Report 323
November 2017

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GLOBAL CHANGE

NOVEMBER 2017

The Economic Projection and Policy Analysis Model for Taiwan: A Global Computable General Equilibrium Analysis

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Abstract: We present and evaluate a new global computable general equilibrium (CGE) model to focus on analyzing climate policy implications for Taiwan's economy and its relationship to important trading partners. The main focus of the paper is a critical evaluation of data and model structure. Specifically, we evaluate the following questions: How do the different reference year data sets affect results of policy simulations? How important are structural and parameter assumptions? Are explicit treatment of trade and international policy important? We find: (1) Higher mitigation costs across regions using data for the year of 2011, as opposed to cases using the 2007 and 2004 data, due to increasing energy cost shares over time. (2) Lower GDP losses across regions under a broad carbon policy using a more complex model structure designed to identify the role of energy and GHG emissions in the economy, because the formulation allows more substitution possibilities than a more simplified production structure. (3) Lower negative impacts on GDP in Taiwan when it carries out its national determined contribution (NDC) as part of a global policy compared with unilateral implementation because, under a global policy, producer prices for fossil fuels are suppressed, benefitting Taiwan's economy.

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1. Introduction

Taiwan has proposed significant reductions in its greenhouse gas (GHG) emissions. An economic analysis of emissions mitigation poses a challenge because the economy of Taiwan is highly dependent on international trade. It is heavily dependent on imports of fossil fuels, which currently account for around 98% of Taiwan's energy supply (Bureau of Energy, 2015). Taiwan can expect its economy to be affected by its own greenhouse gas mitigation efforts, and also by global efforts as they affect prices and demand for its exports and imports. To capture these important trade effects, a global general equilibrium model with energy use and emissions details where Taiwan is explicitly represented is essential for the analyses of policy impacts on Taiwan's economy, energy use, and environment.

The Economic Projection and Policy Analysis (EPPA)-Taiwan model is a version of the MIT EPPA model developed jointly by the Institute of Nuclear Energy Research (IENR) of Taiwan and the MIT Joint Program on the Science and Policy of Global Change (MIT JP). It is a multi-region and multi-sector computable general equilibrium (CGE) model of the world economy that uses the Global Trade Analysis Project database version 9 (GTAP9) (Aguiar *et al.*, 2016). The motivation for the model's development is to study the implications of carbon mitigation policy on Taiwan's economy.

Here, we apply a static version of the model to evaluate (1) the effect of the base year data on simulation results, (2) structural elements of the model, and (3) the role of international linkages and effects through trade. Taiwan has adopted an aggressive emissions reduction goal under its National Determined Contribution (NDC) in the Paris climate agreement, proposing a 50% cut from the business-as-usual level by 2030 (EPA, 2015). Thus, we use policy simulations achieving this goal in our evaluations. In more detail, our evaluation includes sensitivity of model results to:

- *The base year data.* GTAP9 provides comparable data for three separate years. This provides an opportunity to test, other things being equal, the impact of the base year data. Different base years may be a source of variation in model results from different authors or studies over time, and may need to be recognized as an important source of uncertainty in future projections.
- *Structural elements of the model.* We develop two CGE models with identical regions and sectors. One is a highly simplified model structure and parameterization based on the aggregation routine with a stylized CGE model provided in Lanz and Rutherford (2016), henceforth GTAPinGAMS-CGE. The second model is the EPPA-Taiwan model, adopting the production structure and parameterizations in the EPPA model (Chen *et al.*, 2016), developed with specific attention to the energy sector and greenhouse gas abatement. Our question here is: How much difference does this more complex energy sector structure make?
- *International linkages and trade.* The Paris Agreement, of which Taiwan is a part through its NDC, entered into force in November 2016 (UNFCCC, 2016). As a result, most countries of the world will undertake climate policy simultaneously with efforts in Taiwan. Policies abroad may interact with measures taken in Taiwan through trade, affecting the cost and broader consequences for Taiwan. Currently relevant studies on Taiwan are based on a single-country modeling framework (Chen, 2013; Lin *et al.*, 2012, Lin *et al.*, 2009; Li, 2000). A single-country framework, however, is ill-equipped for representing international trade, which is a crucial part of Taiwan's economic activities—exports and imports currently account for 62% and 50% of Taiwan's GDP, respectively (NDC, 2016). Therefore, the third question we would like to explore is: how different are the policy impacts on Taiwan if its NDC targets are enforced in the context of a global effort, versus if they are undertaken unilaterally?

The rest of the paper is organized as follows: Section 2 presents the model structure and data; Section 3 discusses the scenario considered in each simulation and analyzes simulation results; and Section 4 provides a conclusion.

2. Model Structure and Data

In EPPA-Taiwan, there are three types of agents in each region: household, producers, and government. The household provides primary factors (labor, capital, and natural resources) to producers, receives income in return, and allocates income to consumption and savings. Producers convert primary factors and intermediate inputs into goods and services, then sell them domestically or abroad to other producers, households, or governments. The government collects taxes from household and producers to finance government consumption and transfers. These activities can be represented by a series of circular flow diagrams connecting to each other via international trade (**Figure 1**). The model is formulated in a series of mixed complementary problems (MCP) (Mathiesen, 1985; Rutherford, 1995; Ferris and Peng, 1997), and is written and solved using the modeling languages of GAMS and MPSGE (Rutherford, 1999). **Appendix A** provides the core computer code of EPPA-Taiwan written in MPSGE for interested readers.

2.1 Model Structure

EPPA-Taiwan adopts the production structure and elasticities of the static component of EPPA6 (Chen *et al.*, 2016). GTAPinGAMS-CGE includes a highly simplified production structure and standard substitution elasticities provided with the basic model in Lanz and Rutherford

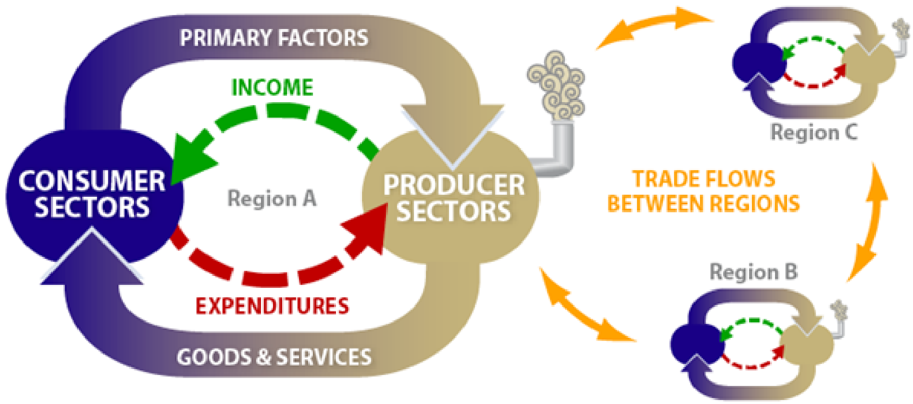

Figure 1. Schematic representation of EPPA-Taiwan.

(2016). Both models utilize the same data aggregation routine to generate models with identical sectors and regions from the GTAP9 data base (Aguiar *et al.*, 2016). This isolates the structural differences around how energy and emissions are modeled as reflected in production structures and elasticity of substitution values.

In both our simple GTAPinGAMS-CGE model and our more complex EPPA-Taiwan model, activities of different agents and their interactions can be described by: 1) zero-profit conditions; 2) market-clearing conditions; and 3) income-balance conditions. For the household and producer, the associated economic activities are utility and output, respectively. A typical zero-profit condition expressed in MCP format is:

$$MC\text{-}MB \geq 0; Q \geq 0 ; [MC\text{-}MB] \cdot Q = 0 \quad (1)$$

For instance, when a zero-profit condition is applied on a production activity, if the equilibrium output is Q positive, the marginal cost MC must equal the marginal benefit MB, and if MC is greater than MB in equilibrium, Q will be zero because the producer has no reason to produce. Note that MC less than MB is not an equilibrium state since in that case Q will increase until MC equals MB. Other activities such as investment, imports, exports, and commodity aggregation modeled using the Armington assumption (Armington, 1969) have their own zero-profit conditions.

For each market-clearing condition, the price level is determined based on market demand and supply. A typical market-clearing condition in MCP format is:

$$S \geq D; P \geq 0 ; [S\text{-}D] \cdot \mathrm{P} = 0 \quad (2)$$

The market-clearing condition states that for each market, if there is a positive equilibrium price P, then P must equalize supply S and demand D. If S is greater than D in equilibrium, then the commodity price is zero. Similarly, S less than D is not an equilibrium state because in that case, P will continue to increase until the market is cleared (S equals D).

The income-balance condition specifies the income of household that supports its spending levels (including savings). A typical income-balance condition in MCP format can be written as:

$$E \geq I; E \geq 0 ; [E\text{-}I] \cdot E = 0 \quad (3)$$

In CGE models, the expenditure E is equal to income I, hence equation (3) can be re-written as an equality of E and I. In EPPA-Taiwan, the price of utility for Taiwan is chosen as the numeraire of the model, so all other prices are measured relative to it.

2.2 Sector, Regions, and Primary Inputs

We use GTAP9 for the base data for both EPPA-Taiwan and GTAPinGAMS-CGE. GTAP 9 classifies the world economy into 140 regions, 57 sectors, 5 primary factors, and provides three reference years: 2004, 2007, and 2011. We aggregate the database into 19 regions (**Table 1**), 14 sectors (**Table 2**), and 4 primary factors (**Table 3**)—these settings are similar to EPPA6 (Chen *et al.*, 2016), except that Taiwan is explicitly identified as another region. The complete mappings for regions, sectors, and primary factors from GTAP9 are provided in **Appendix B**.

2.3 Technology, Preferences, and International Trade

Both EPPA-Taiwan and GTAPinGAMS-CGE use Constant Elasticity of Substitution (CES) functions and the special cases of it, including Leontief (elasticity of substitution of zero) and Cobb-Douglas (elasticity of substitution of one) functions, to characterize production technology and consumer preferences. To provide an example of a CES function applied to represent a production activity, let us consider a technology that uses energy and non-energy inputs, and denote the rental prices of energy input Q_e and

Table 1. Regions.

EPPA-Taiwan region	Symbol
United States	USA
Canada	CAN
Mexico	MEX
Japan	JPN
Australia, New Zealand & Oceania	ANZ
The European Union+	EUR
Eastern Europe and Central Asia	ROE
Russia	RUS
East Asia	ASI
Taiwan	TWN
South Korea	KOR
Indonesia	IDZ
China	CHN
India	IND
Brazil	BRA
Africa	AFR
Middle East	MES
Latin America	LAM
Rest of Asia	REA

Note:+ The European Union (EU-28) plus Norway, Switzerland, Iceland, and Liechtenstein.

Table 2. Sectoral Aggregation.

EPPA-Taiwan sector	Symbol	Subgroup
Crops	CROP	agri
Livestock	LIVE	agri
Forestry	FORS	agri
Food Products	FOOD	naenoe
Coal	COAL	enoe
Crude Oil	OIL	enoe
Refined Oil	ROIL	enoe
Gas	GAS	enoe
Electricity	ELEC	elec
Energy-Intensive Industries	EINT	eint
Other Industries	OTHR	naenoe
Ownership of Dwellings	DWE	naenoe
Services	SERV	naenoe
Transport	TRAN	naenoe

Table 3. Primary factors.

