An Analysis of the US Ban on exports of Semiconductors and Supercomputers to Chinese firms: An Extended Supply Chain Analysis

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Draft Only, please do not reference

Abstract

With the introduction of tariffs into the ImpactECON Supply Chain (IESC) Database, the IESC framework has been adapted to include both the end-use classification and the importing agent of traded goods. In this paper we illustrate how this additional detail on the end-use and importing agent can be useful for global trade policy analysis, particularly as trade policies become more targeted and complex.

To illustrate, we examine the impact of the US's ban on firms exporting semiconductors and supercomputers to Chinese firms. We compare the results of the IESC framework to the GTAP framework, where there is no distinction between imports by firms, investors, and final consumers. We find that specifically targeting the US ban of exports to Chinese firms, rather than on all exports regardless of the importing agent, significantly alters the impact of this policy on the Chinese electronics industry.

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1 Introduction

Global trade models, such as the GTAP model (Hertel and Tsigas, 1997), are widely used to examine the impact of trade policy on the global economy. As trade in intermediates has grown rapidly world-wide, the distinction between trade in intermediates and final goods has become increasingly relevant in policy analysis. The GTAP model and database does not capture this distinction and hence trade policies targeted specifically at supply chains. A number of multi-regional input-output (MRIO) databases have been developed, including Koopman, Wang, and Wei (2014); Lenzen, Moran, Kanemoto and Geschke (2013); Timmer (2012); Tukker, Poliakov, Heijungs, Hawkins, Neuwahl, Rueda-Cantuche, Giljum, Moll, Oosterhaven, and Bouwmeester (2009); Walmsley, Hertel and Hummels (2014), Walmsley and Minor (2016) and Carrico (2019). These papers use the UN's Broad Economic Classification (BEC) and HS6 ComTRADE data to estimate imports of commodities by end-use (i.e., intermediates, final consumption and investment goods), thereby extending the original proportionality assumption employed in first generation MRIO databases (Johnson and Noguera, 2012).

In many MRIO databases (Lenzen, Moran, Kanemoto and Geschke (2013), Timmer (2012), and Tukker, Poliakov, Heijungs, Hawkins, Neuwahl, Rueda-Cantuche, Giljum, Moll, Oosterhaven, and Bouwmeester (2009)) a one-to-one mapping between the BEC categories (intermediate, final consumption and investment goods) and relevant importing agents (i.e., firms, final consumers and the capital goods sector) is assumed; that is, firms purchase intermediate goods only, while final consumers purchase consumption goods only; and the capital goods sector purchases investment goods only. In the MRIO databases based on the GTAP database (Koopman, Wang, and Wei (2014), Walmsley, Hertel and Hummels (2014) and Carrico (2019)), however, the ComTRADE trade data by end-use are reconciled with GTAP imports by agent (obtained from the contributed IO tables), blurring the distinction between imports by BEC end-use category and importing agent.

The blurring of this distinction reflects the fact that most goods do not fit neatly into one BEC end-use category, and hence the BEC is constructed with the *most likely* agent purchasing the good in mind. While the reconciliation of the trade data by BEC end-use with trade by agent using entropy-theoretic techniques allows us to obtain a reconciled MRIO dataset consistent with the GTAP data on importing agents, it causes problems for those wishing to include tariffs by importing agent (Walmsley and Minor (2016) and Carrico (2019), because the link between the HS6 trade data aggregated into BEC categories and the GTAP trade data by agents is lost, and along with it the ability to reconcile the HS6 tariffs with the tariffs by importing agent. Carrico (2019), for instance, uses entropy techniques to ensure adjust the tariffs by end-use to obtain tariffs paid by agents that are consistent with the average tariff supplied by the GTAP data, with additional constraints designed to stop tariffs from falling below zero (i.e., become subsidies). The loss of this link to the HS6 tariffs is a significant weakness for modelers that wish to use HS6 tariff line or BEC end-use tariffs to estimate the shocks to tariffs at the importing agent level.

In the ImpactECON supply chain database, the distinction between importing agents and end-use is explicit in order to accommodate differential tariffs rates paid by importing agent and BEC end-use category, thus allowing the user to analyze the impact of changes in tariffs on specific BEC end-use categories and/or specific purchasing agents. For instance, when tariffs on intermediate goods are subject to greater liberalization than those on final goods in a free trade agreement; or when tariffs are

removed on goods purchased by specific agents, as in the case of duty drawbacks schemes in special economic zones. The model can also be used to examine the impact of more targeted trade policies intended to impact specific end-use commodities and agents, such as the US ban on firms exporting semiconductors, semiconductor equipment and supercomputers to Chinese firms.

On October 7, 2022 the USA introduced new regulations which banned US firms from exporting semiconductors, semiconductor equipment and supercomputers to Chinese entities. The aim of the policy is to limit the flow of technology to the Chinese government and electronics manufacturing firms. The goods being banned (semiconductors, semiconductor equipment and supercomputers) are identified by BEC as intermediate inputs, while the importing agents impacted would include the Chinese government and public sector, the electronics sectors and the capital goods sectors. Private consumers, on the other hand, are unlikely to be directly impacted by the policy.

In this paper we review the methodology for constructing the IESC supply chain database and model and examine the impact of this ban on the Chinese economy, and in particular the electronics sector.

The paper is structured as follows. Following the introduction, the methodology for constructing the IESC supply chain database is outlined. Both the construction of the trade data and differential tariffs paid by end-use and importing agent are discussed. In section 3, we outline the changes to the model and the new policy instruments available in the model. In section 4, we outline the experiment and then in section 5 we analyze the results, comparing them to the results obtained in the standard GTAP model. Section 6 then summarizes and presents the conclusions.

2 The IESC Database

Analytical tools that trace out how traded goods and services flow between global industries and eventually to final consumers are called supply chain databases.[1] Demand for supply chain databases has increased rapidly in recent years, with several projects developed in response.[2]

The GTAP Data Base, which underlies most of the global computable general equilibrium (CGE) models used for trade, climate change, and environmental policy analysis, differs from a well-defined supply chain database. The GTAP Data Base aggregates all imports, by source, at the border and breaks the direct link between supplying countries and individual importing agents (e.g., firms/sectors, households, government and investment). To put this another way, in the GTAP Data Base, importing agents (e.g., firms) know that they are using imports, but they do not know from which country they purchased the import; this information is lost at the border in the GTAP Data Base.

