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Input-Output Analysis:

New Technologies and Extended Time Horizons

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Input–Output Analysis: New Technologies and Extended Time Horizons

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Abstract

Input–output analysts are often confronted with requests for impacts assessments for economic shocks that stretch uncomfortably the assumptions of standard input–output modeling. This paper presents an approach to confronting a subset of these challenges straightforwardly in a way that ameliorates some of the more restrictive input–output assumptions, maintains the inter–industry detail of the input–output model, and enhances the representation of certain economic behaviors without the additional complexities of moving to more complex computable general equilibrium or conjoined econometric input–output models. We conclude with the observation that direct changes to the input–output framework most often necessitate further modifications requiring additional behavioral assumptions and decisions on the part of the modeler.

Key words: Input–output, New Technologies, Forecast Impacts
JEL Categories: C67, R15, Q43

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1 Introduction

Faced with requests for economic impacts assessments, analysts must first select an appropriate analytical tool. A wide range of such tools exists, any one of which might be selected for a particular mix of requirements and resources. One general family of models ranges from economic base and input–output (IO) models through social accounting matrix and econometric models to computable general equilibrium models. These models form a continuum that runs from simple to complex behaviors, from moderate data requirements through data avarice, from lesser to greater required analytical expertise, from little or no industry specificity to hundreds of sectors, from quick turnaround to more extensive response times, and from low to high dollar costs. The IO model might well be among the most commonly used tool for impacts assessments, particularly in the United States (U.S.), in part because it occupies intermediate positions on many of the dimensions of this continuum.

IO analysts are well aware that the model's assumptions make it most appropriate to a well–defined set of problem categories, namely those for which the economic shocks are unlikely to change relative prices in capital, labor, or goods markets, shocks whose impacts can be expected to work their way through an economic system in a relatively short – if unspecified – time, and shocks that are not expected to substantially alter the interindustry structure. Impact shock scenarios that violate these conditions stretch the ability of IO models – and indeed of most models – to perform adequately, although different models have differing strengths in each of these assumption areas. Adequately modeling impacts scenarios that stretch these assumptions often requires an unconventional approach.

To provide prospective researchers with responses to some of the practical issues that often arise in IO modeling, this paper presents an example of an increasingly common type of impacts scenario followed by a demonstration of how several problematic issues can be resolved effectively. Some of the approaches presented will have been used already by analysts, but to our knowledge have not been presented in the literature in formal, replicable form. There will also often be alternatives to and variations on the solutions we offer here and those alternatives will likely result in different impacts estimates. Ultimately, the choices among competing alternatives will likely be a function of data, time and budget constraints, along with the preferences of the analyst. Empirical testing of alternatives would be ideal, but is left for future research. While some might also indicate a preference for using a different model altogether, the intent here is to describe ways to ameliorate the assumptions of the IO model within its application rather than to present an argument for its use over other modeling alternatives.

The input–output framework that serves as the foundation of the methods described in this paper is presented in Section 2. In Section 3, we lay out the impact scenario that will serve as the demonstration vehicle and identify the specific questions for which resolution options will be provided. The resolutions themselves comprise Section 4, followed by a summary discussion in Section 5.

2 Input–Output Framework

The IO framework is likely the most commonly used framework for economic impact assessments. Due to its ease of implementation and mathematical simplicity[1] it is usually the most cost–effective option for clients, especially those with time–sensitive requests.

The commodity by industry input–output framework described in Jackson (1998) is used as the basis for the methods introduced in this paper. This approach is proposed as an accounting framework that is clearly interpreted and provides results that are especially informative for national and regional–level policy purposes. The treatment of imports within this approach focuses the analysis on the impacts of final demand changes to the domestic economy.