Primary factors	Symbol	Subgroup
Capital	CAP	mf
Labor	LAB	mf
Land	LND	sf
Natural resources	FIX	sf

non-energy input Q_n by P_e and P_n, respectively. Following the calibrated share form for CES functions (Rutherford, 1998), the unit cost C for converting Q_e and Q_n into output Q can be formulated as:

$$C = \left[\alpha\left(\frac{P_e}{\bar{P}_e}\right)^{1-\sigma} + (1-\alpha)\left(\frac{P_n}{\bar{P}_n}\right)^{1-\sigma}\right]^{1/(1-\sigma)} \quad (4)$$

where α is the cost share of energy, $\bar{P}_e$ and $\bar{P}_n$ are the base year (pre-shock) levels of P_e and P_n, respectively, and σ is the elasticity of substitution between the energy and non-energy inputs defined as:

$$\sigma = \left[\frac{d\left(\frac{Q_e}{Q_n}\right)}{\left(\frac{Q_e}{Q_n}\right)}\right] / \left[\frac{d\left(\frac{P_n}{P_e}\right)}{\left(\frac{P_n}{P_e}\right)}\right] \quad (5)$$

Based on Condition (1) and Equation (4), if one denotes the equilibrium price of Q by P, which has a base year level of $\bar{P}$, the output of this technology is determined by the following MCP, which is simply the cost-benefit analysis for the production activity:

$$C \geq \frac{P}{\bar{P}};\ Q \geq 0;\ \left(C - \frac{P}{\bar{P}}\right) \cdot Q = 0 \quad (6)$$

The production structure for a sector or the expenditure function for final consumption can be described by a diagram like that shown in **Figure 2**. In this case the diagram shows a cost function with two inputs, with prices P_e and P_n, that combine to produce a good with unit cost, C, and an elasticity of substitution between inputs, s.

The two-input example above can be generalized to a N-input case ($N > 2$), however, a caveat is that all pairs of inputs are restricted to have identical elasticities of substitution. To overcome this restriction, nested CES functions are generally used in CES-based models. In a nested CES

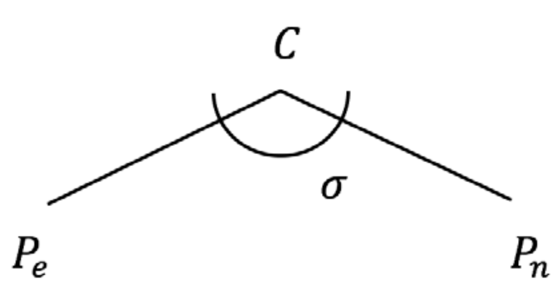

Figure 2. Nesting structure of the two-input CES cost function.

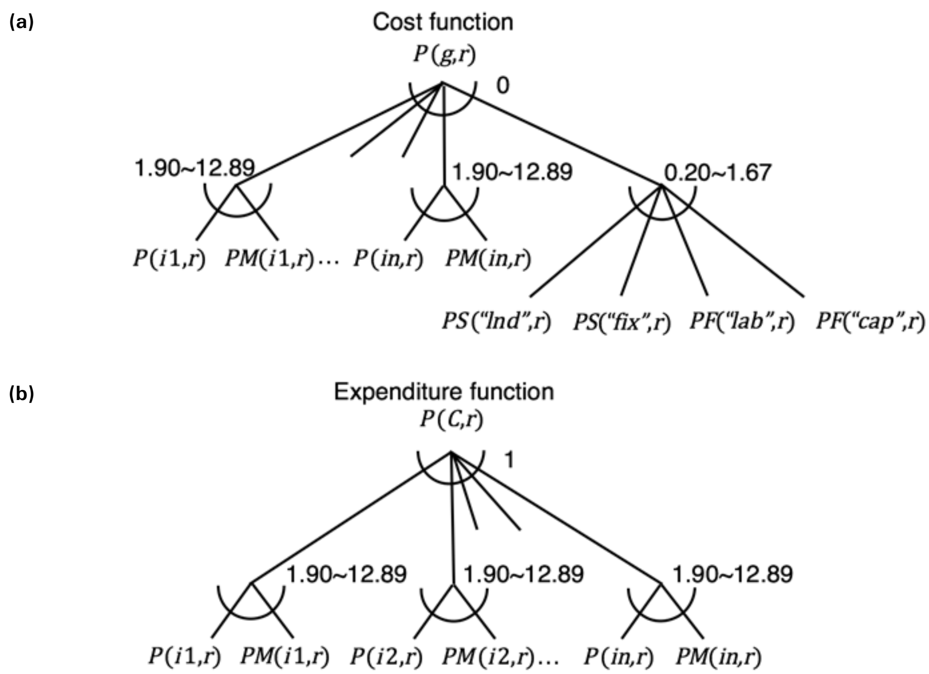

Figure 3. Nesting structures of CES functions used in GTAPinGAMS-CGE.

function, subsets of 2 or more of the N inputs ($N > 2$) can be grouped into a CES nest, and then these CES nests can be combined with a further CES function. Each nest can then be assigned a unique elasticity.

To produce a multi-region, multi-sector CGE model, a production nest must be specified for each production sector for each region, and an expenditure function must be specified for each representative regional household. Each sector uses primary inputs, and intermediate inputs (i.e., output of other sectors) to produce output. Each sector's output is used as an intermediate input or as final consumption. The sectors, regions, and primary inputs are identical for EPPA-Taiwan and GTAPinGAMS-CGE and are as described in Section 2.2. A major difference between the two models is in the complexity of the production nests, which in turn affects the elasticities of substitution that can be assigned to specific pairs of inputs, such as fuels and electricity. The details for the elasticities of substitution of the two models will be presented in Section 2.4.

In GTAPinGAMS-CGE, the cost function nesting structure is identical across sectors, and is composed of (1) a set of intermediate inputs $\{ i1, \ldots, in \}$, one for each of the 14 sectors, with price indices denoted by $\{P(\text{“}i1\text{”}, r), \ldots, P(\text{“}in\text{”}, r)\}$ and $\{PM(\text{“}i1\text{”}, r), \ldots, PM(\text{“}in\text{”}, r)\}$ for each sectoral output and import in each of the 19 regions, and (2) a set of 4 primary inputs denoted by {lnd, fix, lab, cap} with price indices $\{PS(\text{“}lnd\text{”}, r), PS(\text{“}fix\text{”}, r), PF(\text{“}lab\text{”}, r), PF(\text{“}cap\text{”}, r)\}$ for each primary input and region. The intermediate input nest is shown in the upper left of **Figure 3(a)** with an elasticity of substitution of 0 (i.e. Leontief). Primary inputs are in the lower right CES nest. All four of the primary inputs are in a single nest, so the elasticity of substitution among each pair in any sector are the same, but the elasticities across sectors vary between 0.2 and 1.67. Energy (including fossil fuels) inputs are in the Leontief intermediate inputs nest, allowing no direct substitution among fuels (or between fuels and electricity) in the production of goods and services. Final consumption is represented by a single Cobb-Douglas nest, including final consumption of fuels and electricity (**Figure 3(b)**).

EPPA-Taiwan adopts a more complex production structure that varies among sectors, providing greater flexibility in setting elasticities for individual inputs or groups of inputs, especially energy. Similar to GTAPinGAMS-CGE, each commodity can be imported and domestically produced, and they are aggregated together as an Armington good. Under this formulation, imported goods from a production sector and region are treated as imperfect substitutes for goods from the same sector produced domestically or in other regions. The Armington assumption allows a region to be both an importer and exporter of similar products, which reflects observed patterns, and the observation that most goods are differentiated (i.e., German goods produced by the Energy-Intensive Industry are substitutable for American, Japanese or Korean Energy-Intensive Industry goods, but they are not identical products). As a result, prices for similar sectors' goods from different regions can differ. When goods are perfect substitutes, there is a single global price, and a region cannot be both an exporter and importer in the same time period. **Figure 4(a)** provides the Armington aggregations for imported goods from different regions, and for domestic and imported goods. PM, PT, and P are price indices for imports, international transportation service, and domestic production, respectively. Crude oil is modeled as an internationally homogenous good (i.e., crude oil from different regions are perfect substitutes). The Armington aggregation for the domestic and imported good is presented in **Figure 4(b)**, which also includes a carbon penalty with the price index PCO_2 if the relevant policy is in place.

Figure 5 presents, as an example, the nesting structure for the energy-intensive sector. It allows a separate elasticity of substitution for each of the seven nests. PA, P, PF, and PS are price indices for domestic, Armington goods, non-sector-specific primary factor, and sector-specific primary factor, respectively. Specifically, the notation $PA("coal", r)$ at the bottom nest in Figure 5 represents the price index for coal as an Armington good in region r, i.e., coal is one of the inputs to the production activity of the energy-intensive sector in that region. **Figure 6**, on the other hand, provides the nesting structure for the expenditure function of the representative consumer (household), where PW is the price index for utility. The nesting structure for the expenditure function demonstrates that household consumption includes energy, dwelling service, and other Armington goods. As in EPPA6 (Chen *et al.*, 2015), the incentive for savings is taken into account in the expenditure function, and savings equal investment in the model. While this treatment may not be necessary in a static CGE, it provides the ground for developing the dynamic version of EPPA-Taiwan in the future.

In a global CGE, besides interactions among sectors through inter-industry transactions, interactions among regions are considered via bilateral trade flows. As noted above, intermediate inputs and final consumption are Armington goods. The nesting of structures for the cost functions of other sectors or activities are presented in **Appendix C**. We do not allow for a change in capital flows, and thus any change in the total value of exports must be balanced by an equal change in the total value of imports. Each region may export part of its domestic outputs in exchange for imported commodities in a way such that any additional imports relative to the base year levels must be achieved by an increase in exports with similar market values. For most goods, the Armington assumption (see Section 2.1), which is widely used in modeling international trade, is adopted. The only exception in our model is crude oil, which is treated as a perfect substitute for other crude oil in global trade.

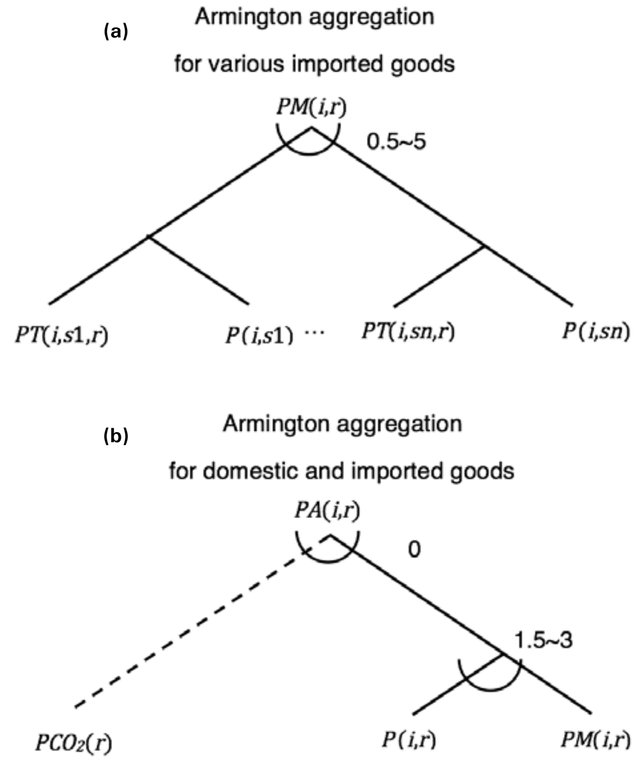

Figure 4. Nesting structure for the cost function of Armington goods.

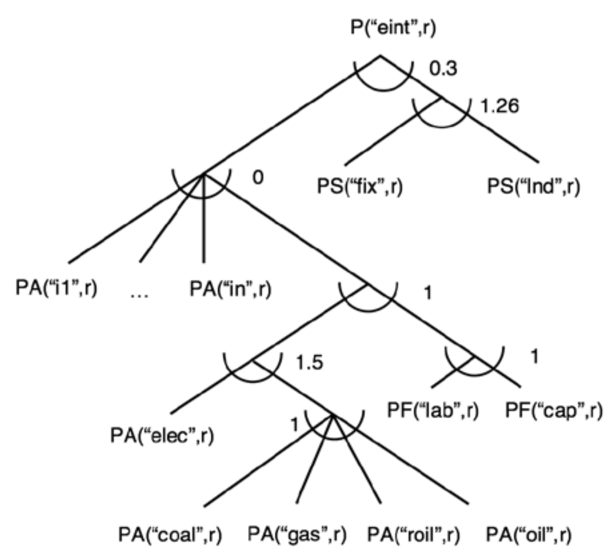

Figure 5. Nesting structure for the cost function of the energy-intensive sector.

