Bureau of Economic Analysis
U.S. DEPARTMENT OF COMMERCE

Technical Document: Methodology for Preparing National Trade in Value Added (TiVA) Statistics for BEA's Global Value Chain Analyzer Tool

Introduction to TiVA Statistics

International trade statistics under the current international guideline of the System of National Accounts (SNA) record gross flows of goods and services each time they cross a border. Over the last several decades, the world's economy has experienced tremendous globalization. Production and international trade in goods and services have been increasingly linked to global value chains (GVCs), which has significantly changed the nature and structure of international trade, especially with growing intermediate goods trade.[1] Globalization has led to increasingly complicated supply chains as intermediate goods (raw materials, for example) move strategically throughout the world as they are transformed step by step into final goods sold to end users. Existing data on gross trade flows continue to answer many important questions about the global economy; however, the growth of GVCs means that additional data are necessary for a more complete and nuanced understanding of global trade.

Trade in Value Added (TiVA) statistics help complete the picture of global trade by tracing the value-added contributions of domestic industries and the role of imported content in the global supply chains that support domestic production. These data are prepared using input-output analytical techniques to estimate the sources of value in the domestic production of goods and services. This paper describes the methodology used by the Bureau of Economic Analysis to prepare these statistics.[2]

Overall Strategy

The TiVA statistics described in this paper are prepared based on national-level supply-use tables for the United States prepared by BEA. These tables have important advantages over statistics prepared in a multi-regional framework. Most notably, national TiVA statistics for the United States can be prepared on a more timely basis and at a more detailed level of aggregation than multi-regional tables, results are more consistent with official national accounts data for the United States, and tables can be customized to emphasize specific industries/products of particular interest for the U.S. economy.

These data also have certain disadvantages relative to results prepared in a multi-regional supply-use framework. In particular, a multi-regional model allows a complete view from start to finish of a global value chain across multiple

[1] https://www.oecd-ilibrary.org/docserver/5k3v1trgnbr4-en.pdf?expires=1638973074&id=id&accname=guest&checksum=00CF2BDE148F9432CB10CE1AD0347E75

[2] BEA's national TiVA statistics were originally developed with support from the National Center for Science and Engineering Statistics (NCSES).

economies. This allows the identification of value that is "double counted" in standard trade statistics as it crosses the same border multiple times as well as value that is exported and later returned to an economy embedded in imported products. However, there are also notable challenges to assembling multi-regional supply-use tables, including inconsistent industry and product classification systems adopted by different regions, varying aggregation levels, and asymmetries in trade data across regions.

Multi-regional tables are built using a collection of national-level supply-use tables as well as other data prepared by individual national statistical offices (NSOs) that facilitate the integration of these tables into a single and consistent global supply-use table. Multi-regional tables generally cannot be compiled by a single NSO from regular national accounts data due to the absence of necessary data about other regions. As a result, multi-regional tables are typically compiled by international organizations or research institutes, which collect and integrate supply-use tables from the various regions.

Industry Detail

BEA's TiVA statistics are generated using make and use tables and import matrices prepared at a 138-industry level of detail, containing a mix of 3-digit and 4-digit North American Industry Classification System (NAICS) details. See Appendix B for a complete list of industries included in the model. In addition to the TiVA statistics themselves, BEA also provides the underlying 138-industry make and use tables and import matrices, which allows users to replicate most aspects of the TiVA calculations as well as use the tables in other types of analysis.

Country/Region Detail

For imports and exports, the TiVA dataset covers seven countries/regions, including Canada, China, Europe, Japan, Mexico, Rest of Asia and Pacific, [3] and rest of the world. BEA continues to examine the possibility of expanding these statistics to include additional countries/regions.

Upstream and Downstream Perspectives

The TiVA estimates can be broadly classified as taking either an upstream or downstream perspective on the analysis of U.S. final demand. One approach is to start at the end of the supply chain with final demand. Through the application of the TiVA framework, we can look upstream and see how domestic value added by industry and imported content by source country/region flow into and make up the products consumed in final demand. Alternatively, we can start at the beginning of the supply chain with total domestic value added for a specific industry or total imports from a specific country/region and look downstream to see the destination to which that value ultimately flows.

