ECONOMIC RESEARCH METHODS

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METHODOLOGICAL ANNEX

Leontief model

Traditional Leontief (Leontief 1966) single-region IO model, a Nobel prize (1973) worth advance in understanding economic impact in a system consisting of multiple interlinked industries, can be described by:

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-\mathbf{1}}\mathbf{f}, \qquad [\ 1\ ]$$

where $\mathbf{x}$ is the total industry output (production) vector, $\mathbf{A}$ is the matrix of technical coefficients, and $\mathbf{f}$ is the vector of total industry final demands. $(\mathbf{I} - \mathbf{A})^{-1}$ is collectively known as Leontief inverse or total requirements matrix. This model requires data input in the form of $n \times n$ transaction matrix $\mathbf{Z} = |z_{ij}|$, as $\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$. Here, z_{ij} represent sector j's demand for input from sector i. For each industry, the sum of its intermediate inputs ($\mathbf{Z}$ column) and value added components should equal the sum of intermediate outputs ($\mathbf{Z}$ row) and final demand components.

In order to account for the fact that an industry may produce more than one commodity (i.e., secondary products), many modern databases typically adopt a commodity-by-industry approach. In this case, $\mathbf{Z}$ is replaced by *Use matrix*, $\mathbf{U} = |u_{ij}|$, where u_{ij} is the value of the purchase of commodity i by industry j, that is presented in conjunction with the transpose of supply matrix, *Make matrix*, $\mathbf{V} = |v_{ij}|$, where v_{ij} is the value of the output of commodity j that is produced by industry j. These two matrices allow to build an analogous industry-based technology single region IO model:

$$\mathbf{q} = (\mathbf{I} - \mathbf{BD})^{-\mathbf{1}}\mathbf{e}. \qquad [\ 2\ ]$$

Here, $\mathbf{q}$ is the vector of total commodity output, $\mathbf{e}$ is the vector of total commodity demand, and $\mathbf{BD}$ is equivalent to $\mathbf{A}$ in the original Leontief model, with $\mathbf{B}$ defined as $\mathbf{B} = \mathbf{U}\hat{\mathbf{x}}^{-1}$, where column j represents the value of inputs of each commodity per dollar's worth of industry j's output, and $\mathbf{D}$ defined as $\mathbf{D} = \mathbf{V}\hat{\mathbf{q}}^{-1}$, where each element d_{ij} in $\mathbf{D}$ denote the fraction of total commodity j output produced by industry i. Derived from *Make* and *Use matrices* $(\mathbf{I} - \mathbf{BD})^{-1}$ is the commodity-by-commodity total requirements matrix. The total requirement matrix can be used to assess the effects of exogenous changes to the final demand for each commodity specified by the model.

Alternatively, one may want to build a commodity-based single-region IO model (Miller and Blair 2009). Research on which method is more economically-sound remains ongoing. Choosing the industry-based model is dictated by proven consistency with Leontief demand-driven model (Jackson and Schwarm 2007; De Mesnard 2004).

Closing the model with respect to households

The $(\mathbf{I}-\mathbf{BD})^{-1}\mathbf{e}$ model depends on the existence of exogenous sectors that are disconnected from the technologically interrelated productive structure and generate final demands for outputs. This includes purchases by households, sales to government, gross private domestic investment, or export. However, a common extension to the IO model is to consider households as an endogenous sector that earns income in return for their labor inputs to production processes and spends that income in a structured fashion (Picek and Schröder 2018). This implies moving the household sector from the final demand column ($\mathbf{f}$ or $\mathbf{e}$) and labor input row and place it inside the matrix $\mathbf{U}$. Sum of labor output is also added to the matrix $\mathbf{V}$. Such a model is commonly referred to as a model closed with respect to households. Closing the model with respect to households is a necessary step for deriving induced EIs.

Linking multiple regions

Policies or any other exogenous changes may have an economic impact not only on the region where they are observed but also on the regions with strong economic ties with the region subjected to the change. A multiregional IO model accounts for that.

Linking multiple spatial components is done by the mean of trade coefficients matrix $\mathbf{C}$. In the multiregional version of the model, the vector of gross outputs by sector and region is given by:

$$\mathbf{q}=(\mathbf{I}-\mathbf{CBD})^{-\mathbf{1}}\mathbf{Ce}. \qquad [3]$$

Here, the matrix of technical coefficients ($\mathbf{BD}$) is combining technical coefficients for each region considered in the model. In a two-region (r,s) example, this matrix takes the form:

$$\mathbf{BD}=\begin{bmatrix}\mathbf{BD}^r & 0\\ 0 & \mathbf{BD}^s\end{bmatrix}, \qquad [4]$$

where $\mathbf{BD}^r$ is the matrix of technical coefficients for region r and $\mathbf{BD}^s$ is the matrix of technical coefficients for region s. The two-region $\mathbf{C}$ matrix takes then the form:

$$\mathbf{C}=\begin{bmatrix}\hat{\mathbf{c}}^{rr} & \hat{\mathbf{c}}^{rs}\\ \hat{\mathbf{c}}^{sr} & \hat{\mathbf{c}}^{ss}\end{bmatrix}, \qquad [5]$$

