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Abstract

The Agri-Food Economic Data System (Ag-FEDS) is an integrated system of economic data that elaborates the linkages between all production and consumption activities throughout the U.S. economy. This data system incorporates developments to provide the most complete accounting of the U.S. food economy to date and is a flexible modeling platform that supports research in this area. This report makes three extensions to Ag-FEDS in preparation for multiplier analysis: (1) complete passthrough accounting of food commodities, (2) inclusion of non-farm food commodities in the food supply chain, and (3) partitioning import/export commodity flows to avoid re-exporting imports. Ag-FEDS is used as the underlying data source for two food-system-specific multiplier models: the Food Dollar and the Resource Requirements of Food Demand. The multiplier models based on the extended Ag-FEDS data are then derived in this report. The resulting output data of this analysis present greater detail and insights into the U.S. food economy's costs and resource use than previously available.

Keywords: Agri-food value chains, food economy, resource flows, social accounting matrix (SAM), multiplier models

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Documentation for the Agri-Food Economic Data System (Ag-FEDS): Multiplier Model Applications

Introduction

USDA's Economic Research Service (ERS) developed the Agri-food Economic Data System (Ag-FEDS) comprised of national economic accounts data that describes how commodities are made, used, and distributed across the domestic economy. Specifically, Ag-FEDS shows how more than 350 production activities (e.g., grain farming, breakfast cereal manufacturing, and truck transportation) culminate into broad and detailed annual food and beverage[1] expenditures. Ag-FEDS accounts have been compiled with the intention to innovate and improve on past work (Canning, 2011; Rehkamp et al., 2021), resulting in a more complete and accurate accounting of food and beverage costs and resource use along the sequence of activities from farm production through points of purchase (Rehkamp & Canning, 2025).

Multiplier models can use economic activity data to analyze effects of changes in final demand. Two multiplier models developed by USDA, ERS are the Food Dollar and the Resource Requirements of Food Demand (RRFD). The Food Dollar multiplier model computes the cost distribution (or, equivalently, value added) across agri-food supply chain activities that produce, process, and distribute food and beverage products to final markets for consumer purchase. The current Food Dollar multiplier model is based on the method outlined in Canning (2011) and produces six tables annually. These tables report the distribution of costs across supply chain stages such as farm production, food processing, and retail trade for consumer expenditures on food, non-alcoholic beverages, and alcoholic beverages at retail markets such as grocery stores and restaurants. For years aligned with benchmark releases of national accounts data from the U.S. Department of Commerce, Bureau of the Census's Bureau of Economic Analysis, the current Food Dollar computes 16 tables that report these cost distributions for specific food-at-home products such as bakery products and fresh vegetables.

The Resource Requirements of Food Demand is a multiplier model bringing in physical unit data to measure natural and human resource use (e.g., employment, energy, and freshwater) linked to the U.S. food system. Similarly, because the underlying economic data are the same as the Food Dollar, past research was limited in the detail that could be reported.

This report first makes three extensions to Ag-FEDS as documented in the companion report by Rehkamp and Canning (2025): (1) complete passthrough accounting, (2) inclusion of non-farm food commodities, and (3) partitioning import/export commodity flows. These extensions are useful for multiplier model applications because they facilitate linkages to Ag-FEDS's level of detail in food-economy accounting and adjust for limitations of previous models (Canning, 2011).

[1] Including both nonalcoholic and alcoholic beverages.

Secondly, the Food Dollar and RRFD multiplier model applications are presented. With Ag-FEDS as the underlying data and the extensions documented herein, the Food Dollar can compute agri-food supply chain cost distributions for additional food-at-home (FAH) tables, food-away-from-home (FAFH) expenditures by outlet, and alcoholic beverages at- and away-from-home on an annual basis. These are in addition to the tables reflecting aggregate food- and alcohol-at-home and food- and alcohol-away-from-home expenditures (for a total of 47 food expenditure tables). Additionally, Ag-FEDS enables the Food Dollar to identify more food and beverage commodity value in food-away-from-home purchases. The market value of food in FAFH expenditures was underreported in the 2011 series by between 46 and 49 percent, compared to the series computed using Ag-FEDS (Rehkamp & Canning, 2025; Baker & Zachary, 2026) due to limitations with the source data. These tables are also used by the RRFD multiplier model to compute resource use distributions in physical units linked to final market food purchases. RRFD has an extended scope to include the resources used to transport and market imported food and beverages, plus the resources linked to home kitchen operations and transportation, for an expanded study of the U.S. food system.

These are the first two models to use Ag-FEDS to generate data to describe the U.S. food system with more accuracy and detail than previously available and answer questions about the food system such as “How much value is added along different parts of the domestic food supply chain?” and “How are natural and human resources used throughout the U.S. food system?” We intend for the Food Dollar and RRFD output data to be made available for stakeholders to glean greater insights into the food economy and for applied research purposes.

Methods

In this section, we specify the model dataset. In the following sections we derive the Food Dollar and Resources Requirements of Food Demand multipliers and present sample output for each series. Table 1 provides a list of equation elements used throughout the report. Mathematical notation follows Rehkamp and Canning (2025):

- A matrix is a rectangular array or table of numbers, arranged in rows and columns, and denoted with bold capitalized letters.
- A vector is a single column or row of numbers, denoted with bold lower-case letters.
- Sets are a pre-defined collection of elements inside of a matrix or vector and are denoted with capitalized and italicized letters.
- Set elements are specific individual or subgroups of elements within a set and are denoted with lower case italicized letters.
- A scalar is a single number and is denoted with nonbold lower case letters.
- Letters are from either the English or Greek alphabet.
- A matrix or vector transpose is denoted with a prime (′).

- A diagonal matrix has zeros off the main diagonal, at least one non-zero main diagonal element, and is denoted with a double prime (″).
- A matrix inversion is indicated by its placement inside brackets as $\{matrix\}^{-1}$
- A matrix to vector transformation by stacking columns from left to right is indicated by vec[*matrix*].
- Concatenations are either the vertical (//) or horizontal (||) joining of vectors and/or matrices to form a matrix having the combined number of rows (//) or columns (||) as the objects being joined.

Table 1
Definitions of equation elements

Equation element	Description	Sets and elements	Description
rSAM	Starting Ag-FEDS model dataset	*F*	Ag-FEDS system of accounts
SAM_fd	Target SAM for Food Dollar multiplier model	*A*	Activity accounts
Z	Endogenous transaction matrix	*C*	Commodity accounts
X	Import-inclusive final demand (injection) matrix	*V*	Voucher accounts
Xf	Import-inclusive final demand matrix for foods and beverages	*I*	Institution accounts
L	Primary factors and imports (leakage) matrix	*X*	Final demand accounts
LX	Exogenous transactions matrix	*L*	Primary factor and import accounts
y	Gross output vector	*FA, FC, FV, FVo FI, FX, FL*	Ag-FEDS subaccounts for activities, commodities, vouchers, voucher overhead costs, institutions, final demand, primary factors, and imports
Ω	Operator to expand or collapse rows or columns	*Xf*	Food, beverage, and food-related final demand accounts
ET	Export transformation matrix to facilitate recording of exports as activities	*xf*	A specific food and beverage final demand account
Z_fd, X_fd, L_fd, y_fd	Transactions, final demand, primary factors, and imports matrices and gross output vector defined for **SAM_fd**	*cal*	Caloric commodities
Λ	Direct requirements, or technical coefficients, matrix	*calxa*	Caloric food and beverage commodities except alcohol
M	Total requirements matrix	*cala*	Caloric alcohol commodities
y_*xf*	Gross output linked to a specific food demand account	*fsc*	Caloric commodities for food service activities
ishrc	Vector of import share of domestic availability by *C*	*Afsc*	Caloric bundling for food services

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Equation element	Description	Sets and elements	Description
XfImp	Margin cost share for imports by **rSAM** table	*Vpro*	Caloric commodity procurement vouchers
Xfadj	Ag-FEDS tables injection matrix net of margin costs for imports	*r1*	Exports
yadj_*xf*	Adjusted gross agricultural output vector	*r2*	Imports
ynet_*xf*	Total net farm sales to downstream markets	*chem*	Chemical manufacturing commodities assembled into food ingredients and sold in food markets
ydnet_*xf*	Sum of **ynet_xf**, net of direct imports in final markets, linked to a specific food demand account	*mg2*	Transportation (*tr*), wholesale and retail trade (*ws,rt*), and voucher overhead (*vo*) margin commodities plus food service commodities (*fs*)
Xdfadj_*xf*	Sum of **Xfadj_xf**, net of direct imports in final markets, linked to specific food demand account	*ag*	Agricultural commodities
ishrXf	Import share of domestic availability by **rSAM** table	*Cfarm*	Farm commodity accounts
V (v)	Value added multiplier matrix (vector)	*xag*	Agricultural commodities sold to other nonfarm activities or sold in “final” markets
VS	Reduced-dimension value added multiplier matrix with subcontractors consolidated into supply chain stages	*S (Sλ)*	Supply chain stage set (element)
Table_*xf*	Ag-FEDS table *xf* for all *xf* in *Xf*	*rm_σ*	Supply chain stages in resources module
E	Resource multiplier matrix	*Σ (σ)*	Resource factor set (element)
ES	Resource multiplier matrix with subcontractors’ resources consolidated into supply chain stages	*T*	Years
Σ (σ)	Matrix (vector) of resources		
Σf (σf)	Matrix (vector) of physical final market transactions		
Σ_*Sλ*	Resource use by supply chain stage		
λ	Equation-defined wildcard variable		

Note. The sets and elements can be combined such as *ACV* representing activities, commodities, and voucher accounts. Title case is used when referring to a specific *Xf* subaccount since these are our target tables (e.g., *Xf1101*).
Source: USDA, Economic Research Service.

Model Dataset

Ag-FEDS (Rehkamp & Canning, 2025) is our input dataset (figure 1), an annual reduced social accounting matrix (**rSAM**) and accompanying resources module (Rehkamp et al., 2025). Ag-FEDS is compiled for each year $\tau \in T$, where $T = \{1997, \ldots, current\}$. Since November 2024, the *current* statistical year is 2023. By way of comparison to the model dataset used in the multiplier model for the

2011 Food Dollar series, the Ag-FEDS database has far greater commodity (*C*) detail and has both activity (*A*) and voucher *(V)* dimensions that did not exist in the 2011 series. To apply the multiplier model to the 2011 series dataset, all food and beverage commodities purchased through foodservice marketing channels were converted to passthrough commodities in the model application stage. This step will also be applied here and will include applying passthrough accounting in markets not covered in the 2011 series. Passthrough accounting in the present context involves the decoupling of all bundled food and beverage final market purchases for all caloric commodities[2] being purchased and the transportation, wholesale, retail, and foodservices being purchased.

Because the Ag-FEDS database expands the accounting of other Gross Domestic Product (GDP) categories that include foodservice activities, such as healthcare services and public administration, we also apply the passthrough accounting to our voucher accounts. To keep track of the origins of GDP we document the transfer of value from these vouchers between the issuing activities and the receiving households. The 2011 Food Dollar Series did not address the problem of data pooling in multiplier models that leads to misallocations of import commodity flows to export commodity markets. The Food Dollar Series also omitted the consideration of food commodities of non-farm origin, such as table salt and chemically manufactured food flavorings. Here, we address the former and include the latter. Both the 2011 series model and the Food Dollar 2.0 model described in this section use conventional type I multipliers;[3] however, we refine some of the equations developed in Canning (2011) and adapt others to handle the added dimensions of the Ag-FEDS dataset. In this report, we describe our approach to these four issues in this order—complete passthrough accounting, partition of import/export commodity flows, inclusion of non-farm food commodities, and type I multipliers.

