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Method for efficient updating of regional supply and use tables

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Abstract

Supply and use tables (SUTs) lay out a detailed picture of the entire economy, providing an overview of the production process and use of commodities. The governmental agencies produce these mainly at the national level to derive components related to the calculation of the gross domestic product (GDP). The national SUTs, however, do not capture the heterogeneity of regions within a single country. The regional SUTs, on the other hand, are difficult and costly to compile.

In the absence of regularly compiled regional SUTs, analysts typically resort to models based on mechanically updated tables with less extensive data requirements. However, the methods currently available in the literature that make the best use of available data do not guarantee a balanced structure of the output. Building on the latest advancements in adopting multiregional generalized RAS, this paper proposes a modification to the structure of the base matrix that guarantees the supply-use accounting balance as well as the identity of GDP by income and GDP by expenditure at the regional level in the output matrix. As a result, the procedure allows for efficient production of regional SUTs appropriate for calculating multiplier effects.

Keywords: multiregional generalized RAS; regional supply and use tables; supply-use balance

Introduction

Supply and use tables (SUTs) lay out a detailed picture of the entire economy, providing an overview of the production process and use of commodities. SUTs are also a building block of models intended for detailed economic impact assessment, extensively applied in many fields, including assessment of the impact of the natural resource use. The governmental agencies produce these mainly at the national level to derive components related to the calculation of the gross domestic product (GDP).

The national SUTs, however, do not capture the heterogeneity of regions within a single country. This deficiency is problematic as the differences between regions and subnational interdependencies can be substantial. It follows from industries' diversification in terms of the production structure that may be related to the location, availability of resources or ability to attract talent. A policy that is targeting a specific sector when the reliance on that sector varies between regions will produce unevenly distributed economic effects.

While it is clear that regional SUTs have a great potential for policymakers who may be interested in the localized effects of their decisions, these are rarely available. Detailed regional tables are often a product of a specific project with a limited sectoral focus, available for a narrow time frame, 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 region's economy. Compiling data from all sectors and ensuring its consistency across takes resources and time. Values are not always available; often, this is because there is a mismatch in the categorization of commodities or industries, and numbers are available only for an aggregate (see, for examples, Jacobsen 2000, Hasegawa et al. 2015 or Rueda-Cantuche et al. 2020a). As a result, timely policy advice based on regional SUTs 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 multiregional generalized RAS (MR-GRAS) technique described in Temursho et al. (2020) offers the most advanced approach to updating a partitioned matrix that needs to conform to new row sums, column sums and, additionally, non-overlapping aggregation constraints. While using row and column constraints is at the core of more traditional updating methods (e.g., RAS method, see Miller and Blair (2009, pp. 313) for details), adding aggregation constraints provides an opportunity to maximize the utilization of available data by making use of the national-level statistics.

Temursho et al.'s (2020) application of the MR-GRAS technique to SUTs, however, does not guarantee a balanced structure of the updated tables. This paper proposes a simple modification to the structure of the base matrix that guarantees the supply-use accounting balance as well as the identity of GDP by income and GDP by expenditure at the regional level in the output matrix. As a result, the procedure allows efficient production of tables appropriate for calculating multiplier effects and estimating regional economic impacts.

This paper's contribution also lies in the empirical application, presenting an elaborate example of using the MR-GRAS method. The economic effects of changes to fish harvest levels can be far-reaching. Fisheries management policies that alter catch limits have a direct impact on commercial harvesters, but at the same time, there is a ripple effect through the economy. Fisheries operations create demand for inputs from other sectors. This demand can be met locally or cause spillover effects into other regions. Understanding the multiregional impacts of changes to fisheries sectors is now more important than ever, considering how globalized it is becoming (OECD 2010). Fish found on the shelf of a local store or on the restaurant menu could easily be harvested on the other side of the globe, or at least in another part of the country. On the production side, the origin of inputs is increasingly distant, implying a gradual shift of economic activity supported by fisheries further away from the fishing grounds. This paper demonstrates how to approach the challenge of assessing the natural resource broader economic impact using the Pacific halibut commercial fishery in Alaska[1] as a case study. The step-by-step instructions on how to apply the approach should be of interest to any researcher working on regional economic analysis, regardless of the focus sector.

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[1] Pacific halibut is also harvested in Washington, Oregon and California, albeit in a relatively small amount. This harvest is combined with other species for US West Coast region. The same principal applies to updated SUTs.