[1] Within the input-output research community, they are known as multi-region, input-output (MRIO) databases.

[2] Examples of early MRIO databases include EXIOBASE (Tukker, Poliakov, Heijungs, Hawkins, Neuwahl, Rueda-Cantuche, Giljum, Moll, Oosterhaven, and Bouwmeester, 2009), WIOD (Timmer, 2012), OECD-TiVA (OECD, 2012) and EORA (Lenzen, Moran, Kanemoto and Geschke, 2013 and Lenzen, Kanemoto, Moran, and Geschke, 2012). Also using GTAP data, Johnson and Noguera (2012) and Koopman, R., W. Powers, Z. Wang and S. Wei (2010) and GTAP.

In contrast to the standard GTAP Data Base, many MRIO or supply chain database traces bilateral trade flows from exporting countries to these individual importing agents, but they do not contain as many policy instruments, such as tariffs, export taxes, quota rents and other sales taxes. The GTAP Data Base is therefore valued for its broad range of policy instruments.

The ImpactECON Supply Chain Database, adapts the GTAP Data Base to separate import flows by exporting country, end-use and importing agent, thereby creating a complete supply chain database from the GTAP Data Base. With this additional information, analysts can now project the impacts of changes in trade flows or policies on both particular goods (e.g., intermediate v final) purchased by particular agents (e.g., firms or final consumers). The benefits of adapting the GTAP Data Base are that it offers broad geographical coverage, numerous policy instruments, and has long term support from a community of researchers and policy makers who employ and update the data on an ongoing basis.

The IESC database differs from other supply chain datasets in two important ways. First, the IESC database includes information on both the end-use as defined by the UN broad economic (BEC) classification, given to each traded commodity, as well as the agent importing the good. Each HS6 commodity is allocated to a BEC end-use category based on the agent 'most likely' to purchase the good (firms, final consumers or the capital goods sector respectively). Most supply chain databases treat the end-use and the importing agent as equivalent, even though it has long been established that goods do not easily fall into one of the three BEC categories; for instance, the BEC concordance choses to categorize some commodities (e.g., motor vehicles) as mixed. Moreover, even in cases where a commodities does fit reasonably well into one BEC category, there are often numerous real-world examples of non-typical agents choosing to purchase goods outside of their main end-use category. Assuming a one-to-one mapping or reconciling the two datasets therefore leads to a loss of information about either the agent purchasing the good or the good itself, which can have implications for policy analysis. In the IESC database, we do not assume an equivalence between the BEC end-use categories and agents and instead keep information on both.

Instead, we recognize that while importing agents purchase predominantly goods that match their end-use category, they may also purchase goods from other end-use categories. We therefore use the differences between the purchases by BEC end-use classification obtained from the trade data and the purchases by agent obtained from the GTAP Data Base to estimate each agent's purchases of the different end-use commodities, thereby tracking both the end-use classification of the import and the importing agent.

The second difference between the IESC database and other supply chain databases is that by including both end-use classification and the importing agent, tariffs can be directly linked back to the HS6 tariff data using the BEC concordance. When end-use category and agent are considered equivalent this link to the HS6 tariffs is lost. Moreover, by including agents separately from end-use classification, the database allows for tariffs and export subsidies to differ by importing agent, as well as end-use. This is particularly useful when analyzing the impact of a trade policy aimed at specific intermediate electronic goods, sold to firms – the example used in this paper to illustrate the IESC framework.

2.1 Inputs into the IESC Database

The version of the IESC database used in this paper is identified by IE-SC_v3.0 and R11.0_2017_Mar2023 of the GTAP Database. This version contains new trade data by end-use and differential tariff rates by end-use corresponding to 2017 and incorporated using the updated to version 5 BEC concordance. A list of the data sources used in its construction include:

1. The GTAP Data Base documented in Aguiar, Chepeliev, Corong, & van der Mensbrugghe (2023);
2. Classification by Broad Economic Categories (BEC) R5 (United Nations Statistics Division, New York)[3];
3. Trade data by HS six-digit (HS6) commodity codes, source and destination (MAcMap HS6 a joint project between the ITC-UNCTAD-WTO and CEPII);
4. Tariff data by HS six-digit commodity, source and destination (MAcMap HS6 a joint project between the ITC-UNCTAD-WTO and CEPII).

2.2 Construction of the Trade data in the IESC Database

In outlining the construction process we begin with the standard GTAP Data Base, consistent with the GTAP v6 model, and the data related to the value of imports. If we ignore the alternative price valuations for the time being and concentrate on those valued at market prices[4], there are four relevant data elements. These are provided in Table 1. Our aim in converting the GTAP Data Base into a supply chain database is to replace these four headers with four new headers that provide additional information on the source (s) and end-use (b), as well as the importing agent (sectors including capital goods j, private consumers and government):

Table 1: Relevant Values in the GTAP and the ISC Databases (market prices)

GTAP	IESC	Description in IESC Database*
$VIFM_{i,j,r}$	$VIFMS_{i,j,b,s,r}$	Value of imports of commodity i, *with end-use b*, *supplied by region* s, and purchased by firms in sector j (including investment) in region r at market prices
$VIPM_{i,r}$	$VIPMS_{i,b,s,r}$	Value of imports of commodity i, *with end-use b*, *supplied by region s*, and purchased by private households in region r at market prices
$VIGM_{i,r}$	$VIGMS_{i,b,s,r}$	value of imports of commodity i, *with end-use b*, *supplied by region s*, and purchased by governments in region r at market prices.
$VIMS_{i,s,r}$	$VIMS_{i,b,a,s,r}$	value of imports of commodity i, *with end-use b*, *supplied by region s*, and *purchased by aggregate agent a*** in region r at market prices.

** Italics indicate additional dimensions added to the four headers as part of the construction of the IESC database.*

*** In the construction of the IESC database the aggregate importing agents are defined as firms, capital goods, and final consumers to match the BEC end-use classifications. In the model these aggregate agents are be defined by the user.*

[3] BEC Revision 5 has been under construction by the UN since 2016 and was released to the public, in the form of concordances, in 2019.The IESC for version 11 of the GTAP database utilizes the BEC Revision 5 concordances, in contrast to prior IESC databases, which utilized the BEC Revision 4 concordances.

