasticity of export demand for commodity i and ϵ_i^m is the price elasticity of import supply for commodity i. The reference levels of the fixed factors for exports ($fix0_i$) and imports ($fim0_i$) are then defined as,

$$fix0_i = \frac{cs\_loe\_x_i}{(1 - cs\_loe\_x_i)} x0_i \tag{5}$$

and

$$fim0_i = cs\_loe\_m_i m0_i. \tag{6}$$

2.2 Estimation

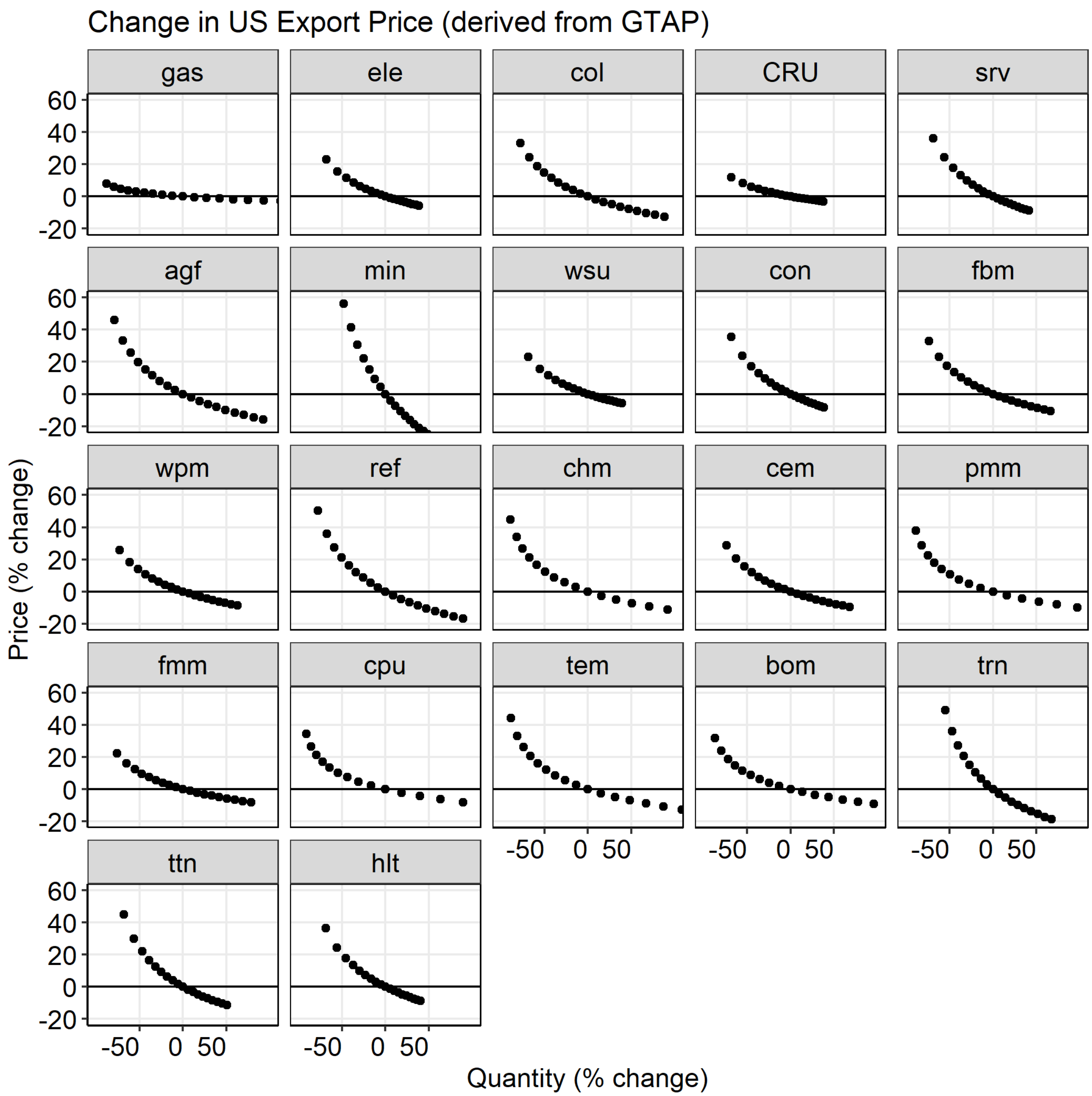
The above calibration of the large open economy assumption relies on exogenous price elasticities for import supply and export demand. To estimate values for these elasticities, we use the GTAPinGAMS core, static model. Using the two region model (USA, ROW), we trace out the export demand and import supply curves by perturbing US exports and imports by commodity via quantity shocks of varying magnitudes. Figures 2 and 3 plot the quantity and price impacts for US exports and imports, respectively, where each dot represents a single model run. In general, the import supply curves tend to be flatter than those for export demand with exception to crude oil.