where $\hat{\mathbf{c}}^{rr}$ and $\hat{\mathbf{c}}^{ss}$ are intraregional trade coefficients matrices of region r and s, and $\hat{\mathbf{c}}^{rs}$ and $\hat{\mathbf{c}}^{sr}$ are interregional trade coefficients matrices derived from transaction matrices. $\hat{\mathbf{c}}^{rs}$ ($\hat{\mathbf{c}}^{rs}$) describe the flow of commodities from region r (s) to region s (r), or how much of good or services used in s (r) comes from region r (s). The trade coefficients indicate the shares of domestic vs. imported input to the domestic production process. This widely used specification (e.g., Bachmann, Roorda, and Kennedy 2015) implies the same pattern of inputs use between domestically produced and imported commodities. This simplification implies that the possibility of different use patterns for domestic vs. imported commodities is not considered.

Multipliers

Output multiplier for sector j is defined as the total value of production in all sectors of the economy necessary to satisfy a dollar's worth of final demand for sector j's output (Miller and Blair 2009, pp. 245). Simple multipliers are obtained from the model with exogenous households by summing the columns of the $(\mathbf{I}-\mathbf{CBD})^{-1}$ matrix. Formally, defining elements of this matrix as l_{ij}, the output multiplier is given by:

$$m(o)_j = \sum_{i=1}^{n} l_{ij}. \qquad [\ 6\ ]$$

This sum reflects direct and indirect effects. Direct effects for sector j are captured by l_{jj}. Matrix closed with respect to households also captures the induced effects.

The same matrices can be used to explore the impact of changes in final demand on jobs created or wages earned. Labor input coefficients (γ_i) - either monetary, in the form of wages per unit of output or physical, in the form of, for example, number of jobs per unit of output - are multiplied by l_{ij} coefficients that relate final demand in sector j to output in sector i:

$$m(l)_j = \sum_{i=1}^{n} \gamma_i l_{ij}. \qquad [\ 7\ ]$$

Employment can be specified on the basis of full-time and part-time jobs, or full-time equivalents. There is significant part-time and seasonal employment in commercial and recreational fishing and many other industries. Employment is an important metric when considering community impacts. The impact on value added that reflects changes in sectors' contribution to the GDP is calculated the same way. The same approach can also be applied to various other variables, for example CO_2 emissions.

It is also worth noting that multipliers based on single-region models may overstate the effects when the industry is operating at or near its capacity, and some of the additional inputs may need to be imported or shifted from exports. This, however, is addressed by using multiregional analysis, where such effects are accounted for (Miller and Blair 2009, pp. 246).

Worth noting is also that standard economic multipliers do not capture intangible benefits of the fish as a resource, for example, ecosystem services or cultural value. However, the non-market values can be consistently incorporated into the IO model (Carbone and Smith 2013). Such an avenue can be explored, but it is not considered at this stage.

Supply-driven approach

The standard input-output approach uses output multipliers to describe the economy-wide backward linked output effects associated with exogenously specified changes in final demand for commodities ($\mathbf{e}$). Demand-side shocks include changes in consumer demand, investment patterns, exports, government spending, or exogenous changes to taxes that affect demand. However, in the case of fisheries that are rather fixed on the supply side as it is the output that is usually targeted by fisheries policies, a supply-driven approach is more appropriate for assessing the economic impact (Leung and Pooley 2002; Steinback and Thunberg 2006; Seung and Miller 2018).

The modified IO approach based on the method developed by Tanjuakio, Hastings, and Tytus (1996) is used to demonstrate the magnitude of changes in supply-constrained industries. Accordingly, the impact assessment is conducted using a modified total requirements matrix. The process of "*extracting*" the sector is done by setting regional purchase coefficients (RCPs, elements of $\mathbf{CBD}$, denoted here by α_{ij}) for exogenized sectors to zero, which implies the elimination of these sectors as suppliers of inter-industrial inputs. Then, the changes in output are modeled as if they originated from the final demand.

Forward linkages

In the input-output framework, changes to the production by a particular sector have two kinds of effects on other industries. Backward linkages refer to the changes to the goods and services that serve as inputs to the affected sector, defining relations with so-called *upstream* sectors. For the fisheries sector, these include, for example, impacts on the vessel building sector or supply stores equipping vessels for their fishing trips. These effects are captured by the equation [3].

Changes in the domestic fisheries output, unless fully substituted by imports, must be associated with production adjustments by industries relying on the supply of fish, such as seafood processors. Forward linkages describe the effects on the industries for which the affected sector is a supplier, defining its relations with the *downstream* industries. While these forward linkages are not typically included in the calculation of economic impacts, mainly because early attempts (e.g., Cai et al. 2005) using Ghosh approach have been criticized for the lack of economic foundation (Oosterhaven 1988, 1989), application of the method described in Seung (2014, 2017) allows for such extension. The proposed method implies exogenous specification of changes in the forward linked industries (here, seafood processors) and setting regional purchase coefficients associated with these industries to zero, the same way as done for the directly impacted industry (as described in section Supply-driven approach). This way, the model does not calculate the effects on downstream industries endogenously because fish processing industries are restricted in terms of the amount of raw fish input. The advantage of this method is that the calculated effects are additive so that the total effects can be consistently derived as a sum of backward and forward linkages.