Currently, the model specifications are open with respect to households although there are expected to be few, if any, differences in terms of methodology for a model that is closed with respect to households. Equations (1) to (3) describe the basic identities underlying this framework in an economy with n industries and k commodities[2]:

$$\mathbf{s} = \mathbf{U}\iota + \mathbf{m} + \mathbf{e} \tag{1}$$

[1] Oosterhaven (1988)

[2] Methods derived by the Bureau of Economic Analysis are used for the treatment of *Noncomparable Imports* , the production of *Scrap, Second-hand and Used Goods*, and also to define the total requirements matrices (see Horowitz & Planting (2006) for additional details on these methods).

$$\mathbf{g} = \mathbf{V}\iota + \mathbf{h} \tag{2}$$

$$\mathbf{h} = \hat{\mathbf{p}}\mathbf{g} \tag{3}$$

where $\mathbf{s}$ is a $k \times 1$ vector of total commodity supply, $\mathbf{U}$ is the $k \times n$ Use matrix where each column describes the corresponding industry's use of commodities in their production process, ι is a summation vector of appropriate dimension, $\mathbf{m}$ is a $k \times 1$ vector of commodity imports (positive values), $\mathbf{e}$ is a $k \times 1$ vector of total commodity final demand that includes household consumption, government expenditures, investment, and exports, $\mathbf{g}$ is an $n \times 1$ vector of total industry output, $\mathbf{V}$ is the $n \times k$ Supply matrix, where each row describes the amount of each commodity produced by a given industry, $\mathbf{h}$ is an $n \times 1$ vector of each industry's total production of scrap, and $\mathbf{p}$ is an $n \times 1$ vector that represents each industry's ratio of the value of scrap produced to total industry output. The $\hat{}$ symbol indicates the diagonalization of a vector. This methodology employs a full Use matrix that includes imported intermediate inputs and represents each industry's use of commodities, irrespective of the origin (domestically produced or foreign imports) of the commodity inputs.

Standardized tables are calculated as follows:

$$\mathbf{B} = \mathbf{U}\hat{\mathbf{g}}^{-1} \tag{4}$$

$$\mathbf{D} = \mathbf{V}\hat{\mathbf{s}}^{-1} \tag{5}$$

$$\mathbf{W} = (\mathbf{I} - \hat{\mathbf{p}})^{-1}\mathbf{D} \tag{6}$$

$\mathbf{B}$ is the $k \times n$ standardized Use table where each column details the value of commodity inputs per million dollar's worth of the respective industry's output. $\mathbf{D}$ is the $n \times k$ standardized Supply table, where each column details the proportion of the respective commodity's output produced by each industry and $\mathbf{W}$ is the $n \times k$ standardized Supply table that has been adjusted for scrap output.

The multiplication of the standardized full Use matrix and the Supply matrix that is standardized by total commodity supply essentially rids the full Use matrix of imported commodity inputs, resulting in a $k \times k$ matrix of direct requirements in commodity by commodity space, $\mathbf{BW}$, whose elements represent commodity inputs per millions dollar' s worth of commodity output. A similar direct requirements matrix in industry by industry space, defined as $\mathbf{WB}$, can also be calculated and represents industry inputs per millions dollar's worth of industry output.[3] It is now possible to define the total requirements matrix $(n \times k)$ in both industry by commodity or industry by industry space as follows:

$$\mathbf{L}_{I\times C} = \mathbf{W}(\mathbf{I} - \mathbf{BW})^{-1} \tag{7}$$

$$\mathbf{L}_{I\times I} = (\mathbf{I} - \mathbf{WB})^{-1} \tag{8}$$

[3] There has been a great deal of debate in the literature concerning choice of industry or commodity technology assumption (see inter alia, de Mesnard (2004)). We choose not to engage in that debate here. Due to its dominance in US application and due to the nature implications of the BEA secondary product reallocation procedures (Horowitz & Planting 2006), we adopt here and focus only on the industry-based technology assumption.

These total requirements matrices represent the domestic row industry input per million dollars of total column commodity final demand, $\mathbf{L}_{I\times C}$, and the domestic row industry input per million dollars of total column industry final demand, $\mathbf{L}_{I\times I}$, respectively.

