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Implications of Updating the Input-output Database of a Computable General Equilibrium Model on Emissions Mitigation Policy Analyses

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Abstract

In this study, we provide a critical evaluation about how updating the input-output data of an energy economic computable generation equilibrium (CGE) model can affect policy results, an assessment that is rarely done in existing literature if any. Specifically, we will explore how datasets with different fossil energy cost shares affect results of policy simulations that aim at reducing CO₂ emissions. We prove analytically that a sudden fossil fuel price surge that provides little time for adjustment through input substitution can lead to a higher CO₂ mitigation cost, and the finding is demonstrated empirically in a full scale CGE model for a base year with lower fossil fuel prices contrasted with results from a base year when fossil fuel prices had spiked. We then propose an adjustment to resolve the issues of using input-output data that embed sudden fossil fuel price hikes.

Keywords: Input-output data; Energy-economic modeling; Emissions mitigation costs

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1. INTRODUCTION

Global economy-wide general equilibrium models with energy details are widely used in climate or energy policy analyses. A typical strategy in building these models is to parameterize them according to the input-output structure of the economy for a particular year and a set of elasticities representing the substitution possibilities between inputs. For instance, the Global Trade Analysis Project (GTAP) database provides the regional input-output data of the world economy, and it also includes estimates of various types of elasticities that are used in the GTAP model (Hertel et al., 2014), one of the global computable general equilibrium (CGE) models that is often used for a diverse range of policy analyses. Another example is the World Input-Output Database (WIOD), which offers the regional input-output structure of the world economy without the elasticities (Timmer et al., 2015). Researchers working on other CGE models often draw the input-output data from these databases, and get the elasticity estimates based on literature reviews or expert elicitation, since different CGE models may have distinct settings in the nesting structures for the production or consumption activities, and therefore the corresponding substitution elasticities needed may not be the same as those provided by GTAP. In general, a goal of model maintenance is to adopt the latest input-output database for modeling exercises, but rarely if ever is there a careful evaluation of the implications of this update in terms of the effect on policy conclusions. Chai et al. (2017) found that climate policy costs were significantly higher for an identical percentage reduction when they formulated a model based on the GTAP 2011 reference year data base than an identical model based on earlier year data bases (2004, 2007). In this paper, we seek to provide an explanation for this difference.

We present an analytical framework and numerical examples to justify explanations for the CO₂ reduction simulation results of a global energy-economic CGE model based on input-output data with various base years. We note that fossil fuel prices are a likely culprit since they are subject to unanticipated price shocks, and since fossil fuels consumption is a primary target for reducing emissions, inflated fossil energy cost shares caused by fossil energy price spikes, for instance, would have direct consequences in simulating the cost of a CO₂ mitigation policy. We argue that an input-output dataset constructed for a year with sudden fossil fuel price spikes, which cause fuel use and fuel cost shares deviate from long-run equilibrium levels, can lead to higher CO₂ mitigation costs. The issue at stake is that the “snapshot” of the economy provided by the dataset may only represent a short-term rather than a long-term equilibrium. Here we refer to the coexistence of short-term equilibrium and long-term disequilibrium as the state where quantities demanded still equal quantities supplied in all markets, except for the fact that capital stocks, which take time to adjust, have not adapted to optimal levels under, for instance, the new energy prices.

Our analysis implies that, when using a dataset with fossil fuel prices that are temporarily extreme due to short-term fluctuation or are permanently higher (or lower) that will continue to induce changes in technologies over time, a newer data set may not necessarily give improved policy conclusions. To overcome this, we propose a solution to resolve the issue. The rest of the paper is organized as follows:

Section 2 presents the analytical framework; Section 3 provides numerical examples; and Section 4 concludes the study and points out a potential path for future research.

2. ANALYTICAL FRAMEWORK

To study the effect of higher fossil fuel prices on CO₂ prices when the emissions mitigation policy is in place, let us consider a simple small open economy with a representative consumer, an aggregated sector A , and two primary factors N (non-energy) and E (energy). Since our focus is on the technology on the supply side, we begin by assuming that the representative consumer has a perfectly inelastic demand for the output of sector A . Later we extend the analysis to the case with an elastic demand for that output. In the economy, we assume the factor prices P_N and P_E are determined internationally rather than domestically, and for every unit of E the sector uses, it produces one unit of emissions. This means that a constraint on energy use is equivalent to a constraint on emissions.

Let us assume that sector A is characterized by a two-input production technology that is strictly convex, twice differentiable, and homothetic:

$$Y = F(E, N) \quad (1)$$

In addition, we assume that the commodity market of sector A is perfectly competitive so that each firm in sector A is a price taker for its output.

Since our focus is to answer the question, other things equal, what is the effect of calibrating the technology under different energy prices, let us consider two different sets of base year data. One is compiled at the time point T_0 under the energy price of P_E^l , and the other is done at T_1 following a sudden energy price hike so that the price becomes P_E^h ($P_E^h > P_E^l$). We assume that the substitution between E and N is possible only in the long-run, and $T_1 - T_0$ is considered a short-run that allows no input substitution. Further assume no economic growth so that the two datasets observed have the same levels of inputs (N_0, E_0).