Materials and methods

The most commonly adopted technique for updating the SUTs is the so-called RAS method (Lahr and de Mesnard 2004; Miller and Blair 2009, pp. 313). 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 context of SUTs, certain areas of the partitioned matrix may include negative numbers, for example, columns containing values describing changes in inventories or rows with net taxes, which may be negative if the value of received subsidies outweighs the value of the tax paid by the given industry. Moreover, it requires a full set of row and column constraints, something not always available to the analyst.

The generalized RAS (GRAS) method (Günlük-Şenesen and Bates 1988; Junius and Oosterhaven 2003) solves the problem with negative numbers. It generalizes the standard RAS method using reciprocals of the exponential transformations of the related Lagrange multipliers. The SUT-RAS approach, another RAS extension proposed by Temurshoev and Timmer (2011), applies the GRAS technique for joint projections SUTs that are guaranteed to be consistent by construction. This method also does not require the availability of total outputs by product for the projection year, a condition often not met in practice. Neither of these methods, however, benefit from data available at a higher aggregation level than the original model, an important shortcoming when attempting to derive regional SUTs with the use of national data.

Incorporating existing pieces of information, even if these are given at a more aggregate level or limited to certain components, improves the final estimates. The MR-GRAS method (Oosterhaven et al. 1986; Gilchrist and St. Louis 1999; Gilchrist and St. Louis 2004; Lenzen et al. 2009) is an extension of the RAS method that allows updating of a partitioned matrix such as SUTs 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 available aggregated data. As a result, this technique can make the multiregional model consistent with aggregated national data[2] and include up-to-date estimates from a limited number of sectors derived from, for example, a focused survey or statistics published by a governmental agency responsible for a specific sector.

Taking the MR-GRAS technique one step further, Temursho et al.'s (2020) approach also allows for adjusting SUTs' positive and negative entries simultaneously. The authors stress that such extension is particularly handy as "there are (far) more possibilities of having negative elements within a multiregional IOT/SUT/SAM setting compared to a national one, due to a higher economic heterogeneity of regions

[2] For example, data from the National Economic Accounts (NEA). 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. The need for consistently matching SUTs with official national statistics is highlighted in Rueda-Cantuche et al. 2020b.

or countries making up the considered economic system." Thus, the technique maximizes the potential for the use of data that may be supplied at various sectoral and regional aggregation levels.

The MR-GRAS approach is based on tri-proportional scaling. The algorithm is set to minimize the weighted logarithm of the relative distance between the entries of the new and the old SUTs, subject to row, column and aggregation constraints. To find the solution that accounts for negative entries, the original matrix serving as an initial input to the scaling procedure is decomposed to a matrix containing positive elements and a matrix containing the negative entries' absolute values. What follows is the adjustment procedure consisting of a sequence of computations deriving adjustment multipliers that is set to stop when the multipliers converge to a solution conforming to a preset sufficiently low tolerance level. The last iteration multipliers are used to derive the output SUTs.

Adopting the extended MR-GRAS technique, as described in Temursho et al. (2020), however, does not guarantee the balanced structure of the updated tables. To address this shortcoming, this paper proposes a simple modification to the structure of the base matrix that imposes the identity of GDP by income and GDP by expenditure at the regional level in the output matrix. As a result, the updated matrix efficiently accommodates regional data on GDP components that are often produced by statistical agencies even when there is no attempt to derive the full set of regional SUTs.

MR-GRAS for updating multiregional SUTs

Temursho et al. (2020) describe adopting the MR-GRAS technique to multiregional SUTs that is well suited to situations when the supply (at least partially) is known at the regional level. However, it is more likely that more detailed regional statistics are available for components related to the calculation of the GDP, that is final demand and value added, as well as trade. Thus, the paper proposes a modification of the MR-GRAS setting for R regions that makes the use of these statistics while at the same time guarantees balanced structure. It is written as follows:

$$X^0 = \left[\begin{array}{cccc|cccc|cccc}
-S_1 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 & S_1^d & 0 & \cdots & 0 \\
0 & -S_2 & \cdots & 0 & 0 & 0 & \cdots & 0 & 0 & S_2^d & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\
0 & 0 & \cdots & -S_R & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & S_R^d \\
\hline
U_{11} & U_{12} & \cdots & U_{1R} & FD_{11} & FD_{12} & \cdots & FD_{1R} & -S_1^d & 0 & \cdots & 0 \\
U_{21} & U_{22} & \cdots & U_{2R} & FD_{21} & FD_{22} & \cdots & FD_{2R} & 0 & -S_2^d & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\
U_{R1} & U_{R2} & \cdots & U_{RR} & FD_{R1} & FD_{R2} & \cdots & FD_{RR} & 0 & 0 & \cdots & -S_R^d \\
\hline
U_1^M & 0 & \cdots & 0 & FD_1^M & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\
0 & U_2^M & \cdots & 0 & 0 & FD_2^M & \cdots & 0 & 0 & 0 & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\
0 & 0 & \cdots & U_R^M & 0 & 0 & \cdots & FD_R^M & 0 & 0 & \cdots & 0 \\
\hline
VA_1 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\
0 & VA_2 & \cdots & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\
0 & 0 & \cdots & VA_R & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0
\end{array}\right] \tag{1}$$