[4] Market prices are tariff and transport inclusive sometimes referenced as "landed duty paid."

Since all these imports are valued at market prices, there are several accounting relations that will need to apply in the final IESC database. Equations 1-4 link the GTAP totals to the further disaggregated data in the IESC model.

$$VIMS_{i,s,r} = \sum_b \sum_a VIMS_{i,b,a,s,r} \quad (1)$$

$$VIFM_{i,j,r} = \sum_b \sum_s VIFMS_{i,b,j,s,r} \quad (2)$$

$$VIPM_{i,r} = \sum_b VIPMS_{i,b,s,r} \quad (3)$$

$$VIGM_{i,r} = \sum_b VIGMS_{i,b,s,r} \quad (4)$$

It is worth remembering that in the GTAP model, the supply of imports from all sources ($VIMS_{i,s,r}$) should equal demand for imports from all agents, where our agents include: the 65 GTAP sectors or firm demand *j* ($VIFM_{i,j,r}$), private households ($VIPM_{i,r}$), government ($VIGM_{i,r}$) and investment ($VIFM_{i,j,r}$ where j $\in$ cgds)). This is illustrated in Equation (5):

$$\sum_s VIMS_{i,s,r} = \sum_j \left[VIFM_{i,j,r}\right] + VIPM_{i,r} + VIGM_{i,r} \quad (5)$$

Equations 6-8 also apply, linking trade by the full set of agents (sectors, private consumers, government and capital goods) to the trade by main aggregate agents (firms, final consumers and capital goods). For instance, imports of the main aggregate "firms" ($VIMS_{i,b,\text{"firms"},s,r}$) is the sum of all the sectoral imports j $\sum_j \left[VIFMS_{i,b,j,s,r}\right]$ (Equation 6) and final consumer imports ($VIMS_{i,b,\text{final},s,r}$) is the sum of private consumer and government imports (Equation 7) and capital goods imports are equal to that sectors imports (equation 8).

$$VIMS_{i,b,\text{"firms"},s,r} = \sum_j \left[VIFMS_{i,b,j,s,r}\right] \quad (6)$$

$$VIMS_{i,b,"final",s,r} = VIPMS_{i,b,s,r} + VIGMS_{i,b,s,r} \quad (7)$$

$$VIMS_{i,b,"cgds",r} = VIFM_{i,b,cgds,r} \quad (8)$$

In order to construct the new import data by BEC end-use classification, source and agent, the following steps are taken, which are explained in greater detail below:

1. Information on trade by commodity (i), end-use (b), source (s) and destination (r) ($VIMS_{i,b,s,r}$) is obtained from the MAcMAPS trade[5] and tariff data.[6]
2. Trade by commodity (i), end-use (b), source (s) and destination (r) ($VIMS_{i,b,s,r}$) is then allocated to the various importing agents ($VIMS_{i,b,a,s,r}$).

[5] Trade data provide bilateral imports by commodity, end-use, source and destination valued at c.i.f prices (equivalent to *VIWS* in GTAP), to which tariffs are added to obtain the value at market prices (*VIMS* in GTAP).

[6] Entropy can still be used to provide an estimate of the sourcing shares by agent ($VIMS_{i,a,s,r}$). Including entropy keeps sourcing shares for the main end-use category consistent with other end-use categories. For instance, firms who purchase intermediates inputs from South Korea for instance, will also tend to source their final and/or capital end-use goods from South Korea, provided they purchase these goods.

3. The sourcing shares for the main aggregate agents are applied to the full set of agents: firms to all sectors j ($VIFMS_{i,j,b,s,r}$), investment to capital goods ($VIFMS_{i,"cgds",b,s,r}$), and final consumers to private consumers ($VIPMS_{i,b,s,r}$) and government ($VIGMS_{i,b,s,r}$).

The end-use classification of a trade flow (step 1) can be obtained using the Broad Economic Categories (BEC). The BEC classify each HS6 commodity into three broad economic categories—intermediate, final, and investment goods—depending on whether the good is thought to be an intermediate input, a final good or used for investment purposes. Since different countries export and import different commodities as defined by the HS6 classification, it is likely that goods categorized as intermediates will be exported by different countries than those categorized as final goods. For instance, concentrated orange juice packed in drums (HS6 code Chapter 20—2009.11) is believed to be an intermediate good in food processing while fresh orange juice not concentrated (HS6 code Chapter 20—2009.12) is thought to be a final good imported primarily by final consumers (in our case, households and government). Once combined with the trade data we might see that concentrated intermediate orange juices come mostly from Brazil, while fresh final orange juice is mostly imported from South Africa. When these HS6 trade data are aggregated to the 65 GTAP commodities by BEC end-use category we obtain the sourcing shares for each BEC end-use category (b) at world (c.i.f) prices. After the inclusion of tariffs by BEC end-use category, obtained from MAcMAPS, these shares are then applied to the GTAP trade data to obtain the value of imports of commodity i, by BEC end-use b, from region s to region r at market prices ($\mathrm{VIMS}_{i,\mathrm{b},\mathrm{s},\mathrm{r}}$).

These distinctions made at the HS6 commodity level lead to different sourcing shares (patterns) by end-use. For instance, Table 2 shows that S.E Asia supplies mostly electronic components / intermediate goods, while Western Europe supplies electronics classified as capital goods.

Table 2: End-use Share of Chinese imports of electronics by region ($US Millions)

BEC end-use category	USA	China	Selected East Asia*	Selected S.E. ASIA**	Western Europe	Rest of World	Total
Investment	10,847	4,619	52,761	16,832	23,777	5,213	114,049
Final	2,102	6,290	6,334	9,255	7,770	881	32,632
Intermediate	16,525	12,547	230,991	96,401	17,011	8,983	382,458
Total	29,474	23,456	290,086	122,488	48,558	15,077	529,139

** Japan, Korea and Taiwan*

*** Malaysia, Thailand, Philippines, Vietnam, Singapore*

Source: ImpactECON analysis of GTAP V11 and MacMap 2017 databases.