The final equation that identifies the full accounting framework can be written in terms of either of these total requirements matrices:

$$\mathbf{g} = (\mathbf{L}_{I\times C})\mathbf{e} \tag{9}$$

$$\mathbf{g} = (\mathbf{L}_{I\times I})\mathbf{W}\mathbf{e} \tag{10}$$

3 Problem Description

Within the energy policy problem domain, programs centering on the deployment of altogether new or existing but little–used production technologies are increasingly common. Among others, candidate technologies might include bio–mass/biofuels, power generation with carbon capture and sequestration, coal liquefaction, and hydraulic fracturing for natural gas production. The deployment of these technologies often requires a multi–year construction period. For some cases, production at less than full capacity can begin while construction continues, while for others production must follow the completion of the facility. For some scenarios of interest at the national level, multiple facilities can be involved, with a deployment schedule that indicates varying numbers of facilities entering their construction phases in each of several years. Hence, construction of varying numbers of individual facilities will begin and end in each year of interest in an impacts time horizon and production capacity gradually increases as the new facilities come on–line. The scenario described in 3.1 is a simplified version intended to be generally illustrative rather than specifically representative of the kinds of issues that can arise and be resolved.

3.1 The Scenario

Eight new coal liquefaction plant facilities are to be constructed and deployed in the U.S. over the next twenty years. Construction will begin for two plants in 2013, three in 2014, two in 2015, and one in 2017. Each plant will cost $500M, and is designed to produce $100M in petroleum and $900M in diesel products per year, which will supplement the domestic supply of these products, potentially substituting this new domestic production for what otherwise would be imported commodities. The facilities require a five year construction period; no output is produced prior to the end of the construction phase but full capacity is immediately available once production commences.[4] Construction costs are distributed throughout the five years of construction according to a 10%, 15%, 30%, 25%, 20% schedule.

[4]Partial or limited operation prior to the completion of construction would result in a production level phase–in, which would require only a minor modification of approach.

3.2 Practical Issues

The general approach to setting up the impacts assessment recognizes two major analytical dimensions. First, the temporal profile of impacts will differ between construction and operation and maintenance (O&M) activities. The primary distinction between construction impacts and O&M is that while O&M impacts will continue for years into the future, construction impacts are temporary and nonrecurring. Although IO analysis carries no explicit temporal dimension, we make the assumption that construction impacts will play out during the year of the construction expenditure.[5] More elaborate assumptions concerning the temporal disposition of construction impacts could be devised by shifting portions of those expenditures forward to subsequent years, but for the purpose of this paper we follow the simpler assumption. O&M expenditure impacts also might play out in periods longer than a year, but over time, annual O&M expenditures will have corresponding annual impacts, so the assumption of impacts occurring during the year of O&M expenditures is less problematic.

The second dimension upon which our approach rests is structural change; as the size and structure of the economy changes, so will the estimated impacts of expenditure distributions. Analysts with sufficient information might be in a position to modify the production functions implicit in the IO structure, but even in the absence of detailed production function forecasts,

[5]See Romanoff & Levine (1986), Romanoff & Levine (1986), and Jackson (1989) for more on time in IO modeling

changes in the relative sizes of industries and final demand distributions still carry through to indirect and induced income impacts and hence, alter multiplier relationships. For these reasons, each year of the impact horizon will have its own corresponding IO table.

A final issue concerns the specification of an exogenous output scenario in the context of the standard endogenous determination of industry output levels in IO systems. Having modeled the new activity as a separate industry, there is a need for a formal mechanism that can be used to ensure that the output of the new industry will be equal to the value indicated in the impacts scenario. As we will discuss further in 4.5, these modifications result in a framework representing a demand–driven system in the face of supply changes rather than a supply–driven system.

Hence, our seemingly simple scenario poses a number of practical problems and issues, including:

1. Modeling multi-year construction schedules
2. Recalibrating Supply and Use tables
3. Modeling a new or expanding industry
4. Modeling import substitution
    (a) Modeling quantity impacts
    (b) Price considerations
5. Impacts Assessments and Output Consistency

These issues will be addressed in order in Section 4.

4 Problem Resolutions

4.1 Modeling multi–year construction schedules

The impact scenario in 3.1 indicates the construction of eight new production facilities, with construction projects initiated in each of four separate years. To clarify modeling terminology, we will refer to the allocation of expenditures to construction projects by their year of initiation, with the understanding that these construction cost allocations will be distributed across 5 subsequent years. In the simpler case, the construction cost commodity distributions are identical for each of the 5 years, while the more complex case involves construction cost distributions that vary with each construction year. In either case, total construction costs for any but the first year have the potential to be combinations of current and previous years' construction allocations. We can express the simpler situation formally as follows.