Here, S_r (r={1, ..., R}) is the supply matrix of dimension commodity (C) by industry (I), where the subscript indicates the region within the analyzed country. This matrix is a transpose of the make matrix that is often denoted by V. The supply matrices are introduced here with negative signs so that the columns containing these will sum to zero. $U_{r,s}$ (r, s={1, ..., R}) is the domestic use matrix of dimension $C \times I$, where the first subscript indicates the region of origin of the used commodity and the second subscript indicates the region where the commodity is used; $FD_{r,s}$ is the domestic final demand of dimension $C \times$ number of final demand categories (D), with subscripts following these for $U_{r,s}$; U_r^M and FD_r^M are use and final demand matrices of the same dimensions, but related to imported products (foreign import, the interstate import is included in domestic U and FD matrices); VA_r is a square matrix with value added values on the diagonal; and S_r^d is a matrix with the supply by commodity on diagonal (i.e., square matrix with diagonal filled with row sums of matrix S_r). Zeros indicate empty matrices (i.e., matrices filled with zeros).

Note that the proposed structure implies that rows of the first row section and columns of the first and third column sections sum to zero. Rows of the second row section sum to negative exports by region and commodity (because supply minus export is domestic use), and rows of the third row section sum to imports by region and commodity. S_r^d matrices are introduced with an intention to preserve the balance in the assembled partitioned matrix (general structure presented in Appendix A: Multiregional model structure - an example for two regions) that requires the row sums equal to column sums.

Equations 2 and 3 summarize the described row (vector u) and column (vector v) sums. E indicates vector of export and M indicates vector of imports. Subscripts indicate each vector's length, where R is the number of regions, I is the number of industries, C is the number of commodities, and D is the number of final demand categories.

$$\boldsymbol{u} = \begin{bmatrix} 0_{[RC]} & -E_{[RC]} & M_{[RC]} & VA_{[RI]} \end{bmatrix} \tag{2}$$

$$\boldsymbol{v} = \begin{bmatrix} 0_{[RI]} & FD_{[RD]} & 0_{[RC]} \end{bmatrix} \tag{3}$$

Application

Pacific halibut case study

Pacific halibut is distributed on the west coast of the USA and Canada, from California to Alaska. The fish are primarily targeted by the commercial longline fishery and by sport fishers, as well as taken for personal use. The fishing levels are set by the International Pacific Halibut Commission (IPHC), established by a Convention in 1923. For commercial fishery, the total allowable catches are set for each of several regulatory areas based on annual stock assessment. While under the Convention, the IPHC's mandate is optimum management of the Pacific halibut resource, which necessarily includes also an economic dimension, the focus has been on the sustainable harvest from the ecological perspective.

Preparing 3-region benchmark SUTs

The model uses as a base the species-based multiregional social accounting matrix (SB-MR-SAM) model developed by Seung et al. (2020) and describing the US economy in 2014. The focus of the model is the commercial fisheries sector, and the tables distinguish ten separate fishing industries. As the goal is to demonstrate the assessment of the economic impact of Pacific halibut in Alaska, other fishing industries are aggregated. For the best use of available state-level statistics, all Alaska regions are aggregated into a single AK region. The final set of tables includes three regions: Alaska (AK – region 1), USA West Coast (WC – region 2), and the rest of the USA (RUS – region 3). For simplicity, services, miscellaneous, state and local government and federal government are merged into broader Services industry.
The final set of industries and commodities considered in the paper is presented in table 1.