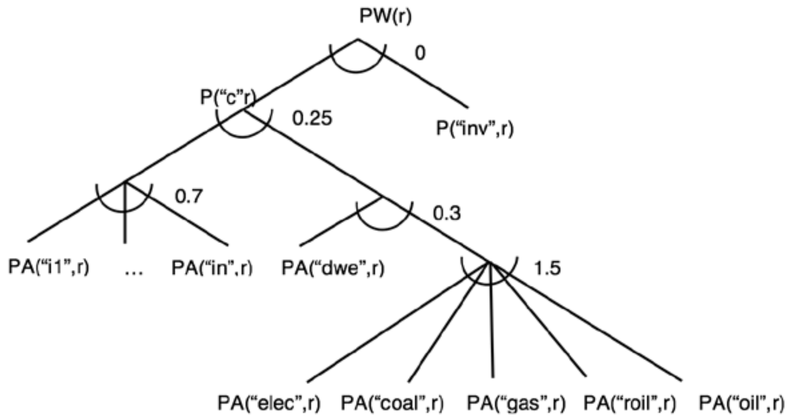

Figure 6. Nesting structure for the expenditure function of the household.

2.4 Social Accounting Matrix

A social accounting matrix (SAM) contains the base year input-output and supply-demand structures of the economy. It provides a consistent picture of production activities, market transactions, and income-expenditure flows between different agents in the economy. **Table 4** provides the structure for the SAM of each region in EPPA-Taiwan.

The SAM structure for GTAPinGAMS-CGE is similar to EPPA-Taiwan, except in GTAPinGAMS-CGE, crude oil products coming from different regions are treated as heterogeneous. In EPPA-Taiwan, crude oil is treated as a homogeneous product, so there are corresponding market and activities for that homogeneous good (explained in detail later). Besides, EPPA-Taiwan treats the Armington aggregation as a separate activity, while for GTAPinGAMS-CGE that aggregation is included as a sub-nest within a cost or an expenditure function, and therefore the aggregation is not separately identified as an activity. Another nuance is that the SAM of GTAPinGAMS-CGE will have activities of allocating each region's land and natural resource, respectively, among sectors, and these activities are modeled by constant elasticity of transformation (CET) functions. On the other hand, as other simpler versions of EPPA where land-use changes are not explicitly modeled, in EPPA-Taiwan land and natural resource are treated as sector-specific endowments. We try both settings for our model, and find they yield very similar results for simulations considered in this study. Therefore, results from EPPA-Taiwan presented later will be based on our own setting.

The SAM of EPPA-Taiwan shown in Table 4 is constructed based on the micro-consistent format of SAM presented in Rutherford (1999)—each row corresponds to a market-clearing condition (Condition 2 in Section 2.1), and columns characterize the zero-profit condition of an activity (Condition 1 in Section 2.1), except for the last column which represents the income-balance condition of the economy (Condition 3 in Section 2.1). Variables in dotted red outline denote output of each activity, supply of each market, or endowment of the representative agent (those in the last column); other variables (in blue) are input of each activity, demand of each market, or aggregate consumption of the representative agent (those in the last column).

The domestic production activities of region r, $Y(i,r)$, are presented in Column 1, where i represents the set for industrial sectors/goods, x denotes the set for sectors that produce globally homogeneous goods (which only includes crude oil), and i^* is all other sectors/goods, i.e., $i^* = i\text{-}x$. In the current setting, since crude oil is a homogeneous product globally, there is a single world market price for crude oil. $vom(i^*,r)$ and $vom(x,r)$ denote the values of base year outputs by production activities of $Y(i^*,r)$ and $Y(x,r)$ respectively. The inputs of domestic production include: $vfm(sf,i,r)$ (land and natural resource inputs), $vfm(mf,i,r)$ (labor and capital inputs), and $voam(j,i,r)$ (energy and non-energy inputs of Armington goods, which are the aggregations for the values of domestic produced product $vdfm(j,i,r)$ and imports $vifm(j,i,r)$). $rto(g,r)$ and $rtf(f,g,r)$ are taxes on output and primary input, respectively. The index g includes i (industrial sectors), C (final consumption of the representative consumer), G (government consumption), and INV (investment).

Columns 2–4 are for activities of total household consumption $Y(C,r)$, the government activity $Y(G,r)$, and capital formation $Y(INV,r)$. The base year value of $Y(C,r)$, which is $vom(C,r)$, includes the Armington good $voam(i,C,r)$ and the associated taxes or subsidies under the rate of $rto(C,r)$. $voam(i,C,r)$ is the sum of domestic produced commodities $vdfm(i,C,r)$, imported commodities $vifm(i,C,r)$, and the associated tax payments under the tax rates of $rtfi(i,C,r)$ (for firm's import tax rates) and $rtfd(i,C,r)$ (for firm's domestic tax rates). Relevant notations and explanations for the values of output and inputs of $Y(G,r)$ and $Y(INV,r)$ are analogous to those of $Y(C,r)$.

Table 4. SAM/MCM for EPPA-Taiwan.

		Zero-Profit Conditions										Income-Balance Conditions
		1	2	3	4	5	6	7	8	9	10	11
		Domestic Production Activity	Consumer Activity	Gov't Activity	Investment Activity (Capital)	Int'l Transport	Import Activity	Armington Goods	Homogeneous Good Export	Homogeneous Good Import	Utility	Representative Consumer
		Y(i,r)	Y(C,r)	Y(G,r)	Y(INV,r)	YT(j)	M(i*,r)	A(i,r)	HOMX(x,r)	[HOMM(x,r)]	W(r)	RA(r)
Market-Clearing Conditions												
Domestic Prod.	P(i*,r)	+vom(i*,r)				vst(i*,r)	vxmd(i*,s,r)	vdfma(i*,r)				
	PH(x,r)	+vom(x,r)	+vom(C,r)			vst(x,r)		vdfma(x,r) [vifma(x,r)]	vhomx(x,r)	[+vhomm(x,r)]		+homadj(x,r)
HH Consump.	P(C,r)			+vom(G,r)							vom(C,r)	
Gov't Consump.	P(G)r				+vom(INV,r)							vom(G,r)
Loanable Funds	P(INV,r)										vom(INV,r)	
Primary Factors	PS(sf,ir)	vfm(sf,i,r)										+vfm(sf,i,r)
	PF(mf,r)	vfm(mf,i,r)										+evom(mf,r)
Int'l Transport	PT(j)					+vtw(j)	vtwr(j,i*,s,r)			[homt(j,x,r)]		+trnadj(j,x,r)
Imports	PM(i,r)						+vim(i*,r)	vifma(i*,r)				
Armington Good	PA(i,r)	voam(j,i,r)	voam(i,C,r)	voam(i,G,r)	voam(i,INV,r)			+voama(i,r)				
CO_2-Penalty	PCO_2(r)	CO_2(j,i,r)	CO_2(i,C,r)	CO_2(i,G,r)	CO_2(i,INV,r)							+CO_2lim(r)
Homogeneous Good	PWH(x)								+homx(x,r)			
Total HH Consump.	PW(r)										+vum(r)	vum(r)
Resources for Tax Payment	TAX(i,g,r)	rto(i,r), rtf(f,i,r)	rto(C,r)	rto(G,r)	rto(INV,r)		rtms(i*,s,r), rtxs(i*,s,r)	rtfda(i,r), rtfia(i,r)	txhom(x,r)	[tmhom(x,r)]		tax revenue(r)
Current Account	P(C,TWN)											+vb(r)

Note: i* denotes sector set i excluding item x; x denotes crude oil, which is an homogeneous good in EPPA-Taiwan.

Columns 5–7 are activities for international transportation service $YT(j)$, trade flow $M(i^*,r)$, and the Armington aggregation $A(i,r)$. The value of $YT(j)$ is $vtw(j)$ with j being the transportation sector, while the regional input of $vtw(j)$ is denoted by $vst(j,r)$. The value of M is denoted by $vxmd(i^*,s,r)$, which is the value of trade flow of commodity i^* from region s to region r. $vxmd(i^*,s,r)$ includes $vim(i^*,r)$, the import value of sector i^* for region r, the transportation margin $vtwr(j,i^*,s,r)$, and the export tax or subsidy imposed by region s based on the tax or subsidy rate $rtxs(i^*,s,r)$, and the tariff imposed by region r based on the rate of $rtms(i^*,s,r)$. The base year value for the Armington output is $voama(i,r)$, which is the CES aggregation of the domestic component $vdfma(i,r)$, and the imported component $vifma(i,r)$. $vdfma(i,r)$ and $vifma(i,r)$ are the sum of $vdfm(i,g,r)$ and $vifma(i,g,r)$, respectively.

Columns 8–9 are activities for the trade flow of homogeneous good x, which is crude oil in our model. Since we treat crude oil as a homogeneous good in EPPA, a country will never be an exporter and importer of crude oil at the same time. The activities of $HOMX(x,r)$ and $HOMM(x,r)$ are net export and net import, respectively, of x in region r. For example, in a region with a net export of crude oil, there is no value for the column $HOMM(x,r)$. The base year value of export is $homx(x,r)$, which is export tax- or subsidy-included, as shown in Column 9. The base year value of import is $vhomm(x,r)$, which is constituted of $homm(x)$, the pre-tariff import value that also excludes transport margin; the transport margin $homt(x,r)$; the tariff based on the rate of $tmhom(x,r)$; and the tax or subsidy rate $txhom(x,r)$.

Columns 10 and 11 are activities for the welfare (utility) function $W(r)$ and the income balance condition of the representative household RA. The welfare W has the base year value of $vum(r)$, and it is derived from consumption and saving, which have the base year values of $vom(C,r)$ and $vom(INV,r)$, respectively. The total household income comes from returns to labor, capital, land, and natural resources, with the base year values being denoted by $evom(f,r)$ ($f =$ labor, capital, land, and natural resources). The base year current account balance value is $vb(r)$. Specifically, when there is a current account surplus, $vb(r)$ will be negative, which can be interpreted as the foreign saving owned by the domestic representative household. In case of a current account deficit, $vb(r)$ will be positive, which means the domestic consumption exceeds the domestic income. Lastly, when CO_2 reduction policies are in place, the penalty will be imposed on the consumption of burning fossil fuels, which include coal, refined oil, and gas. In our model, the government is treated as a passive entity, which collects taxes from household and producers to finance government consumption and transfers. The remaining tax revenues, including those derived from a carbon tax when an emissions mitigation policy exists, are recycled back to the representative household in a lump-sum fashion. When the adjustment of net export/import for homogeneous goods is done, there will be changes in relevant tax revenues and transportation margins, which are reflected in $homadj(x,r)$ and $trnadj(j,x,r)$, and both terms are put in the income-balance condition to make sure the accounting is correct.

2.5 Elasticities of Substitution

The elasticities of substitution of EPPA-Taiwan are drawn from those in EPPA6, which are based on literature review. Substitution elasticities used in EPPA-Taiwan and GTAPinGAMS-CGE are presented in **Table 5**. The energy use data (in terms of energy units), included in the GTAP9 database, are from the International Energy Agency (IEA) (McDougall and Lee, 2006). The reference year CO_2

Table 5. Substitution elasticities used in EPPA-Taiwan and GTAPinGAMS-CGE.