Using auto production as an example, one approach would be to start with final consumption of a vehicle. Some of the value added embedded in the vehicle can be attributed to the auto manufacturing industry itself, but many other inputs are needed to manufacture a vehicle. For example, the mining, primary metals, and auto parts manufacturing industries all play a role in extracting and processing raw ore into auto parts that are incorporated into the final vehicle. TiVA statistics allow us to see the domestic value added and imported inputs building up along each step in the supply chain to reach the

[3] The list of countries in the Asia and Pacific geographic area can be found here. The rest of Asia and Pacific region for National TiVA includes all countries listed except Japan and China.

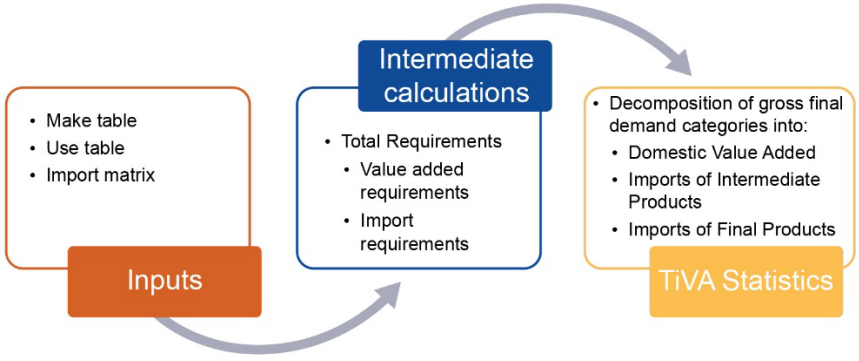
full value in the finished product.

Alternatively, we can start with the value added produced by an industry. For example, we could focus on value added from the mining industry. As discussed above, some of that value added will flow to the auto manufacturing industry through the refining and manufacture of metal products. Other value added will flow into the petroleum and coal product manufacturing industry and then into utilities as those products are used to generate electric power. From this perspective, we can track an industry's value added as it flows throughout the supply chain of U.S. production to see how the industry contributes to each component of U.S. final demand.

With these ideas in mind, TiVA estimates can be used to answer a variety of questions based on the perspective you take. From one perspective, TiVA estimates allow us to answer questions looking up from the end of the supply chain such as "How important is the mining industry for production by the auto manufacturing industry?" or "How much of the value in U.S. personal consumption is derived from the banking industry?" Alternatively, TiVA estimates allow us to answer questions looking down from the beginning of the supply chain such as "How much do services-producing industries contribute to auto production?" or "Which final demand components are most reliant on imports from China?"

Methodology

BEA's experimental TiVA statistics are produced using make and use tables and import matrices on an after redefinitions basis from BEA's Annual Industry Accounts combined with data on bilateral trade in goods and services from BEA's International Transactions Accounts. [4] Using these data as a starting point, the estimation process takes place in three main steps. First, certain conceptual modifications are made to the initial inputs to extend their usefulness in the context of TiVA. Second, the adjusted input tables are used to create total domestic requirements, value added requirements and import requirements matrices from which the TiVA statistics are built.[5] Third, the requirements tables are used to create the TiVA statistics themselves. A complete derivation of the TiVA statistics can be found in Appendix A.



[4] The TiVA services trade statistics consist primarily of statistics published in BEA's U.S. Trade in Services statistics, Table 2.3. U.S. Trade in Services, by Region or Affiliation and by Type of Service. Because some cells in BEA's trade in services table are suppressed, the TiVA statistics include imputed values for the suppressed cells. The methodology used to impute suppressed cell values relied on information from surrounding cells in the published Table 2.3. No information on the underlying suppressed values was used for imputation. The TiVA goods trade statistics consist of statistics publicly available through the U.S. Census Bureau's online database, USA Trade Online.

[5] For information on input-output statistics, please see "A Primer on BEA's Industry Accounts" and "Concepts and Methods of the U.S. Input-Output Accounts"

Conceptual Adjustments

Before developing trade-in-value added statistics, the underlying make and use tables and import matrices are adjusted in several ways to extend their usefulness for analyzing global value chains.

First, the import matrices are broken out into separate matrices for Canada, China, Europe, Japan, Mexico, rest of Asia and Pacific, and rest of the world. This is accomplished using published data on bilateral trade in goods and services from BEA's international transactions accounts. As some cells in these published tables are suppressed, imputations are made by applying ratios from surrounding years where unsuppressed data are available.