Equation 4 presents the structure of the benchmark matrix constructed from SB-

Table 1 Industries and commodities in the SUTs

	Industry ($i \in I$)	Primary commodity produced ($c \in C$)
1	Pacific halibut fishing (AK only)	Pacific halibut (c1)
2	Other fish and shellfish fishing	Other fish and shellfish (c2)
3	Agriculture and natural resources extraction (excluding fishing)	Agriculture and natural resources (excluding fisheries resources)/ANR (c3)
4	Construction	Construction (c4)
5	Utilities	Utilities (c5)
6	Seafood processing	Seafood (c6)
7	Food manufacturing (excluding seafood)	Food (excluding seafood) (c7)
8	Manufacturing (excluding food manufacturing)	Manufactured goods (excluding food) (c8)
9	Transport	Transport (c9)
10	Wholesale	Wholesale (c10)
11	Retail	Retail (c11)
12	Services (including public administration)	Services (including public administration) (c12)

MR-SAM that is used as an updating function input (X^0). It follows the structure of the matrix proposed in equation 1, but specifies regions considered in the model ($r, s = \{ak, rc, us\}$) and separates two value added categories. The final demand (FD) matrices considered here consist of two types of final demand, personal consumption expenditures (PCE) and other final demand (FD^O), including final consumption expenditure by government, final consumption expenditure by non-profit institutions serving households (NPISH), gross fixed capital formation and changes in inventories. Export is considered here separately, as shown in equation 2.

$$X^0 = \left[\begin{array}{ccc|ccc|ccc}
-S_{ak} & 0 & 0 & 0 & 0 & 0 & S^d_{ak} & 0 & 0 \\
0 & -S_{wc} & 0 & 0 & 0 & 0 & 0 & S^d_{wc} & 0 \\
0 & 0 & -S_{us} & 0 & 0 & 0 & 0 & 0 & S^d_{us} \\
\hline
U_{ak,ak} & U_{ak,wc} & U_{ak,us} & FD_{ak,ak} & FD_{ak,wc} & FD_{ak,us} & -S^d_{ak} & 0 & 0 \\
U_{wc,ak} & U_{wc,wc} & U_{wc,us} & FD_{wc,ak} & FD_{wc,wc} & FD_{wc,us} & 0 & -S^d_{wc} & 0 \\
U_{us,ak} & U_{us,wc} & U_{us,us} & FD_{us,ak} & FD_{us,wc} & FD_{us,us} & 0 & 0 & -S^d_{us} \\
\hline
U^M_{ak} & 0 & 0 & FD^M_{ak} & 0 & 0 & 0 & 0 & 0 \\
0 & U^M_{wc} & 0 & 0 & FD^M_{wc} & 0 & 0 & 0 & 0 \\
0 & 0 & U^M_{us} & 0 & 0 & FD^M_{us} & 0 & 0 & 0 \\
\hline
VA^L_{ak} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & VA^L_{wc} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & VA^L_{us} & 0 & 0 & 0 & 0 & 0 & 0 \\
\hline
VA^O_{ak} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & VA^O_{wc} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & VA^O_{us} & 0 & 0 & 0 & 0 & 0 & 0
\end{array}\right] \tag{4}$$

As the SB-MR-GRAS technique requires the consistency of constraints, the original model's trade vector needs to be adjusted. Appendix B: Aligning trade vectors describes these adjustments. It is also important to note that all wild capture production, including all Pacific halibut harvest, is assumed to be supplying the seafood processing industry in this model. This implies a broader scope of the processing sector that also includes entities responsible for product preparation and packaging. Under this assumption, Pacific halibut and other harvested species are sold to other industries or final users only as a seafood commodity as opposed to a fish commodity.

Updating 3-region SUTs

This section demonstrates the adoption of the MR-GRAS technique for updating the multiregional SUTs described in the previous section using the most recent (2019) national-level SUTs published by the US Bureau of Economic Analysis (BEA 2020b; after redefinitions make table, use table and import table), complementary regional data on personal consumption and value added by state (BEA 2020c), data on trade in goods by state (US Census 2020) and fisheries-specific statistics.

First, the BEA tables are aggregated to the same industries and commodities as those listed in table 1. The aggregation key is available in the S1 tab of the supplementary data file.[3] Because the BEA tables do not specify fisheries as a distinct industry (fishing is included in more general industry 113FF: *Forestry, fishing, and related activities*), industries 1-2 are lumped with industry 3, together with other natural resources extracting sectors. Fisheries statistics are used to reallocate fisheries production (supply), as well as input to the seafood processing sector, to align BEA tables with the SB-MR-SAM model and incorporate more detailed information on the focus sector. Fisheries production, including the output of Pacific halibut in Alaska and other fish and shellfish species for each region, is sourced from National Oceanic and Atmospheric Administration (NOAA) *commercial fisheries landings database* (NOAA 2020). Statistics represent a census of the volume and value of finfish and shellfish landed and sold at the dock.