Let T be the number of years in the forecast horizon, K be the number of years required for the construction of a single production facility, and M be the number of commodities (including household labor) in the Supply and Use tables. Let $\lambda = \left\{ \begin{array}{cccccccc} 1 & 1.5 & 1 & 0 & .5 & 0 & \cdots & 0 \end{array} \right\}$ be a T-dimensional vector of construction project costs allocated in each year (in billions of dollars). Let σ be a K-dimensional vector of construction year cost proportions. Recall that for our impacts scenario, $\sigma = \left\{ \begin{array}{ccccc} .1 & .15 & .3 & .25 & .2 \end{array} \right\}$ and let

f be an M-dimensional vector of expenditure cost shares by commodity. Λ will be a matrix whose elements are populated by the elements of λ as shown below.

$$\Lambda = \begin{bmatrix} \lambda_1 & 0 & 0 & 0 & 0 \\ \lambda_2 & \lambda_1 & 0 & 0 & 0 \\ \lambda_3 & \lambda_2 & \lambda_1 & 0 & 0 \\ \lambda_4 & \lambda_3 & \lambda_2 & \lambda_1 & 0 \\ \lambda_5 & \lambda_4 & \lambda_3 & \lambda_2 & \lambda_1 \\ \lambda_6 & \lambda_5 & \lambda_4 & \lambda_3 & \lambda_2 \\ \lambda_7 & \lambda_6 & \lambda_5 & \lambda_4 & \lambda_3 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \lambda_T & \lambda_{T-1} & \lambda_{T-2} & \lambda_{T-3} & \lambda_{T-4} \end{bmatrix} \tag{11}$$

Then, denoting vector or matrix transposition by the $'$ symbol,

$$Z = f\sigma'\Lambda' \tag{12}$$

will be an $M \times T$ matrix whose columns are the cumulative construction cost distributions by commodity for each year of the impacts horizon. Note that if impacts of construction projects had been initiated in the last four years of the impacts horizon, their impacts would not be fully captured since they would be partially distributed to years beyond T.

To incorporate construction cost distributions that vary with each construction year, let f be redefined as an $M \times K$ matrix of commodity construction cost distributions by year. Thus,

$$F = f\hat{\sigma} \tag{13}$$

is now an $M \times K$ matrix of construction cost expenditure shares by row commodity and column year, the sum of whose elements equals unity. Let

$$\bar{F} = vec(F) \tag{14}$$

where the symbol *vec* denotes vectorization of matrix F. Then

$$\tilde{Z} = (\Lambda \otimes I)\,\bar{F}, \tag{15}$$

where the symbol $\otimes$ denotes Kronecker product and I is an M-order identity matrix. $\tilde{Z}$ is now an $(M \times T) \times 1$ column vector whose T M-dimensional partitions are the cumulative construction cost distributions by commodity for each year of the impacts horizon.

Two additional accounting steps are needed to complete the generation of direct construction cost impacts. The construction dollars directed to households represent household income, hence must be tracked and attributed to direct income impacts accordingly. Likewise, the labor purchased by those same construction–to–household dollars represents jobs that are direct construction impacts. If not directly available from the source of construction data, the employment number would either be derived from the total labor payment or per employee compensation estimates.

This set–up of final demand changes that result from modeling the multi–year construction schedules of multiple facilities along with the industry by commodity total requirements matrix, $L_{I \times C}$, is all you need if all you want are the overall impacts of construction. However, the structure of the economy is expected to be changing over this multi–year period as well. Reliable impacts assessments are dependent on accurately representing these structural changes. The next section discusses some options for recalibrating the Supply and Use tables that represent this economic structure.

4.2 Recalibrating Supply and Use tables

The ideal solution in this context would be to have a projection of Supply and Use tables through the years of the impacts horizon. Such forecasts, however, are rarely available. A variety of creative solutions might present themselves, but it is unlikely that any single solution will be universally available to all analysts. Because of the temporal variation in multiplier relationships, however, we hold that any well reasoned approach will lead to impacts assessments that are superior to methods that ignore these fundamental changes in IO structure. We offer here two possible rudimentary approaches for U.S. analysts. Researchers elsewhere will have greater insights into possibilities for their respective economies.