Second, the make and use tables are adjusted to reallocate most value from the "other" row to the commodities outlined in table 2. Unlike the rest of the table, the "other" row is not primarily comprised of related goods or services produced using similar input structures; rather, it is an adjustment row designed to account for things like direct domestic purchases abroad and direct foreign purchases within the United States. The new treatment reallocates value in this adjustment row to specific commodities whose input structures can be traced through the supply-use framework. For example, the "other" row includes an adjustment to properly account for expenditures by foreigners travelling in the United States, and this adjustment value has been reallocated to the accommodation; food services and drinking places; air transportation; and performing arts, spectator sports, museums, and related activities commodities. These changes improve TiVA estimates by accounting for the supply chain linkages necessary to provide these services to foreign travelers in the United States. BEA continues to research the best approach for reallocating the "other" row and expects to incorporate improvements to this process in future versions of the TiVA statistics and eventually to bring these changes into BEA's standard supply-use tables.

Table 1. Reallocation of Values from Commodity "Other"

Value Reallocated to Commodities	
Code	**Description**
23	Construction
311FT	Food and beverage and tobacco products
315AL	Apparel and leather and allied products
325	Pharmaceutical and medicine manufacturing
334	Other computer and electronic product manufacturing
339	Other miscellaneous manufacturing
481	Air transportation
487OS	Other transportation and support activities
711AS	Performing arts, spectator sports, museums, and related activities
721	Accommodation
722	Food services and drinking places
GFGN	Federal general government (nondefense)
HS	Housing

Third, scrap—another component of the "other" row—is separated into produced and non-produced scrap. Produced scrap arises within the current production period and has a traceable supply-chain footprint. For example, metal scrap generated

during fabrication embodies the inputs used to produce the material being scrapped. Non-produced scrap reflects disposal or sale of assets from prior periods and therefore does not embody current-period inputs. Separating these components improves attribution of value added and intermediate consumption across industries.

Requirements Matrices

The next step in preparing the TiVA statistics is to calculate requirements matrices based on the adjusted make and use tables and import matrices. The first step in this process is to prepare a domestic use table. The domestic use table is the standard use table less the import matrix. Next, a commodity-by-industry (CxI) domestic direct requirements table is calculated from the domestic use table by dividing industry use of each commodity by the industry's gross output. This table shows the amount of each commodity directly used for each dollar of gross output produced by an industry. Similarly, an IxC market share matrix is calculated from the make table by dividing commodity output of each industry by total commodity gross output. The resulting table shows the share of output for a given commodity produced by each industry.

Next, a symmetric CxC domestic direct requirements table is calculated by multiplying the CxI domestic direct requirements matrix by the IxC market share matrix. Then, the CxC domestic total requirements table is calculated as the inverse of the CxC identity matrix less the CxC domestic direct requirements table. Finally, the IxC domestic requirements table is calculated by multiplying the IxC market share matrix by the CxC domestic total requirements table. Each cell in this final table shows total domestic production of each industry in the row required at all stages of the supply chain per dollar of output of the commodity in the column delivered to final uses.

Multiplying the IxC domestic requirements table by a diagonal matrix of value added to gross output ratios yields the value added requirements table. Each cell in the value added requirements table shows how much value added from the industry in the row is embedded in one dollar of gross output of the commodity in the column. Similarly, multiplying the IxC domestic requirements table by a diagonal matrix of import to gross output ratios by country/region yields an import requirements table for each country/region. Each cell in these table shows the quantity of goods or services imported from the indicated country by the industry in the row embedded in one dollar of gross output of the commodity in the column.

TiVA Statistics

Domestic value added in U.S. final demand is calculated by multiplying the value-added requirements table by a diagonal matrix of commodities for delivery to final use. Similarly, imports for intermediate use embedded in U.S. final demand is calculated by multiplying an import requirements table for each bilateral trading partner by a diagonal matrix of commodities for delivery to final use. Imports for final use are taken directly from the final use section of each bilateral import matrix. Different TiVA statistics can be calculated by summing results in various ways from the detailed matrices obtained from the processes described above.

Summary

TiVA statistics offer a new and insightful perspective on the role of global value chains in meeting U.S. final demand. When used in tandem with traditional trade statistics, TiVA statistics offer a wealth of detail and insights into the underpinnings of the supply chain. The ability to distinguish between domestic value added and imports embedded in U.S. production allows for analysis into the upstream global integration of industries and estimates of how much of an industry's value added flows to each downstream component of final demand. The estimates are a valuable component of the complete set of integrated national accounts statistics.