Step 2 is to allocate these BEC end-use categories to the main aggregate importing agents (firms, capital goods and final consumers). To do this we assume that each importing agents import primarily from their main BEC end-use category: firms will therefore import intermediates first, final consumers (private and government) will purchase final goods, and the capital goods sector will purchase investment goods.

If imports of the primary end-use category are not sufficient, then the aggregate agent will make up the difference by purchasing goods from other BEC end-use categories. For instance, from Table 3 we see that the Chinese capital goods sector purchases $11,764 million worth of imports from the USA. But the

China only purchases $10,847 million worth of electronics categorized as investment goods by BEC from the USA. This means that China's capital goods sector must purchase $917 million worth of electronic goods from other BEC categories – in this case they purchase electronics classified under BEC as "intermediate". The capital goods sector will not purchase BEC end-use goods classified as "final", since all the "final" end-use goods have been purchased by final consumers. In fact, Table 3 shows that final consumers must also purchase some electronics categorized by BEC as "intermediate" from the USA. Table 3, shows the resulting slice of the trade matrix: $VIMS_{\text{ele},b,a,\text{"usa"},\text{"chn"}}$.

Table 3: Allocation of Chinese imports of electronics from the USA across end-use categories and agents ($US Millions)

BEC category	Main Aggregate agents			total
	Final consumers	Capital goods sector	Firms	
Investment	-	10,847	-	10,847
Final	2,102	-	-	2,102
Intermediate	3,410	917	12,198	16,525
Total	5,512	11,764	12,198	

Source: ImpactECON analysis of GTAP V11

These aggregate values are then allocated across the full set of agents (sectors (j), private and government consumers) assuming the same shares as the corresponding aggregate agent a ($VIMS_{\text{i},b,a,s,r}$) to obtain $VIFMS_{i,j,b,s,r}$, $VIFMS_{i,\text{"cgds"},b,s,r}$, $VIPMS_{i,b,s,r}$ and $VIGMS_{i,b,s,r}$ in step 3. The resulting values meet the various adding up constraints outlined in equations 1-8 above.

2.3 Taxes and Tariffs

Once we have the market value of imports by commodity, end-use, agent, source and destination the next step is to calculate the sales tax inclusive values ($VIFAS_{i,b,j,s,r}$, $VIPAS_{i,b,s,r}$, $VIGAS_{i,b,s,r}$ and $VIFAS_{i,b,cgds,s,r}$). We assume that sales taxes by agent and source are applied at the same rate as sales taxes applied on imports purchased by that agent in general, regardless of the source of the commodity. This assumption seems reasonable since sales taxes are rarely applied differentially by source country. For instance, sales tax paid on juice purchased directly by a private consumer may differ from sales tax applied on a juice purchased as part of a meal at a restaurant, but rarely does a consumer have to pay higher sales tax on a South African juice than on Brazilian juice simply because it is Brazilian (of course they may have a different tax due differences in sugar content, but this is not due to the juice's origin). The same cannot be said for tariffs, to which we now turn our attention.

While imports at market prices ($VIFMS_{i,j,b,s,r}$ etc) and agent prices ($VIFAS_{i,j,b,s,r}$ etc) are defined for the full set of agents, imports at world prices ($VIWS_{i,b,a,s,r}$) and exports at world and market prices

($VXWD_{i,b,a,s,r}$ and $VXMD_{i,b,a,s,r}$) are defined by aggregate agents. The main reason for this is to reduce the dimensions and save on computing power.[7]

The value of imports at world prices (c.i.f) by end-use and aggregate agent ($VIWS_{i,b,a,s,r}$) are estimated by removing the tariffs from the market values ($VIMS_{i,b,a,s,r}$). Since imports by BEC end-use category consist of different HS6 goods it is reasonable to assume that tariffs may differ by BEC end-use category. For instance, cartons of fresh juice may be subject to very different tariffs than juice purchased in a bulk concentrate hence leading to very different tariffs applied on final and intermediate juice.[8] The differential tariffs found using the BEC concordance represent our tariff rates by BEC end-use category.

On the other hand, MAcMAPS does not report any differences in tariffs paid by importing agents on these same goods. That is, the tariff paid on juice purchased in a bulk concentrate by firms is assumed to be the same as that paid by a final consumer – assuming final consumers purchase bulk concentrate. For this reason, tariffs do not differ by importing agent in the underlying data. Of course, the average tariff paid by an importing agent on a commodity (i) will differ because each agent purchases different goods with different end-uses, from different sources.

It is worth noting that in practice, tariff rates paid may differ by importing agent. For instance, the Chinese government reimburses tariffs paid on intermediate goods purchased by exporting firms located in special economic zones, but does not reimburse tariffs paid on intermediate goods purchased by final consumers. For this reason, we allow the user to implement differential tariffs by BEC end-use category and by importing agent in the model, although in the underlying database tariffs only differ by BEC end-use category.

Once tariff rates are known, they can be removed from market values ($VIMS_{i,b,a,s,r}$) to determine c.i.f values ($VIWS_{i,b,a,s,r}$). Tariff revenues are then examined and tariff rates adjusted to ensure that total tariff revenue in the GTAP Data Base remains unchanged. Since GTAP sets a maximum tariff, we do find differences between the MAcMAPS and GTAP tariff rates. In these cases, we reconcile the tariffs to GTAP tariff rates potentially losing information on the differences in tariff rates across BEC categories.[9]

Finally, we assume transportation margins and export subsidies are equal distributed across BEC end-use and aggregate agents, to obtain values for exports at world (f.o.b) and exporter market prices ($VXWD_{i,b,a,s,r}$ and $VXMD_{i,b,a,s,r}$). The inclusion of export values by BEC end-use and aggregate agent allows the user to impose differential export taxes by commodity, end-use, aggregate agent, source and destination in the model. In the application below, we use export taxes by end-use and aggregate agent to impose a ban by the USA on exports of intermediate electronics to Chinese firms.

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7 In the model, users can define their own set of aggregate agents and mapping, including disaggregating them fully for every sector and final consumer. We recommend keeping them aggregated, unless the policy issue being analyzed would benefit from further disaggregation. This is discussed further below in the application of the US ban on Chinese electronics.