There is also a mismatch in the allocation of beverages and tobacco production. BEA uses aggregate 311FT: *Food and beverage and tobacco products*, while SB-MR-SAM isolates food production, including beverages and tobacco with other manufacturing products. This implies that all manufacturing industries (industries 6-8) must be aggregated in both SB-MR-SAM and BEA tables in order to be directly comparable. However, BEA supplementary table *Gross Output by Industry – Detail Level* (BEA 2020a) includes additional data on production by seafood product preparation and packaging (line 217) and beverages and tobacco manufacturing (lines 225-229).[4] Assuming that disregarding these industries' secondary production introduces a minimal bias,[5] the manufacturing output in the national supply table

[3] Supplementary data file is available at:
https://econdat.blob.core.windows.net/data2share/MRGRAS_AK.xlsx.

[4] This includes: (1) soft drink and ice manufacturing (line 225), (2) breweries (line 226), (3) wineries (line 227), (4) distilleries (line 228), and (5) tobacco product manufacturing (line 229).

[5] It is unlikely that either of these industries will produce a substantial supply of other food products (commodity 7, food products, excluding seafood).

can be aligned with the SB-MR-SAM supply tables. Since no additional data are available on use by these industries, the updating model uses the use matrix that aggregates all manufactured commodities, implying no issue with deriving these from BEA tables.

MR-GRAS technique is applied to the SB-MR-SAM model (i.e., the matrix in equation 4) using the following aggregation constraints built based on data for 2019:

1 Supply matrices (S_r), summed elementwise and with merged columns for industries 1-3 and merged columns for industries 6-9 (all manufacturing industries, aggregated because of mentioned earlier mismatch related to the allocation of beverages and tobacco production) must equal BEA-derived supply matrix with the same industries merged (S). Note that S matrix has dimension 12x8, because while columns 1-3 and 6-9 are merged, the number of rows continues to follow the number of all commodities. Production of fisheries commodities (c1 and c2) derived from NOAA fisheries statistics (NOAA 2020) is assigned to the column describing industries 1-3 in aggregate, and production of manufactured commodities data follows from the adjustment based on BEA supplementary table *Gross Output by Industry – Detail Level* (BEA 2020a) noted earlier and adopted for the column describing industries 6-8 in aggregate.

2 Domestic use matrices (all $U_{r,s}$ matrices), summed elementwise and with merged columns for industries 1-3 and 6-8 and merged rows for manufactured commodities (commodities 6-8, accounting for mismatch in the allocation of beverages and tobacco products) must equal BEA-derived domestic use matrix with the same industries and commodities merged (U^d). As all wild capture production, including all Pacific halibut harvest, is assumed to be supplying the seafood processing industry, the fisheries sector's output can be assigned directly as input to production by manufacturing industries (column describing use by industries 6-8). For that reason, there is also no need to merge rows 1-2 with row 3.

3 Domestic final demand matrices (all $FD_{r,s}$) matrices), summed elementwise and with merged rows for manufactured commodities (commodities 6-8) must equal the BEA-derived domestic final demand matrix with the same commodities merged (FD^d). Note that the final demand for fisheries commodities is zero by design.

4 Foreign use matrices (all U_r^M matrices), summed elementwise and with merged columns for industries 1-3 and 6-9 and merged rows for commodities 6-8 must equal the BEA-derived foreign use matrix with the same industries and commodities merged (U^M).

5 Foreign final demand matrices (all FD_r^M matrices), summed elementwise and with merged manufactured commodities (commodities 6-8) must equal the BEA-derived foreign final demand matrix with the same commodities merged (FD^M).

6 Value added matrices (all VA_r^L and VA_r^O) are included in the same form as in the benchmark matrix with the exception of industries that have to be aggregated to align with BEA-supplied data. Value added for labor and other VA components are aggregated for industries 1-3 and for industries 6-8. VA

matrices with aggregates are marked with stars (*). VA statistics by region are derived from table *Gross Domestic Product (GDP) by industry in current dollars* (BEA table SAGDP2) and table *Compensation of employees by industry* (BEA table SAINC6N), which report VA and labor compensation statistics by state (BEA 2020c). These are also adjusted for redefinitions adopted in BEA tables (the model uses *After Redefinitions* set of use tables[6]).

7 Diagonals of the S_r^d matrices summed elementwise must equal BEA-derived vector of supply by commodity (diagonal of S^d). S^{*d} is S^d matrix adjusted for aggregation of commodities in U^d and FD^d, that is S^d with collapsed rows for commodities 6-8.