Substitution	EPPA-Taiwan		GTAPinGAMS-CGE	
	Notation	Value	Notation	Value
Between domestic and imported goods	sdm	1.0–3.0	esubd	1.89~12
Between imported goods	smm	0.5–5.0	esubm	3.57~31
Between energy and non-energy (labor-capital bundle) inputs	e_{kl}	0.1–1.0	esub	0
Between electricity and fossil energy bundle for the aggregated energy	noe_{el}	1.5	esub	0
Between labor and capital	l_k	1	esubva	0.2~1.67
Between fossil energy inputs for the fossil energy bundle	esube	1	esub	0
Between natural resource and other inputs	esup	0.3–0.5	esub	0
Between natural resources and land	Esubva	0.2~1.67	esubva	0.2~1.67
Final consumption	$enoe_{el}$; eed; d_{elas}; delas	0.25~1.5	esub	1

Sources: For EPPA-Taiwan, see Cossa (2004). For GTAPinGAMS-CGE, see Lanz and Rutherford (2016).

emissions of our model are derived from the fossil fuel consumption levels in GTAP9 through emission factors for each type of fossil fuel. The economic data in SAM drawn from GTAP9 are expenditure in terms of a monetary unit. Based on the energy use data (in energy units) provided in GTAP9, we are able to link to base year energy consumption and production (in terms of exajoule (EJ) or terawatt-hour (TWh)) to the corresponding expenditure level (US dollar), and therefore keep track of the evolution of both consumption and production under a counterfactual simulation.

3. Simulations

To answer the questions raised in Section 1, three sets of CO_2 abatement simulations are presented. In the first set, we study the response of EPPA-Taiwan to a global abatement policy shock using the data for the three different base years provided in GTAP9. The next set of simulations compares the response of EPPA-Taiwan with that of GTAPinGAMS-CGE, focused on the latest year data in GTAP9. The final set of simulations compare two scenarios in EPPA-Taiwan using the 2011 data to study the implications on Taiwan's economy when: 1) Taiwan implements a CO_2 reduction policy unilaterally, and 2) Taiwan pursues the reduction goal along with the rest of the world. Running these scenarios allows us to consider the importance of the analysis of climate policy interactions through trade.

3.1 Simulations with Distinct Base Year Data using EPPA-Taiwan

GTAP9 includes comparable base year data for 2004, 2007, and 2011. The illustrative policy that we consider here is a cut of 40% of CO_2 emissions from the base year level. Given this is a static model, this can be interpreted as a cut from a reference (no additional policy beyond any in the base year data). While intended as only an example, Reilly *et al.* (2016) estimated that about a 40% reduction from reference emissions in 2030, with further reductions in later years, would be required to get on a path consistent with the world remaining below 2 degrees C of warming from preindustrial levels.

Figure 7 shows that in general, fossil fuel prices, especially the crude oil price, kept increasing over time. One exception, however, is the natural gas price in the U.S., which demonstrates a decreasing trend due to the U.S. shale gas boom. GTAP data with different base years are associated with various fossil fuels prices. An interesting yet puzzling question is: when emissions mitigation is in place, will higher fossil fuel prices imbedded in the base year data push the shadow price of CO_2 higher or lower? To study this, we will examine the following two contradictory hypotheses:

Hypothesis 1A: *Under the same CO_2 mitigation target, using base year data with higher fossil fuel prices will*

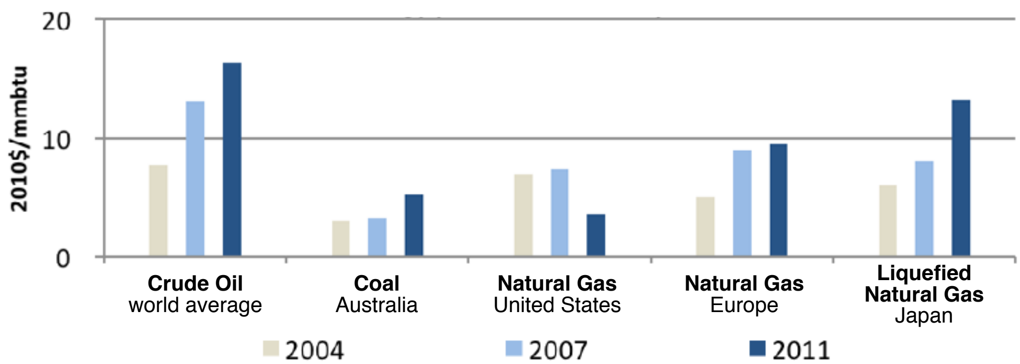

Figure 7. Energy prices in different years (source: The World Bank, 2017; EIA, 2017).

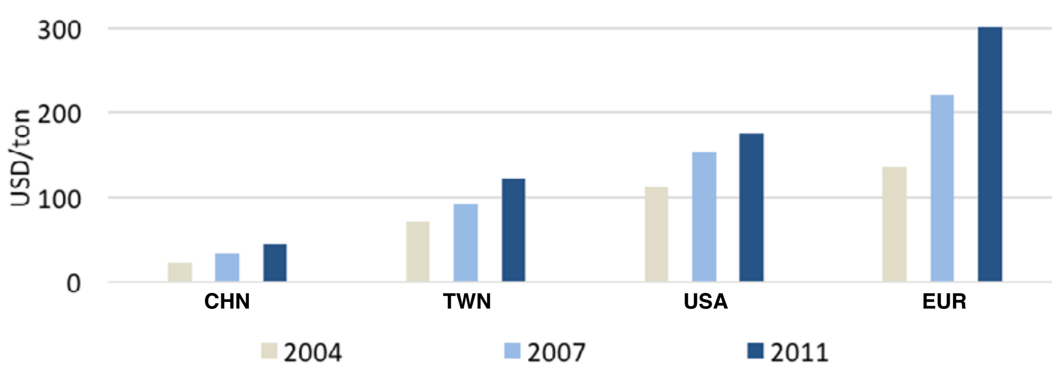

Figure 8. CO_2 prices based on the same model with databases of different years.

make CO_2 prices higher, because 1) higher energy prices translate to larger energy cost shares of the base year data, which makes cutting fossil-related CO_2 emissions trickier; and 2) higher energy prices induce more energy efficiency improvement, and therefore the marginal costs of energy reduction become higher.

Hypothesis 1B: *Under the same CO_2 mitigation target, using base year data with higher fossil fuel prices will make CO_2 prices lower, because 1) higher energy prices facilitate the energy efficiency improvement; and 2) higher energy prices induce the development of more energy efficient technologies and lower the marginal costs of emissions abatement.*

The overall results of these simulations indicate the need for higher CO_2 prices to achieve the 40% emissions reduction when using the 2011 data, as compared with the 2007 and 2004 data. For instance, the CO_2 prices in four EPPA regions including Taiwan are higher for later years (**Figure 8**). Note that CO_2 emissions in GTAP9 are from IEA data, which are for combusted emissions resulting from burning fossil fuels. Therefore, the main reason for higher CO_2 prices for later years is because of the increasing prices for fossil fuels over time. More specifically, the higher fossil fuel prices in 2011, of course, are incorporated into the data of that year in GTAP9, and while higher prices for fossil fuels would induce more significant energy-saving measures or innovation in the long term, the energy consumption structure in terms of physical unit is unlikely to change substantially in the short term due to technology constraints. Therefore, higher prices for fossil fuels in 2011 would translate to higher fossil fuel cost shares in that year, and lower fossil fuel prices in earlier years result in lower fossil fuels cost shares for corresponding years (**Figure 9** demonstrates that fossil fuel cost shares increased in four EPPA regions for later years. **Figure 10** presents the global average fossil fuel cost share for each type of fossil fuels for each base year. We find that the cost share of crude oil has increased significantly from 2004 to 2011). Therefore, using a higher fossil fuel cost share to represent the same technology suggests that emissions reduction becomes more expensive. As a result, our finding supports **Hypothesis 1A**.

3.2 Simulations with different models using the same base year data

In this set of simulations we focus on comparing the economic impacts of a global CO_2 constraint from two models using the same database—EPPA-Taiwan and GTAPinGAMS-CGE. We choose the input-output data of 2011, the latest reference year of GTAP9. As described in Section 2.3, the major difference between the two models is that unlike GTAPinGAMS-CGE, EPPA-Taiwan allows the existence of some substitution possibilities between energy and non-energy inputs and between different en-

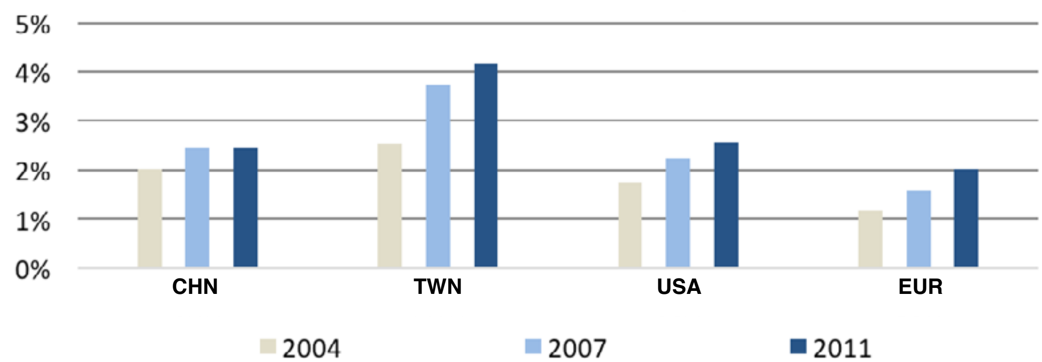

Figure 9. Energy cost shares (source: Aguiar *et al.*, 2016).

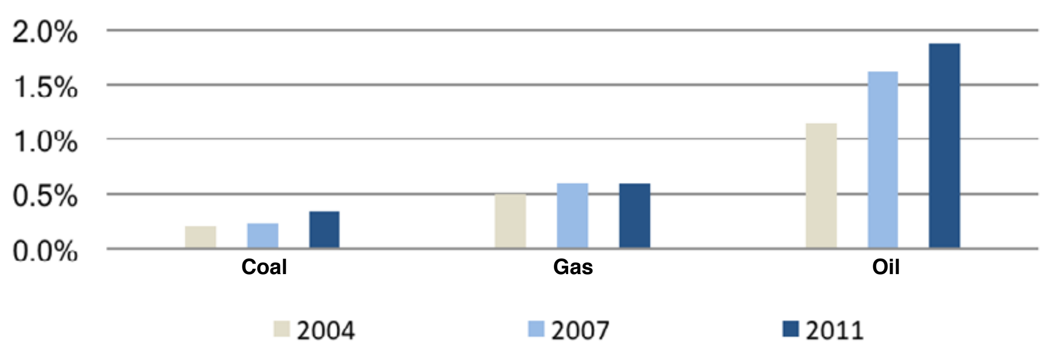

Figure 10. Global average fossil fuels cost shares (source: Aguiar *et al.*, 2016).

ergy inputs. The possible implications of different model settings when the same CO_2 mitigation policies are in place are proposed in the following hypotheses:

Hypothesis 2A: *The projected negative impact on global GDP level will be higher under GTAPinGAMS-CGE, since cutting emissions relies more on reducing outputs rather than switching to less CO_2-intensive economic activities.*

Hypothesis 2B: *The projected negative impact on global GDP levels will be lower under GTAPinGAMS-CGE, since energy importers will benefit more from lower crude oil prices resulting from decreased economic activities elsewhere, compared with results from EPPA-Taiwan.*

We consider a policy scenario where each region cuts its CO_2 emissions by 40%. The results reveal that compared with outputs from GTAPinGAMS-CGE, EPPA-Taiwan demonstrates lower GDP losses across regions (**Figure 11**). The main reason behind this is because unlike GTAPinGAMS-CGE, our model allows some substitution possibilities between energy and non-energy inputs and also among fossil fuel inputs. In our model, cutting CO_2 emissions can be achieved not only by reducing output, but also by either improving energy efficiency or switching to a less carbon-intensive fossil fuel, while for GTAPinGAMS-CGE, the last two channels of emissions mitigation are not presented.

Note that for both models, each commodity used as an intermediate or a final consumption is an Armington good, and the substitution between goods produced domestically and abroad is allowed, as well as the substitution among goods produced by different regions abroad (Table 5). As a result, under the considered emissions reduction, to mitigate the welfare loss, for both models, the domestic component of an Armington good can be replaced by the foreign counterpart with a lower carbon footprint.