8 Abstracting for the moment from the fact that juice is classified in the aggregate GTAP sector which includes other beverages and tobacco products.

9 For this reason, data and shocks files are provided to change the tariffs to the MAcMAPS tariff rates by BEC end-use category. This is done using an altertax experiment and more details can be found in Walmsley and Minor (2023).

3 The Model

The ImpactECON Global Supply Chain (IESC) model is based on the version 6 of the GTAP model (Hertel and Tsigas, 1997).[10] The GTAP model is a standard global computable general equilibrium (CGE) model with a regional household that collects all the income from factors of production (land, labor and capital) and taxes and allocates this to final consumption and savings (by governments and private households) using a Cobb Douglas demand function. Final consumers (government and private households) then allocate this spending across commodities and between domestic and imported varieties (Armington assumption) using nested demand functions.[11] Imports by government and private consumer are represented by $QGM_{i,r}$ and $QPM_{i,r}$, respectively in Figure 1. Each country/region has the same model structure, although the underlying data for each country differ, causing their behavior in response to policy changes to differ.

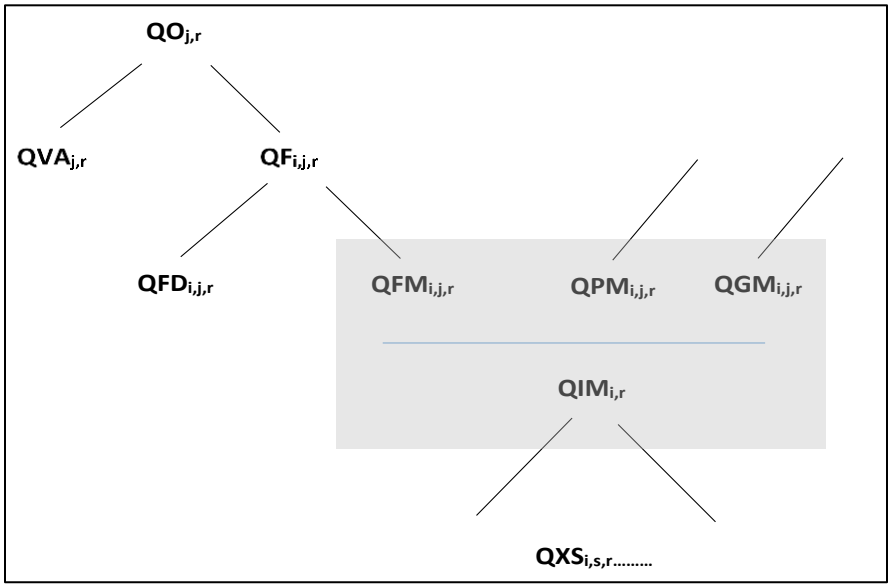
Goods and services in each country are produced using a mix of factors of production and intermediate goods (Leontieff). Like final consumers, firms allocate their demand for goods between imported and domestic varieties using a constant elasticity of substitution (CES) function (Armington): see allocation between domestic ($QFD_{i,j,r}$) and imported ($QFM_{i,j,r}$) intermediates goods in Figure 1. Produced goods and services are supplied to the domestic market or exported, depending on demand. Factors, supplied by the regional household, are assumed fixed and move across sectors (not regions) in response to firms demand or changes in factor returns (wages). At the global level, savings by government and private households are collected from all regions and allocated across regions to fund investment (i.e., production of the capital goods sector), based on each region's rate of return.

Demand for imports by all agents (sectors $QFM_{i,j,r}$, private $QPM_{i,r}$, government $QPM_{i,r}$ and capital goods $QFM_{i,"cgds",r}$) are then aggregated in to obtain total imports ($QIM_{i,j,r}$) in Figure 1 before being allocated across sources (s) ($QXS_{i,s,r}$) using a CES demand function (Armington); where export supply must equal imports demanded. This is done because data on imports by BEC end-use category, agent and destination are not available in the GTAP Data Base. This lack of supply chain data on imports also precludes the inclusion of differential tariffs by BEC end-use category and agent.

10 Both models are solved using Gempack (Harrison and Pearson, 2007)

11 Constant different elasticity is used at the top level, while constant elasticity of substitution (CES) is used in allocating between domestic and imported varieties.

Figure 1: Armington structure of the GTAP model

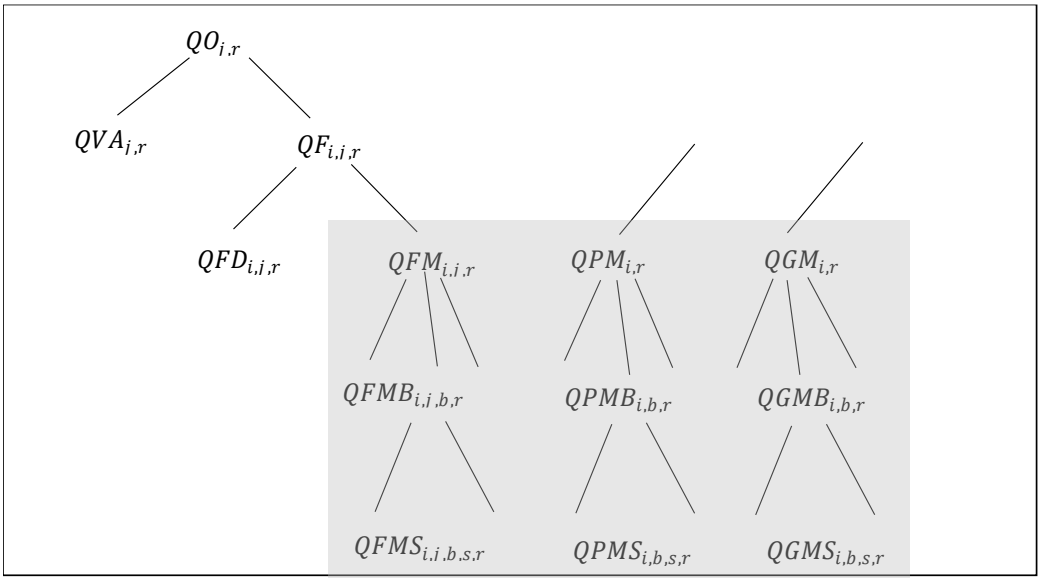


Where: $QO_{j,r}$ is output of commodity j in region r; $QVA_{j,r}$ is value added used in production of j; $QF_{i,j,r}$ is intermediate (including capital goods sector) demand for commodity i in production of j (domestic ($QFD_{i,j,r}$) and imported ($QFM_{i,j,r}$) intermediate demand); $QPM_{i,r}$ is private consumers demand for imports of commodity i; $QGM_{i,r}$ government demand for imports of commodity i. $QIM_{i,r}$ is aggregate imports of commodity i by all agents; and $QXS_{i,s,r}$ is total imports of commodity i by both source and destination.