Appendix A: Mathematical Derivation of TiVA Statistics

From make and use tables, the following are defined:

^: A symbol that, when placed over a vector, indicates a square matrix in which the elements of the vector appear on the main diagonal and zeros elsewhere.

q: A column vector in which each entry shows the total amount of each commodity's output.

g: A column vector in which each entry shows the total amount of each industry's output.

V: Make matrix in which the column shows for a given commodity the amount produced in each industry. This is an industry-by-commodity matrix.

U: Intermediate portion of the use matrix in which the column shows for a given industry the amount of each commodity it uses. This is a commodity-by-industry matrix.

U_m: Intermediate portion of the import matrix in which the column shows the amount of imported commodity used by a given industry. This is a commodity-by-industry matrix.

U_m^c: Intermediate portion of the bilateral import matrix for country *c* in which the column shows the amount of imported commodity from country *c* used by a given industry. This is a commodity-by-industry matrix.

U_d: Domestic intermediate inputs in which the column shows for a given industry the domestically-produced amount of each commodity it uses. This is a commodity-by-industry matrix.

$$U_d = U - U_m \quad (1)$$

B_d: Direct domestic input coefficients matrix in which entries in each column show the domestically-produced amount of a commodity used by an industry per dollar of output of that industry. This is a commodity-by-industry matrix.

$$B_d = U_d \cdot \hat{g}^{-1} \quad (2)$$

D: A matrix in which entries in each column show, for a given commodity, the proportion of the total output of that commodity produced in each industry. In the model, it is assumed that each commodity is produced by the various industries in fixed proportions. This is an industry-by-commodity matrix. D is also referred to as the market share matrix or transformation matrix.

$$D = V \cdot \hat{q}^{-1} \quad (3)$$

i: Unit (summation) vector column containing only l's.

I: Identity matrix, where $I = \hat{\imath}$.

F: Final demand portion of the use matrix in which the column shows for a given final demand category the amount of each commodity it uses. This is a commodity-by-final demand category matrix.

F_m: Final demand portion of the import matrix in which the column shows for a given final demand category the amount of imported commodity it uses. This is a commodity-by-final demand category matrix.

F_m^c: Final demand portion of the bilateral import matrix for country *c* in which the column shows the amount of imported commodity from country *c* delivered to a given final demand category. This is a commodity-by-final demand category matrix.

F_d: Domestic final demand matrix in which the column shows for a given final demand category the domestically-produced amount of each commodity it uses. This is a commodity-by-final demand

category matrix.

$$F_d = F - F_m \text{ (4)}$$

e: A column vector in which each entry shows an industry's value added.

m^c: A column vector in which each entry shows an industry's purchase of imports from country *c*.

f_d^p: A column vector in which each entry shows the amount of a domestically-produced commodity delivered to final demand component *p*.

From the above definitions, the following identities are derived:

$$q = U_d \cdot i + F_d \cdot i \text{ (5)}$$

$$g = V \cdot i \text{ (6)}$$

Equation (5) shows that the row sum of a domestic use table equals commodity output, and equation (6) shows that the row sum of the make table equals industry output.

From (2) and (5), we derive:

$$q = B_d \cdot g + F_d \cdot i \text{ (7)}$$

From (3) and (6), we derive:

$$g = D \cdot q \text{ (8)}$$

Substituting (8) into (7) and solving for q gives:

$$q = B_d \cdot D \cdot q + F_d \cdot i$$

$$(I - B_d \cdot D)q = F_d \cdot i$$

$$q = (I - B_d \cdot D)^{-1} \cdot F_d \cdot i \text{ (9)}$$

The matrix $(I - B_d \cdot D)^{-1}$ from equation (9) is known as the commodity-by-commodity domestic requirements matrix, and it shows, on a per-dollar basis, the domestic commodity output the economy must generate in order to deliver commodities to final users. Note that equation (9) also includes the identity that the commodity-by-commodity domestic requirements multiplied by domestic final demand equals commodity output.