Under these considerations, the technology that is calibrated at T_0 based on $(N_0, E_0; P_N, P_E^l)$ will be F_l , and that which is calibrated at T_1 based on the after-shock data $(N_0, E_0; P_N, P_E^h)$ will be F_h . The two technologies are differentiated only in terms of energy and non-energy cost shares. Without the constraint on energy use (or emissions) level, let us denote the equilibrium output and price levels under the technology F_i by Y_0^i and P_0^i , respectively. The optimization problem of each firm in sector A is:

$$\max P_0^i \cdot F_i - P_N \cdot N - P_E^i \cdot E \quad (2)$$

Now, suppose that to achieve the emissions reduction target, the energy use should be reduced from E_0 to E_1 , i.e., the optimization problem is now subject to a binding constraint $E = E_1$. Let us denote the equilibrium output and price levels under the technology F_i by Y_1^i and P_1^i , respectively ($i = l$ or h). The constrained optimization problem becomes:

$$\max P_1^i \cdot F_i - P_N \cdot N - P_E^i \cdot E \quad s.t. \quad E_1 - E = 0 \quad (3)$$

Since the demand is perfectly inelastic, the optimal output remains at Y^* after the energy use constraint $E = E_1$ is imposed. In addition, if the technology is calibrated based on $(N_0, E_0; P_N, P_E^l)$, with the energy use constraint, the non-energy input should be increased from N_0 to N_1^l . On the other hand, if $(N_0, E_0; P_N, P_E^h)$ is used to calibrate the technology, with the constraint the non-energy input needs to increase from N_0 to N_1^h , with $N_1^h > N_1^l$ (**Figure 1**). Let us denote λ_i as the shadow price for the constraint ($i = l$ or h). Note that for the technology F_i , the optimal input bundle (N_1^i, E_1) for the constrained optimization problem (Problem (3)) is also the solution to the unconstrained optimization problem facing the relative price of $-P_N/(P_E^i + \lambda_i)$. Therefore, if we impose an energy tax of λ_i for each unit of energy use, the energy consumption level would decrease to E_1 . To answer our research question, we will show that $\lambda_h > \lambda_l$ holds. To proof this, we first present the following lemma:

Lemma 3.1

Per the two technologies F_h and F_l considered in this section, $\frac{\partial P_E^h}{\partial E} < \frac{\partial P_E^l}{\partial E} < 0$.

Proof:

Since the two technologies are differentiated only in terms of energy and non-energy cost shares, we may consider a homothetic function $G(E, N)$ that is strictly convex, twice differentiable with respect to E and N , and with $G(\alpha_l E, N) = F_l(E, N)$ and $G(\alpha_h E, N) = F_h(E, N)$, where the parameter $\alpha_i > 0$ is an increasing function of the energy cost share, i.e., $\alpha_h > \alpha_l > 0$. The slope of the isoquant for F_i is $\left(\frac{dE}{dN}\right)_i = -\frac{G_N}{\alpha_i G_E} = -\frac{P_N}{P_E^i}$, where $G_N = \frac{\partial G}{\partial N}$ and $G_E = \frac{\partial G}{\partial E}$. Note that $\frac{\partial P_E^i}{\partial E} = \alpha_i P_N \cdot \frac{G_{EE}G_N - G_E G_{NE}}{G_N^2}$, where $G_{EE} = \frac{\partial^2 G}{\partial E^2}$ and $G_{NE} = \frac{\partial^2 G}{\partial N \partial E}$. As G is strictly convex, $\frac{d}{dE} \left(\frac{dE}{dN}\right)_G = -\frac{G_{NE}G_E - G_N G_{EE}}{G_E^2} < 0$, i.e., $G_{EE}G_N - G_E G_{NE} < 0$, and so $\frac{\partial P_E^h}{\partial E} < \frac{\partial P_E^l}{\partial E} < 0$ ■

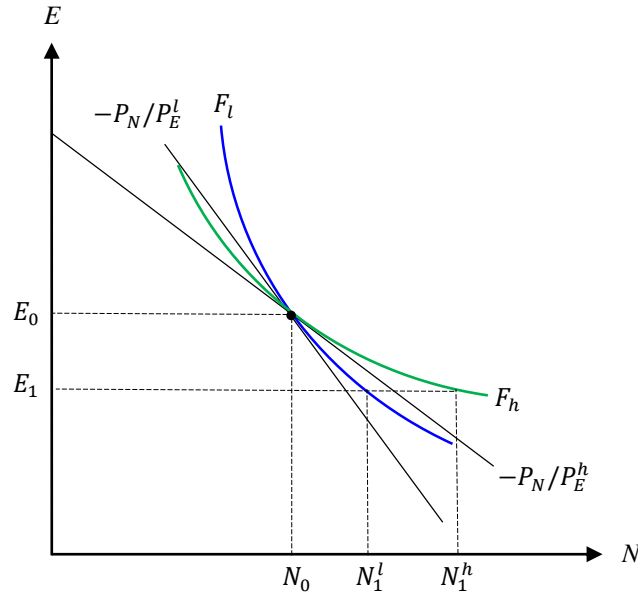


Figure 1. Two-input production technologies calibrated to different prices.

Proposition 3.1

For the economy considered in this section, if the technology is calibrated to the same input bundle (N_0, E_0) but with a higher energy price level P_E^h (and therefore it has a higher energy cost share), then the shadow price of cutting the energy use (and therefore the CO₂ level) will be higher.

Proof:

From the first-order conditions of Problem (2) and Problem (3), $\lambda_i = P_1^i \frac{\partial F_i}{\partial E} \big|_{F_i=Y^*, E_1} - P_0^i \frac{\partial F_i}{\partial E} \big|_{F_i=Y^*, E_0}$, i.e., $\lambda_i = P_E^i|_{E_1} - P_E^i|_{E_0} = \int_{E_0}^{E_1} \left(\frac{\partial P_E^i}{\partial E} \right)_{Y^*} dE$. Since $E_1 < E_0$ and $\left(\frac{\partial P_E^i}{\partial E} \right)_{Y^*} < 0$ (Lemma 3.1), we have $\lambda_i > 0$. To demonstrate $\lambda_h - \lambda_l > 0$, note that $\lambda_h - \lambda_l = \int_{E_0}^{E_1} \left[\frac{\partial (P_E^h - P_E^l)}{\partial E} \right]_{Y^*} dE$, since $\frac{\partial P_E^h}{\partial E} - \frac{\partial P_E^l}{\partial E} < 0$ (Lemma 3.1), $\int_{E_0}^{E_1} \left[\frac{\partial (P_E^h - P_E^l)}{\partial E} \right]_{Y^*} dE > 0$ ■

Based on the above analysis, we can derive the following relations:

$$Y_0 = Y_0^l = Y_0^h = Y_1^l = Y_1^h \quad (4)$$

$$P_1^l - P_0^l > 0 \quad (5)$$

$$P_1^h - P_0^h > 0 \quad (6)$$

$$P_0^h > P_0^l \quad (7)$$

$$P_1^h > P_1^l \quad (8)$$

Condition (4) is simply the result of the demand assumption, Conditions (5), (6), and (7) have been demonstrated in the proof for Proposition 3.1. Condition (8) holds because of Condition (7), $\alpha_h > \alpha_l$, and $\lambda_h|Y > \lambda_l|Y$ (Proposition 3.1).¹ **Figure 2** provides examples for illustration purposes.