Social accounting matrix

Even when considering the model closed with respect to households, the input-output framework provides little insight into the demographics of the workforce that builds the market for supply and demand of labor. This can be accomplished by means of a so-called social accounting matrix (SAM). Adopting SAM, the calculated effects account for commuting patterns where the labor's place of employment and place of residence differ. It is of particular use when focusing on industries that employ a considerable share of non-residents for temporary assignments that imply a negative net flow of income to the region and, consequently, impacts on households are not necessarily equal to impacts on earnings in the region. The SAM approach can be also used to trace the flow of profits related to non-resident investment in production factors. This can accommodate the returns to quotas and permits that should be allocated according to the residency of their beneficial owners rather than their users.

The SAM-based model with endogenous households also allows for detailed accounting of household earnings by place of residence, including earnings from other sources (e.g., government transfers, dividends, interest, and rent), outflows to the government (e.g., personal income taxes), and households net savings by region.

The SAM model can be expressed as follows:

$$\mathbf{x}^{\mathrm{SAM}} = (\mathbf{I} - \mathbf{S})^{-1}\mathbf{f}^{\mathrm{SAM}}, \qquad [\,8\,]$$

where $\mathbf{x}^{\mathbf{SAM}}$ is a total production vector, $\mathbf{f}^{\mathbf{SAM}}$ is a vector of SAM exogenous accounts, $\mathbf{S}$ is a matrix of direct SAM coefficients ($\mathbf{S} = (\mathbf{SAM})\widehat{\mathbf{x}^{\mathrm{SAM}}}^{-1}$) and $(\mathbf{I} - \mathbf{S})^{-1}$ is SAM total requirements matrix.

The PHMEIA model components largely align with these considered in Seung (2014). The SAM-derived total requirement matrix capture induced effects that account for commuting patterns and flow of investment earnings. The SAM framework also allows for endogenizing additional sectors, for example, government expenditures or savings and investment. This extension of the modeling framework is not considered at this stage.

Disaggregation

Accurate economic impact assessment of a specific sector that has not been distinguished in the original IO or SAM matrix (or supply and use tables that can be used to build IO or SAM matrix) requires disaggregation of the IO or SAM data using external information. Although these external data may be fragmentary, research finds that disaggregation of IO data, even if based on a few real data points, is superior to using aggregates in determining IO or SAM multipliers (Lenzen 2011; Su et al. 2010). Severe aggregation bias occurs, especially if sectors within an aggregate are heterogeneous with regards to their economic and environmental characteristics (Lenzen 2011).

Thus, as opposed to analyzing the Pacific halibut sector as a component of a larger fishing sector, the PHMEIA model disaggregates Pacific halibut sectors. In the preliminary version of the model, the disaggregation is based on the available secondary data. The final model will be based on the collected primary data (see IPHC economic survey section for details).

Updating

Fully balanced national SUTs, if available, are published with a considerable time lag, often counted in years. Detailed, regional tables are often a product of a specific project and available only for a particular year, and rarely set for routine updating. This is because such products are data-intensive, requiring information on the whole range of industries that comprise the economy of the given country. Compiling data from all sectors and ensuring its consistency across takes time. As a result, timely policy advice based on such tables is rare. Instead, inputs to policy-making decisions tend to be based on tables updated with limited data using a hybrid approach in which superior information (e.g., focused survey, expert opinion) is incorporated into otherwise mechanically updated tables.

The most common updating technique is the so-called RAS method (Lahr and de Mesnard 2004). It is a biproportional technique used to estimate a new matrix from an existing one by scaling row and column entries to exogenously given totals. The major shortcoming of this method is that it can only handle non-negative matrices. In the PHMEIA model, certain areas of the partitioned matrix may include negative numbers, e.g., columns containing values describing changes in inventories or rows with net taxes, which may be negative if value of received subsidies outweighs the value of tax paid by the given industry. The method also cannot benefit from data available at a higher aggregation level than the original model.

A multiregional generalized RAS (MR-GRAS) method (Temursho, Oosterhaven, and Cardenete 2020) is an extension of the RAS method that allows updating of a partitioned matrix such as SUTs or SAM with non-exhaustive row and column totals and non-exhaustive non-overlapping aggregation constraints. The updated tables can incorporate partial information on its components while continuing to conform to the predefined balanced structure. As a result, this technique can make the multiregional model consistent with aggregated national data, for example, data from the National Economic Accounts (NEA), and include up-to-date estimates from a limited number of sectors derived from, for example, focused survey. NEA data provide a comprehensive view of national production, consumption, investment, exports and imports, and income and saving. These statistics are best known by summary measures such GDP, corporate profits, personal income and spending, and personal saving.

Incorporation of existing pieces of information, even if these are given at a more aggregate level or limited to certain components, often improves the final estimates (Temursho et al. 2020).

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