The remainder of this report will include more than 50 equations reported in 5 subsections to facilitate replication and adaptation of the compiled SAM and multiplier calculations. To allow readers the option of following all the steps without having to read through every equation, each subsection that follows will be introduced with a formatted summary, covering objectives and steps caried out within the subsection and a brief description of the equations. To begin, denote **SAM_fd** our target type I multiplier-model dataset and initially populate this social accounting matrix (SAM) with the Ag-FEDS reduced SAM account, **rSAM**:

1. $\mathbf{SAM\_fd}^{\tau} = \mathbf{rSAM}^{\tau}, \forall\ \tau \in T$

Figure 1 is a schematic depiction of this Ag-FEDS **rSAM** account and our starting point, reproduced from Rehkamp and Canning (2025).

[2] We use “caloric commodities” to represent all farm and processed food and beverage commodities that are either purchased for human consumption or purchased as a food or beverage ingredient for preparation and sale for human consumption. We note that some of these commodities (like bottled water) have no calories.

[3] A type I multiplier is derived from our SAM account organized such that households are exogenous and any incomes linked to a model simulation are not distributed to households, which would induce new household spending. Type I models are also called simple multipliers (see chapter 6 in Miller and Blair, 2022).

Figure 1

Agri-food Economic Data System (Ag-FEDS) Social Accounting Matrix (SAM) schematic with voucher subaccounts

Row	Activities (*FA*)	Commodities (*FC*)	Vouchers (*FV*)		Institutions and rest of world		Total
	Fa001 … *Fa363*	*Fc001* … *Fc363*	*Fv01* … *Fv13*	*Fvo1* *Fvo2*	*FXf* *FXh* *FXg* *FXk*	*FXr1*	
Activities *Fa001* ⋮ *Fa363*	**Z**[*FA,FA*](=0)	**Z**[*FA,FC*] (=**S**[*FA,FC*])	**Z**[*FA,FVc*](=0)	**Z**[*FA,FVo*](=0)	**X**[*FA,FXI*](=0)	**X**[*FA,FXr1*](=0)	Gross output (**y**)
	Endogenous transactions (ET): inner-inner matrix ($\mathbf{Z}_{in,in}$)		**ET: inner-outer matrix** ($\mathbf{Z}_{in,out}$)		**Injection matrix (X)**		
Commodities *Fc001* ⋮ *Fc363*	**Z**[*FC,FA*] (=**U**[*FC,FA*])	**Z**[*FC,FC*](=0)	**Z**[*FC,FVc*]	**Z**[*FC,FVo*](=0)	**X**[*FC,FXI*] (=**U**[*FC,FXI*])	**X**[*FC,FXr1*] (=**U**[*FC,FXr1*])	
Vouchers	**ET: outer-inner matrix** ($\mathbf{Z}_{out,in}$)		**ET: outer-outer matrix** ($\mathbf{Z}_{out,out}$)				
Fv01 ⋮ *Fv13*	**Z**[*FVc,FA*]	**Z**[*FVc,FC*](=0)	**Z**[*FVc,FVc*](=0)	**Z**[*FVc,FVo*](=0)	**X**[*FVc,FXI*]	**X**[*FVc,FXr1*](=0)	
Fvo1 *Fvo2*	**Z**[*FVo,FA*]	**Z**[*FVo,FC*](=0)	**Z**[*FVo,FVc*](=0)	**Z**[*FVo,FVo*](=0)	**X**[*FVo,FXI*](=0)	**X**[*FVo,FXr1*](=0)	
Institutions and rest of world *FLh* *FLg* *FLk*	**L**[*FLI,FA*] (=**U**[*FLI,FA*])	**L**[*FLI,FC*] (= 0)	**L**[*FLI,FVc*]	**L**[*FLI,FVo*]	**LX**[*FLI,FXI*]	**LX**[*FLI,FXr1*](=0)	GDI + imports
	Leakage matrix (L)				**Exogenous transactions (LX)**		
FLr2	**L**[*FLr2,FA*] (= 0)	**L**[*FLr2,FC*] (=(-**U**[*FC,FLr2*])')	**L**[*FLr2,FVc*](=0)	**L**[*FLr2,FVo*]	**LX**[*FLr2,FXI*](=0)	**LX**[*FLR,FLR*](=0)	
Total	Gross output (**y'**)				GDP + imports		

Z = Endogenous transactions. **X** = Injection matrix. **L** = Leakage matrix. **LX** = Exogenous transactions. GDP = Gross Domestic Product. GDI = Gross domestic income. *FA* = activity subset of *F* account. *FC* = commodity subset of *F* account. *FXI* = Institutional subset of *F* account within injection matrix. *FLI* = Institutional subset of *F* account within leakage matrix. *FXr1* = Rest-of-world exports subset of *F* account within injection matrix. *FXr2* = Rest-of-world imports subset of *F* account within leakage matrix. *FVc* = is the voucher commodity subset of *F* account. *FVo* = is the voucher overhead subset of *F* account.

Note: Institutional accounts (*I*) are partitioned into households (*h*), governments (*g*), and saving/investment (*k*). Rest-of-world accounts (*R*) are partitioned into international exports (*r1*), and international imports (*r2*).

Source: USDA, Economic Research Service adapted from Canning, P., Rehkamp, S., & Yi, J. (2022). Environmental input-output models for food systems research: Application and extensions. In C.J. Peters & D.D. Thilmany (Eds.), *Food systems modelling: Tools for assessing sustainability in food and agriculture* (pp. 179–211). Elsevier.

Complete Passthrough Accounting for Food and Beverage Commodities

In this section, food, beverage, and foodservice commodities are decoupled into individual components so that food and beverage quantities can be modeled to change without requiring fixed bundles of commodities to change with it in the same proportion. Equations 2–9 describe how the bundles are split up and relocated through their appropriate accounts and deducted from where they are removed. Equations 10–17 allocate the commodities behind the vouchers into their appropriate Xf accounts. These voucher accounts are further broken out into domestically produced and imported sources. Passthrough accounting for all food, beverage, and foodservice commodities purchased by or for all domestic consumption, as typically applied only to purchases obtained for off-premises consumption, is desirable in the context of our Food Dollar multiplier model because it allows us to consider individual food and beverage commodity purchases, rather than only considering fixed bundles purchases. For example, we can consider components of a meal purchased or provided away from home. The accounting also allows for the netting out of imported food and beverage commodities directly purchased and served through the different foodservice marketing channels, which is important for the Food Dollar data product.

To achieve this passthrough accounting and assign the direct food and beverage commodity outlays among all food expenditure accounts listed in table 2, we denote caloric commodity bundles *cala* (all alcoholic beverage commodities) and *calxa* (all food and beverage commodities excluding alcoholic beverages) such that $cala \cup calxa = cal$. Denote *fsc* the set of caloric commodities for the three FAFH (food away from home) foodservice activities. The three foodservice activities are full-service restaurants, limited-service restaurants, and all other food and drinking places. We first decouple these commodities, which appear in most of the *1200* and *2200* level *Xf* subaccounts (see all

Table 2
Agri-food Economic Data System (Ag-FEDS) food, beverage, and foodservice expenditure accounts

Account number	Account name	Account type
Xf1000	Food	All food
Xf1100	Food at home	All food-at-home
Xf1101	Cereals	Food-at-home
Xf1102	Bakery products	Food-at-home
Xf1103	Beef	Food-at-home
Xf1104	Pork	Food-at-home
Xf1105	Other meats	Food-at-home
Xf1106	Poultry	Food-at-home
Xf1107	Fish and seafood	Food-at-home
Xf1108	Fresh milk	Food-at-home
Xf1109	Processed dairy products	Food-at-home
Xf1110	Fresh eggs	Food-at-home
Xf1111	Processed eggs	Food-at-home
Xf1112	Fats and oils (including mayonnaise)	Food-at-home

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Account number	Account name	Account type
Xf1113	Fresh fruits	Food-at-home
Xf1114	Fresh vegetables	Food-at-home
Xf1115	Canned, frozen, and dried fruits and vegetables	Food-at-home
Xf1116	Sugar and sweets	Food-at-home
Xf1117	Snack foods	Food-at-home
Xf1118	Frozen prepared foods	Food-at-home
Xf1119	Processed fruit and vegetable canning and drying (e.g., soups, catsup, pickles)	Food-at-home
Xf1120	Seasonings, sauces (except tomato), and dressings (excluding mayonnaise)	Food-at-home
Xf1121	Dry, condensed, and evaporated dairy and non-dairy products	Food-at-home
Xf1122	Tree nuts and peanuts (unprocessed)	Food-at-home
Xf1123	Fresh cut produce plus grab-and-go foods	Food-at-home
Xf1124	Miscellaneous foods and ingredients	Food-at-home
Xf1125	Fruit and vegetable juices	Food-at-home
Xf1126	Food consumed on farms	Food-at-home
Xf1127	Coffee, tea, and beverage materials (except soft drinks)	Food-at-home
Xf1128	Soft drinks and bottled water	Food-at-home
Xf1200	Food away from home	All food-away-from-home
Xf1201	Food at full-service restaurants	Food-away-from-home
Xf1202	Food at limited-service restaurants	Food-away-from-home
Xf1203	Food at other food and drinking places	Food-away-from-home
Xf1204	Food at schools and colleges	Food-away-from-home
Xf1205	Food furnished to employees (including military)	Food-away-from-home
Xf1206	Institutional and employer furnished meals plus food assistance	Food-away-from-home
Xf1207	Food and non-alcoholic beverages at work (per diem and expensing)	Food-away-from-home
Xf2000	Alcohol	All alcohol
Xf2100	Alcohol at home	All alcohol-at-home
Xf2101	Beer	Alcohol-at-home
Xf2102	Wine	Alcohol-at-home
Xf2103	Spirits	Alcohol-at-home
Xf2200	Alcohol away from home	All alcohol-away-from-home
Xf2201	Alcohol at full-service restaurants	Alcohol-away-from-home

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Account number	Account name	Account type
Xf2202	Alcohol at limited-service restaurants	Alcohol-away-from-home
Xf2203	Alcohol at other food and drinking places	Alcohol-away-from-home

Note. The account names vary slightly compared to table 5 in Rehkamp & Canning (2025) but represent the same content.
Source: USDA, Economic Research Service, Agri-Food Economic Data System.

indented listings below the *Xf1200*[4] and *Xf2200* subtotal accounts in table 2). Additionally, we must decouple these commodities in the export account *(Xr1)* to facilitate a later step:

2.a $\mathbf{SAM\_fd}^{\tau}(calxa,\lambda) = \mathbf{SAM\_fd}^{\tau}(calxa,\lambda)$

2.b $+ \mathbf{SAM\_fd}^{\tau}(calxa,Afsc) \times \{[\mathbf{\Omega}_{1,calxa} \times \mathbf{SAM\_fd}^{\tau}(calxa,Afsc)]''\}^{-1}$

2.c $\times [\mathbf{\Omega}_{Afsc,fsc} \times \mathbf{SAM\_fd}^{\tau}(fsc,\lambda)],$

2.d $\lambda \in (Xf1201, Xf1202, Xf1203, Xf1204, Xf1207, Xr1)$

3.a $\mathbf{SAM\_fd}^{\tau}(fsc,Afsc) = \mathbf{SAM\_fd}^{\tau}(fsc,Afsc) + \mathbf{SAM\_fd}^{\tau}(fsc,\lambda) \times \mathbf{\Omega}_{\lambda,Afsc},$

3.b $\lambda \in (Xf1201, Xf1202, Xf1203, Xf1204, Xf1207, Xr1)$

4.a $\mathbf{SAM\_fd}^{\tau}(calxa,Afsc) = \mathbf{SAM\_fd}^{\tau}(calxa,Afsc)$

4.b $- \mathbf{SAM\_fd}^{\tau}(calxa,Afsc) \times \{[\mathbf{\Omega}_{1,calxa} \times \mathbf{SAM\_fd}^{\tau}(calxa,Afsc)]''\}^{-1}$

4.c $\times [\mathbf{\Omega}_{Afsc,fsc} \times \mathbf{SAM\_fd}^{\tau}(fsc,\lambda) \times \mathbf{\Omega}_{\lambda,1}]'',$