The results in Figures 2 and 3 are used as data inputs to a least squares procedure that fits an isoelastic function of the form:

$$log(q_i) = \beta_0 + \beta_1 log(p_i) + \epsilon_i, \tag{7}$$

where q_i and p_i are quantity and prices of commodity i, ϵ_i is an error term and β_1 is the estimated

Figure 2: Export Demand Simulations

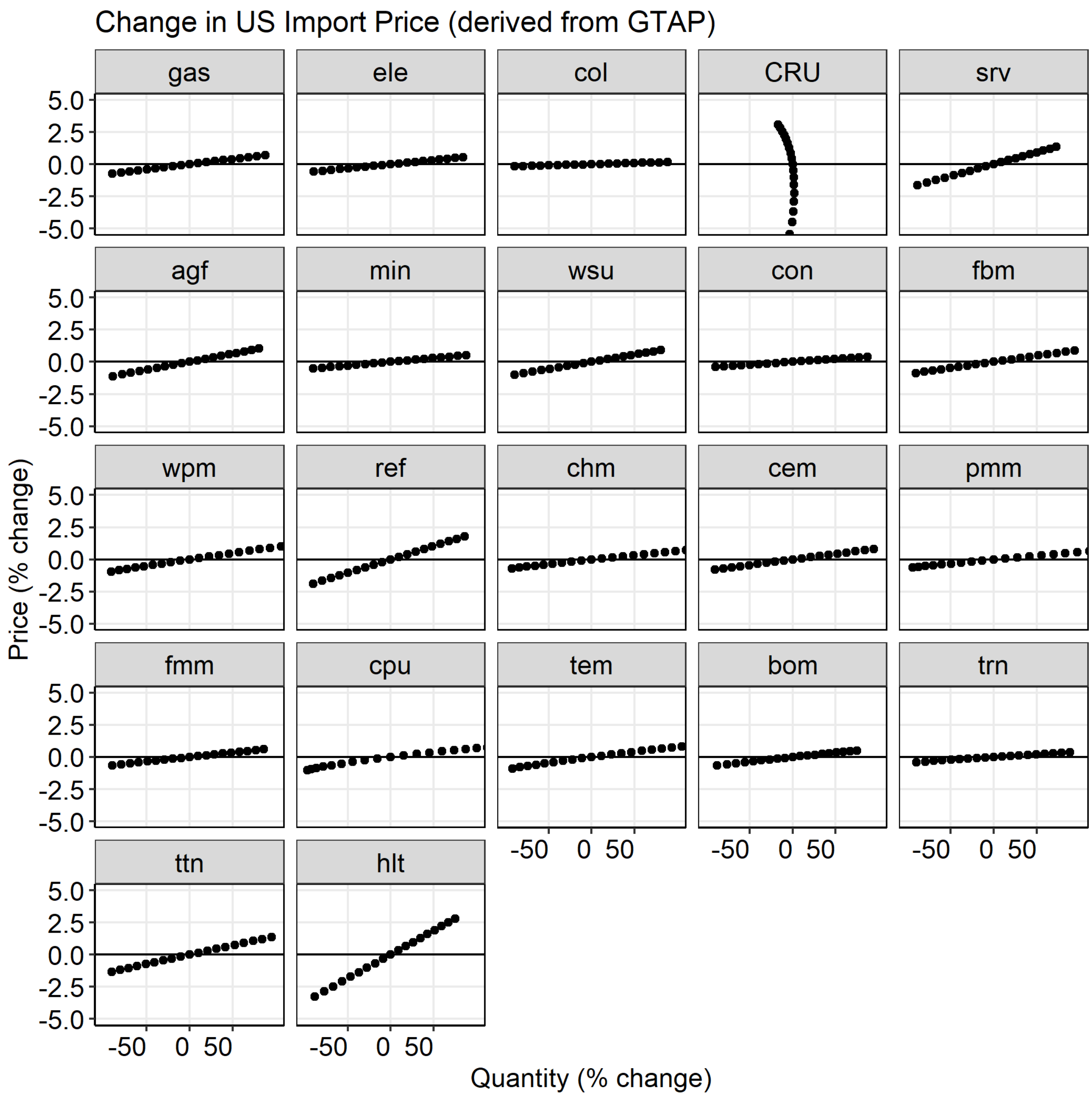


elasticity. The results for β_1 of the estimation procedure are reported in Table 2 in columns labeled as "Estimated".

2.3 Policy Simulations

To compare the three competing GTAPinGAMS frameworks (two region model, single region large open economy model (LOE), and single region small open economy model (SOE)), we run

Figure 3: Import Supply Simulations



a set of sector specific productivity shocks equal to $1 billion to mimic the requirements of an environmental regulation. Here, we assume a proportional increase in all inputs in the reference production schedule for a given sector. For more information on this type of shock, see Marten et al. (2020) and Marten et al. (2019).