The comparison between model results reveals that under the same mitigation scenario, the (producer) price of crude oil, a homogeneous good, is higher in EPPA-Taiwan (**Figure 12**). The lower crude oil price in GTAPinGAMS-CGE constitutes a double whammy to the GDP loss of the region MES, which includes many oil exporting countries, through the terms of trade effect. In short, based on our findings, compared to EPPA-Taiwan, GTAPinGAMS-CGE produces a higher level of decrease in global GDP under the CO_2 mitigation scenario, which supports **Hypothesis 2A** (Figure 12).

3.3 International Linkages and Trade Effects: Unilateral Mitigation versus Global Effort

To explore the implications on Taiwan's economy when it pursues its NDC to cut emissions, we calibrate the model so that it produces a business-as-usual (BAU) environment for the global economy in 2030—a strategy also known

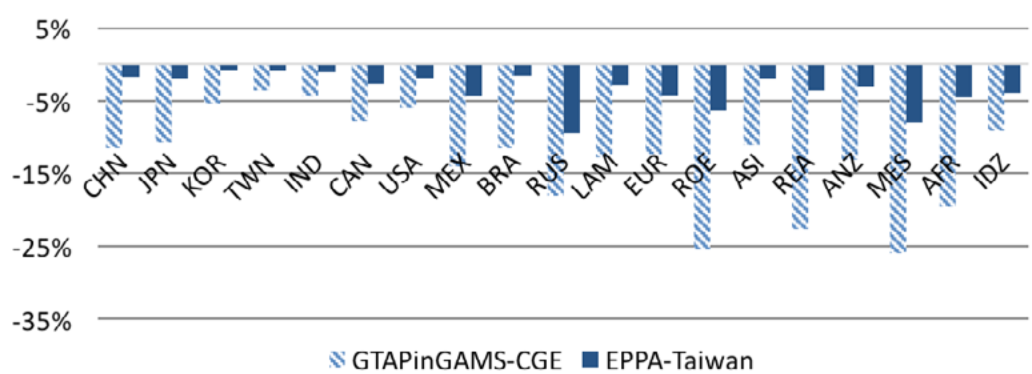

Figure 11. Changes in regional GDP under the 40% CO_2 reduction scenario.

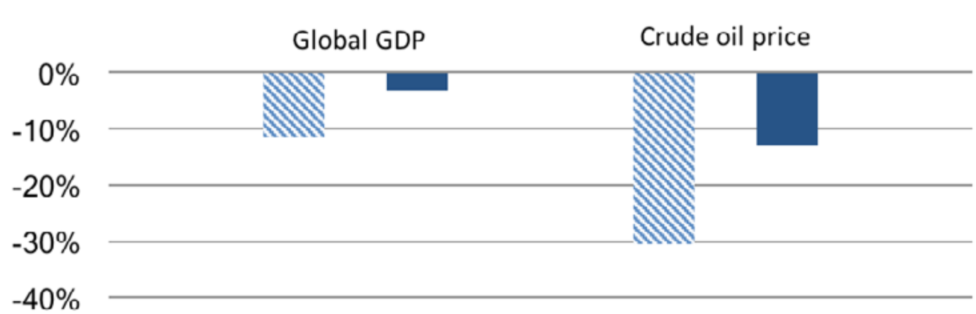

Figure 12. Changes in crude oil prices and GDP under the 40% CO_2 reduction scenario.

as "forward calibration." To do this, for each region, we calculate the total factor productivity level such that the projected BAU GDP in 2030 is consistent to the assumed BAU GDP growth rate and the given levels of labor, capital and autonomous energy efficiency improvement (AEEI). The growth rates of BAU GDP, labor, capital, and AEEI are drawn from Jacoby *et al.* (2017).

The policy scenarios we considered in this set of simulations include: 1) Taiwan implements a CO_2 reduction policy unilaterally, and 2) Taiwan carries out the reduction goal when global emissions mitigation efforts exist. According to Taiwan's NDC, the goal is to cut 50% of BAU GHG emissions by 2030 (EPA, 2015). In both scenarios, we represent this target by cutting Taiwan's CO_2 emissions down to 50% of the BAU level. For the second scenario where the rest of the world also pursues emissions mitigation, we draw the emissions reduction profiles from Jacoby *et al.* (2017) to represent NDCs of other EPPA regions. Specifically, for regions other than Taiwan, we draw from Jacoby *et al.* (2017) the projected emissions levels with regional NDCs in 2030 and the BAU emissions levels of the same year, and calculate the rate of emissions reduction relative to BAU in 2030 for each region. Subsequently, the reduction rate of each region is used as the target for CO_2 mitigation of that region considered in this simulation.[1]

Before examining the implications of foreign mitigation policies when Taiwan pursues its NDC, two plausible outcomes are proposed:

> **Hypothesis 3A:** *Compared to the scenario where Taiwan carries out its NDC unilaterally, when the emissions mitigation becomes a global effort, the negative GDP impact on Taiwan's economy becomes higher because of the decrease in foreign demand for products made in Taiwan.*
>
> **Hypothesis 3B:** *Compared to the scenario where Taiwan carries out its NDC unilaterally, when the emissions mitigation becomes a global effort, the negative GDP impact on Taiwan's economy becomes lower because of the decrease in fossil fuels prices.*

As indicated in Section 1, international trade is crucial for Taiwan's economy. Therefore, we will study simulation results for Taiwan's domestic outputs and net exports of selected sectors under different policy scenarios. In particular, we focus on the energy-intensive sector (EINT), other manufacturing sector (OTHR, with electrical and electronic manufacturers being the main players), and service sector (SERV). Based on the GTAP9 database, these sectors together accounted for around 83% of Taiwan's total domestic output in the base year. The BAU results based on forward calibration for the year of 2030 show that, compared with other regions (especially developed countries), while Taiwan's EINT sector has relatively high levels of energy intensity (energy use per unit of output) and CO_2 intensity (carbon footprint per unit of output), those intensities are lower for Taiwan's OTHR and SERV sectors. The projected regional energy and CO_2 intensities of these sectors for 2030 are provided in **Appendix D**.

Results from our model show that when Taiwan pursues its NDC, the negative impact on the EINT sector is higher than on the OTHR and SERV sectors, regardless of whether other regions also pursue their NDCs. The sectoral output profile does not change much when concerted mitigation efforts exist at the global level (**Figure 13**), and similar patterns are observed as changes in net exports at the sectoral level are minimal for these sectors (**Figure 14**). These findings suggest that Hypothesis 3A might not hold, especially if, compared with the scenario where Taiwan pursues its NDC unilaterally, prices of imported fossil fuels become much lower under the global mitigation scenario—which is exactly what the results of our simulation reveal (**Figure 15**).

Finally, we compare the impact on Taiwan's GDP under both scenarios, and find that when emissions reduction becomes a global effort, the negative impact on GDP is somewhat lower than the case where Taiwan carries out its NDC unilaterally (**Figure 16**). As discussed, prices for fossil fuels are further suppressed due to a reduced demand for fossil fuels when the rest of the world also participates in the mitigation efforts, and because it depends heavily on fossil fuels imports, Taiwan will reap the benefit of lower fossil fuel prices (Figure 15). Therefore, **Hypothesis 3B** is supported by our findings.

4. Conclusions

Global economy-wide equilibrium models have been used extensively by researchers in many countries to assess the effects of energy or climate policies, where sectoral and regional interactions need to be taken into account carefully. For Taiwan, which depends heavily on international trade and energy imports, relevant studies so far were conducted solely under a single-country modeling framework, which cannot capture effects such as impacts of climate mitigation policies abroad. To bridge this gap, we build a version of EPPA, a global energy-economic CGE model, where Taiwan is explicitly represented. The model allows us to answer questions raised by this study, including the implications of 1) using input-output data of different years; 2) applying the same input-output data on distinct models; and 3) pursuing Taiwan's emissions reduction target, as documented in its NDC, with and without a global mitigation effort. With regard to 1), we found that, in general, base years with higher fuel prices were associated with higher marginal CO_2 abatement costs, due to the higher fuel cost share of production. This may reflect the model structure that, lacking extensive

1 Since most GHG emissions of Brazil are form land-use changes, which are not considered in our model, we draw Brazil's reduction rate of fossil CO_2 emissions from Jacoby *et al.* (2017) and use it as the reduction target of Brazil in our simulation.

low-carbon options, produces a short-run response. Given that energy prices can be quite volatile over time, changes in the base year can contribute to different policy costs. With regard to 2), we demonstrated that a simple production structure can produce very different policy costs—in this case, much higher costs. However, this simple model was not designed with a focus on energy, and represented few options for reducing fuel use, short of reducing overall economic activity. We conclude that for realistic policy assessment, attention to model design is needed, especially toward goods and inputs that are targets of policy interest. With regard to 3), we demonstrated that a small country that depends heavily on trade should consider the policies of other countries as well as its own, as policies abroad can

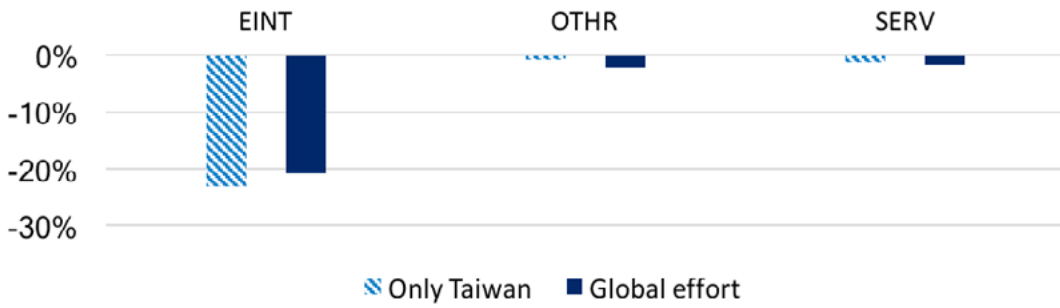

Figure 13. Changes in outputs for selected sectors of Taiwan under different scenarios.

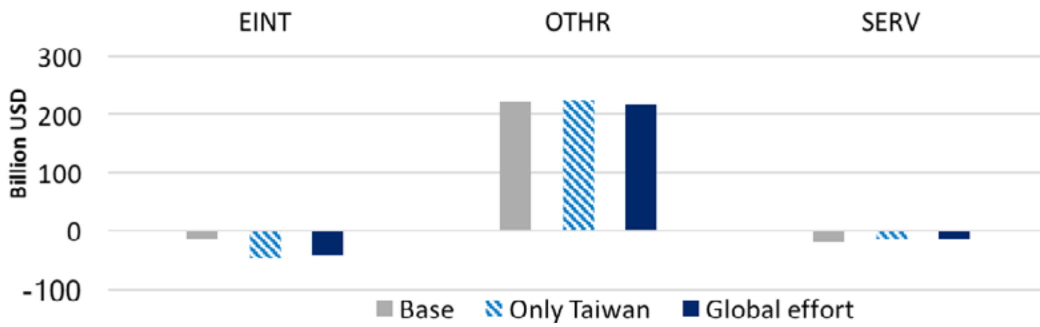

Figure 14. Net exports for selected sectors of Taiwan under different scenarios.

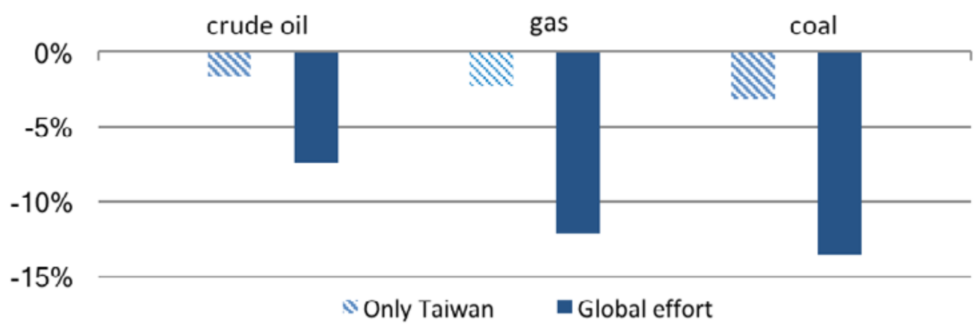

Figure 15. Changes in the prices of imported fossil fuels under different scenarios.