¹ $\alpha_h > \alpha_l$ suggests that the energy cost share for technology h is higher than that for technology l . $\lambda_h|Y > \lambda_l|Y$ means that after imposing the constraint $E = E_1$, $P_E^h + \lambda_h|Y^* > P_E^l + \lambda_l|Y^*$. The combination of a higher energy cost share and a higher consumer price for energy leads to a higher level of price increase for the commodity produced by sector A , i.e., $P_1^h - P_0^h > P_1^l - P_0^l$. Since $P_0^h > P_0^l$, therefore $P_1^h > P_1^l$.

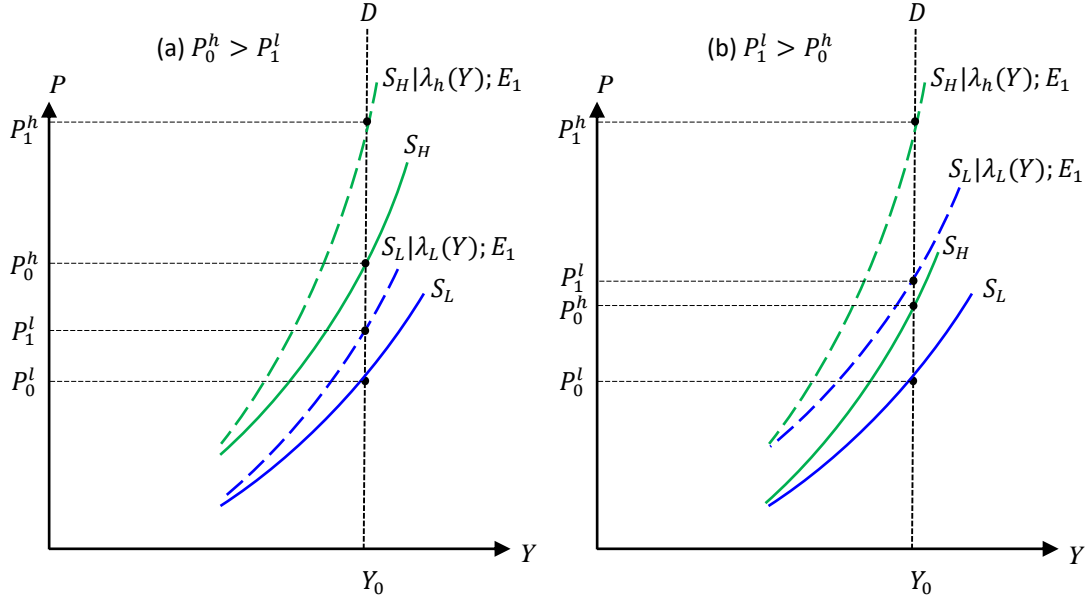


Figure 2. Equilibrium price and output when the demand is perfectly inelastic.

In the following proposition, we will demonstrate that under a binding energy use constraint, the shadow price of that constraint will increase when the output increases.

Proposition 3.2

For the economy considered in this section, for a given technology, the shadow price of the constraint on energy use is an increasing function of the output.

Proof:

Since F is homothetic, the expansion path is a straight line. Suppose under the binding constraint $E = E_1$, the optimal bundle is (N_1, E_1) with a relative price of $-P_N/(P_E^i + \lambda_1|Y_1)$, where λ_1 is the shadow price of the energy use constraint under the output level Y_1 (**Figure 3**). Along the expansion path, let us consider the output level Y_2 ($Y_2 > Y_1$) that is achieved by the input bundle of $(\tilde{N}_2, \tilde{E}_2)$ (see point B in Figure 3). Since $\tilde{E}_2 > E_1$, to achieve the output level Y_2 with $E = E_1$, the input bundle (N_2, E_1) must have $N_2 > \tilde{N}_2$ (see point C in Figure 3). Note that the tangent line of $F|Y_2$ at $(\tilde{N}_2, \tilde{E}_2)$ has the same slope of that of $F|Y_1$ at (N_1, E_1) . Therefore, we have $\lambda_2|Y_2 > \lambda_1|Y_1$ since F is strictly convex ■

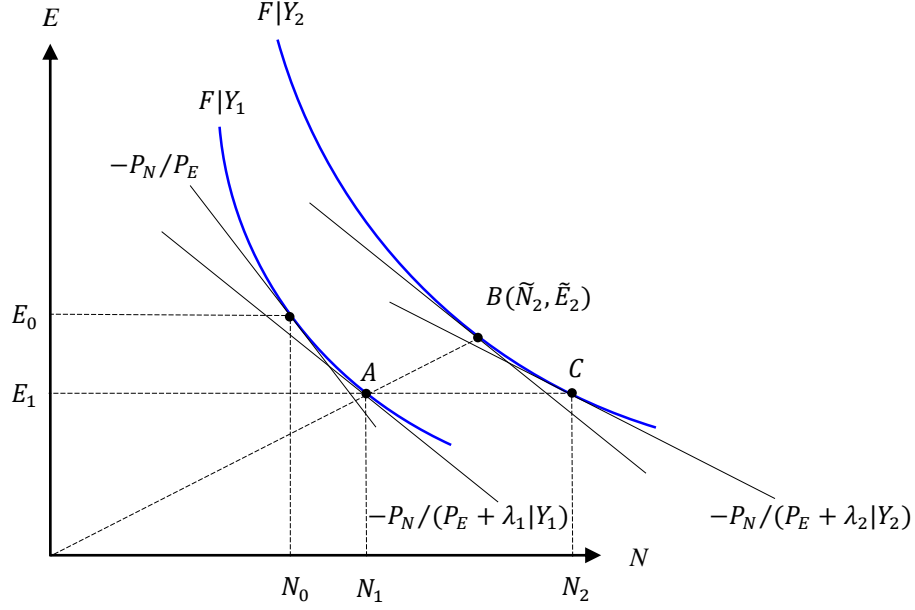


Figure 3. Input, output and the shadow price on energy use constraint ($E = E_1$).