Source: Hertel and Tsigas (1997)

The IESC model is an extension of the GTAP model that takes account of supply chains and differential tariffs by BEC end-use category and importing agent. As in the IESC database the main feature of the IESC model is that bilateral trade flows and tariffs are distinguished by the BEC end-use category and importing agent. In Figure 2**Error! Reference source not found.**, this is evidenced by the fact that imports are not aggregated across agents (as in Figure 1), instead imports by agents are distinguished by end-use ($QFMB_{i,j,b,r}$, firms (including the capital goods sector); $QPMB_{i,b,r}$, private and $QGMB_{i,b,r}$, government) and then by source ($QFMS_{i,j,b,s,r}$, firms (including the capital goods sector); $QPMS_{i,b,s,r}$, private and $QGMS_{i,b,s,r}$, government). Hence, we track the imports by agent by commodity, end-use, source and destination. Variables and coefficients added to the model are listed and defined in appendix 1.

Figure 2: Armington structure of the IESC model



QOj,r is output of commodity j in region r; QVAj,r is value added used in production of j; QFi,j,r is intermediate (including capital goods sector) demand for commodity i in production of j (domestic (QFDi,j,r) and imported (QFMi,j,r) intermediate demand); QPMi,r is private consumers demand for imports of commodity i; QGMi,r government demand for imports of commodity i; QFMBi,b,j,r, QPMBi,b,r and QGMBi,b,r are imports of commodity i by agent (firms (including capital goods sector)) private consumers and government), end-use and destination; and QFMSi,b,j,s,r, QPMSi,b,s,r and QGMSi,b,s,r are imports of commodity i by agent (firms (including capital goods sector)) private consumers and government), ed-use category, source and destination.

Source: Walmsley and Minor (2016b)

There are now separate armington nests for each agent and each armington nests now contains three levels: domestic-imports, BEC end-use, and source (Figure 2). The different levels are implemented as CES functions with elasticities determined by ESUBD, ESUBB and ESUBM. No changes have been made to the GTAP values of ESUBD and ESUBM. The elasticities for ESUBB depend on the agent. We assume the following:

- ESUBB(TRAD_COMM,"firms") = ESUBB_F(TRAD_COMM,j) = 0 (Leontieff)
- ESUBB(TRAD_COMM,"cgds") = ESUBB_F(TRAD_COMM,"cgds") = 0 (Leontieff)
- ESUBB(TRAD_COMM,"priv") = ESUBB_P(TRAD_COMM) = 1 (Cobb Douglas)
- ESUBB(TRAD_COMM,"govt") = ESUBB_G(TRAD_COMM) = 1 (Cobb Douglas)

The choice of Leontieff and Cobb Douglas reflects the way in which these agents chose between commodities, given that BEC end-use categories signify different goods. For instance, fixed shares (Leontief) is used when examining firms demand for commodities. In the application we examine how sensitive the results are to altering these elasticities.

In the case of demand for imports by firms (and the cgds sector) the armington equations are:

$$qfmb(i,j,b,r) = qfm(i,j,r) - ESUBB\_F(i,j) * [pfmb(i,j,b,r) - pfm(i,j,r)] \quad (9)$$

$$qfms(i,j,b,s,r) = qfmb(i,j,b,r) - ESUBM(i) * [pifs(i,j,b,s,r) - pfmb(i,j,b,r)] \quad (10)$$

where: pifs(i,b,s,r) is the agent price of imports (inclusive of sales taxes) on commodity i, of end-use b, from region s, paid by sector j in region r;

pfmb(i,j,b,r) is a share weighted sum of pifs(i,b,s,r); and

pfm(i,j,r) is a share weighted sum of pfmb(i,b,r).

There are similar equations for private consumers and government.

Imports by agent ($QFMS_{i,j,b,s,r}$, firms (including the capital goods sector); $QPMS_{i,b,s,r}$, private and $QGMS_{i,b,s,r}$, government) are then mapped to exports by agent qxsf(i,b,a,s,r), where these are exports of commodity i, end-use category b, imported by agent a from source s to destination r:

qxsf(i,b,PROD_COMM,s,r) = qfms(i,PROD_COMM,b,s,r) (9)

qxsf(i,b,PRIV_AGENT,s,r) = qpms(i,b,s,r) (10)

qxsf(i,b,GOVT_AGENT,s,r) = qpms(i,b,s,r) (11)

where qxsf is defined for the full set of agents (set FAGENT) including sectors (TRAD_COMM), capital goods (CGDS_COMM), private consumers (PRIV_AGENT) and government (GOVT_AGENT). We define this and a corresponding value $VIMSA_{i,b,f,s,r}$ over the set of full agents to facilitate the aggregation of agents:

$$VIMSA_{i,b,f,s,r} = VIFMS_{i,b,f,s,r}, \quad \text{where f} \in \text{PROD\_COMM (TRAD\_COMM + CGDS\_COMM)} \tag{6}$$

$$VIMSA_{i,b,f,s,r} = VIPM_{i,b,s,r}, \quad \text{where f} \in \text{PRIV\_AGENT} \tag{7}$$

$$VIMSA_{i,b,f,s,r} = VIGM_{i,b,s,r}, \quad \text{where f} \in \text{GOVT\_AGENT} \tag{7}$$