4.d $\lambda \in (Xf1201, Xf1202, Xf1203, Xf1204, Xf1207, Xr1)$

5. $\mathbf{SAM\_fd}^{\tau}(fsc,\lambda) = 0, \lambda \in (Xf1201, Xf1202, Xf1203, Xf1204, Xf1207, Xr1)$

6.a $\mathbf{SAM\_fd}^{\tau}(cala,\lambda) = \mathbf{SAM\_fd}^{\tau}(cala,Xf220\lambda)$

6.b $+ \mathbf{SAM\_fd}^{\tau}(cala,Afsc) \times \{[\mathbf{\Omega}_{1,cala} \times \mathbf{SAM\_fd}^{\tau}(cala,Afsc)]''\}^{-1}$

6.c $\times [\mathbf{\Omega}_{Afsc,fsc} \times \mathbf{SAM\_fd}^{\tau}(fsc,Xf220\lambda)], \lambda \in (1, 2, 3)$

7. $\mathbf{SAM\_fd}^{\tau}(fsc,Afsc) = \mathbf{SAM\_fd}^{\tau}(fsc,Afsc) + \mathbf{SAM\_fd}^{\tau}(fsc,Xf220\lambda) \times \mathbf{\Omega}_{Xf220\lambda,Afsc}, \lambda \in (1, 2, 3)$

8.a $\mathbf{SAM\_fd}^{\tau}(cala,Afsc) = \mathbf{SAM\_fd}^{\tau}(cala,Afsc)$

8.b $- \mathbf{SAM\_fd}^{\tau}(cala,Afsc) \times \{[\mathbf{\Omega}_{1,cala} \times \mathbf{SAM\_fd}^{\tau}(cala,Afsc)]''\}^{-1}$

8.c $\times [\mathbf{\Omega}_{Afsc,fsc} \times \mathbf{SAM\_fd}^{\tau}(fsc,Xf220\lambda) \times \mathbf{\Omega}_{Xf220\lambda,1}]'', \lambda \in (1, 2, 3)$

9. $\mathbf{SAM\_fd}^{\tau}(fsc,Xf220\lambda) = 0, \lambda \in (1, 2, 3)$

Equations 2 and 6 use the other caloric commodity budget shares (equation line 2.b) and alcohol commodity budget shares (equation line 6.b) to share the value of caloric commodity bundle outlays by the *Xf* or *Xr1* tables for other calories (equation line 2.c) and alcohol (equation line 6.c) and to the specific commodities that are bundled together. These are added to the outlays on these

[4] Ag-FEDS tables *Xf1205* and *Xf1206* do not purchase any foodservice caloric commodity bundles (*fsc*).

commodities, measured by lines 2.a for other caloric commodities and 6.a for alcohol commodities. These allocations are offset by a swapping of the caloric bundle commodities between the target *Xf* or *Xr1* accounts and the caloric bundle activities as recorded in equations 7 and 9 for alcohol commodities, and equations 3 and 5 for other caloric commodities. But before these bundles are zeroed out in equations 5 and 9, their values are needed to deduct the commodity outlays of these bundling activities in equations 4 and 8. All that remains for conversions from vouchers to caloric commodities is the procurement vouchers.

The caloric commodity procurement voucher group (*Vpro*) comprises vouchers *v06* to *v13*, which are also redeemable for one or more farm commodities (*Cfarm*) comprising of *c003* to *c010*, excluding *c009* (these are respectively, vegetables and melons; fruits and tree nuts; greenhouse, nursery, and floriculture; other crops; dairy cattle and milk; beef cattle; animal production except cattle and poultry). Food expenditure accounts within the *Xf1100* group and the export account (*Xr1*) have outlays on *Vpro* vouchers, and these are swapped for *Cfarm* commodities as follows:

10. $\mathbf{ishrc} = \mathbf{SAM\_fd}(Fr2,C) \times \{[\mathbf{\Omega}_{1,AL} \times \mathbf{SAM\_fd}^{\tau}(AL,C)]''\}^{-1}$

11.a $\mathbf{SAM\_fd}(C,\lambda) = \mathbf{SAM\_fd}(C,\lambda) - \mathbf{ishrc}'' \times \mathbf{SAM\_fd}(C,\lambda)$,

11.b $\lambda \in \{v06, v07, v08, v09, v10, v11, v12, v13\}$

12.a $\mathbf{SAM\_fd}(Fr2,\lambda) = \mathbf{SAM\_fd}(Fr2,\lambda) + [\mathbf{ishrc}'' \times \mathbf{SAM\_fd}(C,\lambda)] \times \mathbf{\Omega}_{\lambda,1}$,

12.b $\lambda \in \{v06, v07, v08, v09, v10, v11, v12, v13\}$

13a. $\mathbf{SAM\_fd}(Fr2,Cfarm) = \mathbf{SAM\_fd}(Fr2,Cfarm) - \mathbf{\Omega}_{1,\lambda} \times [\ \mathbf{ishrc}'' \times \mathbf{SAM\_fd}(C,\lambda)]'$,

13.b $\lambda \in \{v06, v07, v08, v09, v10, v11, v12, v13\}$

14.a $\mathbf{SAM\_fd}^{\tau}(Cfarm,\lambda) = \mathbf{SAM\_fd}^{\tau}(Cfarm,\lambda)$

14.b $+ \mathbf{SAM\_fd}^{\tau}(Cfarm,Vpro) \times \{[\mathbf{\Omega}_{1,Cfarm} \times \mathbf{SAM\_fd}^{\tau}(Cfarm,Vpro)]''\}^{-1}$

14.c $\times \mathbf{SAM\_fd}^{\tau}(Vpro,\lambda)]$,

14.d $\forall\ (\lambda|Vpro|Cfarm) \in \{(Xf1103|v06|c008),(Xf1104|v07|c010),$

14.e $(Xf1105|v08|[c010,c012]),(Xf1108|v09|c007),(Xf1109|v10|c007),$

14.f $(Xf1113|v11|c004),(Xf1114|v12|[c003,c005,c006]),$

14.g $(Xr1|v08|[c010,c012]), (Xr1|v10|c007)\}$

15.a $\mathbf{SAM\_fd}^{\tau}(Vpro,Vpro) = \mathbf{SAM\_fd}^{\tau}(Vpro,Vpro) + \mathbf{SAM\_fd}^{\tau}(Vpro,\lambda) \times \mathbf{\Omega}_{\lambda,Vpro}$,

15.b $\forall\ (\lambda|Vpro) \in \{(Xf1103|v06), (Xf1104|v07), (Xf1105|v08), (Xf1108|v09), (Xf1109|v10),$

15.c $(Xf1113|v11), (Xf1114|v12]),(Xr1|v08), (Xr1|v10)\}$

16.a $\mathbf{SAM\_fd}^{\tau}(Cfarm,Vpro) = \mathbf{SAM\_fd}^{\tau}(Cfarm,Vpro)$

16.b $- \mathbf{SAM\_fd}^{\tau}(Cfarm,Vpro) \times \{[\mathbf{\Omega}_{1,Cfarm} \times \mathbf{SAM\_fd}^{\tau}(Cfarm,Vpro)]''\}^{-1}$

16.c $\times [\mathbf{SAM\_fd}^{\tau}(Vpro,\lambda) \times \mathbf{\Omega}_{\lambda,1}]''$, 16.d $\forall\ (\lambda|Vpro|Cfarm)\ \in \{(Xf1103|v06|c008), (Xf1104|v07|c010),$

16.e $(Xf1105|v08|[c010,c012]),(Xf1108|v09|c007),$

16.f $(Xf1109|v10|c007), (Xf1113|v11|c004),$

16.g $(Xf1114|v12|[c003,c005,c006]),(r1|v08|[c010,c012]),$

16.h $(r1|v10|c007)\}$

17.a $\mathbf{SAM\_fd}^{\tau}(Vpro,\lambda) = 0,$

17.b $\forall\ (\lambda|Vpro) \in \{(Xf1103|v06), (Xf1104|v07), (Xf1105|v08), (Xf1108|v09),$

17.c $(Xf1109|v10), (Xf1113|v11), (Xf1114|v12), (Xr1|v08), (Xr1|v10)\}$

Equation 10 computes the share of imports in total commodity availability. In equation 11, this share is multiplied by the retail voucher commodities, then subtracted from the value of retail voucher commodities to reflect the reduction of voucher purchases that are from imports. Equation 12 updates the value of imports for the retail vouchers to indicate the value has been redirected from purchases of domestic commodities to purchases of imports. Equation 13 reduces the value of farm commodity imports by the value of imports required for voucher purchases. Equation 14 swaps *Vpro* vouchers among relevant *Xf* (food-expenditure) and *Xr1* (export) accounts. From any initial holdings of the target farm commodities that are measured on equation line 14.a, the value of *Vpro* voucher holdings (equation line 14.c) are distributed to outlays for the target farm commodities in proportion to holdings of each such commodity in the voucher portfolio, as measured in equation line 14.b. Five of the seven *Vpro* vouchers only hold one target *Cfarm* commodity, such that the ratio in 14.b equals 1. The vouchers held by the *Xf* and *Xr1* accounts are turned over to the voucher accounts in equation 15, but before the accounts are zeroed out in the *Xf* and *Xr1* accounts in equation 17, this value is needed to measure the *Cfarm* commodities to be deducted from the *Vpro* accounts (equation 16).

Table Salt From Mines and Chemically Manufactured Food Ingredients

Mined table salt and chemically manufactured food ingredients are produced by activities that generally produce large amounts of commodities that are not directly used by the food system. However, the salt and chemically manufactured food ingredients that are used by the food system need to be modeled for the food system multiplier models to perform properly. Because of this, two final procurement activities/commodities are added to the model, one for salt and one for chemically manufactured food ingredients. First, equations 18.s and 18.c reassign all final market sales of mining and chemical commodities embedded in food expenditures to their corresponding assembly activities. The outputs of these activities are assembled into market commodities in equations 19.s and 19.c. Equations 20.s and 20.c reclassify these final market procurements of mining and chemical commodities as purchases of the assembled food ingredient commodities, and equations 21.s and 21.c zero out the final market procurements of mining and chemical commodities.

Two final procurement activities/commodities are incorporated to assemble table salt from mining activities and to assemble food ingredients from chemical manufacturing activities, both exclusively for all food-related final market sales. These steps are necessary to allow our supply chain multiplier analysis presented in the next section to perform correctly. Because the source commodities that are procured and sold as salt and food ingredients are not produced from supply chain activities, we designate these as activities/commodities. Denote *chem* the set of chemical manufacturing commodities assembled into food ingredients (*a365*) and sold exclusively in food markets (*Xf)*. A small share of the nonmetallic mineral mining commodity (*c019*) is assembled into table salt commodity (*c364*) by its corresponding activity (*a364*) for food market sales (*Xf)*. We compile and allocate these salt (s) and chemical ingredient (c) accounts as follows:

18.s $\mathbf{SAM\_fd}^{\tau}(c019,a364) = \mathbf{SAM\_fd}^{\tau}(c019,Xf) \times \mathbf{\Omega}_{Xf,a364}$

19.s $\mathbf{SAM\_fd}^{\tau}(a364,c364) = \mathbf{\Omega}_{a364,c019} \times \mathbf{SAM\_fd}^{\tau}(c019,a364) \times \mathbf{\Omega}_{a364,c364}$

20.s $\mathbf{SAM\_fd}^{\tau}(c364,Xf) = \mathbf{\Omega}_{c364,c019} \times \mathbf{SAM\_fd}^{\tau}(c019,Xf)$

21.s $\mathbf{SAM\_fd}^{\tau}(c019,Xf) = 0$

18.c $\mathbf{SAM\_fd}^{\tau}(chem,a365) = \mathbf{SAM\_fd}^{\tau}(chem,Xf) \times \mathbf{\Omega}_{Xf,a365}$

19.c $\mathbf{SAM\_fd}^{\tau}(a365,c365) = \mathbf{\Omega}_{a365,chem} \times \mathbf{SAM\_fd}^{\tau}(chem,a365) \times \mathbf{\Omega}_{a365,c365}$

20.c $\mathbf{SAM\_fd}^{\tau}(c365,Xf) = \mathbf{\Omega}_{c365,chem} \times \mathbf{SAM\_fd}^{\tau}(chem,Xf)$

21.c $\mathbf{SAM\_fd}^{\tau}(chem,Xf) = 0$

Equations 18.s and 18.c reassign all food market sales of mining and chemical commodities to their corresponding food ingredient assembly activities. The outputs of these activities are assembled into market commodities in equations 19.s and 19.c. Equations 20.s and 20.c reclassify these final market procurements of mining and chemical commodities as purchases of the assembled food ingredient commodities, and equations 21.s and 21.c zero out the final market procurements of mining and chemical commodities. Unlike for meat, dairy, and fresh produce, we do not move the assembly of margin costs to these voucher accounts because they are already measured in the food expenditure accounts (*Xf)*. Rather than assume these ingredients have the same import market shares as the commodities from where they are extracted, we assume they are entirely assembled domestically from the source commodities. Because of this, import shares of their source commodities will be measured as imported inputs in domestically produced products.