Equation 5 represents the structure of the final aggregation constraints matrix. The full aggregation matrix is available in the S2 tab of the supplementary data file.[7]

$$\boldsymbol{W^1} = \begin{bmatrix} -S & 0 & S^d \\ U & FD & -S^{*d} \\ U^M & FD^M & 0 \\ VA_{ak}^{*L} & 0 & 0 \\ VA_{wc}^{*L} & 0 & 0 \\ VA_{us}^{*L} & 0 & 0 \\ VA_{ak}^{*O} & 0 & 0 \\ VA_{wc}^{*O} & 0 & 0 \\ VA_{us}^{*O} & 0 & 0 \end{bmatrix} \tag{5}$$

To align all model components, the following BEA trade vector adjustments are applied:

1 Export and import of ANR commodity (c3) are reduced by export and import of unprocessed fish and shellfish (NAICS[8] 1125: *Farmed Fish And Related Products* and NAICS 1141: *Fish, Fresh/chilled/frozen & Other Marine Products*) reported in the US Trade database (US Census 2020). This adjustment aligns data used for updating with the original tables that assume all fisheries products are passing through the seafood processing industry before reaching any other industry or final demand.

2 Seafood trade statistics are derived from US Trade as a sum of NAICS 1125, NAICS 1141 and NAICS 3117 (*Seafood Prods, Prepared, Canned & Packaged*). The value reported under NAIC 3117 is also deducted from the food production trade recorded in BEA tables to account for seafood disaggregation for general food commodity that previously included processed seafood.

3 As the SB-MR-SAM model allocates beverages and tobacco production to other manufactured goods category (c8) and BEA reports values for aggregate

[6] A redefinition is a transfer of a secondary product from the industry that produced it to the industry in which it is primary. See Horowitz and Planting (2009, chapter 5) for more information about redefinitions in relation to BEA data.

[7] Supplementary data file is available at:
https://econdat.blob.core.windows.net/data2share/MRGRAS_AK.xlsx.

[8] NAICS stands for North American Industrial Classification System. NAICS is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the US business economy.

311FT: *Food and beverage and tobacco products*, reallocation of beverage and tobacco production is applied based on US trade statistics for NAICS 3121: *Beverages* and NAICS 3122: *Tobacco Products*.

MR-GRAS technique is applied to the original model using the following row and column constraints built based on data for 2019:

1 Per model structure, rows of the first row section of X^0 sum to zero.

2 The sum of rows of the second row section must equal negative export vectors (because supply minus export is domestic use). State-level statistics on trade from US Trade (US Census 2020) are available only for goods, not services. Thus, trade in services is derived from aggregation constraints defined in W^1 matrix rather than being defined as row constraint. By the fisheries product definition adopted here, the export of commodities c1 and c2 is restricted to zero.

3 The sum of rows of the third row section must equal the import vectors (because these describe the use of imported commodities). As noted in the previous point, state-level statistics on trade are available only for goods, not services, and therefore import of services is derived from aggregation constraints defined in W^1 matrix rather than being defined as row constraint. By fisheries product definition, import of commodities c1 and c2 is restricted to zero.

4 The sum of rows of the fourth and fifth row sections must equal vectors with value added components (labor and other VA components) by region. These are equivalent to these described in point 6 of the aggregation constraints description. However, no row constraints are applied for rows containing VA related to aggregated industries. These are derived from aggregation constraints defined in W^1 matrix.

5 Per model structure, columns of the first column section of X^0 sum to zero.

6 In the second column section of X^0, the first column of final demand by each region sums to the final demand by households. These are reported by state in BEA's table SAEXP1 *Total personal consumption expenditures (PCE) by state*.

7 Per model structure, columns of the third column section of X^0 sum to zero.

Constraints on row (vector u) and column (vector v) sums are summarized by equations 6 and 7.

$$\boldsymbol{u} = \begin{bmatrix} 0_{[3C]} & -E_{[3C]} & M_{[3C]} & VA^L_{[3I]} & VA^O_{[3I]} \end{bmatrix} \tag{6}$$

$$\boldsymbol{v} = \begin{bmatrix} 0_{[3I]} & PCE_{ak} & FD^O_{ak} & PCE_{wc} & FD^O_{wc} & PCE_{us} & FD^O_{us} & 0_{[3C]} \end{bmatrix} \tag{7}$$

The output matrix is also adapted to accommodate specific fisheries-related data. Fisheries production statistics (output of Pacific halibut in Alaska and other fish and shellfish species by region) from the NOAA commercial fisheries landings database (NOAA 2020) are used to constraint the supply of commodity 1 (for Alaska) and commodity 2 (for all three regions). This is done by setting diagonals of subsection

S_r^d of matrix X^0 for commodities 1-2 to zero and fixing the sum of rows related to fisheries output to negative reported fish production. This is because the supply S_r is introduced in X^0 with a negative sign to balance the use. Adopting this constraint requires also adjusting W^1 for consistency.