Using these values, we then further aggregated exports by agent (qxsf defined over FAGENT) to obtain exports by aggregated agents (qxs defined over AGENT) using a mapping (AGNTMAP(f)):

qxs(i,b,a,s,r) = **sum**(f, FAGENT AGNTMAP(f) = **$POS**(a), SHRVIMSA(i,b,f,s,r) * qxsf(i,b,f,s,r)) (12)

where: SHRVIMSA(i,b,f,s,r) = VIMSA(i,b,f,s,r)/ VIMS(i,b,a,s,r)

These exports, along with domestic demand and demand for international margins, are then supplied by producers in exporting country s (qo) as in the GTAP model, but with exports now aggregated across BEC categories and agents, since production is by commodity only.

qo(i,r) = SHRDM(i,r) * qds(i,r) + SHRST(i,r) * qst(i,r)

+ sum(s, REG, sum(b, BEC, sum(a, AGENT, SHRXMD(i,b,a,r,s) * qxs(i,b,a,r,s))))

+ tradslack(i,r); (13)

With imports and exports separated by BEC end-use and aggregate agent, prices and transport margins are also redefined by BEC end-use and aggregate agent and linked to the import prices by the following price linkage equations:

Prices (f.o.b) depends on costs of production in exporting country s less any exports subsidies, which now depend on BEC and aggregate agent:

pfob(i,b,a,s,r) = pm(i,s) - tx(i,s) - txs(i,b,s,r) - txs_a(i,b,a,s,r) (14)

Prices (c.i.f) depends on f.o.b price plus any transportation margins, which now depend on BEC end-use and aggregate agent:

$$pcif(i,b,a,r,s) = FOBSHR(i,b,a,r,s) * pfob(i,b,a,r,s) + TRNSHR(i,b,a,r,s) * ptrans(i,b,a,r,s) \quad (15)$$

Market prices in the importing country then depend on the c.i.f price and import tariffs, which now depend on BEC end-use and aggregate agent:

$$pims(i,b,a,s,r) = tm(i,r) + tms(i,s,r) + tms\_a(i,b,a,s,r) + pcif(i,b,a,s,r) \quad (16)$$

Market prices by the full set of agents depend on the prices of the aggregate agents, which is again implemented using the mapping:

pifms(i,j,b,s,r) = sum(a, AGENT: $POS(a) = AGNTMAP(j), pims(i,b,a,s,r))

pipms(i,b,s,r) = sum(a, AGENT: $POS(a) = sum(v, PRIV_AGENT, AGNTMAP(v)), pims(i,b,a,s,r))

pigms(i,b,s,r) = sum(a, AGENT: $POS(a) = sum(g, GOVT_AGENT, AGNTMAP(g)), pims(i,b,a,s,r))

(17)

Agent prices are then linked to market prices through sales taxes:

pifs(i,j,b,s,r) = tfms(i,f,b,s,r) + pifms(i,j,b,s,r)

pips(i,b,s,r) = tpms(i,b,s,r) + pipms(i,b,s,r)

pigs(i,b,s,r) = tgms(i,b,s,r) + pigms(i,b,s,r)

(18)

Iceberg (ams(i,b,a,s,r) and willingness to pay (dpms(i,b,a,s,r)) variables have also been included in the tab code provided.

4 The Experiment

On October 7, 2022 the Biden administration introduced new regulations to ban exports of cutting-edge semiconductors used for supercomputing and artificial intelligence to Chinese entities. The new export controls ban the export to China of cutting-edge chips, as well as chip design software, chip manufacturing equipment, and US-built components of manufacturing equipment. Not only do the prohibitions cover exports from American firms, but also apply to any company worldwide that uses US semiconductor technology — which would cover all the world's leading chipmakers. The new rules also forbid US citizens, residents, and green-card holders from working in Chinese chip firms.

The policy is likely to be far reaching and difficult to enforce, but it demonstrates how trade policies are increasingly targeting not only specific commodities, but also specific importing agents and

multinational firms. While this model is unable to capture the impact of banning US owned multinational firms, it can examine the impact of banning exports to specific Chinese entities, such as the Chinese government and the electronics sector.

According to the IESC data provided in Table 4, China imported approximately $US530b in electronics in 2017, of which 72 percent were classified as intermediate goods according to BEC. Fifty-five percent of China's imports come from Japan, Korea and Taiwan, followed by South-East Asia with 23 percent, and then the EU and the USA supply 9 and 6 percent, respectively. The EU and the USA supply relatively more electronics goods characterized as investment goods.

Table 4: Chinese imports of electronics ($US Millions)

BEC	Agent	USA	China	Japan, Korea and Taiwan	S.E. Asia	Western Europe	Rest of world
Intermediate	Firms	12,198	8,221	170,574	71,093	12,570	6,643
	Capital goods sector	917	448	12,829	5,332	947	501
	Government	7	5	91	38	7	4
	Private Consumers	3,404	3,873	47,496	19,937	3,487	1,835
Investment	Capital goods sector	10,847	4,619	52,761	16,832	23,777	5,213
Final	Government	4	8	12	18	14	2
	Private Consumers	2,098	6,282	6,322	9,237	7,756	879

5 The results

6 Conclusions

Bibliography

Appendix 1

New Sets

BEC end-use (intermediate, final, investment)

PRIV_AGENT private consumers (priv)

GOVT_AGENT government (govt)

FAGENT full list of agents (PROD_COMM (=TRAD_COMM + CGDS_COMM), PRIV_AGENT, GOVT_AGENT)

AGENT aggregated agents

- For data construction we use: (firms, cgds, final)
- For model: User defined aggregation of FAGENT (e.g., firms, cgds, priv, govt)