Converting International Commodity Exports to Activity Exports

To avoid modeling reexports (i.e., importing food and beverages in order to export them), exported commodities are transformed back into the activities from which they were created. For example, if an exported commodity is produced by two different domestic activities, the one export commodity is reclassified as two export activities with each activity assigned a share of this export based on the share it produced of this export commodity. This transformation prevents the possibility of exporting commodities that are directly imported since imports are classified as commodities and exports are *now classified as activities. Equations 22 and 23 relocate the exports as activity outputs and equations 24 and 25 scale and adjust the SAM to account for the relocation of the exports.*

In a standard multiplier model compiled from account **SAM_fd** (discussed below), there exists a pool of each commodity available for all uses which is measured as domestic production plus imports ($\mathbf{\Omega}_{1,AL} \times \mathbf{SAM\_fd}^{\tau}[AL,C] = \mathbf{y}[C]'$). All uses of each commodity draw from this pool and the likelihood of using product sourced from a domestic activity or from imports is equal to each source's share of the pool. One such category of user is the export market; however, the nature of the data on imports is such that it does not include transshipments of imports.[5] This accounting practice rules out the use of a commodity import to meet an export market demand. A conventional multiplier model analysis is not able to avoid directing a share of commodity imports to meeting export demand. This outcome leads to underestimates of imported commodities embedded in domestic food value chains, as is the case for the 2011 Food Dollar series (Canning, 2011). There are several ways to correct this problem, and the most direct method is to bypass the assembly of commodities from domestic activity production serving the export market (see equation 1 in Golan & Vogel, 2000). This is facilitated by an export transformation matrix, $\mathbf{ET}^{\tau}(A,C)$:

22. $\mathbf{ET}^{\tau}(A,C) = \mathbf{SAM\_fd}^{\tau}(A,C) \times \{[\mathbf{\Omega}_{1,A} \times \mathbf{SAM\_fd}^{\tau}(A,C)]''\}^{-1}$

23. $\mathbf{SAM\_fd}^{\tau}(A,Xr1) = \mathbf{ET}^{\tau}(A,C) \times \mathbf{SAM\_fd}^{\tau}(C,Xr1)$

24. $\mathbf{SAM\_fd}^{\tau}(C,Xr1) = 0$

25. $\mathbf{SAM\_fd}^{\tau}(A,C) = \mathbf{SAM\_fd}^{\tau}(A,C) - \mathbf{ET}^{\tau}(A,C) \times \mathbf{SAM\_fd}^{\tau}(C,Xr1)''$

The effect of equations 22 and 23 is to move the export accounts up to the activity rows (figure 1) before they are zeroed out in the commodity rows in equation 24. Equation 25 scales back the transformation of activity outputs into commodities by the exact amount that covers commodity exports. Since export vouchers were converted back to their source commodities, they are included in this transformation.

As a result of the transformation and reallocations outlined in equations 22–25, exports are now recorded as activity outputs which eliminates the possibility that they will draw from the commodity pool where imports reside. Our expectation is that, other things being equal, the new Food Dollar data product will show a higher share of imported inputs domestic food dollars. This is consistent with the findings of Baker and Zachary (2026) that show the new Food Dollar model has higher imported inputs than the previous model introduced by Canning (2011) for both food away from home and food at home.

Derivation of the Food Dollar 2.0 Multipliers

The Food Dollar records the market values of agricultural commodity output and agri-food supply chain industry group output linked to final market purchases of domestically produced food. This section begins by defining subaccounts within ***SAM_fd*** *in equations 26–32. Next, we identify the relevant subset of activity, commodity, and voucher accounts that constitute the agri-food value chain and use the multiplier model to compute total gross output linked to food and beverage demand in*

[5] Goods are recorded as transshipments through country 'b' if the goods originate from origin country 'a' and are enroute to destination country 'c' for use in this country.

equation 33. Then, we deduct the margin costs (transportation, wholesale, retail) linked to imported foods and beverages marketed directly to consumers in equations 34–38, while keeping the value of the imported foods and beverages represented in our injection vector. This process is done because the multiplier model keeps track of imports directly sold in final markets, but the margin costs of marketing these imports is best removed from the injection vector. From there, we compute the values recorded in the Food Dollar data product. Equations 39–43 derive the farm share by computing total domestic agricultural commodity output linked to food and beverage demand, netting out farm-to-farm transactions, adjusting for imports in final markets, and summing total expenditures in each food expenditure account. Equations 44–53 show the procedure for identifying supply chain industry groups and computing the value-added contribution of each industry group and by each primary factor input to the total market value of domestic food production. These factors are then concatenated into a table showing, for a given Food Dollar expenditure category, the market value contributions to the total value chain by the different industry groups and primary factor inputs in equations 54–56.

For the USDA, ERS Food Dollar data product, food dollars are defined as the market value of all annual food and beverage acquisitions for domestic consumption. Domestic consumption refers to total food and beverage acquisitions for human consumption, excluding acquisitions for persons not residing in the United States (such as international visitors on either business or leisure travel).[6] Of these total food dollars, the Food Dollar data product is concerned with that portion that is acquired from domestic production. We refer to this portion as “domestic food dollars” and the various partitions of these dollars (e.g., acquisitions for off-premises consumption, or food at home) are referred to as Food Dollar tables (e.g., food-at-home dollar). Tables are developed for each of the 41 non-overlapping categories listed with indented table numbers in table 2. Tables are also compiled for each of the six total and subtotal accounts listed with bold table numbers in table 2.

Each table in the Food Dollar data product reports results from the multiplier analysis using Ag-FEDS that answers two questions:

> Q1. What is the cost of “marketing” all farm commodities produced domestically to meet annual domestic food demand, and what is the farmers’ share of domestic food dollars?
>
> Q2. How are the costs of producing domestic food attributed to the value added by supply chain stage?

To answer these questions, we compile the new Food Dollar multiplier model as follows (suppressing time period superscripts):

26. $\mathbf{Z\_fd}[ACV,ACV] = \mathbf{SAM\_fd}(ACV,ACV)$

27. $\mathbf{X\_fd}[ACV,Ir1] = \mathbf{SAM\_fd}(ACV,Ir1)$

28. $\mathbf{L\_fd}[Ir2,ACV] = \mathbf{SAM\_fd}(Ir2,ACV)$

29.a $\mathbf{y\_fd}[ACV] = \mathbf{Z\_fd}(ACV,ACV) \times \mathbf{\Omega}_{ACV,1} + \mathbf{X\_fd}[ACV,Ir1] \times \mathbf{\Omega}_{Ir1,1}$

[6] Food acquisitions by or for international visitors residing in the United States and not on business or leisure travel are included in measures of domestic food dollars.

29.b $= \mathbf{\Omega}_{1,ACV} \times \mathbf{Z\_fd}(ACV,ACV) + \mathbf{\Omega}_{1,Ir2} \times \mathbf{L\_fd}[Ir2,ACV]$

30. $\mathbf{\Lambda\_fd}[ACV,ACV] = \mathbf{Z\_fd}[ACV,ACV] \times \{\mathbf{y\_fd}[ACV]''\}^{-1}$

With reference to figure 1, we use all endogenous transactions in the Ag-FEDS account. The remaining subaccounts follow from this such that equations 26–28 define the endogenous transaction (**Z**), injection (**X**), and leakage (**L**) matrices which are the building blocks for our Food Dollar multiplier model. Equation 29 compiles the gross output vector (**y**) and confirms that the identity holds which states supply equals use for all activities and commodities (including voucher commodities). The direct requirement, or technology matrix, is defined in equation 30 and measures all intermediate input requirements per unit of output across all commodities and activities.

Multiplying both sides of equation 30 by the gross output vector (**y**) gives us:

31. $\mathbf{Z} = \mathbf{y} \times \mathbf{\Lambda}$,

and if we replace this expression for **Z** in equation 32.a, we have (suppressing set notation and account ids):

32.a $\mathbf{y} = \mathbf{\Lambda} \times \mathbf{y} + \mathbf{x}$, where $\mathbf{x} = \mathbf{X\_fd}[ACV,Ir1] \times \mathbf{\Omega}_{Ir1,1}$

32.b $(\mathbf{i''} - \mathbf{\Lambda}) \times \mathbf{y} = \mathbf{x}$, where $\mathbf{y} = \mathbf{i''} \times \mathbf{y}$

32.c $\mathbf{y} = \{\mathbf{i''} - \mathbf{\Lambda}\}^{-1} \times \mathbf{x}$

32.d $\mathbf{y} = \mathbf{M} \times \mathbf{x}$, where $\mathbf{M} = \{\mathbf{i''} - \mathbf{\Lambda}\}^{-1}$, where **i** is a unit vector, and ″ is a diagonalized vector

The total requirement (or multiplier **M**) matrix is defined in equation 32.d. If these were linear algebra expressions in equation 31, we could simply move **y** to the left side of the expression and then factor it out by dividing both sides by (1-Λ). However, equation 31 is a matrix algebra expression and the term $\{\mathbf{i''} - \mathbf{\Lambda}\}^{-1}$ is an inversion of the matrix containing technical coefficients. This operation produces the multiplier matrix, **M**. The names “total requirement” and “multiplier” come from the fact that multiplying through the final demand vector (**x**) by this matrix produces the gross output vector (**y**), describing total production, import, and assembly requirements of activities, commodities, and vouchers to accommodate this final demand.

A property of this multiplier model that facilitates its use for our analysis of food dollars is that of linear homogeneity. This property implies that a proportional change to any element of the injection vector (**x**)produces the same proportional change in the gross output vector (**y**). For example, $\mathbf{M} \times (\mathbf{x} \times 2) = (\mathbf{y} \times 2)$. In other words, if it requires **y** to meet a final demand of **x**, it requires twice **y** to meet a final demand of twice **x**. This identity holds for all subsets of the final demand vector. For example, each of the food expenditure columns within the **X_fd**[*ACV,Xf]* subaccount is a subset of the vector **x** (recall this vector was created by collapsing all columns of matrix **X**) that represents the annual expenditures on various food, beverage, and foodservice commodities by or for all domestic households within this economy. The linear homogeneity property implies that the gross output of both activities and commodities throughout the economy to accommodate these food expenditures is measured as:

33. $\mathbf{y\_}xf = \mathbf{M} \times \mathbf{X\_fd}(ACV,xf), \forall\, xf \in Xf$

The measurement of meals obtained at work (*Xf1207*), institutionally furnished meals (*Xf1206*), and school meals (*Xf1204*) required decoupling what are recorded as intermediate expenses of other activities such as State and local government and nursing homes and reclassifying the meals as final market sales. To avoid double counting these expenditures as both an intermediate expense and a final market sale, we swapped vouchers for commodities between the voucher and food expenditure accounts. For example, table *Xf1207* already measures the annual expenditures for meals at work. Using our type I multiplier model to translate observed expenditures into measures of output and incomes linked to those observed expenditures, it is likely that most or all *Xf* accounts would induce additional meals at work expenditures, should we make our voucher accounts procure these caloric commodities and foodservices. To avoid having the multiplier model double count the value of meals at work induced by, for example, annual expenditures for beer at home, we attribute these induced meals at work to acquisitions of vouchers to cover overhead costs for voucher redemptions. These overhead costs are included in the leakage matrix (**L_fd**) and treated as operating surplus. Doing this avoids inducing additional food-at-work spending which is already measured in the total food-at-work final demand account (*Xf1207*). The same approach is applied for final demand accounts *Xf1206* and *Xf1204*.