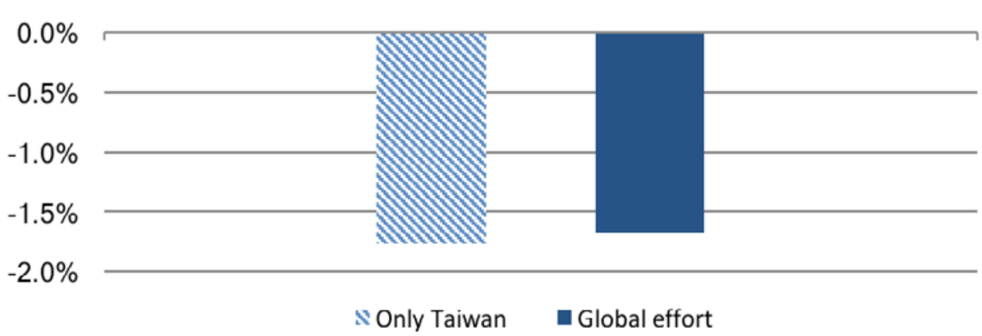

Figure 16. Changes in Taiwan's GDP under different scenarios.

affect the domestic economy. In the specific case of Taiwan, we found that a global policy benefitted Taiwan, compared with a case where Taiwan acted alone. We traced this to the global policy significantly reducing crude oil prices—an important import of Taiwan's economy. These questions are interesting and crucial from both the modeling and policy perspectives, and answering them helps researchers and policy makers to be aware of the potential implications of updating the economic database, demonstrates the importance of model setting, and highlights the roles of policies implemented abroad in determining the domestic policy implications of Taiwan.

Our major goal in this paper was to thoroughly evaluate the first stage development of EPPA-Taiwan as a static model. We have identified several additional steps to make the model more realistic. We plan to adopt the GTAP9-Power data base which provides greater disaggregation of the electricity sector. We may also incorporate engineering data into the model to represent "backstop technologies" that are not present in the base year, but may play crucial roles with energy or climate that significantly change the effective price of some fuels. We also expect to develop a dynamic version of the model to better address issues about how changes in economic condition and policy stringency over time may affect the economy and emissions.

Acknowledgments

We are thankful for the financial support provided by National Energy Program-Phase II and Atomic Energy Council, Executive Yuan, Taiwan, and the valuable comments from participants of the MIT EPPA meeting, the 2016 Taiwan Association of Environmental and resource Economics, and the 20th Annual Conference on Global Economic Analysis held in Purdue University. We are also grateful to Jamie Bartholomay for their excellent edits in improving the paper. All remaining errors are our own.

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APPENDIX A. The code for the static CGE component of EPPA-Taiwan

```
$title this is a static version of EPPA-Taiwan in MPSGE
**This file is derived from both the static component of EPPA6 (Chen et al., 2016) and the static model of GTAPinGAMS
(Lanz and Rutherford, 2016)
*$if not set yr $set yr 11
$if not set source $set source 2011eppaTaiwan_19
$set ds %source%
$include .\readgtap
$include .\transhomo
$include ..\parameters\GTAPinGAMSelas
Set rnum2(r) /TWN/;

$ontext
$model:eppaTaiwan

$sectors:
  Y(g,r)$vom(g,r)                        ! Supply-billion us dollars
  M(i,r)$(vim(i,r) and not x(i))         ! Imports
  YT(j)$vtw(j)                           ! Transportation services
  A(i,r)$voama(i,r)                      ! Armington goods Supply-
  W(r)$w0(r)                             ! Utility
  HOMM(i,r)$homm0(i,r)$x(i)              ! import sector for homogenious goods
  HOMX(i,r)$homx0(i,r)$x(i)              ! export sector for homogenious goods
$commodities:
  P(g,r)$(vom(g,r) and (not x(g)))       ! Domestic output price
  PH(g,r)$(x(g))                         ! Domestic output price
  PM(j,r)$(vim(j,r) and not x(j))        ! Import price
  PT(j)$vtw(j)                           ! Transportation services5
  PF(f,r)$evom(f,r)$mf(f)                ! Primary factors rent
  PS(f,g,r)$(sf(f) and vfm(f,g,r))       ! Sector-specific primary factors
  PA(i,r)$voama(i,r)                     ! Armington goods price
  PW(r)$w0(r)                            ! Utility price
  PCO2(r)$sclim(r)                       ! co2 price(us dollars per ton)
  PWH(i)$x(i)                            ! world price for homogenious googs
$consumers:
  RA(r)                                  ! Representative agent

*armington goods
$prod:A(i,r)$(voama(i,r) and (not x(i)))   esu:selas(i,"sdm",r)
  o:PA(i,r)              q:voama(i,r)          p:1
  i:P(i,r)$(not x(i))    q:vdfma(i,r)          p:(1+rtfda0(i,r))       esu:               a:RA(r) t:rtfda(i,r)
  i:PM(i,r)$(not x(i))   q:vifma(i,r)          p:(1+rtfia0(i,r))       esu:               a:RA(r) t:rtfia(i,r)

$prod:A(i,r)$(voama(i,r) and x(i))
  o:PA(i,r)              q:voama(i,r)          p:1
  i:PH(i,r)$(x(i))       q:vhfma(i,r)          p:(1+rtfha0(i,r))                          a:RA(r) t:rtfha(i,r)

* government and investment index
$prod:Y(g,r)$vom(g,r)$gi(g)   s:esub(g)
+                        gas(s):0   coal(s):0   oil(s):0   roil(s):0
  o:P(g,r)               q:vom(g,r) P:(1-rto0(g,r))                                       a:RA(r) t:rto(g,r)
  i:PA(enoe_,r)          q:voam(enoe_,g,r)                             enoe_.tl:
  i:PA(i,r)$elec(i)      q:voam(i,g,r)
  i:PA(i,r)$ne(i)        q:voam(i,g,r)
  i:PCO2(r)#(enoe_)$sclim(r) q:eco2(enoe_,g,r)                         enoe_.tl:

* consumption index
$prod:Y(g,r)$vom(g,r)$con(g) u:delas   a(u):d_elas(r)   dw(u):eed(r) en(dw):selas("hh","noe_el",r)
+                        gas(en):0   coal(en):0   oil(en):0   roil(en):0
  o:P(g,r)               q:vom(g,r) P:(1-rto0(g,r))                                       a:RA(r) t:rto(g,r)
  i:PA(i,r)$nend(i)      q:voam(i,g,r)                                 a:
  i:PA(i,r)$dwe(i)       q:voam(i,g,r)                                 dw:
  i:PA(enoe_,r)          q:voam(enoe_,g,r)                             enoe_.tl:
  i:PA(i,r)$elec(i)      q:voam(i,g,r)                                 en:
  i:PCO2(r)#(enoe_)$sclim(r) q:eco2(enoe_,g,r)                         enoe_.tl:

* set agri = {crop live fors}
$prod:Y(g,r)$(vom(g,r) and agri(g))  a:pnesta(g,r)   va(a):selas(g,"l_k",r)  fx(a):esup(g,r)  e(fx):selas(g,"e_kl",r)
ne(e):ene(g,r)
+                        en(e):selas(g,"noe_el",r)   en1(en):esube(g,r)   bva(fx):esubva(g)
+                        gas(en1):0   coal(en1):0   oil(en1):0   roil(en1):0
```

```
  o:P(g,r)                   q:vom(g,r) P:(1-rto0(g,r))                                         a:RA(r) t:rto(g,r)
  i:PA(enoe_,r)              q:voam(enoe_,g,r)                              enoe_.tl:
  i:PA(i,r)$elec(i)          q:voam(i,g,r)                                  en:
  i:PA(i,r)$ne(i)            q:voam(i,g,r)                                  ne:
  i:PS(sf,g,r)               q:vfm(sf,g,r)         p:(1+rtf0(sf,g,r))       bva:                a:RA(r) t:rtf(sf,g,r)
  i:PF(mf,r)                 q:vfm(mf,g,r)         p:(1+rtf0(mf,g,r))       va:                 a:RA(r) t:rtf(mf,g,r)
  i:PCO2(r)#(enoe_)$sclim(r) q:eco2(enoe_,g,r)                              enoe_.tl:

* set eint = {eint}
$prod:Y(g,r)$(vom(g,r) and eint(g))   b:esup(g,r)   a(b):pnesta(g,r)   ee(a):selas(g,"e_kl",r)
+                            va(ee):selas(g,"l_k",r) en(ee):selas(g,"noe_el",r)
+                            en1(en):esube(g,r)    bva(b):esubva(g)
+                            gas(en1):0   coal(en1):0   oil(en1):0   roil(en1):0
  o:P(g,r)                   q:vom(g,r) P:(1-rto0(g,r))                                         a:RA(r) t:rto(g,r)
* i:PA(i,r)$enoe(i)          q:voam(i,g,r)                                  en1c:
  i:PA(enoe_,r)              q:voam(enoe_,g,r)                              enoe_.tl:
  i:PA(i,r)$elec(i)          q:voam(i,g,r)                                  en:
  i:PA(i,r)$ne(i)            q:voam(i,g,r)                                  a:
  i:PS(sf,g,r)               q:vfm(sf,g,r)         p:(1+rtf0(sf,g,r))       bva:                a:RA(r) t:rtf(sf,g,r)
  i:PF(mf,r)                 q:vfm(mf,g,r)         p:(1+rtf0(mf,g,r))       va:                 a:RA(r) t:rtf(mf,g,r)
  i:PCO2(r)#(enoe_)$sclim(r) q:eco2(enoe_,g,r)                              enoe_.tl:

* domestic production index
* note the negation of aenoe.  set aenoe = {crop live fors coal oil roil gas elec eint}
* so this block is for set Naenoe ={food othr serv tran dwe}
$prod:Y(g,r)$(vom(g,r)$(Naenoe(g)))   b:esup(g,r)   a(b):pnesta(g,r)   ee(a):selas(g,"e_kl",r)
+                            a(ee):selas(g,"l_k",r)   en(ee):selas(g,"noe_el",r)
+                            en1(en):esube(g,r)   bva(b):esubva(g)
+                            gas(en1):0   coal(en1):0   oil(en1):0   roil(en1):0
  o:P(g,r)                   q:vom(g,r) P:(1-rto0(g,r))                                         a:RA(r) t:rto(g,r)
  i:PA(enoe_,r)              q:voam(enoe_,g,r)                              enoe_.tl:
  i:PA(i,r)$elec(i)          q:voam(i,g,r)                                  en:
  i:PA(i,r)$ne(i)            q:voam(i,g,r)                                  a:
  i:PS(sf,g,r)               q:vfm(sf,g,r)         p:(1+rtf0(sf,g,r))       bva:                a:RA(r) t:rtf(sf,g,r)
  i:PF(mf,r)                 q:vfm(mf,g,r)         p:(1+rtf0(mf,g,r))       va:                 a:RA(r) t:rtf(mf,g,r)
  i:PCO2(r)#(enoe_)$sclim(r) q:eco2(enoe_,g,r)                              enoe_.tl:

* set enoe = {coal oil roil gas}
$prod:Y(g,r)$(vom(g,r)$(enoe(g)))   b:esup(g,r)   a(b):pnesta(g,r)   va(a):selas(g, "l_k",r)
 en(a):selas(g,"noe_el",r)
+                            en1(en):esube(g,r)   bva(b):esubva(g)   en1c(en1):0
+                            gas(en1):0   coal(en1):0   oil(en1):0   roil(en1):0
  o:P(g,r)$(not x(g))        q:vom(g,r) P:(1-rto0(g,r))                                         a:RA(r) t:rto(g,r)
  o:PH(g,r)$(x(g))           q:vom(g,r) P:(1-rto0(g,r))                                         a:RA(r) t:rto(g,r)
  i:PA(enoe_,r)              q:voam(enoe_,g,r)                              enoe_.tl:
  i:PA(i,r)$elec(i)          q:voam(i,g,r)                                  en:
  i:PA(i,r)$ne(i)            q:voam(i,g,r)                                  a:
  i:PS(sf,g,r)               q:vfm(sf,g,r)         p:(1+rtf0(sf,g,r))       bva:                a:RA(r) t:rtf(sf,g,r)
  i:PF(mf,r)                 q:vfm(mf,g,r)         p:(1+rtf0(mf,g,r))       va:                 a:RA(r) t:rtf(mf,g,r)
  i:PCO2(r)#(enoe_)$sclim(r) q:eco2(enoe_,g,r)                              enoe_.tl:

* set elec = {elec}
$prod:Y(g,r)$(vom(g,r) and elec(g))   s:esub(g)   va:esubva(g)   ss:0
+                            gas(s):0   coal(s):0   oil(s):0   roil(s):0
  o:P(g,r)                   q:vom(g,r) P:(1-rto0(g,r))                                         a:RA(r) t:rto(g,r)
  i:PA(enoe_,r)              q:voam(enoe_,g,r)                              enoe_.tl:
  i:PA(i,r)$elec(i)          q:voam(i,g,r)
  i:PA(i,r)$ne(i)            q:voam(i,g,r)
  i:PS(sf,g,r)               q:vfm(sf,g,r)         p:(1+rtf0(sf,g,r))       va:                 a:RA(r) t:rtf(sf,g,r)
  i:PF(mf,r)                 q:vfm(mf,g,r)         p:(1+rtf0(mf,g,r))       va:                 a:RA(r) t:rtf(mf,g,r)
  i:PCO2(r)#(enoe_)$sclim(r) q:eco2(enoe_,g,r)                              enoe_.tl:

* net imports of homogenous goods
* vhomm0(x,r) = (homm0(x,r)+homt0(x,r))*(1+tmhom(x,r))
* homt0: value of homogenous goods transport cost; tmhom: tariff on homogenous goods

$prod:HOMM(i,r)$homm0(i,r)$x(i)         s:0
  o:PH(i,r)                  q:vhomm0(i,r)
  i:PWH(i)                   q:homm0(i,r)          p:(1+tmhom0(i,r))                            a:RA(r)  t:tmhom(i,r)
  i:PT(j)                    q:homt0(j,i,r)        p:(1+tmhom0(i,r))                            a:RA(r)  t:tmhom(i,r)
```

```
* net exports of homogenous goods
* vhomx0(x,r) = homx0(x,r)/(1+txhom(x,r))
* txhom: export tax on homogenous goods
$prod:HOMX(i,r)$homx0(i,r)$x(i)
  o:PWH(i)                  q:homx0(i,r)
  i:PH(i,r)                 q:vhomx0(i,r)         p:(1+txhom0(i,r))                         a:RA(r)  t:txhom(i,r)

*utility index
$prod:W(r)$w0(r)            s:ew(r)
  o:PW(r)                   q:w0(r)
  i:P("i",r)                q:vom("i",r)
  i:P(con,r)                q:vom(con,r)

$prod:YT(j)$vtw(j)          s:eyt
  o:PT(j)                   q:vtw(j)
  i:P(j,r)$(not x(j))       q:vst(j,r)
  i:PH(j,r)$(x(j))          q:vst(j,r)

$prod:M(i,r)$(vim(i,r) and not x(i))  s:selas(i,"smm",r)  s.tl:0
  o:PM(i,r)                 q:vim(i,r)
  i:P(i,s)                  q:vxmd(i,s,r)         p:pvxmd(i,s,r) s.tl: a:RA(s) t:(-rtxs(i,s,r)) a:RA(r)
t:(rtms(i,s,r)*(1-rtxs(i,s,r)))
  i:PT(j)#(s)               q:vtwr(j,i,s,r)       p:pvtwr(i,s,r) s.tl: a:RA(r) t:rtms(i,s,r)

$demand:RA(r)
  d:PW(r)                   q:w0(r)
  e:P(con,rnum)             q:vb(r)
  e:P("g",r)                q:(-vom("g",r))
  e:PF(mf,r)                q:evom(mf,r)
  e:PS(sf,i,r)              q:vfm(sf,i,r)
  e:PCO2(r)$sclim(r)        q:clim(r)
  e:PH(g,r)$x(g)            q:homadj(g,r)
  e:PT(j)                   q:trnadj(j,r)

$report:
  v:R_ARM(i,r)              o:PA(i,r)  prod:A(i,r)! realized vafm (Armington good output, billion US$)
  v:R_ARM_E(e,g,r)          i:PA(e,r)  prod:Y(g,r)! realized vafm _energy (Armington good output, billion US$)
  v:R_VOM_NX(g,r)           o:P(g,r)   prod:Y(g,r)! realized vom_non homo good (sectoral output, billion US$)
  v:R_VOM_X(g,r)            o:PH(g,r)  prod:Y(g,r)! realized vom_homo good (sectoral output, billion US$)
  v:R_CONS(r)               o:PW(r)    prod:W(r)  ! realized vum (total final consumption, billion US$)
  v:R_VDFM(i,r)             i:P(i,r)   prod:A(i,r)! Realized vdfm (domestic supply, billion US$)
  v:R_VIFM(i,r)             i:PM(i,r)  prod:A(i,r)! Realized vifm (import supply in billion US$)
  v:R_VFMSF(f,g,r)          i:PS(f,g,r)prod:Y(g,r)! Realized vfm_sf (supply of sluggish factor, billion US$)
  v:R_VFMMF(f,g,r)          i:PF(f,r)  prod:Y(g,r)! Realized vfm_mf (supply of mobile factor, billion US$)
  v:R_VXMD(i,s,r)           i:P(i,s)   prod:M(i,r)! Realized vxmd (region r's importing from region s, billion US$)
  v:R_VST(j,r)              i:P(j,r)   prod:YT(j) ! Realized vst (Transportation services, billion US$)

$offtext
$sysinclude mpsgeset eppaTaiwan

*PA.L(i,r)     = 1+rtfaa0(i,r);
*PCO2.L(r)$sclim(r)=1e-6;
P.FX("c",rnum2)  = 1;
sclim(r)=no;
eppaTaiwan.workspace = 256;
eppaTaiwan.iterlim = 0;
eppaTaiwan.optfile = 1;
$include eppaTaiwan.gen
solve eppaTaiwan using mcp;

$set sim base
$include .\report.gms

**=====shock
$include ..\active\INDCshock.gms
```