Substituting (7) into (8) and solving for g gives:

$$g = D \cdot (B_d \cdot g + F_d \cdot i\,)$$

$$g = D \cdot B_d \cdot g + D \cdot F_d \cdot i$$

$$(I - D \cdot B_d)g = D \cdot F_d \cdot i$$

$$g = (I - D \cdot B_d)^{-1} \cdot D \cdot F_d \cdot i \text{ (10)}$$

The matrix $(I - D \cdot B_d)^{-1}$ from equation (10) is known as the industry-by-industry domestic requirements matrix and it shows, on a per-dollar basis, the output that each industry (row) on average produces in order to provide industry (column)

output to final users. The vector $D \cdot f_d \cdot i$ is a final demand vector where each entry shows the final demand for a domestic industry's output. Note that equation (10) also includes the identity that the industry-by-industry domestic requirements multiplied by final demand from domestic industries equals industry output.

Substituting (9) into (8) yields:

$$g = D \cdot (I - B_d \cdot D)^{-1} \cdot F_d \cdot i \ (11)$$

The matrix $D \cdot (I - B_d \cdot D)^{-1}$ from equation (11) is known as the industry-by-commodity domestic requirements matrix and it shows, on a per-dollar basis, the output that each industry generates in order to provide commodity output to final users. Note that equation (11) also includes the identity that the industry-by-commodity domestic requirements multiplied by domestic final demand equals industry output.

The value added requirements matrix (VA^{req}) is calculated by pre-multiplying the industry-by-commodity domestic requirements matrix by a diagonalized matrix of value added to output ratios by industry:

$$VA^{req} = [\hat{e} \cdot \hat{g}^{-1}] \cdot [D \cdot (I - B_d \cdot D)^{-1}] \ (12)$$

Bilateral import requirements matrices ($IMP^{req,c}$) are calculated for each country *c* by pre-multiplying the industry-by-commodity domestic requirements matrix by a diagonalized matrix of import to output ratios by industry:

$$IMP^{req,c} = [\hat{m}^c \cdot \hat{g}^{-1}] \cdot [D \cdot (I - B_d \cdot D)^{-1}] \ (13)$$

A decomposition of each final demand component *p* into domestic value added (DVA^p) and imports by source country/region ($IMP^{c,p}$) can be calculated by multiplying the value added and import requirements matrices by diagonalized commodity vectors for each final demand component:

$$DVA^p = VA^{req} \cdot \hat{f}_d^p \ (14)$$

$$IMP^{c,p} = IMP^{req,c} \cdot \hat{f}_d^p \ (15)$$

Equation (14) is an industry-by-commodity matrix showing domestic value added in domestically-produced output delivered to final demand component *p*. Equation (15) is an industry-by-commodity matrix showing imports for intermediate use from country *c* in domestically-produced output delivered to final demand component *p*. TiVA statistics in the Global Value Chain Analyzer Tool reflect these results combined with imports for final use by country (F_m^c).

As a reminder, these calculations use a hybrid technology approach that embeds both the industry-technology assumption (ITA) and the commodity-technology assumption (CTA) methods.[6] The mathematical derivation follows the ITA mathematical derivation, but the source tables used are after redefinition tables that are prepared based on the CTA. As a result of utilizing a hybrid of the ITA and CTA approaches, these requirements tables are a more effective tool for analyzing

[6] The ITA proposes that all commodities made by an industry share the same input structure. In contrast, the CTA proposes that each commodity has a unique input structure that is independent of the producing industry. For more information on the hybrid technology approach see Guo, Lawson, and Planting "From Make-Use to Symmetric I-O Tables; An Assessment of Alternative Technology Assumptions."

supply-chain relations among industries.

Appendix B: Industry Detail

Industry	Description
111	Crop production
112	Animal production and aquaculture
113FF	Forestry, fishing, and related activities
211	Oil and gas extraction
212	Mining, except oil and gas
213	Support activities for mining
2211	Electric power generation, transmission, and distribution
2212NW	Natural gas distribution and water, sewage and other systems
23EH	Education, hospital, and health structures
23MR	Maintenance and repair construction
23OC	Office and commercial structures
23OR	Other residential construction
23OT	Other nonresidential structures
23PC	Power and communication structures
23SF	Single-family residential structures
23TH	Transportation structures and highways and streets
321	Wood products
327	Nonmetallic mineral products
3311IS	Iron and steel mills and manufacturing from purchased steel
3313NF	Nonferrous metal production and processing and foundries
332	Fabricated metal products
33311	Agricultural implement manufacturing
33312	Construction machinery manufacturing
33313	Mining and oil and gas field machinery manufacturing
3332OM	Other machinery
3341	Computer and peripheral equipment manufacturing
3342	Communications equipment manufacturing
3344	Semiconductor and other electronic component manufacturing
3345	Navigational, measuring, electromedical, and control instruments manufacturing
334X	Other computer and electronic product manufacturing
335	Electrical equipment, appliances, and components
336111	Automobile manufacturing
336112	Light truck and utility vehicle manufacturing
33612	Heavy duty truck manufacturing
3362BP	Motor vehicle body, trailer, and parts manufacturing
3364	Aerospace product and parts manufacturing
3365AO	All other transportation equipment manufacturing
337	Furniture and related products
3391	Medical equipment and supplies manufacturing
3399	Other miscellaneous manufacturing
311	Food manufacturing
3121	Beverage manufacturing
3122	Tobacco product manufacturing