Under the same technology assumption, let us consider the case with an elastic demand. Without a constraint on energy use, the equilibrium output and price levels under the technology F_i are denoted by $Y_0^{l'}$ and $P_0^{l'}$, respectively. Similarly, when the energy use is capped at E_1 , we denote the equilibrium output and price levels under the technology F_i by $Y_1^{l'}$ and $P_1^{l'}$, respectively. Based on these considerations, we have:

$$Y_0 = Y_0^{l'} > Y_0^{h'} \quad (9)$$

$$Y_0^{l'} > Y_1^{l'} \quad (10)$$

$$Y_0^{h'} > Y_1^{h'} \quad (11)$$

$$P_1^{h'} - P|S_h(Y_1^{h'}) > P|(S_l|\lambda_l(Y_1^{h'}); E_1) - P|S_l(Y_1^{h'}) \quad (12)$$

$$P_1^{l'} - P|S_l(Y_1^{l'}) > P|(S_l|\lambda_l(Y_1^{h'}); E_1) - P|S_l(Y_1^{h'}) \quad (13)$$

These properties are presented graphically in **Figure 4**. In particular, Conditions (9) through (11) hold because the demand is elastic, Condition (12) can be derived based on $\lambda_h|Y > \lambda_l|Y$ (Proposition 3.1) and $\alpha_h > \alpha_l$, and Condition (13) is justified by Proposition 3.2.

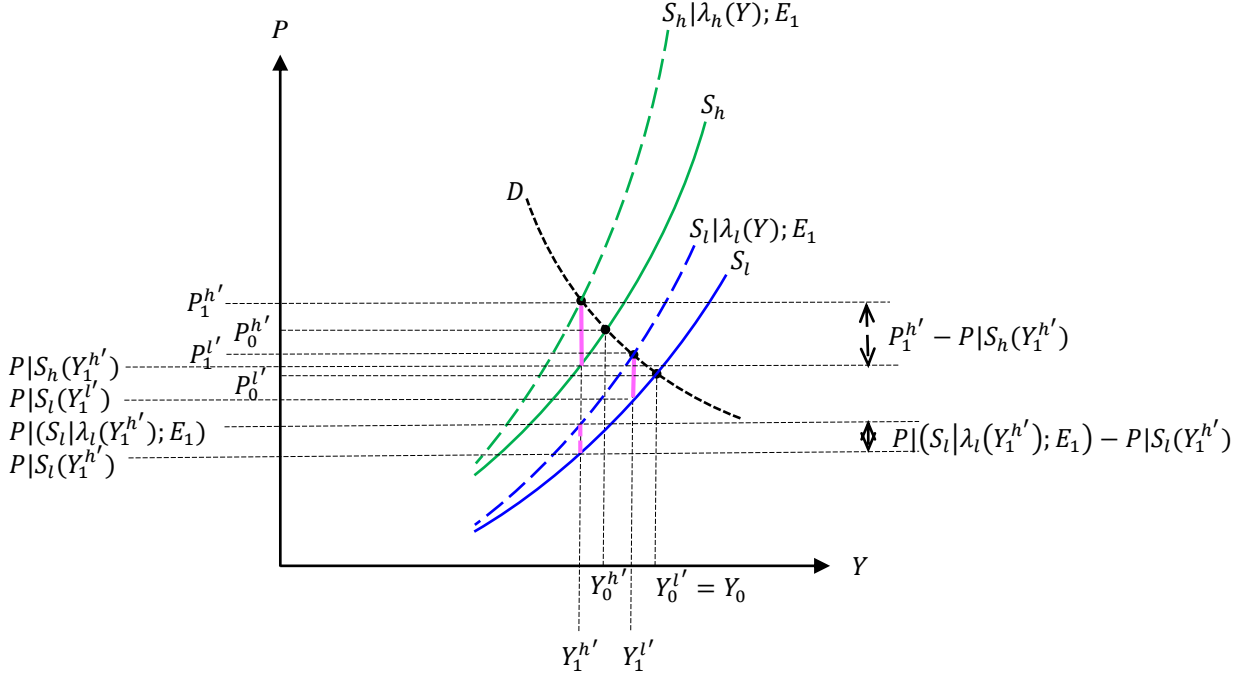


Figure 4. Equilibrium price and output with an elastic demand and the constraint $E = E_1$