APPENDIX B. Nesting structures of other sectors

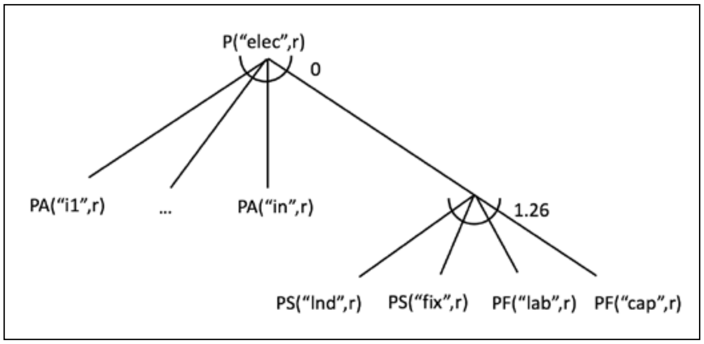

Figure B1. Nesting structure of electricity sector.

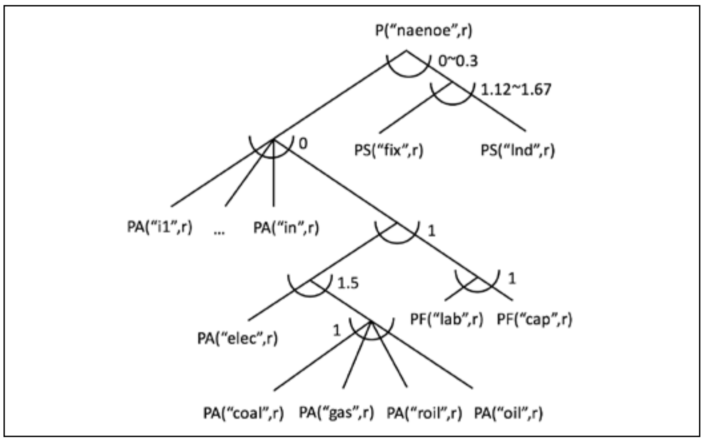

Figure B2. Nesting structure of dwelling, food, other, service, and transportation sector.

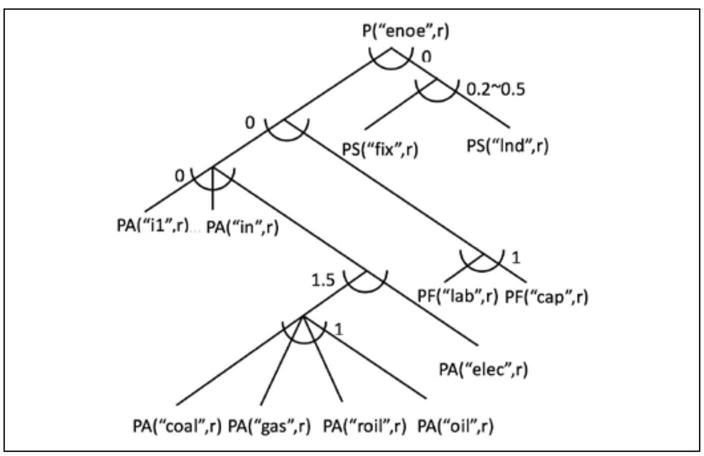

Figure B3. Nesting structure of oil, gas, refined oil and coal sector.

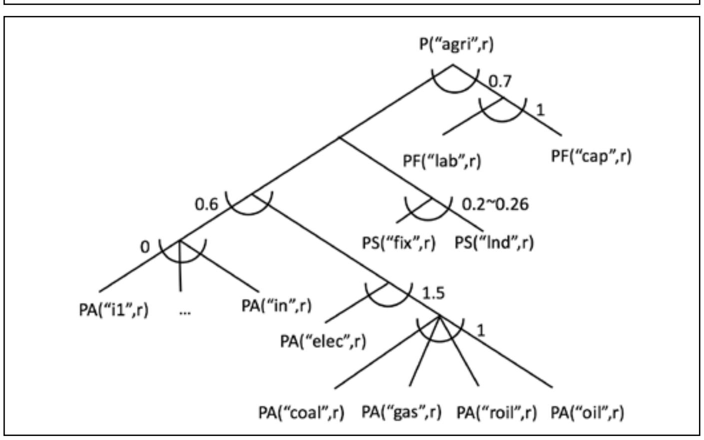

Figure B4. Nesting structure of crop, live, and forest sector.

APPENDIX C. Mappings of sectors, regions, and factors

Table C1. Mapping for regions from GTAP 9 to EPPA-Taiwan.