One solution alternative requires access to a series of annual econometric forecasts of output by industry. Several major commercial sources provide forecasts of output and the various components of final demand. Since we have accepted the assumption of fixed industry production functions, changes to the *standardized* Use matrix will be minimal – though we will identify a limited set of optional modifications in a later subsection.[6] Hence, the focus here is on the Supply matrix, for which two modifications are indicated. The first modification of the Supply table involves adjusting for changes in output levels. Percentage increases in output by industry are applied to each row in the Supply table, generating a time series of Supply tables.

The second and more challenging modification requires an estimate of commodity imports by year for each commodity in the accounting framework. This estimate is necessary to the computation of total supply ($\mathbf{s}$) for each time period. Ideally, the econometric forecast provides a forecast of commodity imports directly. If not, the following options, or some combination of the two might prove satisfactory. First, trends in commodity imports estimates might be established based upon historical series. Second, forecasts of industry output and aggregate final demands by type could be used in conjunction with benchmark commodity distributions by final demand activity to generate import estimates using supply–demand pooling methods (gross output less intermediate and final demand equals imports, or $\mathbf{X} - \mathbf{AX} - \mathbf{Y} = \mathbf{M}$, where $\mathbf{Y}$ includes export demand); see Jackson (1998) for more details on this method.

An alternative solution for recalibration takes advantage of the availability of the long range forecasts for Supply and Use tables generated by the U.S. Bureau of Labor Statistics (BLS). The BLS currently publishes Supply and Use forecasts for the year 2018. Tables for intervening years can be in-

[6]If an analyst did have superior data on the nature of production function change, such information would be straightforwardly embedded in the Use table.

terpolated. Depending on the length of the impacts time horizon, tables for years beyond 2018 could either be extrapolated (with due caution) or held constant at 2018 levels. As with any forecasts, margins of error are expected to increase with increasing time horizons.

4.3 Modeling a new or expanding industry

4.3.1 New industry

Most modern IO databases are founded on the Supply and Use, industry and commodity accounting framework. An activity modeled as a new industry will have its own row in the Supply table and its own new column in the Use table. The new Supply table row will list the values of commodities produced by the new industry. If our industry and commodity classification scheme has separate sectors for petroleum products and diesel products, we would add $100M and $900M per new production facility, in the respective commodity column cells of the industry row in the 6th year following construction initiation. For our example scenario, the values in Table 1 apply.

Table 1: Supply Row Changes, $M

	Increment		Cumulative Increment	
	Petroleum Products	Diesel Fuel	Petroleum Products	Diesel Fuel
2018	200	1800	200	1800
2019	300	2700	500	4500
2020	200	1800	700	6300
2021	0	0	700	6300
2022	100	900	800	7200
2023	0	0	800	7200
2024	0	0	800	7200
2025	0	0	800	7200

The production technology of the coal liquefaction industry is new to the U.S. economy, so a new Use table column is needed to represent the new industry. Adding a new Use table column requires an estimate of the production cost distribution on current account for the new industry, typically obtained from a reliable source of engineering–based data. A less accurate but potentially viable approach in the absence of engineering data is to use as much reliable information as is available to modify a Use column for a closely related existing industry. If there currently is no output production level, a placeholder industry still can be established using an arbitrary output quantity small enough to have no discernible effect on the system representation (e.g., $100). Corresponding placeholders would likewise be used in the Supply table, with 90% of the output value in the diesel column and the other 10% in petroleum products.

Because the commodities produced by the new production technology in our example scenario already exist, there is no need for new Supply columns or Use rows. The addition of the former – a Supply column – would be relatively straightforward, since it simply serves to list the output value for the new industry; i.e. if any other industry were already producing it, it would not be a new commodity so no new column would be required. However, adding a new Use row would require a comprehensive series of assumptions concerning how the new commodity would be used by industries as an intermediate input, by final demand activities including households, and how it will participate in trade. If the new commodity were expected to substitute perfectly for an existing commodity, the corresponding Use column could be edited accordingly to offset the increased use of the new commodity. More complicated scenarios can certainly be conceived, and direct editing of the respective Use columns would be a required aspect of the resolution, but this problem lies outside the scope of the current paper.