One thing that is uncertain is under the same energy use constraint, whether the corresponding shadow price with a technology calibrated based on a higher energy price (F_h) will still be higher than the one calibrated based on a lower energy price (F_l), i.e., whether $\lambda_h|Y_1^{h'} > \lambda_l|Y_1^{l'}$ holds. The uncertainty exists because the equilibrium output with F_l is higher than that with F_h (i.e., $Y_1^{l'} > Y_1^{h'}$). Note that Condition (14) below is the necessary condition for $\lambda_h|Y_1^{h'} > \lambda_l|Y_1^{l'}$:

$$P_1^{h'} - P|S_h(Y_1^{h'}) > P_1^{l'} - P|S_l(Y_1^{l'}) \quad (14)$$

Also, compared with $Y_1^{l'}$, $Y_1^{h'}$ will be reduced further under a higher price elasticity of demand. Consequently, if the demand elasticity is high enough, Condition (14) may not hold, and in that case $\lambda_h|Y_1^{h'} > \lambda_l|Y_1^{l'}$ will not hold. Nevertheless, if the price elasticity of demand is not too high such that the change in equilibrium output $Y_1^{l'} - Y_1^{h'}$ is small, then under the technology F_l , if we compare the shadow price for the energy use constraint associated with the output level of $Y_1^{l'}$ with that associated with the output level of $Y_1^{h'}$, the difference will be small, i.e., $\lambda_l|Y_1^{l'} - \lambda_l|Y_1^{h'}$ will be a small positive number. Since $\lambda_h|Y_1^{h'} > \lambda_l|Y_1^{h'}$ (Proposition 3.1), if $\lambda_l|Y_1^{l'} - \lambda_l|Y_1^{h'}$ is small enough, we will have $\lambda_h|Y_1^{l'} > \lambda_l|Y_1^{h'}$, i.e., when the price elasticity of demand is not too high so the demand response is relatively low, the shadow price for the energy use constraint $E = E_1$ will still be higher when the underlying technology is calibrated based on a higher energy cost price.

Finally, let us consider the case with a change in economic output (e.g., economic growth) such that the two input-output data compiled at different time point have different output levels. We will consider the case where the mitigation goal is to cut the emissions level (and therefore the energy use) proportionally and the demand is elastic.

Proposition 3.3

Let us consider the case where F_l calibrated based on the input-output data D_0 compiled at T_0 has an output level Y_0 , and F_h calibrated according to the input-output data D_1 compiled at T_1 has an output level Y_1 , and $T_0 < T_1$; $Y_0 \neq Y_1$. If the goal is to cut the emissions (and therefore energy use) proportionally, using D_1 will always result in a higher shadow price on the energy use constraint than the case of using D_0 , even under an elastic demand.

Proof:

For the technology F_i ($i = l$ or h), the unconstrained input bundles (N_0, E_0) and (N_1, E_1) produce output levels Y_0 and Y_1 , respectively, and the constrained input bundles (N'_0, E'_0) and (N'_1, E'_1) produce output levels Y_0 and Y_1 , respectively, with $r = E'_0/E_0 = E'_1/E_1 \in (0, 1)$, as the energy reduction proportion is constant (**Figure 5**). Since F is homothetic, the expansion path is a straight line, and the tangents to the isoquant along the expansion path are parallel to each other. Therefore, $\lambda_i|Y_1 = \lambda_i|Y_0$ ($Y_1 \neq Y_0$). According to Proposition 3.1, $\lambda_h - \lambda_l > 0$ for a given level of output Y , so, we have $\lambda_h|Y_1 > \lambda_l|Y_1 = \lambda_l|Y_0$ and $\lambda_h|Y_0 > \lambda_l|Y_0 = \lambda_l|Y_1$, which means under the proportional reduction, $\lambda_h - \lambda_l > 0$ always holds regardless of the corresponding output levels ■

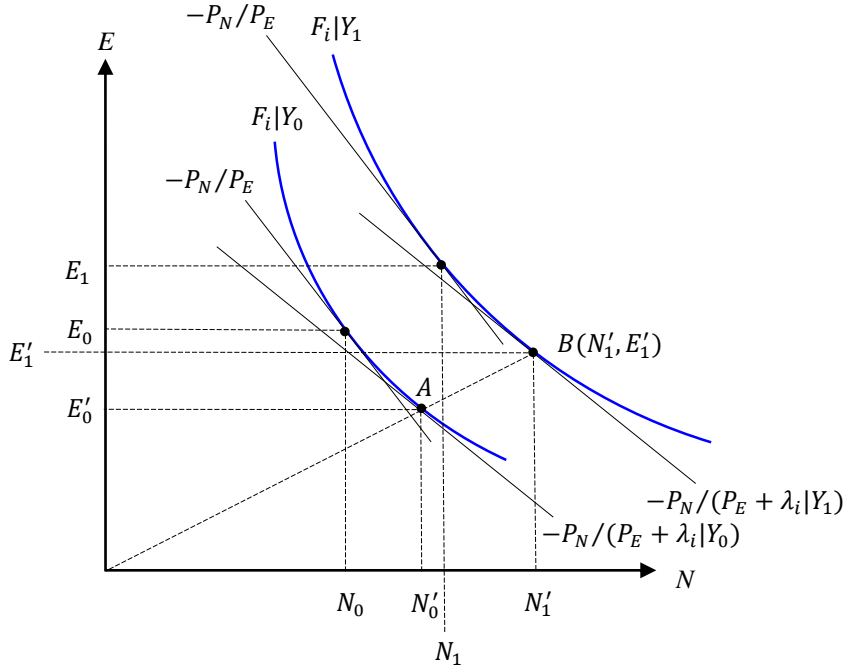


Figure 5. Input, output and the shadow price on energy use constraint ($r \in (0,1)$).

Proposition 3.3 demonstrates that for the economy considered in this section, when the underlying input-output databases have different output levels and energy cost shares, if the goal is to cut the emissions level (and therefore the energy use) proportionally, using the input-output data with a higher energy cost share can always result in a higher shadow price on energy constraint, even when the demand is elastic. The findings of this section will provide explanations for results of numerical simulations presented in the following section.

3. NUMERICAL EXAMPLES

To provide numerical examples for our theoretical analysis, in this section, using different base year data, we simulate the CO₂ prices under a carbon mitigation scenario based on a global computable general equilibrium (CGE) model, which will be introduced shortly. With various base year data, besides differences in fossil fuel prices, other economic and physical variables that affect CO₂ prices may also vary due to shocks other than changes in fossil fuel prices. As a result, we will also reproduce data that control for those shocks beyond fossil fuel prices and demonstrate numerically the effect of changes in fossil fuel prices on CO₂ prices. In addition, we will provide a solution to address the issue of using a base year database with extreme fossil fuel prices due to short-term fluctuations.