New Mappings

AGNTMAP(f) is the mapping between FAGENT and AGENT

New or redefined coefficients and corresponding variables

Value	Quantity	Price	Sets	Description
$VIFMS_{i,j,b,s,r}$	$QFMS_{i,j,b,s,r}$	$PFMS_{i,j,b,s,r}$	i ∈ TRAD_COMM, j ∈ PROD_COMM, b ∈ BEC, s ∈ REG, r ∈ REG	Imports of commodity i, *with end-use b*, *supplied by region s*, and purchased by firms in sector j (including investment) in region r at market prices
$VIPMS_{i,b,s,r}$	$QPMS_{i,b,s,r}$	$PPMS_{i,b,s,r}$	i ∈ TRAD_COMM, b ∈ BEC, s ∈ REG, r ∈ REG	Imports of commodity i, *with end-use b*, *supplied by region s*, and purchased by private households in region r at market prices
$VIGMS_{i,b,s,r}$	$QGMS_{i,b,s,r}$	$PGMS_{i,b,s,r}$	i ∈ TRAD_COMM, b ∈ BEC, s ∈ REG, r ∈ REG	Imports of commodity i, *with end-use b*, *supplied by region s*, and

				purchased by governments in region r at market prices.
$VIFAS_{i,j,b,s,r}$	$QFMS_{i,j,b,s,r}$	$PIFS_{i,j,b,s,r}$	i ∈ TRAD_COMM, j ∈ PROD_COMM, b ∈ BEC, s ∈ REG, r ∈ REG	Imports of commodity i, *with end-use b*, *supplied by region s*, and purchased by firms in sector j (including investment) in region r at agent prices
$VIPAS_{i,b,s,r}$	$QPMS_{i,b,s,r}$	$PIPS_{i,b,s,r}$	i ∈ TRAD_COMM, b ∈ BEC, s ∈ REG, r ∈ REG	Imports of commodity i, *with end-use b*, *supplied by region s*, and purchased by private households in region r at agent prices
$VIGAS_{i,b,s,r}$	$QGMS_{i,b,s,r}$	$PIGS_{i,b,s,r}$	i ∈ TRAD_COMM, b ∈ BEC, s ∈ REG, r ∈ REG	Imports of commodity i, *with end-use b*, *supplied by region s*, and purchased by governments in region r at agent prices.
$VIMSA_{i,b,f,s,r}$	$QXSF_{i,b,f,s,r}$	$PIMS_{i,b,a,s,r}$	i ∈ TRAD_COMM, b ∈ BEC, f ∈ FAGENT, a ∈ AGENT, s ∈ REG, r ∈ REG	Imports of commodity i, *with end-use b*, *supplied by region s*, and *purchased by agent a*** in region r at market prices.
$VIMS_{i,b,a,s,r}$	$QXS_{i,b,a,s,r}$	$PIMS_{i,b,a,s,r}$	i ∈ TRAD_COMM, b ∈ BEC, a ∈ AGENT, s ∈ REG, r ∈ REG	Imports of commodity i, *with end-use b*, *supplied by region s*, and *purchased by aggregate agent a* in region r at market prices.
$VIWS_{i,b,a,s,r}$	$QXS_{i,b,a,s,r}$	$PCIF_{i,b,a,s,r}$	i ∈ TRAD_COMM, b ∈ BEC, a ∈ AGENT, s ∈ REG, r ∈ REG	Imports of commodity i, *with end-use b*, *supplied by region s*, and *purchased by aggregate agent a* in region r, at world c.i.f prices.
$VXWD_{i,b,a,s,r}$	$QXS_{i,b,a,s,r}$	$PFOB_{i,b,a,s,r}$	i ∈ TRAD_COMM, b ∈ BEC, a ∈ AGENT, s ∈ REG, r ∈ REG	Exports of commodity i, *with end-use b*, *supplied by region s*, and *purchased by aggregate agent a* in region r, at world f.o.b prices.
$VXMD_{i,b,a,s,r}$	$QXS_{i,b,a,s,r}$	$PMS_{i,b,a,s,r}$	i ∈ TRAD_COMM, b ∈ BEC, a ∈ AGENT, s ∈ REG, r ∈ REG	Exports of commodity i, *with end-use b*, *supplied by region s*, and *purchased by aggregate agent a* in region r at market prices.
$VTMFSD_{m,i,b,a,s,r}$	$QTMFSD_{i,b,a,s,r}$	PT_m	m ∈ MARG_COMM, i ∈ TRAD_COMM, b ∈ BEC, a ∈ AGENT, s ∈ REG, r ∈ REG	Transport margin m on exports of commodity i, *with end-use b*, *supplied by region s*, and *purchased by aggregate agent a*

Other parameters and policy variables

Value	Sets	Description
$ESUBB_{i,a}$	i ∈ TRAD_COMM, a ∈ AGENT	Armington on imports of commodity i by aggregated agent a
$TMS_{i,b,a,r,s}$	i ∈ TRAD_COMM, b ∈ BEC, a ∈ FAGENT, s ∈ REG, r ∈ REG	Imports tariff on commodity i, *with end-use b*, *supplied by region s*, and *purchased by agent a* in region r.
$AMS_{i,b,a,r,s}$	i ∈ TRAD_COMM, b ∈ BEC, a ∈ FAGENT, s ∈ REG, r ∈ REG	Iceberg cost on imports of commodity i, *with end-use b*, *supplied by region s*, and *purchased by agent a* in region r.
$ATMFSD_{m,i,b,a,r,s}$	m ∈ MARG_COMM, i ∈ TRAD_COMM, b ∈ BEC, a ∈ AGENT, s ∈ REG, r ∈ REG	Technology on transport margin m on exports of commodity i, *with end-use b*, *supplied by region s*, and *purchased by aggregate agent a*
$TXS_{i,b,a,r,s}$	i ∈ TRAD_COMM, b ∈ BEC, a ∈ AGENT, s ∈ REG, r ∈ REG	Exports tax on commodity i, *with end-use b*, *supplied by region s*, and *purchased by aggregate agent a* in region r.
$TFMS_{i,j,b,s,r}$	i ∈ TRAD_COMM, j ∈ PROD_COMM, b ∈ BEC, s ∈ REG, r ∈ REG	Sales tax on imports of commodity i, *with end-use b*, *supplied by region s*, and purchased by firms in sector j (including investment) in region r at market prices
$TPMS_{i,b,s,r}$	i ∈ TRAD_COMM, b ∈ BEC, s ∈ REG, r ∈ REG	Sales tax on imports of commodity i, *with end-use b*, *supplied by region s*, and purchased by private households in region r at market prices
$TGMS_{i,b,s,r}$	i ∈ TRAD_COMM, b ∈ BEC, s ∈ REG, r ∈ REG	Sales tax on imports of commodity i, *with end-use b*, *supplied by region s*, and purchased by governments in region r at market prices.

The model and application are provided with the paper.