Additionally, Alaska's direct marketers, catcher processors, catcher exporters, buyer exporters, shore-based processors, or floating processor permit holders are required to complete and submit to the Alaska Department of Fish and Game (ADFG) a Commercial Operator's Annual Report (COAR 2020). COAR reports on the by species statewide wholesale value of the processed seafood. This value is used as a constraint on the supply by Alaskan seafood processing sector, that is the supply of commodity 6 in S_{ak}. This also implies adjustment of the S_{ak}^d, in which the diagonal element related to seafood production must be set to 0. As with fisheries production, what follows is that matrix W^1 is adjusted for consistency, although in this case, because the constraint applies only to one of the regions in the model, the cell related to seafood commodity in S^d and S^{*d} is not set to zero because it continues to represent seafood production by the two remaining regions.

The updated matrix (X^{2019}) is derived using benchmark matrix X^0 and described constraints using the iterative algorithm proposed by Temursho et al. (2020).[9]

Results

The structure of the updating output (X^{2019}) is the same as the structure of the X^0 matrix. Table 2 summarizes how much the final output SUTs deviate from implemented constraints. The results suggest a good fit of the final product.

Table 3 compares multipliers for commodity 1 (Pacific halibut) derived from 2014

Table 2 X^0 **deviation from constraints**

	SUTs updated to 2019
Aggregation constraints	Constraints fully met (deviation $<$ USD 1)
Row constraints	USD 0.3 million
Column constraints	USD 38.3 million
Total supply$^{(1)}$	USD 37.8 trillion

$^{(1)}$Total supply is provided for comparison/scale of deviation.

benchmark table and SUTs updated to 2019. Since Pacific halibut is managed using total allowable catches (TACs), the economic impact is estimated using a supply-driven approach (Leung and Pooley 2002; Steinback and Thunberg 2006; Seung and Miller 2018).[10] The modified approach is based on the method developed by Tanjuakio et al. (1996). 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 for exogenized sectors to zero, which implies

[9]The algorithm adopted in this paper minimizes the weighted logarithm of the relative distance between the entries of the new and the old SUTs, subject to row, column and aggregation constraints. One may also consider adding more weight to the difference between entries related to focus sectors. Such additional consideration, however, was out of this paper's scope.

[10]When analyzing the impact of output changes, the final demand approach is inappropriate, and in many cases it will substantially underestimate the true impact (Leung and Pooley 2002).

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. See Miller and Blair (2009, pp. 624) for application details.

Table 3 also includes reference model results, that is the model based on the benchmark table updated using the same set of updating inputs as these used for deriving X^{2019}, but compiled for 2014. The discrepancy between the benchmark model and the reference model is likely a result of retrospectively corrected figures. For example, the original tables suggest GDP equal to USD 17.65 trillion, while currently published figures for 2014 imply the GDP of USD 17.53 trillion. Moreover, while the best effort was made to correctly allocate all industries and commodities, some discrepancy in categorization may have remained. Thus the primary comparison of the results is made between *Reference model (2014)* and *Updated model (2019)*.

The results suggest an increase in the Pacific halibut's economic contribution to the United States' economy over the last few years. The increase is more pronounced in the regions not directly affected by the exogenous shock, implying increasing interdependence between regions and growing reliance on imports in Alaska.

Table 3 Comparison of multipliers derived from benchmark model and updated model

	Benchmark model	Reference model (2014)	Updated model (2019)	% change[(1)]
AK	1.2676	1.5366	1.6724	8.8%
WC	0.0628	0.1340	0.1801	34.4%
RUS	0.3047	0.5866	0.7217	23.0%

[(1)]Percent change indicates the updated model relative to the reference model.

Discussion and conclusions

This paper presents a modification of the MR-GRAS method that is making the best use of typically available regional statistics, while guaranteeing balanced structure of the output matrix. The proposed framework focuses on updating regional SUTs when detailed regional statistics are available for components related to the calculation of the GDP, that is final demand and value added, as well as trade. This is a common situation for the analyst to come across. At the same time, the output of the proposed approach guarantees the identity of GDP by income and GDP by expenditure at the regional level. This is a notable advantage as supply-use accounting balance is necessary for deriving any meaningful economic impact assessment estimates.

The paper also offers an elaborate example of updating SUTs for calculating economic impacts at the regional level. While the IPHC's focus is establishing harvest limits that permit the optimum yield from the fishery and maintain the stock at the sustainable level, understanding the human dimension is part of its optimum management of the natural resource. A good understanding of how a regulatory change is going to affect the resource stakeholders should always be sought as a part of the decision-making process.