Because our interest is in domestic food dollars, we need to deduct direct sales of imported commodities after tracing through total requirements of total food dollar demand (including imports). To do this, we identify and deduct all domestic margin costs linked to imports directly sold in final markets. For example, for imported cheese that is acquired at a grocery store, the model measures no direct or indirect domestic outputs linked to this imported cheese; however, domestic transportation, wholesale, and retail activities are linked to the absorption and marketing of this imported cheese. It is straightforward to deduct the imported cheese sales after the multiplier model is applied, but deducting the margin costs from the multiplier output would require identifying and deducting all direct and indirect commodities linked to these margin commodities. The work-around is to include the imported cheese purchases within the *Xf* matrix but identify and deduct the direct margin costs linked to these imported cheese purchases from this same *Xf* vector. More generally:

34. **ishrc**(*cal*)' = {**y_fd**[*cal*]"}$^{-1}$ × **L_fd**[*Fr2,cal*], where ' indicates a transposed vector or matrix

35. **ishrXf**(*Xf*)' = **ishrc**(*cal*)' × **X_fd**[*cal,Xf*] × {(**i**(*cal*)' × **X_fd**[*cal,Xf*])"}$^{-1}$

36. **XfImp_fd**(*ACV,Xf*) = 0

37. **XfImp_fd**(*mg2,Xf*) = **X_fd**[*mg2,Xf*] × **ishrXf**(*Xf*)"

38. **Xfadj_fd**[*ACV,Xf*] = **X_fd**[*ACV,Xf*] – **XfImp_fd**(*ACV,Xf*)

For equations 34–38, the *cal* set is as previously defined and covers all food and beverage commodities. The *Xf* set is also as previously defined and covers all Food Dollar tables listed in report table 2. Then, *r2* identifies the imports row of the leakage matrix as was also previously defined. A new set designation, *mg2*, references the set of margin commodities that includes all foodservices (*fs*) plus all overhead vouchers (*vo*), transportation (*tr*), and trade (*ws,rt*) margin commodities. Collectively, this set covers all the distribution, marketing, and foodservice costs involved with facilitating final market food and beverage acquisitions at their various points of acquisition. Equation 30 measures the market shares of the domestic availability for imports across all caloric commodities. Equation 31 applies this import market share parameter to measure the import value share of total caloric commodities acquired for each food expenditure account (*Xf).* This share parameter is used to measure how much of all margin costs are dedicated to marketing import commodities for each food expenditure account. This calculation is stated in equations 36 and 37. Although there are other ways to measure margin costs for imports, this approach applies the same percentage markup for both imported and domestically sourced commodities and is preferred since our source data are not of sufficient detail to apply different rates to the two sources. Equation 38 deducts all margin costs for imports from the food expenditure portion of the injection matrix, while keeping the imported caloric commodity outlays in the table, for the reasons motivated above.

With the calculation in equation 38, we can restate the expression in equation 33 to initiate our answer to question 1 (from this point forward we suppress the account identifiers (**_fd**):

39. $\mathbf{yadj\_}xf[ag] = \mathbf{M}[ag,ACV] \times \mathbf{Xfadj}[ACV,xf], \forall\, xf \in Xf$

The set designation, *ag*, introduced in equation 39 identifies all agricultural commodities in **SAM_fd**. An adjusted gross agricultural output vector (**yadj_***xf*) is generated for each food expenditure account. From this output we must deduct all farm-to-farm sales to avoid double counting, including indirect sales involving one or more intermediate non-farm transactors:

40. $\mathbf{ynet\_}xf[ag] = (\mathbf{i''}[ag] - \mathbf{\Lambda}[ag,ag] - \mathbf{\Lambda}[ag,xag] \times \mathbf{M}[xag,xag] \times \mathbf{\Lambda}[xag,ag]) \times \mathbf{yadj\_}xf[ag]$

The product of the adjusted gross agricultural output vector (**yadj_***xf*) and the three expressions within the outer brackets ( ) on the right side of the equality in equation 40 deducts all farm-to-farm sales. The product of the first bracketed expression simply reproduces the adjusted gross output vector, from which the second expression deducts all direct farm-to-farm sales (e.g., sale of cattle to a feed-lot operation) and all resulting farm-to-farm sales linked to all direct and indirect farm outputs tied to the initial food expenditure. What products are not sold directly to other farms are sold to other nonfarm activities (*xag*) or sold in final markets, where final market sales are "final," at least in terms of the accounting period, which cannot lead to any indirect sales to other farms. This leaves all sales to nonfarm activities, measured as $\mathbf{\Lambda}[xag,ag]\times\mathbf{yadj\_}xf[ag]$. The product of this measure and the middle term in the third bracketed expression ($\mathbf{M}[xag,xag]$) translates all farm-to-nonfarm sales into total gross output (direct and indirect) of all nonfarm activities to accommodate all farm-to-nonfarm sales. From this measure we simply quantify all nonfarm-to-farm sales directly required for all this nonfarm gross output and since all this output was initiated by a farm purchase, all subsequent purchases of farm outputs measure all indirect farm-to-farm sales. The resulting measure, $\mathbf{ynet\_}xf[ag]$, represents total net farm sales to downstream markets.

To finally answer question 1, we must deduct any direct final market farm sales to final food markets that are sourced from imports and sum, and we must deduct both these sales plus other caloric commodity sales to final food markets and sum:

41. $\text{ydnet\_}xf = \mathbf{i'}[ag] \times \mathbf{ynet\_}xf[ag] - [\mathbf{\Omega}_{ag,cal} \times \mathbf{ishrc}(cal)]' \times \mathbf{ynet\_}xf[ag], \forall\, xf \in Xf$

42. $\text{Xdfadj\_}xf = \mathbf{i'}[ACV] \times \mathbf{Xfadj\_fd}[ACV,xf] - \mathbf{ishrc}(cal)' \times \mathbf{Xfadj\_fd}[cal,xf], \forall\, xf \in Xf$

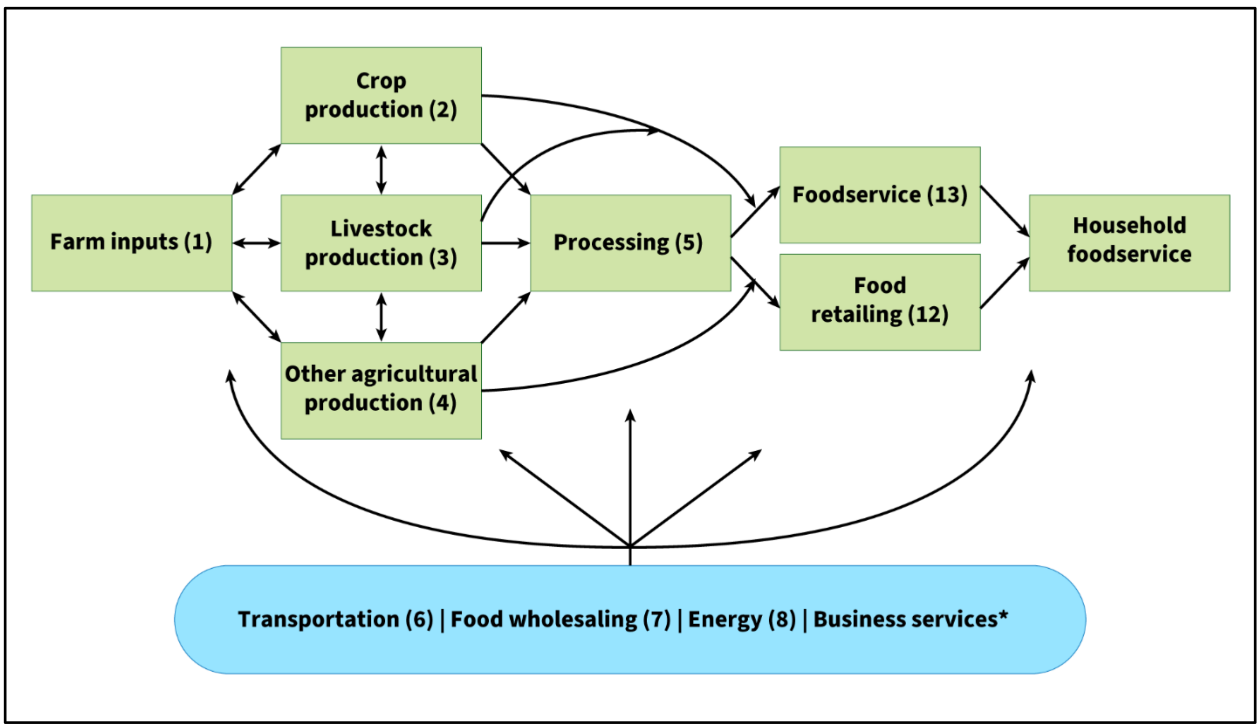
43. $\text{xf} = \mathbf{i'}[ACV] \times \mathbf{xf}(ACV), \forall\, \mathbf{xf}(ACV) \in \mathbf{X}(ACV,Xf)$

Equation 41 sums net farm sales to downstream markets then deducts the import share of caloric agricultural commodity sales in final markets. Equation 42 sums adjusted food expenditures then deducts the import share of all caloric commodity sales in final markets. Both measures exclude the value of imported caloric commodities sold directly in final markets, as well as the expanded margin costs (including foodservices) linked to these imports. Equation 43 sums each individual food expenditure account and is referred to as the total food dollars, which are inclusive of direct imports. All three measures are scalars, or single numbers, that will be reported in the Food Dollar data product. Additionally, the ratio ydnet_*xf*/Xdfadj_*xf* has come to be known as the farm share of domestic food dollars.

For question 2—How are the costs of producing domestic food attributed to the value added by supply chain stage? the focus turns to the value additions of different supply chain industry groups contributing to the total cost of domestically produced food. For each of the accounts listed in tables 2 and 4, the food value chain is depicted in figure 2.

Each rectangular box and each partition within the oval shape in figure 2 represents a supply chain stage and is defined by a grouping of Ag-FEDS activities and commodities. All other Ag-FEDS activities and commodities not grouped into a supply chain stage are grouped into a single non-supply chain activity and commodity group. We seek to measure the value added of all supply chain stages such that value added by all other activities and imported commodities are attributed to these supply chain groups in precise proportions to their use by each group.

Figure 2
Food system supply chain stages



*Business services include finance and insurance (9), legal and accounting (10), and advertising (11).
Source: USDA, Economic Research Service using Canning et al. (2022). Environmental input-output models for food systems research: Application and extensions. In C.J. Peters & D.D. Thilmany (Eds.), *Food systems modelling: Tools for assessing sustainability in food and agriculture* (pp. 179–211). Elsevier.

To represent this structure in the multiplier model, a matrix reorganization is developed as an alternative to aggregation (Leontief, 1967; Canning et al., 2022). This involves reorganizing the data into supply chain activities, commodities, and vouchers (*SACV* ⊂ *ACV)*, and non-supply chain activities and commodities (*NAC* ⊂ *AC),* where *SACV* ∪ *NAC* = *ACV*. Restating equation 29 using *S* and *N* as shorthand for *SACV* and *NAC,* we have (suppressing account ids):

44. $$\overbrace{\begin{bmatrix} \mathbf{y}\_xf[S] \\ \mathbf{y}\_xf[N] \end{bmatrix}}^{\mathbf{y}\_xf} = \overbrace{\left\{\begin{bmatrix} (\mathbf{i}[S]'' - \mathbf{\Lambda}[S,S]) & -\mathbf{\Lambda}[S,N] \\ -\mathbf{\Lambda}[N,S] & (\mathbf{i}[N]'' - \mathbf{\Lambda}[N,N]) \end{bmatrix}\right\}^{-1}}^{\{\mathbf{i}'' - \mathbf{\Lambda}\}^{-1}(=\mathbf{M})} \times \overbrace{\begin{bmatrix} \mathbf{xf}[S] \\ \mathbf{0}[N] \end{bmatrix}}^{\mathbf{xf}}, \forall\, \mathbf{xf}(ACV) \in \mathbf{X}(ACV,Xf)$$

Equation 44 is a restatement of equation 33 with a reclassification of set elements. For our target supply chain stages identified in figure 2, all activities, commodities, and vouchers directly linked to each of the 13 supply chain stages are associated with sets *S*, and all other activities and commodities are associated with set *N*.