3.1 Model

We use the static version of the Economic Projection and Policy Analysis model for Taiwan (EPPA-Taiwan) to demonstrate numerically the implications of using input-output data of various years on CO₂ prices when a global CO₂ reduction policy is in place. The model is a multi-region and multi-sector energy-economic CGE model of the world economy. For each region in the model, there is a representative household, a government, and a representative producer for each production sector. The household is the owner of primary factors, including labor, capital, and natural resources. It earns income by providing the primary factors to producers, and allocates income to consumption and savings. Producers convert intermediate inputs and primary factors into goods and services, and then sell them to other domestic or foreign producers, households, or governments. In each region, the government consumption and transfers are financed by taxes the government collects from producers and the representative household.

Similar to the theoretical framework presented in Section 2, EPPA-Taiwan uses CES functions to represent production technologies and preferences, which are both formulated in mixed complementary problems (MCP) (Mathiesen, 1985; Rutherford, 1995; Ferris and Peng, 1997). The model is written and solved using the modeling languages of General Algebraic Modeling System (GAMS) and Mathematical Programming System for General Equilibrium analysis (MPSGE), which is now a subsystem of GAMS (Rutherford, 1999). Interested readers may refer to Chai et al. (2017) for more details about the model.

The input-output data of EPPA-Taiwan are from the GTAP 9 database (Aguilar et al., 2016), which provides three reference years: 2004, 2007, and 2011, and classifies the world economy into 140 regions, 57 sectors, and 5 primary factors. For EPPA-Taiwan currently we aggregate the data into 19 regions, and combine them into 14 sectors and 4 primary factors (**Appendix A**).

3.2 Simulations

We present the response of EPPA-Taiwan to a global CO₂ abatement policy using the data for the two different base years (2007 and 2011) provided in GTAP 9. We note that Reilly et al. (2016) estimated that getting on a path consistent with the world remaining below 2 degrees C of warming would require about a 40% reduction from reference emissions in 2030, with further reductions in later years. Intended only as an example, we apply a similar 40% global emissions reduction as an illustrative policy. For each region, the target is achieved by imposing an economy-wide carbon tax.

When comparing the 2007 and 2011 datasets, in general the 2011 fossil fuel prices are much higher (except for the lower gas price in the U.S. for that year) (**Figure 7**). Since in general fossil fuel prices fell after 2011, If we regard the fossil fuel price hikes in 2011 as temporary and—to avoid overestimating the CO₂ prices and simultaneously control for factors beyond fossil fuel prices—replace the 2011 fossil fuel prices in the input-output data with those of the 2007 levels, we can produce an adjusted database for 2011 with a shock only from changes in fossil fuel costs, which are set to the 2007 levels. With the adjustment, while equilibrium prices and quantities will not be the same as the pre-shock levels, the changes are only induced from the cost shock. We can then use the adjusted database as the input for EPPA-Taiwan, conduct a CO₂ mitigation policy, and compare CO₂ prices with those using the original 2011 and 2007 data. This is exactly how we present the following example for demonstration purposes. It is worth emphasizing that our goal is simply numerical. Whether the fossil fuel prices in 2007 can be considered as long-run equilibrium levels is a separate research topic.

To produce the adjusted database, we put the GTAP 9 data into EPPA-Taiwan, using 2011 data for all except fossil fuel prices, for which we use the lower 2007 levels (in this scenario, therefore, costs are also lower, since according to the model's setting economic profits are zero in equilibrium). After running this scenario, results for the new equilibrium constitute a balanced social accounting matrix (SAM). We assume the fossil fuels consumption levels in response to sudden fossil fuel price hikes would not change much, and therefore the aforementioned SAM, which represents the new equilibrium, is mapped to the original 2011 energy consumption levels from GTAP 9 to form a complete adjusted 2011 energy-economic dataset, which is in turn used as inputs of EPPA-Taiwan for running the CO₂ reduction simulation. Compared with the original 2011 data, in the adjusted data, global average cost shares decrease in both industrial use and final consumption for refined oil by about 4.0% and 6.2%, for coal by 18.7% and 0.2%, and for gas by 1.6% and 12.1%, respectively.

We now compare the regional CO₂ prices for the original data and adjusted data under a 40% emissions reduction. The results demonstrate that, as expected, using the adjusted data leads to lower CO₂ prices (**Figure 8**). The regional CO₂ prices based on the 2007 data are also presented for comparison purposes. All prices are in 2007 US dollars.

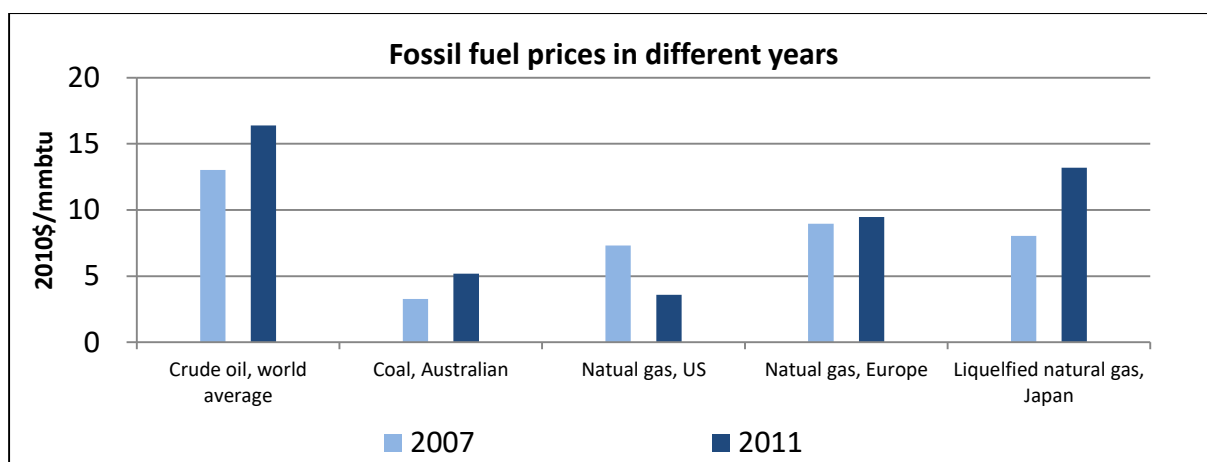


Figure 7. Fossil fuel prices in different years (source: The World Bank, 2017; EIA, 2017).