Few important points regarding the MR-GRAS technique and its potential for informing decision-making need to be noted. First, when adopting exhaustive constraints, that is applying a full set of row, column and aggregation constraints, all constraints have to be mutually consistent and consistent with the benchmark input matrix. In case of discrepancies between sources, it is an analyst's decision what component to adjust instead of the algorithm finding the most efficient solution. Second, the algorithm is only applicable to the cases with non-overlapping aggregation constraints, that is the disaggregated item can be a part of only one aggregated set. While this type of setup represents a prevalent situation the analyst may come across, overlapping and possibly conflicting constraints require adopting an alternative methodology, for example the KRAS (Lenzen et al. 2009) or general-purpose constrained optimization solver. Third, MR-GRAS sign-preserving property should be carefully considered when applying the method. Shifts between positive and negative values may occur from year to year. If such transition or fluctuations are expected, redefining variables may be the best option. For example, one may consider separating taxes and subsidies instead of adopting net tax to guarantee that the signs mach.

Moreover, adopting this method across years assumes that changes in the GDP are largely independent of changes in the underlying sectoral interactions. However, household budget allocations across various expenditure categories change when the economy is in recession or expansion (Kamakura and Du 2012). Thus any significantly disproportional GDP changes between regions may not manifest correctly in the SUTs updated using the technique described in this paper.

Appendix A: Multiregional model structure - an example for two regions

		Region 1 (R1)		Region 2 (R2)		Final demand	**Total outputs**
		Industries	Commodities	Industries	Commodities		
Region 1 (R1)	Industries		Make matrix (R1) – V1 = t(S1)				Total industry output (R1) – x1
	Commodities	Use matrix (R1) – U1			Transaction matrix (region 1 to region 2) – T12	Final demand (R1) – FD1	Total commodity output (R1) – q1
Region 2 (R2)	Industries				Make matrix (R2) – V2 = t(S2)		Total industry output (R2) – x2
	Commodities		Transaction matrix (region 2 to region 1) – T21	Use matrix (R2) – U2		Final demand (R2) – FD2	Total commodity output (R2) – q2
Value added		Value added (R1) – VA1		Value added (R2) – VA2			
Total inputs		Total industry input (R1) - x1	Total commodity input (R1) – q1	Total industry input (R2) – x2	Total commodity input (R2) – q2		

Appendix B: Aligning trade vectors

To align the model with BEA SUTs, the following modifications were applied to trade vectors:

1 As BEA tables suggest no import of construction commodity (c4) at the national level, the positive import of this commodity by RUS in SB-MR-SAM is reduced to 0. To preserve model balance, the export of this commodity by RUS is reduced by the same amount.
2 As BEA tables suggest no import of wholesale commodity (c10) at the national level, the positive import of this commodity by RUS in SB-MR-SAM is reduced to 0. To preserve model balance, the export of this commodity by RUS is reduced by the same amount.
3 As BEA tables suggest no import or export of retail commodity (c11) at the national level, positive import and export of this commodity by RUS in SB-MR-SAM is reduced to 0. Introduced by this adjustment imbalance is corrected by adjusting the capital account. This modification preserves the production structure of the original model.
4 The export of transport commodity (c9) by RUS outweighs the domestic production of this commodity. Although this does not imply model imbalance, this is inconsistent with the model specification that assumes ≥ 0 domestic use of domestic production (i.e. model adjusted for re-exports such as BEA SUTs). Thus, the export and import are adjusted (reduced) by averaged between import and export discrepancy with values from BEA SUTs.

Abbreviations

- ADFG - Alaska Department of Fish and Game
- AK - Alaska
- ANR - agriculture and natural resources
- BEA - US Bureau of Economic Analysis
- COAR - Commercial Operator's Annual Report
- FD - final demand
- GDP - gross domestic product
- GRAS - generalized RAS
- IPHC - International Pacific Halibut Commission
- MR-GRAS - multiregional generalized RAS
- NAICS - North American Industrial Classification System
- NEA - National Economic Accounts
- NOAA - National Oceanic and Atmospheric Administration
- NPISH - non-profit institutions serving households
- PCE - personal consumption expenditures
- RUS - rest of the USA
- SB-MR-SAM - species-based multiregional social accounting matrix
- SUTs - supply and use tables
- TAC - total allowable catch
- VA - value added
- WC - USA West Coast

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Supplementary data file is available at: https://econdat.blob.core.windows.net/data2share/MRGRASAK.xlsx.

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