313TT	Textile mills and textile product mills
315AL	Apparel and leather and allied products
322	Paper products
323	Printing and related support activities
324	Petroleum and coal products
3251	Basic chemical manufacturing
3252	Resin, rubber, and artificial fibers manufacturing
3254	Pharmaceutical and medicine manufacturing
325X	Other chemical manufacturing
326	Plastics and rubber products
4231	Motor vehicle and motor vehicle parts and supplies merchant wholesalers
4234	Professional and commercial equipment and supplies merchant wholesalers
4236	Household appliances and electrical and electronic goods merchant wholesalers
4238	Machinery, equipment, and supplies merchant wholesalers
423X	Other durable goods merchant wholesalers
4242	Drugs and druggists sundries merchant wholesalers
4244	Grocery and related products merchant wholesalers
4247	Petroleum and petroleum products merchant wholesalers
424X	Other nondurable goods merchant wholesalers
425	Wholesale electronic markets and agents and brokers
42ID	Customs duties
441	Motor vehicle and parts dealers
445	Food and beverage stores
452	General merchandise stores
444	Building material and garden equipment and supplies dealers
446	Health and personal care stores
447	Gasoline stations
448	Clothing and clothing accessories stores
454	Nonstore retailers
4A0X	All other retail
481	Air transportation
482	Rail transportation
483	Water transportation
484	Truck transportation
485	Transit and ground passenger transportation
486	Pipeline transportation
48A	Scenic and sightseeing transportation and support activities
492	Couriers and messengers
493	Warehousing and storage
5111	Newspaper, periodical, book, and directory publishers
5112	Software publishers
512	Motion picture and sound recording industries
515	Broadcasting (except Internet)
5171	Wired telecommunications carriers
5172	Wireless telecommunications carriers (except satellites)
5174OT	Other telecommunications, including satellite
518	Data processing, hosting, and related services

519	Other information services
521CI	Federal Reserve banks, credit intermediation, and related activities
523	Securities, commodity contracts, and investments
524113	Direct life insurance carriers
5241XX	Insurance Carriers, except Direct Life Insurance
5242	Agencies, brokerages, and other insurance related activities
525	Funds, trusts, and other financial vehicles
HSO	Owner-occupied housing
HST	Tenant-occupied housing
ORE	Other real estate
532RL	Rental and leasing services and lessors of intangible assets
5411	Legal services
5415	Computer systems design and related services
5412	Accounting, tax preparation, bookkeeping, and payroll services
5413	Architectural, engineering, and related services
5416	Management, scientific, and technical consulting services
5417	Scientific research and development services
5418	Advertising, public relations, and related services
541X	Specialized design services and other professional, scientific, and technical services
55	Management of companies and enterprises
5613	Employment services
5617	Services to buildings and dwellings
561X	Other administrative and support services
562	Waste management and remediation services
61	Educational services
6211	Offices of physicians
6212	Offices of dentists
6213	Offices of other health practitioners
6214	Outpatient care centers
6215OH	Other ambulatory health care services
622	Hospitals
623	Nursing and residential care facilities
624	Social assistance
711AS	Performing arts, spectator sports, museums, and related activities
713	Amusements, gambling, and recreation industries
721	Accommodation
722	Food services and drinking places
811	Repair and maintenance
812	Personal and laundry services
813	Religious, grantmaking, civic, professional, and similar organizations
814	Private households
GFGD	Federal general government (defense)
GFGN	Federal general government (nondefense)
GFE	Federal government enterprises
GSLGE	State and local government educational services
GSLGH	State and local government hospitals and health services
GSLGO	State and local government other services

GSLE	State and local government enterprises