Before reporting preliminary results, we first verify the calibration of the reduced form large open economic specification. The right side of Table 2 entitled "Calibrated" are the implicit export

Table 2: Elasticities Assuming Isoelastic Functional Form

	Estimated		Calibrated	
Commodities	*Exports*	*Imports*	*Exports*	*Imports*
gas	-27.037	167.769	-27.037	167.771
ele	-5.596	210.534	-5.594	210.571
col	-5.051	725.143	-5.050	725.126
cru	-10.150	10.000	-10.149	9.999
srv	-3.769	75.167	-3.769	75.165
agf	-4.015	108.096	-4.015	108.105
min	-1.474	231.664	-1.474	231.684
wsu	-5.587	121.658	-5.587	121.652
con	-3.796	304.153	-3.794	304.136
fbm	-4.673	140.241	-4.673	140.249
wpm	-5.606	132.067	-5.606	132.071
ref	-3.632	65.032	-3.632	65.035
chm	-5.786	194.726	-5.785	194.937
cem	-5.275	153.557	-5.275	153.525
pmm	-6.749	215.718	-6.749	215.847
fmm	-6.992	193.315	-6.990	193.310
cpu	-7.981	188.470	-7.977	188.623
tem	-5.740	156.732	-5.740	156.849
bom	-7.317	192.471	-7.317	192.633
trn	-2.120	313.901	-1.583	313.886
ttn	-3.206	92.216	-2.865	92.215
hlt	-3.737	37.104	-3.736	37.104