Dividing through each element of the leakage matrix (**L_fd**[*lr2,ACV*]) defined in equation 28 by the gross output vector (**y_fd**[*ACV*]) defined in equation 29 yields the value-added multiplier matrix (again suppressing set notation and account ids):

45. $\mathbf{V'} = \{\mathbf{y''}\}^{-1} \times \mathbf{L'}$

The product of the gross-output and value-added multiplier vector ($\mathbf{v'} = \mathbf{i'} \times \mathbf{V'}$) equals gross domestic income (GDI) plus imports:

46. $\mathbf{y'} \times \mathbf{v} = \mathbf{i'}[ACV] \times \mathbf{L'} \times \mathbf{i}[lr2]$,

where **i** is a unit vector (all 1s) with dimensions in brackets. The expression to the right of the equality in equation 46 measures total value of the leakage matrix. We can verify from manipulation of equation 32.b and the linear homogeneity property that total GDI plus imports (as measured in equation 46) equals total GDP plus imports (GDI=GDP). This formula translates to $\mathbf{i'}[lr2] \times \mathbf{L} \times \mathbf{i}[ACV] = \mathbf{i'}[ACV] \times \mathbf{X} \times \mathbf{i}[lr1]$. If we replace this second term for the first in equation 46 and apply the linear homogeneity property, we get:

47. $\mathbf{yadj\_}xf' \times \mathbf{v} = \mathbf{i'}_{ACV} \times \mathbf{Xfadj}[ACV,xf], \forall\, xf \in Xf$

The right side of this equality measures the total adjusted expenditures (net of margin costs on imports) for each food expenditure account. The left side measures the value-added contribution of every activity, commodity value of all imported production inputs, and the voucher value of all vouchers linked to each food expenditure account. The number of contributions to the value of each food expenditure account can include several hundred sources. For example, a laundry service that is used to clean the uniforms of a restaurant chain contributes value to many or most food markets. Because equation 47 is an equality, the combined value contributions from the hundreds of activities, commodities, and vouchers on the left side of the equation exactly explains the market value of the food expenditures on the right side of the equation. Once imported caloric commodities sold directly in final markets are deducted from both sides of equation 47, we have an answer to our second question. But this answer offers too much information. The laundry service example is a case in point. These services are provided to a restaurant and so the value added should be attributed to the foodservice supply chain stage. Similar laundry services may also be provided to a meat packing operation, and those services should be attributed to the processing supply chain stage.

To reduce the dimensions of the model, we return to our reclassification of accounts in equation 44. All non-supply chain industries are considered subcontractors, such that each supply chain activity procures other supply chain outputs and primary factors required by their subcontractors. We consolidate the value-added multipliers by all subcontractors, which measures value added per unit of output, into their contributions among contractors and denote this supply chain augmented value-added multiplier matrix **VS**, with dimensions $Ir2 \times S$ recalling S is shorthand for $SACV$ and comprises all supply chain activities, commodities including voucher commodities. This is compiled as follows (suppressing account ids):

48. $\mathbf{VS'} = \mathbf{V'}[Ir2,S] + \mathbf{M'}[S,S]^{-1} \times (\mathbf{M'}[N,S] \times \mathbf{V'}[Ir2,N])$ ↔ reduced dimension value added multiplier

The first expression to the right of the equality in equation 48 is the conventional measure of direct value added by primary factor per unit of output among contractors. The matrix product inside of parentheses to the right of the equality compiles the total subcontractor value added per unit of contractor output; however, because total requirements per unit factors in additional contractor output per direct unit requirement of such output, the expression, $\mathbf{M'}[S,S]^{-1}$, scales contractor outputs back to a single unit of primary direct requirement.[7]

Supply chain stages are presented in figure 2. The various final points of purchase are listed in table 1. Denote $S\lambda \subset S$ for $\lambda = 1$ to 13 (see figure 2 for numeric concordances to stages). We answer question 2 as follows:

49. $\mathbf{VA\_}S\lambda(Ir2,Xf) = \mathbf{VS}(Ir2,S\lambda) \times \mathbf{M}(S\lambda,C) \times \mathbf{Xfadj}(C,Xf), \forall \lambda \in \{2 \text{ to } 13\}$

50. $\mathbf{VA\_}S\lambda(r2,Xf) = \mathbf{VA\_}S\lambda(r2,Xf) - \mathbf{ishrc}(cal)' \times [\mathbf{\Omega}_{cal,S\lambda} \times \mathbf{Xfadj}(S\lambda,Xf)], \forall \lambda \in \{2 \text{ to } 5\}$

51.a $\mathbf{VA\_}S1(Ir2,Xf) = \mathbf{VA\_}S2(Ir2,Xf) + \mathbf{VA\_}S3(Ir2,Xf) + \mathbf{VA\_}S4(Ir2,Xf)$

51.b $- [\mathbf{V}(Ir2,S2)\times\mathbf{M}(S2,C)+\mathbf{V}(Ir2,S3)\times\mathbf{M}(S3,C)+\mathbf{V}(Ir2,S4)\times\mathbf{M}(S4,C)] \times \mathbf{Xfadj}(C,Xf)$

52. $\mathbf{VA\_}S\lambda(Ir2,Xf) = \mathbf{V}(Ir2,S\lambda) \times \mathbf{M}(S\lambda,C) \times \mathbf{Xfadj}(C,Xf), \forall \lambda \in \{2 \text{ to } 4\}$

53. $\mathbf{VA\_}S\lambda(r2,Xf) = \mathbf{VA\_}S\lambda(r2,Xf) - \mathbf{ishrc}(cal)' \times [\mathbf{\Omega}_{cal,S\lambda} \times \mathbf{Xfadj}(S\lambda,Xf)], \forall \lambda \in \{2 \text{ to } 4\}$

Equation 49 applies to all supply chain stages except stage 1 (farm inputs). It measures the gross outputs for each of the supply chain activities/commodities/vouchers and sums the products of these gross outputs and their subcontractor augmented value added multipliers (**VS**). Recalling that direct sales of imported caloric commodities should be deducted after application of the multiplier model, equation 50 performs this step, and only on supply chain stages 2–5 since these stages encompass the importation of all the caloric commodities.

To explain equations 51–53 we note that our definition of farm inputs in this context are the sum-total of all "subcontracting" accounts among agricultural stages $S2$ to $S4$. In equation 49 we compile the direct plus subcontracting value added by primary factors for all stages, so in equation 51 we sum these values for stages $S2$ to $S4$ then deduct the sum-total of the direct value added (**V**) for these same

[7] For a detailed mathematical derivation of equation 44, see equation 15 in Leontief (1967).

three stages. Lastly, in equations 52 and 53 we overwrite the direct plus subcontractor value added for stages *S2* to *S4* with measures of only their direct value added (equation 52) net of directly marketed caloric imports (equation 53).

Food Dollar tables are compiled for each food expenditure account listed in table 2. The tables include answers to the two questions we introduced above, and are compiled mathematically as follows:

54. $\mathbf{Table\_xf}\,(S,Ir2) = \mathbf{VA\_}S1(Ir2,xf)' \;//\; \dots \;//\; \mathbf{VA\_}S13(Ir2,xf)'\;,\; \forall\, xf \in Xf$

55. $\mathbf{Table\_xf}\,(0S,Ir2) = [(\mathbf{i'}[S] \times \mathbf{Table\_xf}(S,Ir2)) \;//\; \mathbf{Table\_xf}(S,Ir2)]\;,\; \forall\, xf \in Xf$

56.a $\mathbf{Table\_xf} = [\mathbf{Table\_xf}\,(0S,Ir2) \,||\, \mathbf{Table\_xf}\,(0S,Ir2) \times \mathrm{i}(Ir2)]$

56.b $\quad // \; [0(14,Ir2) \,||\, \mathrm{xf}] \;//\; [0(15,FIr2) \,||\, \mathrm{Xdfadj\_}xf] \;//\; [0(16,FIr2) \,||\, \mathrm{ydnet\_}xf],\; \forall\, xf \in Xf$

For each account, $xf \in Xf$, equation 54 pivots and sequentially stacks supply chain stage value added vectors and denotes this as **Table_*xf***. Equation 55 sums down each column of **Table_*xf*** and stacks this column total row vector on top of the existing **Table_*xf*** matrix, denoting this row as stage 0. Equation 56 first adds a row total column to each row representing total value added by stage, then stacks the three parameters that address question 1 at the bottom, under the total (far-right) column with zeros inserted in the primary factor columns for each new row, denoted in rows 14 to 16. Table 3 displays compiled table *Xf1100* (food-at-home dollar) for 2023.

Table 3
Food-at-home dollar (Table Xf1100), 2023

Stage	Stage name	Salary and benefits	Output taxes	Property income	Imported inputs	Total
		U.S. dollars, millions				
0	Total	426,026	68,274	340,680	68,749	903,729
1	Agribusiness	16,424	3,115	15,170	8,920	43,629
2	Crops	8,673	-3,387	29,808	6,581	41,675
3	Livestock	4,540	5,248	31,796	676	42,261
4	Forestry, fishing, and agricultural services	6,527	354	2,481	1,949	11,311
5	Food processing	119,829	8,075	82,175	30,630	240,708
6	Transportation and storage	32,489	2,046	22,273	2,385	59,193
7	Food wholesale	55,492	5,895	40,811	3,713	105,911
8	Food retail	140,795	41,092	70,358	5,435	257,681
9	Food services	1,410	213	591	54	2,269
10	Energy	7,891	3,422	16,615	5,193	33,121
11	Finance and insurance	16,508	1,253	15,814	1,924	35,500
12	Legal and accounting	7,398	496	4,783	371	13,049
13	Advertising	8,050	451	8,003	919	17,422

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Stage	Stage name	Salary and benefits	Output taxes	Property income	Imported inputs	Total
		U.S. dollars, millions				
14	Total food dollars	—	—	—	—	1,068,290
15	Domestic food dollars	—	—	—	—	903,766
16	Farm share	—	—	—	—	168,732

2 of 2

Source: USDA, Economic Research Service.

Derivation of the Resource Multipliers

In this section, we present several equations to describe how we extend what was presented above in the Food Dollar 2.0 multipliers section and derive the resource multipliers, in physical units, to estimate total U.S. food system resource use. Equations 57 and 58 make relevant subcontractor adjustments and then 59 overwrites these equations with direct resources only. Equation 60 shows how we incorporate both direct and indirect household resource use into the analysis and equation 61 shows how one could replicate national resource data.

Concurrent to launch of the new Food Dollar data product, USDA, ERS anticipates launching a new data product called Resource Requirements of Food Demand (RRFD) that is documented in recent USDA, ERS technical bulletins (Rehkamp & Canning, 2025; Rehkamp et al., 2025) and, further, in this section. These data produce measures of resource use for a similar set of tables as the Food Dollar, but in physical units. Currently, the RRFD data covers employment measured in full-time and part-time jobs, energy use by type of energy commodity (measured in British thermal units (Btu)), and freshwater withdrawals (i.e., blue water) measured in gallons. Updates to the RRFD data series, including added resource and material accounts, may be introduced in the future with documentation made available once all updates have been tested and validated.

