ImpactECON Global Supply Chain Model

Documentation of model changes

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ImpactECON

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Acronyms

CGE	computable general equilibrium
c.i.f.	cost insurance and freight
GTAP	Global Trade Analysis Project
IESC	ImpactECON supply chain
NTMs	Non-tariff measures

Abstract

The ImpactECON Global Supply Chain (IESC) model is based on the GTAP model (Hertel and Tsigas, 1997) and solved in GEMPACK (Harrison and Pearson, 1996). The GTAP model is a relatively standard global computable general equilibrium (CGE) model. The main difference between the IESC model and the GTAP model is the treatment of imports. The IESC model tracks the importing agent and exporting country of each imported commodity, along with differential tariff rates by agent and source. By capturing imports and tariffs by commodity, agent, source and destination, the IESC model provides further flexibility in examining the impact of various policies on welfare, production, trade and employment.

The aim of this paper is to document the changes made to the GTAP model to incorporate global supply chains. The paper provides an outline of the model, as well as the new auxiliary programs available for the decomposition of welfare.

1 Introduction

The ImpactECON Supply Chain (IESC) model is based on the GTAP model (Hertel and Tsigas, 1997) and solved in GEMPACK (Harrison and Pearson, 1996). The GTAP model is a relatively standard global computable general equilibrium (CGE) model. The main difference between the IESC model and the GTAP model is the treatment of imports. In the GTAP model, imports by sectors, government, households and investment (henceforth known as agents) are aggregated into a composite import before being combined with domestic purchases in the second tier of the Armington import equation. In contrast, the IESC model tracks the importing agent and exporting country of each imported commodity, along with differential tariff rates by agent and source. This allows substitution between imports across exporting countries to occur for each agent. Since the GTAP commodities are aggregates over numerous HS-6 categories, the GTAP commodity (e.g., electronics) sold to sectors for intermediate demand may be fundamentally different to the same commodity (electronics) sold to households. As such, we'd expect tariffs and non-tariff measures to differ by the agent purchasing the commodity, as well as by the source and destination of the commodity. By capturing imports and tariffs by commodity, agent, source and destination, the IESC model provides further flexibility in examining the impact of various policies on welfare, production, trade and employment. For instance:

— the extent to which domestic or international trade policies result in increased imported intermediates that can raise competitiveness, domestic production and hence employment, as opposed to raising imports for final consumption, which in turn may reduce domestic production and employment. The repercussions of alternative treatment of intermediate and final imports can only be examined in a model that contains supply chains.

— initial tariffs on the GTAP aggregate commodities are likely to differ by agent and be treated differently during trade negotiations that are likely to impact the results of policy analysis. In addition to fundamental differences between the types of goods purchased by different agents, tariffs on imports may also differ due to government policy; for instance, duty drawback schemes or special economic zones, such as those in China and Mexico.

— non-tariff measures (NTMs) are likely to differ between commodities sold for intermediate production and those sold to final consumers, again affecting policy analysis. Walmsley and Minor (2015), for instance, found differences between tariff equivalents for trade facilitation on imports for intermediate, investment and final use.

— the extent to which a policy or shock can benefit or hinder a country's participation in global supply chains can only be captured in a model that recognizes supply chains. Many countries are interested in what policies they can implement to help them

participate more fully in global supply chains; and how being integrated into these global supply chains affects economic growth, future development and structural change and their vulnerability to external shocks.

In this document we outline the changes made to the GTAP model to incorporate supply chains. Underlying the model is a database that contains information on trade and tariff rates by agent. This database is documented in Walmsley and Minor (2016), we do not discuss this database or its construction in this document, except to the extent necessary to explain the model changes. Following this introduction, section 2 outlines the model changes including the new equations and variables. In section 3 the welfare decomposition and auxiliary programs are outlined. Section 4 then concludes the paper.

2 The ImpactECON Supply Chain Model

In this section we outline the changes made to the GTAP model to include the supply chain equations. First, are the coefficients that are taken from the supply chain database; next we introduce the variables, before providing the equations and discussing the closure.

2.1 Coefficients

Table 1 provides a summary of the new coefficients in the supply chain database and which of the GTAP database coefficients are being replaced.