4.3.2 Expanding industry

There are two possibilities when the industrial activity slated for expansion is already present and a part of an existing industry in the economy. If it has production and output characteristics similar enough to its aggregate industry, output increments could simply be used to proportionally increase the aggregate industry's Supply table row and Use table column values each year as new production increases. Alternatively, were the targeted activity judged to be markedly different from its aggregate industry, it would be preferable to model it as an entirely new industry with its own production function and output distribution. Doing so would require expressing the cost distribution of the targeted activity in the dollar format comparable to the representation of the aggregate industry from the Use table. The targeted activity's column would be subtracted from the aggregate industry's column on an element–by–element basis, with the remainder forming a new aggregate industry that excludes the targeted activity. The new industry column representing only the target activity would then be added to the Use table. Likewise, subtracting the targeted activity's commodity production from its aggregate industry row and adding a row corresponding to the targeted industry's commodity output would appropriately edit the Supply table.

4.4 Modeling Import Substitution

In Subsection 3.2 we identified an issue concerning the size of the impact relative to the changing structure of the overall economy. Note that as the target industry develops and corresponding commodity production increases, total commodity supply, s, increases. This change alone would have a modifying effect on the industry by industry requirements table, $\mathbf{WB}$, since elements in the commodity columns of the respective commodities are changing. Because of the temporal variation in Supply and Use tables, multiplier relationships also vary temporally. Further, and potentially more importantly, changes in commodity output and final demand levels over time also will change the commodity imports levels, which will then carry through to changes in any commodity columns of W for which the domestic supply percentages change.

Many applications also focus on the effects of increases in production as they relate to import substitution. Unlike conventional final demand driven IO impacts analyses, modeling import substitution must also reflect the structural economic changes that result from the substitution of domestic production for imports. In our example scenario, the domestic production of petroleum products and diesel fuels can substitute for imports. For simplicity, however, the remainder of this section will address the generic case of import substitution by the increase of production of the j^{th} commodity.

4.4.1 Modeling quantity impacts

Increasing domestic production can be assumed either to a) augment total production without any impact on imports, or b) offset imports. The former assumption implies an increase in total supply equal to the increase in new domestic production. In this case, the respective values in the Rest–of–World (Imports) Supply table row will retain the forecast values they held prior to the introduction of the new activity. Were there no other structural changes to intermediate or domestic final demand, this assumption would imply an increase in exports equal to the increase in production. While perhaps at first counterintuitive, countries and regions often both import and export the same commodities. Given the latter assumption, if domestic production completely offsets imports then the Rest–of–World Supply table row will list the forecast values prior to the introduction of the new activity less the value of new production. Because these will be mechanical changes to the augmented Supply table, intermediate solutions that lie between zero and full import substitution could just as easily be applied should the analyst be so motivated.

Up to this point, these modifications to the Supply table imply that import prices and the price of the domestically produced commodity are equal. This enables, for example, an increase in dollar value in the domestic sector row to be offset by an identical value in the Imports Supply table row. This implies that the domestic and import price of commodity j are equal, the quantity production increase is offset by the quantity import decrease, and the domestic cost share increases by the same amount that the imports cost share decreases. This situation, of course, would likely be the exception rather than the rule. Below, we provide a method for dealing with price differences between imports and domestic production that is consistent with the IO framework.

4.4.2 Price considerations

In the absence of behavioral functions governing input substitution behaviors, the incorporation of price change effects within IO frameworks are limited largely to mechanical adjustments, and even these simple adjustments will require some assumptions concerning behavior (Bazzazan & Batey (2003) offer a comprehensive treatment of IO price models). By convention, prices in the IO framework are fixed, but they nonetheless are implicit in the formulation of the model in financial units. The value of a cell in a Use or Supply table is the product of a (fixed) price and a physical quantity, as is the value of a cell in an interindustry transactions table. There are two prices involved in a direct requirements coefficient. Cell a_{ij} of an interindustry coefficients table, $\mathbf{A} = \mathbf{WB}$, for example, is shown in its component parts in equation 16.