To specify subcontractor augmented resource multipliers, we replace the GDP multiplier matrices (**V** and **VS**) reported in equation 48 with the resource multiplier matrices (**E** and **ES**), extending Rehkamp and Canning (2025) and Rehkamp et al. (2025). We use the full import-inclusive **Xf** matrix and denote $S\lambda \subset S$ for $S\lambda = 1$ to rm_σ (the number of stages in the resources module varies by resource factor and also differs from the supply chain stages in the Food Dollar application). We define Σ as the set of all resource factors covered, $\sigma \in \Sigma$, where table 5 reports all resources currently measured. We further denote any vector or matrix of resource use measures as **σ** and **Σ** respectively. Lastly, any vector or matrix whose elements contain physical measures of a final market transaction involving a resource, $\sigma \in \Sigma$, is denoted **σf** and **Σf** respectively.

Equations 57–59 follow equations 49 and 51–52 above. Equation 57 measures gross outputs for each of the supply chain activities/commodities/vouchers and sums the products of these gross outputs and their subcontractor augmented resource multipliers (**ES**). This applies to all supply chain stages, except stage 1 (farm inputs). Equation 58 sums the direct plus subcontracting resources for stages $S2$ to $S4$ then deducts the sum-total for these same three stages applying the direct resource multiplier matrix (**E**) and applies it to stage $S1$. Then, in equation 59, we overwrite the direct plus subcontractor resources for stages $S2$ to $S4$ with measures of only their direct resources.

With this notation, we measure our supply chain resource use as follows:

57. $\mathbf{\Sigma}\_S\lambda(\Sigma,Xf) = \mathbf{ES}(\Sigma,S\lambda) \times \mathbf{M}(S\lambda,C) \times \mathbf{Xf}(C,Xf), \forall \lambda \in \{2 \text{ to } (rm\_\sigma)\}$

58.a $\mathbf{\Sigma}\_S1(\Sigma,Xf) = \mathbf{\Sigma}\_S2(\Sigma,Xf) + \mathbf{\Sigma}\_S3(\Sigma,Xf) + \mathbf{\Sigma}\_S4(\Sigma,Xf)$

58.b $- [\mathbf{E}(\Sigma,S2)\times\mathbf{M}(S2,C)+\mathbf{E}(\Sigma,S3)\times\mathbf{M}(S3,C)+\mathbf{E}(\Sigma,S4)\times\mathbf{M}(S4,C)] \times \mathbf{Xf}(C,Xf)$

59. $\mathbf{\Sigma}\_S\lambda(\Sigma,Xf) = \mathbf{E}(\Sigma,S\lambda) \times \mathbf{M}(S\lambda,C) \times \mathbf{Xf}(C,Xf), \forall \lambda \in \{2 \text{ to } 4\}$

In equations 57–59, *Xf* represents the accounts presented in table 2 but incorporating the resource matrices. Then, for equations 60–61, we define the additional food-related final expenditure tables in table 4 that are part of the RRFD data series.

60.a $\mathbf{\Sigma}\_S17(\Sigma,Xf) = \mathbf{E}(\Sigma,A) \times \mathbf{M}(A,C) \times \mathbf{Xf}(C,Xf)+ \mathbf{\Sigma f}(\Sigma,Xf),$

60.b $\forall\ Xf \in \{Xf3001,Xf3002,Xf3003,Xf3004,Xf3005\}$

Note that for only *Xf3004* and *Xf3005* are there non-zero values in $\mathbf{\Sigma f}(\Sigma,Xf)$. In the equations above, $\mathbf{M}(A,C) \times \mathbf{Xf}(C,Xf)$ could be restated as their matrix product which equals gross output vector for foods and beverages, $\mathbf{yf}(A,Xf)$.

To recover the national resource budget of all domestic resource use, we can collapse columns of the entire final demand injection matrix (figure 1), $\mathbf{x} = \mathbf{X} \times \mathbf{i}$, and the final market direct resource use matrix, $\mathbf{\sigma f} = \mathbf{\Sigma f}(\Sigma,X) \times \mathbf{i}$:

61. $\mathbf{\sigma}(\Sigma) = \mathbf{E}(\Sigma,A) \times \mathbf{M}(A,C) \times \mathbf{x}(C)+ \mathbf{\sigma f}(\Sigma)$

Table 4
Additional Resource Requirements of Food Demand (RRFD) food-related accounts

Account number	Account name
Xf3001	Home kitchen operations: Fleet
Xf3002	Home kitchen operations: Appliances
Xf3003	Home kitchen operations: Equipment and supplies
Xf3004	Home kitchen operations: Utilities
Xf3005	Home transportation (grocery): Petroleum use

Note: Table 2 and table 4 make up the complete set of Resource Requirements of Food Demand accounts. *Xf3000* is an aggregate of the accounts beginning with *Xf300-* and represents home kitchen operations and transportation (i.e., households).
Source: USDA, Economic Research Service.

There are two important extensions in RRFD compared to the Food Dollar analysis: (1) we expand the scope to consider resources used to deliver imports to final demand, and (2) we incorporate a household stage in the supply chain analysis (*S17*). An example of extension 1 is the distribution and marketing costs from the point of unlading to the consumer of a direct import. For extension 2, we measure embodied resource use for household kitchen operations in equation 60. This includes embodied resources for home kitchen operations including home kitchen appliances, equipment, and supplies and kitchen utilities. It also includes the embodied resources to maintain the fleet of vehicles and the fuel for grocery trips.

Additionally, equation 60 adds the subset of the direct resources allocated to food-related household final demand. We represent the direct resource use in food-related final demand as $\mathbf{\Sigma f}(\Sigma, Xf)$. This applies to the energy and water factors.

To calculate the food-related direct resource use, we document the data sources in table 5. We use a variety of data sources to determine household energy use including energy consumption by fuel and use (U.S. Department of Energy, Energy Information Administration, 2023a and n.d.), grocery share of total annual vehicle miles traveled (U.S. Department of Transportation (DOT), Federal Highway Administration (FHWA), n.d.; Food Industry Association (FMI), 2024), average fuel efficiency (DOT, Bureau of Transportation Statistics, n.d.), and total U.S. households (U.S. Department of Commerce, Bureau of the Census, n.d.). We apply 15 percent to domestic (total) water use (see table 4a in Rehkamp et al., 2025) to represent kitchen faucet water for food-related activities including washing dishes, rinsing fruits and vegetables, or cleaning up. The indirect resource use is calculated using the resource multiplier matrices, such as the embodied water in generating the electricity for home kitchen operations. The household stage applies to the at-home subset (i.e., table numbers *Xf1100* and *X f2100*) and we are not able to disaggregate the household resource use to individual categories.

Table 5
Development of data for food-related direct resource use in final demand

Resource factors	Description	Data source	Data and data source for allocation
Employment Full- and part-time employees	N/A[a]	N/A	N/A
Energy Coal, electricity, natural gas, petroleum products, renewable fuels	Fuel for trips to the grocery store and energy used in the home kitchen (e.g., electricity for kitchen lighting)	Residential and transportation energy use (DOE, EIA, 2023b)	Energy consumption by fuel and use (DOE, EIA, 2023a; DOE, EIA, n.d.), grocery share of total annual vehicle miles traveled (DOT, FHWA, n.d.; FMI, 2024), average fuel efficiency (DOT, BTS, n.d.), and total U.S. households (DOC, USCB, n.d.).
Water Freshwater withdrawals from surface and groundwater sources	Faucet water use for home kitchen operations	Total domestic water use (Rehkamp & Zachary, 2024; Rehkamp et al., 2025)	15 percent[b]

DOE, EIA = U.S. Department of Energy, Energy Information Administration; DOT, FHWA = U.S. Department of Transportation, Federal Highway Administration; FMI = Food Industry Association; DOT, BTS = U.S. Department of Transportation, Bureau of Transportation Statistics; DOC, USCB = U.S. Department of Commerce, Bureau of the Census.

[a] Unpaid household labor in the kitchen is beyond our scope.

[b] There is no estimate that we have been able to find in the literature on the kitchen faucet water use as a percentage of total household water use. Additionally, the ways household water is used would vary based on the household size, geographic location, the types of appliances in the home, local water restrictions, and other factors. Past research has used 15 percent (Rehkamp et al., 2021; Rehkamp & Canning, 2018) of use, drawing on the Residential End Uses of Water reports that estimate faucet water use to be 15.7 percent of indoor per capita use (Mayer et al., 1999) or 20 percent of indoor household use (DeOreo et al., 2016). Using an agent-based model of household water use, Linkola et al. (2013) found cooking and drinking water to be 18.2 percent when measured and 6.5 percent when modeled, as a percentage of total average water consumption per capita per day in the United States. Bastidas Pacheco et al. (2023) found that faucets accounted for 18.9 percent of indoor water use per capita in a case study of two cities in Utah. This area of research could better inform our model parameters and is a limitation of our study.

Source: USDA, Economic Research Service using data cited in the table.

Then, equation 61 exactly replicates the national resources budgets, including all resources allocated to final demand. Equations 54–56 above in the Food Dollar 2.0 section also apply to the resources module results compiled for data output tables, in addition to households (total embodied resources for home kitchen operations and transportation reported in aggregate as stage 17) and aside from the stages that only apply to Food Dollar 2.0 (stages 14–16).

Table 6
Total U.S. food system resources use by supply chain stage, 2022

Stage	Stage name	Resource		
		Employment (thousand full- and part-time jobs)	Energy (trillion Btu)	Water (billion gallons)
0	Total	25,223	10,203	29,776
1	Agribusiness	257	301	30
2	Crops	273	527	21,188
3	Livestock	181	591	2,148
4	Forestry, fishing, and agricultural services	222	17	0
5	Food processing	2,226	2,058	437
6	Transportation and storage	795	671	15
7	Food wholesale	1,196	337	43
8	Food retail	4,973	1,124	75
9	Food services	13,082	2,126	222
10	Energy	231	-	4,150
11	Finance and insurance	449	-	-
12	Legal and accounting	197	-	-
13	Advertising	236	-	-
17	Households	904	2,452	1,468

Btu = British thermal units.
Note: The stages 14–16 presented in table 3 for the Food Dollar 2.0 application are not relevant to the Resource Requirements of Food Demand.
Source: USDA, Economic Research Service, authors' calculations.

We present 2022 data in table 6 since the data sources and their releases differ from the Food Dollar 2.0 application. The RRFD data inputs include Ag-FEDS data documented in the methods section of Rehkamp and Canning (2025), data inputs documented in Rehkamp et al. (2025),[8] and also the data inputs documented in table 5.

Conclusion

This report presented three adaptations to Ag-FEDS that are described in-depth and with matrix algebra. First, we decoupled food and beverage commodities from the foodservice activities for complete passthrough accounting. Second, we accounted for non-farm commodities used in food, such as mined salt. Third, we adjusted the model to avoid reexporting imported commodities that would understate the value of direct imports. These three steps prepare Ag-FEDS for multiplier analysis. Then, the Food Dollar 2.0 and Resource Requirements of Food Demand (RRFD) Type I multiplier models were presented using matrix algebra. These two applications of Ag-FEDS generate

[8] For the results presented in table 6, one modification was made from the documentation in Rehkamp and Zachary (2024)—the public supply regression was run with State-level data instead of county-level data.

detailed data to better understand the U.S. food system and can inform questions such as, “How much value is added along different parts of the domestic food supply chain?” and “How are natural and human resources used throughout the U.S. food system?”

This report, along with recent companion reports (Baker & Zachary, 2026; Rehkamp & Canning, 2025; Rehkamp et al., 2025), document the data and improved methods for Food Dollar and RRFD. For the Food Dollar, this report represents a decennial review that results in modifications to the data product. Notably, redirecting farm and food commodities to their appropriate marketing channels and including non-alcoholic beverages in the definition of food will reduce the farm share of the food-at-home marketing bill and increase the farm share of the food-away-from-home marketing bill compared to the 2011 model (Baker & Zachary, 2026). The farm production share has been separated into three new industry groups—crops, livestock, and forestry; fishing; and agricultural services—collectively providing more detail on the role of agricultural production in the food supply chain. Other modifications are discussed in Baker and Zachary (2026). RRFD is a new, anticipated data product that describes how and where resources are used throughout the U.S. food system. Improvements reflected in both Food Dollar and RRFD include additional food category breakouts in an annual series. For example, there is a new frozen prepared foods category reported or the beef, pork, and other meats category is disaggregated into separate categories. These food-at-home food categories were previously available only on benchmark years and are now available annually. Additionally, for resources, analyses had been completed for one resource over time or several resources in one time period, but the analysis across the three resources can now be done annually.