Table 1: New coefficients and relationship to original GTAP coefficients

New header	GTAP coefficients		IESC coefficients	New definition
IFAS	VIFA(i,j,r)		VIFAS(i,j,s,r)	Value of imported commodity i from source region s purchased by sector j in region r, at agent prices
IPAS	VIPA(i,r)		VIPAS(i,s,r)	Value of imported commodity i from source region s purchased by private households in region r, at agent prices
IGAS	VIGA(i,r)		VIGAS(i,s,r)	Value of imported commodity i from source region s purchased by government in region r, at agent prices
IFMS		VIFM(i,j,r)	VIFMS(i,j,s,r)	Value of imported commodity i from source region s purchased by sector j in region r, at market prices
IPMS	VIMS(i,s,r)	VIPM(i,r)	VIPMS(i,s,r)	Value of imported commodity i from source region s purchased by private households in region r, at market prices
IGMS		VIGM(i,r)	VIGMS(i,s,r)	Value of imported commodity i from source region s purchased by government in region r, at market prices
IFWS			VIFWS(i,j,s,r)	Value of imported commodity i from source region s purchased by sector j in region r, at c.i.f. prices
IPWS	VIWS(i,s,r)		VIPWS(i,s,r)	Value of imported commodity i from source region s purchased by private households in region r, at c.i.f. prices
IGWS			VIGWS(i,s,r)	Value of imported commodity i from source region s purchased by government in region r, at c.i.f. prices

For the purposes of the GTAPAgg aggregation program the old coefficients are also kept in their original headers. As far as possible we have attempted to retain consistency with the GTAP notation, by adding "S" to the end of coefficient names to signify that these values are now by source region.

The appropriate sums of the new coefficients equal the old coefficients to a reasonable level of accuracy. The coefficients – *VIFMS*, *VIPMS* and *VIGMS* – replace both imports by source at market prices (*VIMS*) and imports by agents at market prices (*VIFM*, *VIPM* and *VIGM*). Likewise imports by source at world prices (*VIWS*) is now separated into three headers – *VIFWS*, *VIPWS* and *VIGWS* – one each for each of the agents.

As in the standard GTAP Data Base investment is included in intermediate demands under "*cgds*". All other headers are identical to the standard GTAP Data Base.

In addition to the new coefficients added to the database, some additional coefficients are derived in the model, including sales tax revenues by agent and source (*IFTAXS(i,j,s,r)*, *IPTAXS(i,s,r)* and *IGTAXS(i,s,r)*); tariff revenues by agent and source (*MFTAX(i,j,s,r)*, *MPTAX(i,s,r)* and *MGTAX(i,s,r)*); and several shares (*FMSHRS(i,j,s,r)*, *PMSHRS(i,s,r)* and *GMSHRS(i,s,r)*) that are used to derive composite prices.

2.1 Variables

Each new value in the database is associated with a price and a quantity as depicted in Table 2. As with coefficients presented earlier, we have attempted to retain consistency with the GTAP notation, by adding "*s*" to the end of variables names to signify the variable includes source information for the imported commodity. The use of "*m*" to signify imports and market prices is modified somewhat. As in GTAP "*m*" in prices and values means market prices, while "*m*" elsewhere, in quantities for instance, means imports. We utilize *tt_* for import or trade taxes and *ts_* for sales taxes on imports by source. Finally, the import-augmenting technical changes (*ams* variable in GTAP) are now by agent and source increasing the flexibility with which these shocks can be implemented. The relationships between these variables are discussed in the next section.

2.1 Equations

2.1.1 PRICE LINKAGES

The equations that define the linkages between the world, market and agent prices of imports by agent and source are presented first. All imports enter the country at the cost insurance and freight (c.i.f.) price, regardless of which agent is purchasing the good. Tariffs are then applied to obtain the market price of imports.

In percent change form, the market price of imports by agent and source depends on the percent change in the c.i.f. price and any changes in tariffs:

$$pfms(i,j,s,r) = tm(i,r) + tms(i,s,r) + tt\_fms(i,j,s,r) + pcif(i,s,r);$$

$$ppms(i,s,r) = tm(i,r) + tms(i,s,r) + tt\_pms(i,s,r) + pcif(i,s,r);$$

$$pgms(i,s,r) = tm(i,r) + tms(i,s,r) + tt\_gms(i,s,r) + pcif(i,s,r);$$

Table 2: New variables and their relationship to the new coefficients

IESC Coefficients	Price	Quantity	Taxes	Tariffs	import-augmenting technical change
VIFWS(i,j,r,s)	pcif(i,r,s)	qfms(i,j,r,s)			
VIPWS(i,r,s)	pcif(i,r,s)	qpms(i,r,s)			
VIGWS(i,r,s)	pcif(i,r,s)	qgms(i,r,s)			
VIFMS(i,j,r,s)	pfms(i,j,r,s)	qfms(i,j,r,s)		tt_fms(i,j,r,s)	
VIPMS(i,r,s)	ppms(i,r,s)	qpms(i,r,s)		tt_pms(i,r,s)	
VIGMS(i,r,s)	pgms(i,r,s)	qgms(i,r,s)		tt_gms(i,r,s)	
VIFAS(i,j,r,s)	pifs(i,j,r,s)	qfms(i,j,r,s)	ts_fms(i,j,r,s)		afms(i,j,r,s)
VIPAS(i,r,s)	pips(i,r,s)	qpms(i,r,s)	ts_pms(i,r,s)		apms(i,r,s)
VIGAS(i,r,s)	pigs(i,r,s)	qgms(i,r,s)	ts_gms(i,r,s)		agms(i,r,s)

Changes in tariffs can be implemented in three alternatives ways. *tm* allows the user to shock tariffs from all sources and agents, *tms* all agents respectively and *tt_fms*, *tt_pms* or *tt_gms* can be used to shock each agent and source differently.

Agent prices are then linked to market prices through sales taxes.[1]

$$pifs(i,j,s,r) = ts\_fms(i,j,s,r) + pfms(i,j,s,r);$$

$$pips(i,s,r) = ts\_pms(i,s,r) + tp(r) + ppms(i,s,r);$$

$$pigs(i,s,r) = ts\_gms(i,s,r) + pgms(i,s,r);$$

Composite agent prices[2] by agent (*pfm*, *ppm* and *pgm*) are then determined as weighted shares of the agent prices by source (*pifs*, *pips* and *pigs*), adjusted to take account of the relevant import-augmenting technical change.

$$pfm(i,j,r) = \textbf{sum}(s, REG, FMSHRS(i,j,s,r) * [pifs(i,j,s,r) - afms(i,j,s,r)]);$$

$$ppm(i,r) = \textbf{sum}(s, REG, PMSHRS(i,s,r) * [pips(i,s,r) - apms(i,s,r)]);$$

$$pgm(i,r) = \textbf{sum}(s, REG, GMSHRS(i,s,r) * [pigs(i,s,r) - agms(i,s,r)]);$$

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[1] Note we have removed *atp* and included the variable *tp* inside the equation.
[2] Note that the use of '*m*' in *pfm*, *pgm* and *ppm* signifies imports, as in standard GTAP. We have chosen not to alter the original GTAP notation.

2.1.1 ARMINGTON

Figure 1 illustrates the difference between the Armington structures in the two models. In the standard GTAP model (panel A of Figure 1) each agent determines the total quantity of imports (*QFM*, *QPM* and *QGM*) by maximizing production or utility subject to a budget constraint and then choosing between domestic and imports based on a constant elasticity of substitution (CES) or Armington structure. Once total imports by each agent are determined they are aggregated into a composite import and then there is a second CES or Armington equation that determines where those imports are sourced from. In the IESC model (panel B of Figure 1) imports by each agent are not aggregated into a composite, instead each agent determines the source of its own imports. Since different agents source their imports from different countries, and different products are defined as intermediate and final goods, according to the underlying data, policy shocks, such as the reduction or removal of tariffs, and their impacts will differ between firms and consumers—a major improvement over the standard GTAP model which averages shocks across agents and sources of supply regardless of the agent-source linkage and the nature of the underlying goods.

The one equation in the GTAP model that determines all imports by source:

qxs(i,r,s) = -ams(i,r,s) + qim(i,s) - ESUBM(i) * [pms(i,r,s) - ams(i,r,s) - pim(i,s)];

is replaced with three equations, one for each of our agent groups:

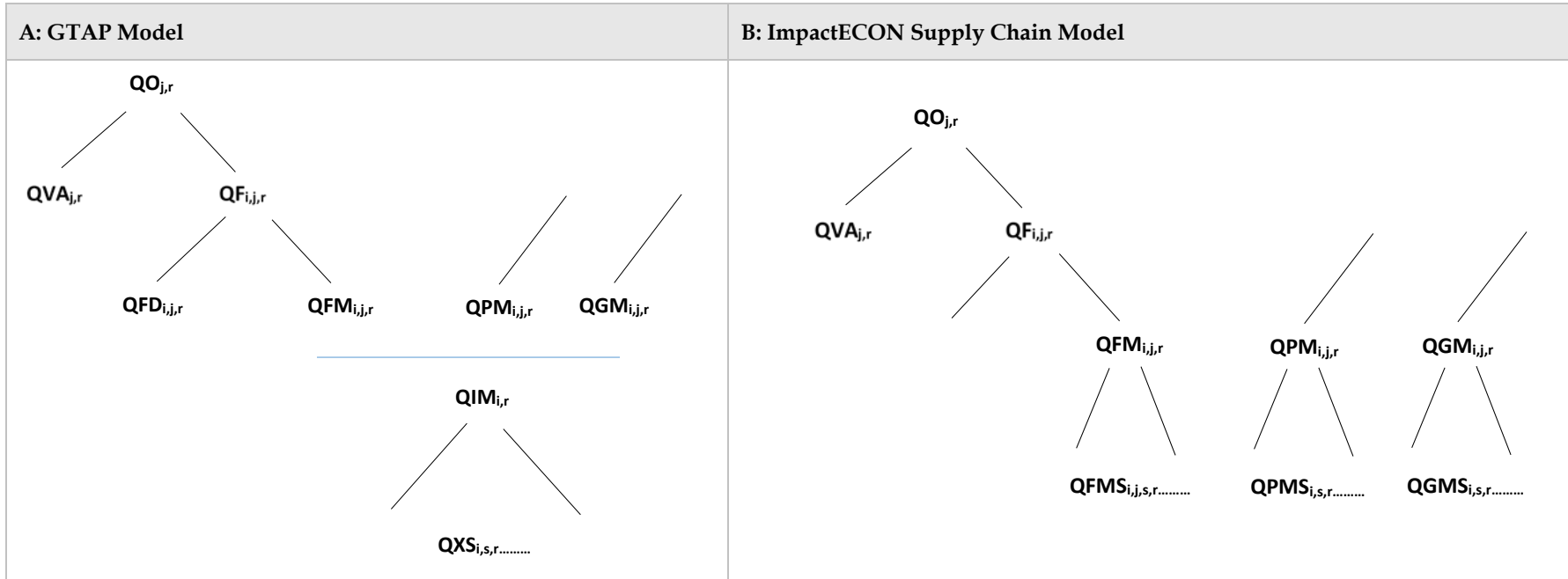qfms(i,j,s,r) = -afms(i,j,s,r) + qfm(i,j,r) - ESUBM(i) * **[**pifs(i,j,s,r) - afms(i,j,s,r) - pfm(i,j,r)**]**;

qpms(i,s,r) = -apms(i,s,r) + qpm(i,r) - ESUBM(i) * **[**pips(i,s,r) - apms(i,s,r) - ppm(i,r)**]**;

qgms(i,s,r) = -agms(i,s,r) + qgm(i,r) - ESUBM(i) * **[**pigs(i,s,r) - agms(i,s,r) - pgm(i,r)**]**;

Total imports by source (*qxs*) are then determined as a weighted aggregate of the imports of each agent (firms *qfms*, households *qpms* and government *qgms*):

qxs(i,s,r) = **sum**(j,PROD_COMM, SHRIFWS(i,j,s,r) * qfms(i,j,s,r)) + SHRIPWS(i,s,r) *
                        qpms(i,s,r) + SHRIGWS(i,s,r) * qgms(i,s,r);

Figure 1: Production and Armington structures

A: GTAP Model	B: ImpactECON Supply Chain Model

A: GTAP Model

$QO_{j,r}$

$QVA_{j,r}$ $QF_{i,j,r}$

$QFD_{i,j,r}$ $QFM_{i,j,r}$ $QPM_{i,j,r}$ $QGM_{i,j,r}$

$QIM_{i,r}$

$QXS_{i,s,r........}$

B: ImpactECON Supply Chain Model

$QO_{j,r}$

$QVA_{j,r}$ $QF_{i,j,r}$

$QFM_{i,j,r}$ $QPM_{i,j,r}$ $QGM_{i,j,r}$

$QFMS_{i,j,s,r........}$ $QPMS_{i,s,r........}$ $QGMS_{i,s,r........}$

2.1 Closure

The new closure for the model replaces the old taxes, tariffs and import-augmenting technical change with the new variables by source and destination.

exogenous
  ast
  afall afcom
  afeall afecom afereg
  afesec
  afreg afsec
  aoall aoreg
  aosec
  atd atf atm ats
  au
  avareg avasec
  cgdslack endwslack incomeslack
  pfactwld
  pop
  profitslack psaveslack
  qo(ENDW_COMM,REG)
  tm tms
  tt_fms tt_pms tt_gms
  to
  tp
  tradslack
  tx txs
  afms apms agms
  dpsave dpgov dppriv
  ;
rest endogenous ;

Note that *ts_fms*, *ts_pms* and *ts_gms* have been condensed out of the model and therefore are not listed in the closure as exogenous.