	GTAP 9 Region	EPPA-Taiwan Region
1	Albania	ROE
2	Argentina	LAM
3	Armenia	ROE
4	Australia	ANZ
5	Austria	EUR
6	Azerbaijan	ROE
7	Bahrain	MES
8	Bangladesh	REA
9	Belarus	ROE
10	Belgium	EUR
11	Benin	AFR
12	Botswana	AFR
13	Brazil	BRA
14	Brunei Darussalam	REA
15	Bulgaria	EUR
16	Burkina Faso	AFR
17	Cambodia	REA
18	Cameroon	AFR
19	Canada	CAN
20	Caribbean	LAM
21	Central Africa	AFR
22	Chile	LAM
23	China	CHN
24	Colombia	LAM
25	Costa Rica	LAM
26	Cote d'Ivoire	AFR
27	Croatia	EUR
28	Cyprus	EUR
29	Czech Republic	EUR
30	Denmark	EUR
31	Dominican Republic	LAM
32	Ecuador	LAM
33	Egypt	AFR
34	El Salvador	LAM
35	Estonia	EUR
36	Ethiopia	AFR
37	Finland	EUR
38	France	EUR
39	Georgia	ROE
40	Germany	EUR
41	Ghana	AFR
42	Greece	EUR
43	Guatemala	LAM
44	Guinea	AFR
45	Honduras	LAM
46	Hong Kong	CHN
47	Hungary	EUR
48	India	IND
49	Indonesia	IDZ
50	Iran, Islamic Republic of	MES
51	Ireland	EUR
52	Israel	MES
53	Italy	EUR
54	Jamaica	LAM
55	Japan	JPN
56	Jordan	MES
57	Kazakhstan	ROE
58	Kenya	AFR
59	Korea, Republic of	KOR
60	Kuwait	MES
61	Kyrgyzstan	ROE
62	Lao People's Dem. Rep.	REA
63	Latvia	EUR
64	Lithuania	EUR
65	Luxembourg	EUR
66	Madagascar	AFR
67	Malawi	AFR
68	Malaysia	ASI
69	Malta	EUR
70	Mauritius	AFR
71	Mexico	MEX
72	Mongolia	REA
73	Morocco	AFR
74	Mozambique	AFR
75	Namibia	AFR
76	Nepal	REA
77	Netherlands	EUR
78	New Zealand	ANZ
79	Nicaragua	LAM
80	Nigeria	AFR
81	Norway	EUR
82	Oman	MES
83	Pakistan	REA
84	Panama	LAM
85	Paraguay	LAM
86	Peru	LAM
87	Philippines	ASI
88	Plurinational Rep. of Bolivia	LAM
89	Poland	EUR
90	Portugal	EUR
91	Puerto Rico	LAM
92	Qatar	MES
93	Romania	EUR
94	Russian Federation	RUS
95	Rwanda	AFR
96	Saudi Arabia	MES
97	Senegal	AFR
98	Singapore	ASI
99	Slovakia	EUR
100	Slovenia	EUR
101	South Africa	AFR
102	South Central Africa	AFR
103	Spain	EUR
104	Sri Lanka	REA
105	Sweden	EUR
106	Switzerland	EUR
107	Taiwan	TWN
108	Tanzania, United Rep. of	AFR
109	Thailand	ASI
110	Togo	AFR
111	Trinidad & Tobago	LAM
112	Tunisia	AFR
113	Turkey	ROE
114	Uganda	AFR
115	Ukraine	ROE
116	United Arab Emirates	MES
117	United Kingdom	EUR
118	United States of America	USA
119	Uruguay	LAM
120	Venezuela	LAM
121	Viet Nam	REA
122	Zambia	AFR
123	Zimbabwe	AFR
124	Rest of Central America	LAM
125	Rest of East Asia	REA
126	Rest of Eastern Africa	AFR
127	Rest of Eastern Europe	ROE
128	Rest of EFTA	EUR
129	Rest of Europe	ROE
130	Rest of Former Soviet Union	ROE
131	Rest of North Africa	AFR
132	Rest of North America	LAM
133	Rest of Oceania	ANZ
134	Rest of S African Customs Union	AFR
135	Rest of South America	LAM
136	Rest of South Asia	REA
137	Rest of Southeast Asia	REA
138	Rest of the World	ANZ
139	Rest of Western Africa	AFR
140	Rest of Western Asia	MES

Table C2. Mapping for sectors from GTAP 9 to EPPA-Taiwan.

	GTAP 9 Sector	EPPA-Taiwan Sector
1	paddy rice	CROP
2	wheat	CROP
3	cereal grains nec	CROP
4	vegetables/fruit/nuts	CROP
5	oil seeds	CROP
6	sugar cane/sugar beet	CROP
7	plant-based fibers	CROP
8	crops nec	CROP
9	bo horses	LIVE
10	animal products nec	LIVE
11	raw milk	LIVE
12	wool/silk-worm cocoons	LIVE
13	forestry	FORS
14	fishing	LIVE
15	coal	COAL
16	oil	OIL
17	gas	GAS
18	minerals nec	OTHR
19	bo meat products	FOOD
20	meat products	FOOD
21	vegetable oils and fats	FOOD
22	dairy products	FOOD
23	processed rice	FOOD
24	sugar	FOOD
25	food products nec	FOOD
26	beverages and tobacco products	FOOD
27	textiles	OTHR
28	wearing apparel	OTHR
29	leather products	OTHR
30	wood products	OTHR
31	paper products/publishing	EINT
32	petroleum/coal products	ROIL
33	chemical/rubber/plastic products	EINT
34	mineral products nec	EINT
35	ferrous metals	EINT
36	metals nec	EINT
37	metal products	EINT
38	motor vehicles and parts	OTHR
39	transport equipment nec	OTHR
40	electronic equipment	OTHR
41	machinery and equipment nec	OTHR
42	manufactures nec	OTHR
43	electricity	ELEC
44	gas manufacture/distribution	GAS
45	water	OTHR
46	construction	OTHR
47	trade	SERV
48	transport nec	TRAN
49	water transport	TRAN
50	air transport	TRAN
51	communication	SERV
52	financial services nec	SERV
53	insurance	SERV
54	business services nec	SERV
55	recreational and other services	SERV
56	public admin/defence/education/health	SERV
57	ownership of dwellings	DWE

Table C3. Mapping for primary factors from GTAP 9 to EPPA-Taiwan.

	GTAP 9 Primary Factor	EPPA-Taiwan Primary Factor
1	Officials and Mangers legislators (ISCO-88 Major Groups 1-2)	LAB
2	Technicians technicians and associate professionals	LAB
3	Clerks	LAB
4	Service and market sales workers	LAB
5	Agricultural and unskilled workers (Major Groups 6-9)	LAB
6	Land,	LND
7	Capital,	CAP
8	Natural resources	FIX

APPENDIX D. Projected energy and CO_2 intensities by region in 2030

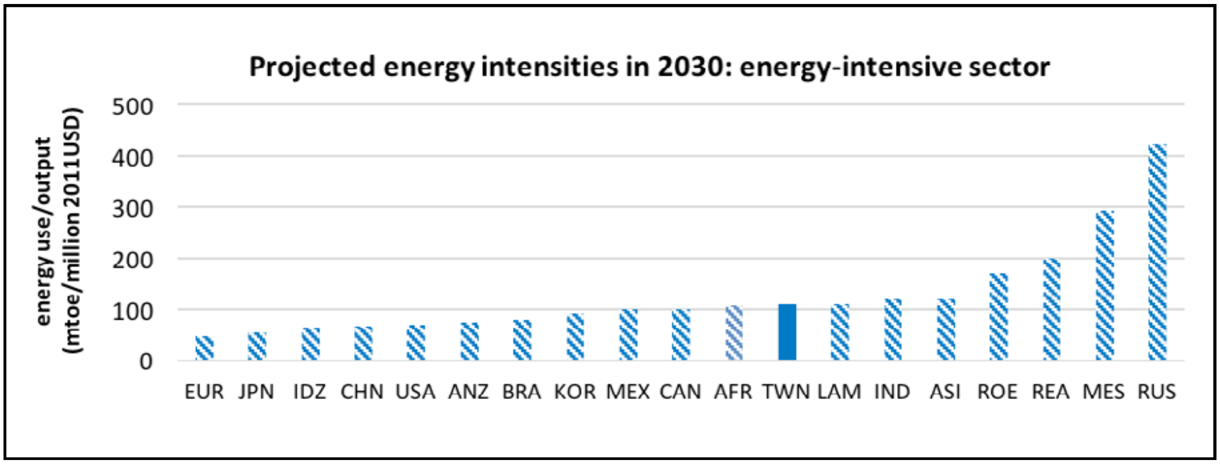

Figure D1. Projected energy intensities of the energy-intensive sector in 2030.

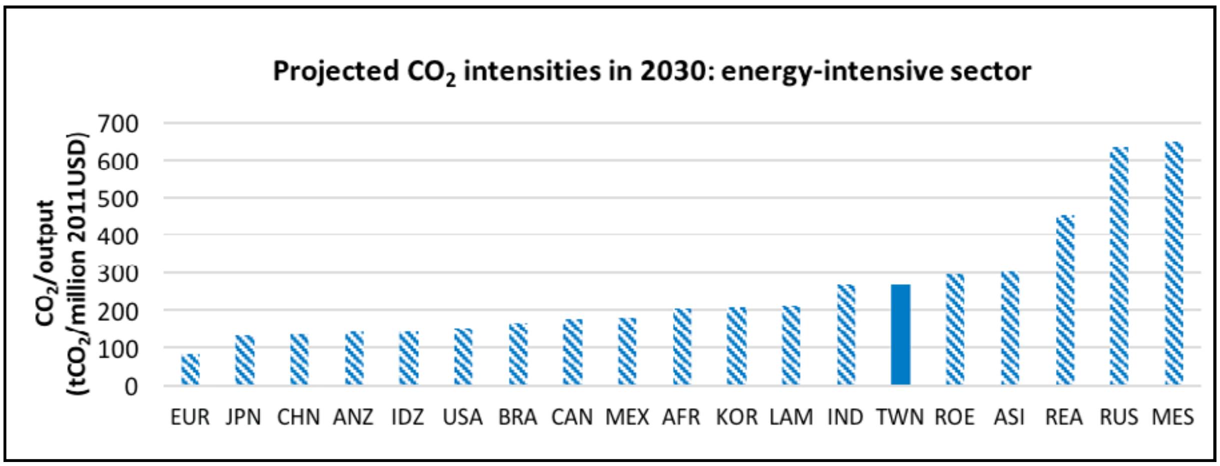

Figure D2. Projected CO_2 intensities of the energy-intensive sector in 2030.

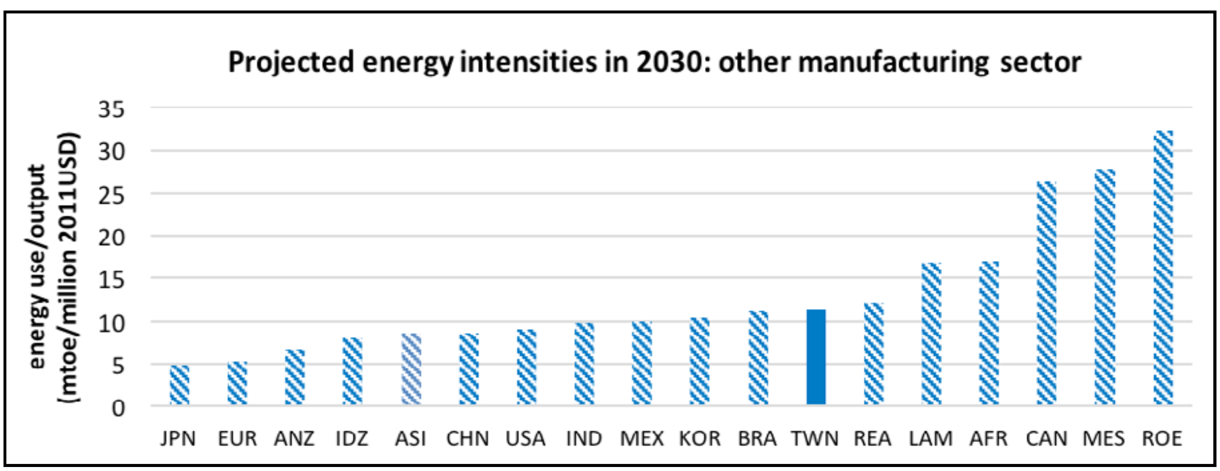

Figure D3. Projected energy intensities of the other manufacturing sector in 2030.

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