The future applications for these data are plentiful. The Food Dollar multiplier model facilitates a detailed study of several dimensions of the commodity composition of food demand. For example, given a year-over-year change in expenditures recorded in a Food Dollar table, the Food Dollar model could be used to compute the change in producer and margin values of the specific commodities that make up that food product. Moreover, the Food Dollar model can compute the market values of commodities purchased as production inputs. With suitable price and quantity indexes, such as those published by the U.S. Department of Commerce, Bureau of Economic Analysis, a study of price and commodity-level changes in food production over time is possible. Researchers and policymakers concerned with supply chain pricing pressures from changes in food expenditures may be interested in these data.

The earlier Food Dollar report (Canning, 2011) served as a template for deriving similar value distributions in global settings. Notably, Canning et al. (2016) developed an estimate of returns to Canadian farm commodity producers from food expenditures (i.e., a “farm share”) using a Type I multiplier and Canadian System of National Accounts data, based on the method outlined in Canning (2011). Analogously, the methods outlined in this report can be applied to other regions and countries with sufficient national accounts data organized into a commodity-by-industry input-output table as described in, for instance, Miller and Blair (2022), or a reduced social accounting matrix format as described in Rehkamp and Canning (2025). Sufficient data on resource use that can be linked to national accounts data could be added to generate resource multipliers to describe a regional or national food system. This work could potentially serve as a roadmap for other countries to follow.

RRFD could facilitate scenario analysis to evaluate a change in food system resource use. These changes may be due to population change, changes in average diets (e.g., a shift to healthier diets), or other technological advances (e.g., food loss and waste interventions). Additionally, a structural decomposition analysis could be carried out to understand what is driving the changes in resource use and by how much over time.

Both the Food Dollar and RRFD model-derived data inform our understanding of different dimensions of the U.S. food system and there are plentiful opportunities for future analysis. Furthermore, because of its flexibility as modeling platform, Ag-FEDS could also be used in conjunction with other types of models, such as a SAM multiplier or computable general equilibrium model (CGE), for further research to inform both public and private decisionmakers.

References

Baker, Q., & Zachary, J. C. (2026). *A more detailed Food Dollar: Enhanced accounting of U.S. food costs* (Report No. ERR-357). U.S. Department of Agriculture, Economic Research Service.

Bastidas Pacheco, C. J., Horsburgh, J. S., & Attallah, N. A. (2023). Variability in consumption and end uses of water for residential users in Logan and Providence, Utah, U.S. *Journal of Water Resources Planning and Management*, *149*(1), 05022014.

Canning, P. (2011). *A revised and expanded Food Dollar series: A better understanding of our food costs* (Report No. ERR-144). U.S. Department of Agriculture, Economic Research Service.

Canning, P., Rehkamp, S., & Yi, J. (2022). Environmental input-output (EIO) models for food systems research: Application and extensions. In C. J. Peters & D. D. Thilmany (Eds.), *Food systems modelling: Tools for assessing sustainability in food and agriculture* (pp. 179–211). Elsevier.

DeOreo, W. B., Mayer, P., Dziegielewski, B., & Kiefer, J. (2016). *Residential end uses of water, version 2: Executive report.* Water Research Foundation.

FMI, The Food Industry Association. (2024). Food Industry Facts and personal correspondence.

Golan, A., & Vogel, S. J. (2000). Estimation of non-stationary social accounting matrix coefficients with supply-side information. *Economic Systems Research*, *12*(4), 447–471.

Leontief, W. (1967). An alternative to aggregation in input-output analysis and national accounts. *The Review of Economics and Statistics*, 412–419.

Linkola, L., Andrews, C. J., & Schuetze, T. (2013). An agent-based model of household water use. *Water*, *5*(3), 1082–1100.

Mayer, P. W., DeOreo, W. B., Opitz, E. M., Kiefer, J. C., Davis, W. Y., Dziegielewski, B., & Nelson, J. O. (1999). *Residential end uses of water.* AWWA Research Foundation and American Water Works Association.

Miller, R. E., & Blair, P. D. (2022). *Input–output analysis: Foundations and extensions (3rd edition).* Cambridge University Press.

Rehkamp, S., & Canning, P. (2018). Measuring embodied blue water in American diets: An EIO supply chain approach. *Ecological Economics*, *147*, 179–188.

Rehkamp, S,. Canning, P., & Birney, C. (2021). *Tracking the U.S. domestic food supply chain's freshwater use over time* (Report No. ERR-288). U.S. Department of Agriculture, Economic Research Service.

Rehkamp, S., & Zachary, J. C. (2024). Estimating U.S. subnational freshwater withdrawals by water use category from 1995 to 2021. *Water Resources Management,* 1–14.

Rehkamp, S., & Canning, P. (2025). *Documentation for the Agri-Food Economic Data System (Ag-FEDS): A more complete accounting of the U.S. agri-food economy* (Report No. TB-1973). U.S. Department of Agriculture, Economic Research Service.

Rehkamp, S., Canning, P., Gómez, M. I., Zachary, J. C., & Baker, Q. (2025). *Linking resource flows to economic sectors in the United States* (Report No. TB-1972), U.S. Department of Agriculture, Economic Research Service.

U.S. Department of Commerce, Bureau of the Census (USDOC, Bureau of the Census) (n.d.). *Total Households [TTLHH]*.

U.S. Department of Energy, Energy Information Administration (EIA) (n.d.). *Annual energy outlook products - archive*.

U.S. Department of Energy, Energy Information Administration (EIA) (2023a). *Annual energy outlook 2023*.

U.S. Department of Energy, Energy Information Administration (EIA) (2023b). *State Energy Data System (SEDS): 1960–2022* (complete).

U.S. Department of Transportation, Bureau of Transportation Statistics (BTS) (n.d.). *Average fuel efficiency of U.S. light duty vehicles*.

U.S. Department of Transportation, Federal Highway Administration (FHWA) (n.d.). *Summary of travel trends, National Household Travel Survey*.

Appendix Table A.1: Example R code for using Ag-FEDS to generate the Ag-FEDS multipliers

This R code uses Ag-FEDS to generate the Ag-FEDS multipliers.

This code is written for an imported data file where data are reported in

millions of U.S. dollars for one year. Each data element (VALUE) represents a unique (ROW)

and column (COL) combination as shown in the Ag-FEDS matrix (Figure 1 of this report).

The following code reshapes the linearized data into a matrix, including zeros in some

submatrices. A list of account codes for activities and commodities (F-accounts) is in

Table A.1 of ERS Technical Bulletin Number 1973.

```
## add data import statement
### Part 1: Construct rSAM components and assemble rSAM.

## Keep all columns except year

agfeds = subset(agfeds, select = c('ROW', 'COL', 'VALUE'))
##--------------------------------------------------------------------------------------------##
##  This is the matrix of intermediate transactions (T). It shows              ##
##  commodity production and purchases by activities.                          ##
##--------------------------------------------------------------------------------------------##
## vector of all account codes
tcol = subset(agfeds,
        ROW == 'A001' & !(substr(COL, 1, 1)=='X'),
        select = 'COL')
## extract values
T_long = subset(agfeds,
         !(substr(ROW, 1, 1) == 'L') & !(substr(COL, 1, 1) == 'X'))
## order by row, col
T_long = T_long[order(T_long$ROW, T_long$COL),]
## convert to matrix
T_ = matrix(T_long[,3], ncol = nrow(tcol), byrow = TRUE)
##------------------------------------------------------------------------##
##  This is the matrix of final market expenditures (X), including food  ##
##  expenditures (Xf). The sum of the entries in this matrix equals      ##
##  GDP + imports. This is also called the "injection matrix".         ##
##------------------------------------------------------------------------##
## vector of all expenditure account codes
xcol = subset(agfeds,
        ROW == 'A001' & substr(COL, 1, 1)=='X',
```

```
      select = 'COL')
## extract values
X_long = subset(agfeds,
       !(substr(ROW, 1, 1) == 'L') & substr(COL, 1, 1) == 'X')
## order by row, col
X_long = X_long[order(X_long$ROW, X_long$COL),]
## convert to matrix
X_ = matrix(X_long[,3], ncol = nrow(xcol), byrow = TRUE)

##---------------------------------------------------------------------##
## This is the matrix of primary factor inputs and imports (L). The sum ##
## of entries in this matrix equals GDI + imports. It is also called  ##
## the "leakages matrix".                    ##
##---------------------------------------------------------------------##
## vector of leakage account codes
lcol = subset(agfeds,
      substr(ROW, 1, 1) == 'L' & COL == 'A001',
      select = 'ROW')
## extract values
L_long = subset(agfeds,
       substr(ROW, 1, 1) == 'L' & !(substr(COL, 1, 1) == 'X'))
## order by row, col
L_long = L_long[order(L_long$ROW, L_long$COL),]
## convert to matrix
L_ = matrix(L_long[,3], ncol = nrow(tcol), byrow = TRUE)

##---------------------------------------------------------------------##
## This is the exogenous transactions (LX) matrix. All entries are 0.  ##
##---------------------------------------------------------------------##
## row and column codes are determined by L_ and X_, respectively
## extract values
LX_long = subset(agfeds,
        substr(ROW, 1, 1) == 'L' &
         substr(COL, 1, 1) == 'X')
## order by row, col
LX_long = LX_long[order(LX_long$ROW, LX_long$COL),]
## convert to matrix
LX_ = matrix(LX_long[,3], ncol = nrow(xcol), byrow = TRUE)
## assemble Ag-FEDS rSAM
T_X_ = cbind(T_, X_)
L_LX_ = cbind(L_, LX_)
rsam = rbind(T_X_, L_LX_)

##---------------------------------------------------------------------##
## Verify row and column accounts balance. This demonstrates that total ##
```

```
## intermediate and final purchases of commodities (i.e., outlays)      ##
## equal total production and imports of commodities                    ##
## (i.e., availability).                                                ##
##----------------------------------------------------------------------##
row_s = rowSums(rsam[1:nrow(tcol),])
col_s = colSums(rsam[,1:nrow(tcol)])
acctbal = round(row_s - col_s, 0)
balance1 = data.frame(row_s, col_s, acctbal)

##----------------------------------------------------------------------##
## Verify the sum of expenditures and imports in final markets equals   ##
## the sum of value added and imports.                                  ##
## That is, GDP + imports = GDI + imports.                              ##
##----------------------------------------------------------------------##
rsam_gdp = sum(rsam[,(nrow(tcol)+1):ncol(rsam)])
rsam_gdi = sum(rsam[(nrow(tcol)+1):nrow(rsam),])
balance2 = round(rsam_gdp - rsam_gdi, 0)

### Part 2: Construct the model and verify balance.
##---------------------------------------------------------------------##
## generate matrices
##----------------------------------------------------------------------##
Y_ = rowSums(rsam[1:nrow(tcol),]) ## total output
A_ = T_ %*% solve(diag(Y_)) ## direct requirements
M_ = solve(diag(length(Y_)) - A_) ## total requirements
W_ = as.matrix(L_) %*% solve(diag(Y_)) ## value added and imports multiplier

##---------------------------------------------------------------------##
## verify the model balances
##---------------------------------------------------------------------##
## total requirements times final demand reproduces gross output
balance3 = round((M_ %*% rowSums(X_)) - Y_, 0)
## gross output times value added and imports multiplier equals GDI + imports
balance4 = round(t(Y_) %*% t(W_) - rowSums(L_), 0)
## GDI + imports = GDP + imports
balance5 = round(sum(t(Y_) %*% t(W_)) - sum(X_), 0)
```