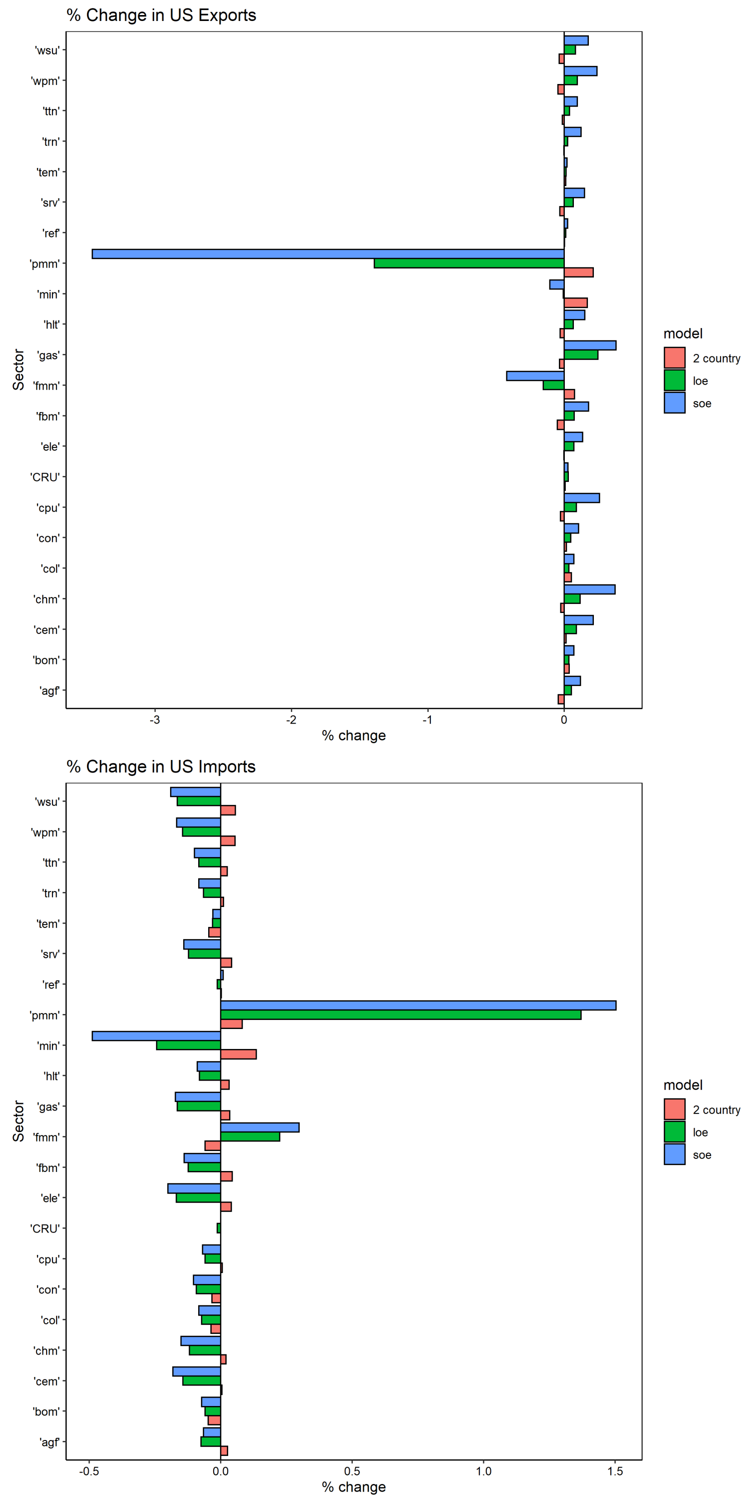
demand and import supply elasticities in the model. The values are computed by perturbing the price of imports or exports slightly and solving the model to calculate the percent change in quantities relative to prices. The calibration procedure appears to be robust given the similarities with the exogenously imposed values used to calibrate the fixed factors.

While we have generated results for each sector specific shock, we only report preliminary results in Figure 4 for the shock to the primary metal manufacturing sector. Associated welfare impacts computed from the policy simulation across the three frameworks are reported in Table 3. Additional results will be updated prior to the conference.

3 SAGE

A description of the SAGE modeling framework as well as illustrative simulations exploring the reduced form large open economy framework can be found in Marten et al. (2020). This section

Figure 4: Quantity Impacts From Shock to Primary Metal Manufacturing



will be updated prior to the conference to include a more extensive study of interactions with the more complicated elements of the modeling framework outside of what can be captured with the

Table 3: % Change in Equivalent Variation

Model	*% Change*
SOE	-0.0100
LOE	-0.0102
2 Country	-0.0105

core GTAPinGAMS model.

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