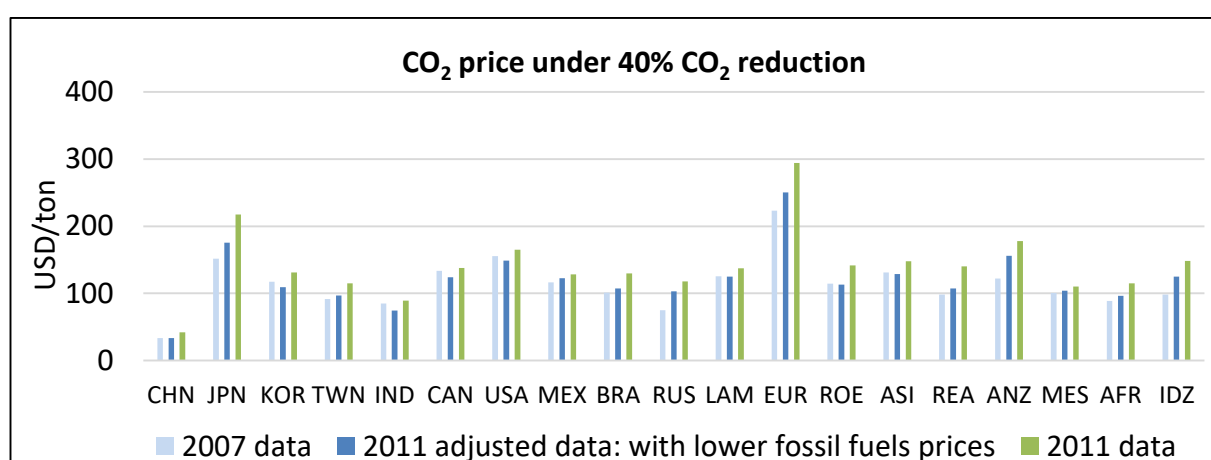


Figure 8. CO₂ prices using the original and adjusted databases.

We proceed by calculating the world average CO₂ prices weighted by regional emissions levels. We find that using the original 2011 data, the adjusted 2011 data, and the 2007 data, the world average CO₂ prices are \$144.2/t-CO₂, 122.2\$/t-CO₂, and \$126.6/t-CO₂ in terms of the 2011 US dollar, respectively, i.e., the simulated CO₂ price using the adjusted 2011 data is much closer to that using the 2007 data with only 3.5% deviation, as opposed to the simulated CO₂ price using the original 2011 data, which deviates from that using the 2007 data by 13.9% (**Figure 9**).

Therefore, if one believes that fossil fuel prices in 2007 are closer to the long-run equilibrium levels and those price hikes in 2011 are simply short-term phenomena, then using the original 2011 data to simulate a carbon constraint scenario would overestimate the world average CO₂ price by 18%, compared with the simulated CO₂ price using the 2011 data adjusted with 2007 fossil fuel prices.

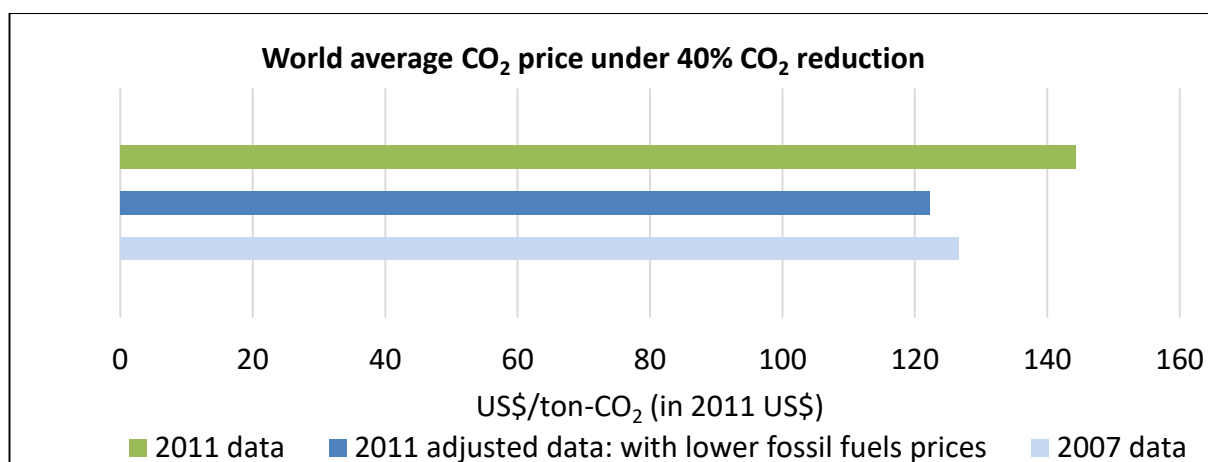


Figure 9. World CO₂ prices using the original and adjusted databases.