3 Welfare decomposition and auxiliary programs

In this section we outline the changes made to the auxiliary files contained in RunGTAP. Changes are made to include a new welfare decomposition, and to ensure that the GTAPVol, GTAPView, GTAPSAM, shocks and tax rates are all being taken from the supply chain model and database.

3.1 Welfare Decomposition

Two of the components in the GTAP welfare decomposition outlined in Huff and Hertel (2001) are adapted to take account of the supply chain changes: the allocative efficiency and technological change components.

The allocative efficiency component relates to the interaction between taxes and quantities. In the new supply chain model sales taxes on imports and tariffs are now by agent and source that requires changes to their calculation.

In the case of sales taxes the following adjustment is made:

$$+ \textbf{sum}(i,\text{TRAD\_COMM}, \textbf{sum}(j,\text{PROD\_COMM}, \textbf{sum}(s,\text{REG}, \text{IFTAXS}(i,j,s,r) * [qfms(i,j,s,r) - pop(r)])))$$
$$+ \textbf{sum}(i,\text{TRAD\_COMM}, \textbf{sum}(s,\text{REG}, \text{IPTAXS}(i,s,r) * [qpms(i,s,r) - pop(r)]))$$
$$+ \textbf{sum}(i,\text{TRAD\_COMM}, \textbf{sum}(s,\text{REG}, \text{IGTAXS}(i,s,r) * [qgms(i,s,r) - pop(r)]))$$

In the case of tariffs the following adjustment is made:

$$+ \textbf{sum}(i,\text{TRAD\_COMM}, \textbf{sum}(j, \text{PROD\_COMM}, \textbf{sum}(s,\text{REG}, \text{MFTAX}(i,j,s,r) * [qfms(i,j,s,r) - pop(r)])))$$
$$+ \textbf{sum}(i,\text{TRAD\_COMM}, \textbf{sum}(s,\text{REG}, \text{MGTAX}(i,s,r) * [qgms(i,s,r) - pop(r)]))$$
$$+ \textbf{sum}(i,\text{TRAD\_COMM}, \textbf{sum}(s,\text{REG}, \text{MPTAX}(i,s,r) * [qpms(i,s,r) - pop(r)]))$$

The technological change component also needs to be adjusted to take account of the fact that the import-augmenting technical change is also now agent specific.

$$+ \textbf{sum}(i,\text{TRAD\_COMM}, \textbf{sum}(j,\text{PROD\_COMM}, \textbf{sum}(s,\text{REG}, \text{VIFAS}(i,j,s,r) * afms(i,j,s,r))))$$
$$+ \textbf{sum}(i,\text{TRAD\_COMM}, \textbf{sum}(s,\text{REG}, \text{VIPAS}(i,s,r) * apms(i,s,r)))$$
$$+ \textbf{sum}(i,\text{TRAD\_COMM}, \textbf{sum}(s,\text{REG}, \text{VIGAS}(i,s,r) * agms(i,s,r)))$$

3.2   Auxiliary programs

Changes were also made to the auxiliary programs to ensure that they are reading the correct headers in the database and hence using the correct values. Those auxiliary programs that calculate tax rates also needed to be adapted to calculate the new tax rates by both source and agent. When using RunGTAP you will need to type in the names of the files created (tfms.shk, tpms.shk and tgms.shk respectively) since the tms.shk file is no longer appropriate. Examples are provided with the model and RunGTAP application package.

4 Conclusions

In this documentation we outline the revisions made to GTAP model to incorporate supply chains. The inclusion of supply chains in a global CGE model improves our ability to capture how changes in tariff and non-tariff barriers can impact a country or region's ability to integrate into global supply chains, as well as examine the benefits and costs of such integration. Moreover, we can more accurately implement changes in the barriers aimed at particular agents, such as intermediate demand by firms that then allow us to provide better advice on issues such as employment.

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