$$a_{ij} = \frac{p_i q_i}{p_j q_j} \tag{16}$$

Now, allowing for import and domestic price differences and assuming that import and domestic quantities substituted are equal, the value added to the appropriate Supply table cell will be different than that subtracted from the Supply table Imports cell. Except in the case of non–economic incentives (e.g., national security motivations or trade barriers), the latter would be expected to be smaller than the former. Because the mix of imported and domestic supply has shifted, and given the differences in imported and domestic commodity j unit prices, the composite price of commodity j used in the economy will also have changed. The increase to the Supply table domestic production and Imports rows will reflect the new composite prices if they are valued appropriately in domestic and import prices.

The new composite commodity j price can be incorporated in the Use accounts by multiplying each element in the j^{th} commodity row by the ratio of new to old composite price, γ. Thus, limiting the following to commodity j, let p_i and p_d be the import and domestic prices, q_i and q_d be the initial quantities imported and produced domestically, and Δq_i and Δq_d be the changes in imports and domestic production, respectively. Then,

$$p^{old} = \left[\frac{p_i q_i + p_d q_d}{(q_i + q_d)}\right] \tag{17}$$

$$p^{new} = \left[\frac{p_i(q_i + \Delta q_i) + p_d(q_d + \Delta q_d)}{(q_i + q_d)}\right] \tag{18}$$

So,

$$\gamma = \frac{p^{new}}{p^{old}} \tag{19}$$

$$= \frac{p_i q_i + p_d q_d + p_i \Delta q_i + p_d \Delta q_d}{p_i q_i + p_d q_d} \tag{20}$$

$$= 1 + \frac{p_i \Delta q_i + p_d \Delta q_d}{p_i q_i + p_d q_d} \tag{21}$$

$$\tag{22}$$

And in the case where $\Delta q_i = \Delta q_d = \Delta q$,

$$\gamma = 1 + \frac{(p_i + p_d)\,\Delta q}{p_i q_i + p_d q_d} \tag{23}$$

The scalar γ multiplies the j^{th} Use row, but since the j^{th} industry's column continues to be valued in domestic prices, it remains unadjusted. However, note that without further adjustment, Use column sums will now differ by the change in price paid for commodity j. If the price changes are assumed simply to be incorporated in the value of output, the standardized Use table, $\mathbf{B}$, will now have been standardized by a new industry output vector, $\mathbf{g}$. To maintain consistency with the Supply accounts, however, this new industry output value would need to be used to adjust the Supply table.

The simplest adjustment would be the multiplication of each row element by the ratio of new–to–old output values. Alternate scenarios could be developed and applied, each with its own implied behavioral changes. The solution above implies that price change effects are absorbed by intermediate and final consumers. At another extreme, price change effects could be absorbed by adjustments to gross operating surplus (GOS), in which case industry output values would have remained unaffected, implying no necessary

Supply table changes; only the GOS and commodity j Supply rows would change. As was the case with intermediate solutions for import substitution, assumptions indicating sharing of impacts by GOS and consumers in indicated proportions are also feasible. Indeed, any exogenously determined substitution relationship can be incorporated as desired.

4.5 Impacts Assessments and Output Consistency

The result of these modifications is a new structural representation of the economy. Generating the impacts of the structural change is accomplished by driving the new and the old structures by identical commodity final demands and comparing the output, employment, income, and other annual estimates. Because the Supply table is standardized by totals that include Rest–of–World commodity supply, the commodity final demands are not adjusted for imports. We address commodity final demands only since, "[i]n commodity–industry models, one of the basic premises is that commodities are the products of industries, and therefore it is commodities that are used to satisfy final demand. Hence, the notion of "industry final demand," ... is not very meaningful in commodity–industry models." Miller & Blair (2009, 197).

The introduction of a new industry and technology (or potentially, industries and technologies in more complex scenarios) will be responsible for two kinds of impacts. First, because of the new industry's positive contributions to the Supply table, the proportions of imports for the respective commodities will be reduced in the new structural representation, which accounts for the import substitution effects. Second, there will be impacts that are attributable to the production of the commodities by different production methods, hence different intermediate input structures and labor costs. This second impact type is not expected to generate dramatic differences in system outputs, but is nevertheless an explicit dimension of the estimated impacts.