Fossil fuels have been subject to periodic price spikes with relatively long periods in between of fairly stable, lower prices. The price spikes are generally unanticipated. Reducing fuel use in response to such prices is generally going to take some time since such adjustment depends on sunk capital, fuel contracts, and other considerations. Especially if fuel users see these prices spikes as temporary, they may have little reason to substitute away from the fuel. Even when the changes are considered as permanent, it takes time to retire old technologies and replace them with new ones or, more generally, to adjust the structure of the economy. Since the input-output data CGE models use can be regarded as a snapshot of the economy, we do not expect the data to be free from potential issues caused by short-term price fluctuations, as in the database there is no dimension to distinguish short-term phenomena from longer-term ones. Further, since intrinsically the input-output data assume the underlying economy is in equilibrium, they also cannot, for example, reflect the ongoing technological adjustments under higher fossil fuel prices that are considered as perpetual.

With all those potential issues, another important question to ask is: if the underlying fossil fuel prices embedded in the input-output data of CGE models could inadvertently change the estimates for emissions mitigation costs, as our finding demonstrates, which estimates are more plausible than others? Our analysis suggests that one way to resolve the issue is to check the underlying fossil fuel prices presented in the input-output data and, based on other studies, adjust price levels that are considered extreme to more reasonable ones and produce a revised (and balanced) energy-economic dataset following the approach shown earlier in this section.

Taking the 2011 data from GTAP 9 as an example, by changing the associated marginal costs of crude oil production while keeping other fossil fuel production costs unchanged, we produce a series of the revised energy-economic datasets for the policy simulation, following the aforementioned procedure. Using these adjusted datasets to run the same CO₂ reduction simulation previously presented, we conduct a sensitivity analysis on the world average CO₂ price under different crude oil price assumptions (**Figure 10**). For instance, using the 2011 input-output data when the crude oil prices were \$94.88/barrel (WTI - Cushing, Oklahoma) and \$111.26/barrel (Brent, Europe) (EIA, 2018), if one believes those price hikes were simply short-term phenomena and more reasonable price levels should be just 70% of the 2011 levels, under the same world-wide 40% emissions reduction scenario considered previously, compared with results based on the original 2011 data that lead to a

CO₂ price of \$144/t-CO₂, the projected CO₂ price would decrease by 4.1% to around \$138/t-CO₂, as Figure 10 shows.

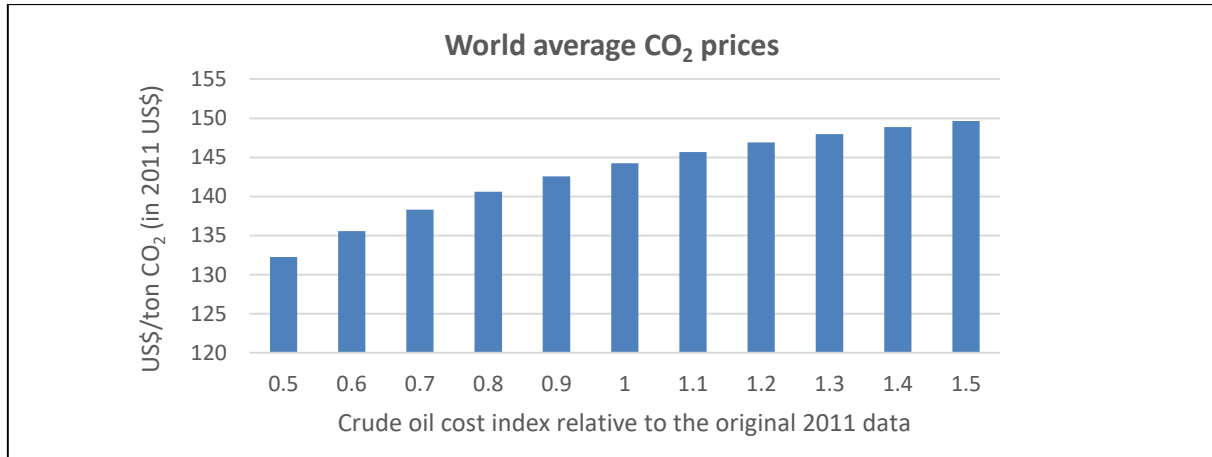


Figure 10. World CO₂ prices using databases with various crude oil cost assumptions.

5. CONCLUSIONS

Large-scale economy-wide equilibrium models are widely used for assessing energy or climate policies. As different models often produce diversified outcomes for similar policies, researchers have been trying to understand reasons behind this observation, including cost assumptions for mitigation options, model structure, policy design, and timing (Clarke *et al.*, 2015; Chen *et al.*, 2016). In this study, we focus on analyzing how updating the input-output database of a CGE model could inadvertently change the model output, which has not been carefully examined but could also be an important source that accounts for variations in simulation results of distinct models.

To answer the research question, we provide an analytical framework that elucidates how using a database with a higher energy price raises the CO₂ mitigation cost when the substitution between inputs is relatively limited in the short-run, regardless of whether the price hike is temporary or permanent. We also provide a numerical example for the analysis, and propose an adjustment to resolve the issue of using the input-output data with prices for fossil fuels and the corresponding consumption levels deviating from a more sustainable state.

Our focus in this paper is on how changes in fossil fuel cost shares of input-output data affect the CO₂ mitigation costs. In general, price surges in other commodities may affect policy results that are closely related to those hikes through various channels. Therefore, a potential avenue for future research is to study those channels and examine to what extent policy results are affected. Besides, economic development as well as policy intervention may result in, for instance, a shift from fossil generation to low-carbon alternatives, or a transition toward a less energy-intensive economy. In these cases, the underlying industrial structure would be very different from before. Thus, another future research pathway would be to explore the roles of these changes in determining emissions or pollution

mitigation costs, as those changes could constitute another crucial dimension that contributes to variations in simulation results based on databases with different reference years.

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APPENDIX A. Regions, sectors and primary factors in EPPA-Taiwan

Table A1. Regions.

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

Note: The European Union (EU-28) plus Norway, Switzerland, Iceland, and Liechtenstein. See details in Chai et al. (2017).

Table A2. Sectors.

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

Note: See details in Chai et al. (2017).

Table A3. Primary factors.

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

Note: See details in Chai et al. (2017).

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