There is, however, one remaining issue that can result in a potentially undesirable and possibly inconsistent result. Because IO models generate endogenous estimates of output required to meet specified final demands, the output levels of the new industry can diverge somewhat from those specified in the initial impacts scenario. If production levels are fixed and known *ex ante*, it will be necessary to provide a mechanism that converts the endogenously determined industry output level to the scenario value. The introduction of capacity constraints in one or more industries of an IO system introduces non–linearities that make closed–form solutions elusive Lahiri (1983). Hence, we outline an alternative that will generate a first approximation solution: for each solution year, change the new industry output level to its scenario value, convert the industry output difference to commodity output differences for the new industry, and change the output of industries whose primary outputs correspond to the relevant commodities by the adjusted amounts. In our example, were the coal liquefaction output values endogenously overestimated by \$10K, coal liquefaction output would be reduced to the scenario value, while the Petroleum Products and Diesel Fuel industries' outputs would be increased by \$1K and \$9K, respectively. These new output values would then be used to recompute the employment, income, and any other impacts estimates (e.g., Value Added) in the industries involved in the adjustments. Although this solution is less than optimal, our experience with this approach suggests that the quantities involved in the reallocations are quite small relative to the total output levels of the respective industries, hence are unlikely to introduce substantial errors. Jackson et al. (2008). Once again, we note that this approach represents a demand–driven IO framework in the face of supply changes rather than a supply–driven IO framework.

5 Summary

This paper has identified multiple ways in which detrimental effects of violating the assumptions of impacts assessments in the IO framework can be ameliorated. The remediation methods we have presented address situations that are commonly encountered, specifically focusing on shocks that are distributed over extended time periods and those that involve the introduction of new technologies. The approaches identified also address situations whose consequences have the potential to alter very substantially the estimates of economic impacts. Although IO analysts have likely applied at least some aspects of the methods presented here, we believe this paper is the first to formalize the analytical modifications indicated.

We used an example impacts scenario to structure the presentation. We provided a formal discussion of steps to follow in incorporating new or expanding technologies and production functions within the Supply and Use accounting framework, addressing both increases in commodity output over time from the new technology and the structural changes in the distribution of supply and demand across all industries and activities in the economy. We also recognized explicitly the need to treat construction impacts differently from operation and maintenance impacts. We provided a formal mechanism for dealing with multi–year construction schedules, including those for which construction expenditures vary both across years and within each construction year, and we noted the need for separate accounting of the direct employment and income impacts of construction projects modeled as increments to final demands. Indeed, this additional direct impacts accounting procedure potentially applies to any activity modeled using an approach that translates an activity's total expenditure into final demand components, and this aspect of impacts assessments can easily be overlooked.

We also identified implications of and options for representing the import substitution impacts of new or expanding technologies and the accompanying effects on commodity supply. The shifting composition and system effects of domestic production and import supply are implicitly captured by the way in which the Supply table, augmented by a Rest–of–World imports row, is modified. New domestic commodity production can be assumed to partially or even fully substitute for imports and can be correspondingly represented in the Supply table. Finally, we presented formal expressions for dealing with relative price differentials between imports and domestic production.

The remediation mechanisms we provided here are largely mechanical. It is important to recognize and state explicitly, however, that few methods for modifying the modeling framework are as simple or straightforward as they might at first appear. In nearly all cases, because the transactions represented in the Supply and Use framework are a part of a consistently defined system, changes in one value will require other changes to retain the consistency of the system representation. These "downstream" changes can in a very few cases simply involve restoring a balance relationship, but in most cases they involve making additional assumptions concerning the behavior of industries, households, or final demand activities.

The most obvious example in this paper of the need for new behavioral assumptions is the decision concerning resolving the input and output balances caused by composite input price changes. Some kind of behavioral response – over and above simple mechanics – must be assumed to properly restore the integrity of the system representation. The choice of behavioral responses to be incorporated in the model adaptations will reflect the resources, understanding, and abilities of the analyst and emphasizes that impacts estimation is as much an art as it is a science.

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