Measuring Backward and Forward Linkages in the U.S. Food and Fiber System

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Abstract

The interindustry flows required to support the output of the U S food and fiber system are decomposed into backward and forward linkages Our purpose is to evaluate the relative importance of farm versus food- and fiber-processing activities For the United States in 1977, backward linkages accounted for 11 percent ($80 billion) of nonfarm business activity of the food and fiber system Forward linkages dominated, accounting for 89 percent ($626 billion)

Keywords

Linkages, input-output, food and fiber system

Introduction

A hypothesis in the development literature is that investment in sectors with large interindustry linkages will promote more rapid economic growth than investment in a broad array of sectors of the economy (*12, 13*).[1] Hirschman defined two types of linkages that promote economic development.

1 The input-provision, derived demand, or *backward linkage (BL) effects*—that is, every nonprimary economic activity will induce attempts to supply through domestic production the inputs needed in that activity

2. The output-utilization or *forward linkage (FL) effects*—that is, every activity that does not by its nature cater exclusively to final demands will induce attempts to utilize its outputs as inputs in some new activities (*5*, p 100)

Attempts to test the linkages hypothesis have led to a lively debate on how to measure linkages (see *2, 7, 8, 9, 12, 13*)[2]

A related issue in developed economies concerns the stimulative effects of exports and domestic consumption of raw versus processed goods (*1, 10*) Our purpose here is to estimate the BL and FL effects in the U S food and fiber system to evaluate further the relative importance of farm versus food- and fiber-processing activities Beyond their use as descriptive indicators of the interrelatedness of sectors in the U S. economy, linkage measures help us trace the repercussions of change in a given industry through its impacts directly and indirectly on all sectors

For the United States, it is appropriate to differentiate between BL and FL because of the composition of final demand for U S farm products Farm exports of raw commodities have substantial impacts through BL effects on nonfarm sectors In contrast, exports of raw commodities do not generate domestic FL effects like those attributable

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[1]Italicized numbers in parentheses refer to items in the References at the end of this article

[2]This debate centers on the issue of how linkage indexes should be constructed Jones makes a strong case that BL indexes are measured best by the column sum of the usual Leontief inverse (*7*) Jones also claims that FL indexes are measured best by row sums of the 'output" inverse—that is, a matrix inverse derived from assuming constant output shares as the "technical output' coefficients However, as Yotopoulos and Nugent (*13*) show, the selection of a linkage index procedure partly depends on the research objectives at hand Given that there is no unique index or procedure for estimating linkages for all research needs, we proceed to decompose selected input-output flows in a developed economy Our purpose is to estimate the relative importance to the U S economy of sectors that are input suppliers to agriculture versus sectors that utilize the output of agriculture

to personal consumption for food and fiber in the United States As we will demonstrate, FL effects in the U S food and fiber system are substantially larger than all BL effects The linkages between the farm and nonfarm industries in the United States are dominated by FL effects generated by domestic personal consumption of food and fiber products. Our FL measure traces the linkages from raw farm sales to nonfarm processors and distributors of food and fiber to final users This FL notion is a measure of nonfarm output that results from the need to process and deliver the farm goods sold to domestic processors during the year In terms of domestic income and employment effects, significant benefits are obtained from the promotion of domestic consumption and exports of processed food relative to raw farm commodities

Linkages in the Food and Fiber System

Building on the work of Davis and Goldberg (*3*), since 1967 the Economic Research Service (ERS) of the U S Department of Agriculture (USDA) has developed an input-output (IO) measure of economic activity associated with the food and fiber sectors of the U S economy (*4*)[3] ERS has constructed Personal Consumption Expenditures (PCE) and export final demand vectors for food and fiber products These vectors are used with the Leontief inverse to obtain total gross output in the economy attributable to these final demand expenditures Because these estimates are on a current account basis, neither capital investment for replacement nor net investment is considered, although we could incorporate these elements as additional final demand expenditures

[3]"In 1957, Professors John Davis and Raymond Goldberg of the Harvard Business School coined the term 'agribusiness' as a reference to businesses related to agriculture Davis and Goldberg identified these businesses by their contribution to the economic activity required to support the eventual delivery of food, clothing and shoes, and tobacco to domestic consumers and to support agricultural exports They measured this economic activity using input output analysis When the Economic Research Service presented this type of measure in the early 70's they used a term other than 'agribusiness' They chose Food and Fiber System and estimated the equivalent of 17 8 million workers were employed in this system in 1967 (tables 1, 5) This accounted for 22 percent of total civilian employment compared with Davis and Goldberg s 41 percent in 1947 and 37 percent in 1954" (*4* p 1)

The estimation procedure for the output of the U S food and fiber system for a year when an I-O table exists is straightforward IO analysis Thus

$$Q = (I-A)^{-1}Y$$

where·

- Q = an nxl vector of sector outputs required to deliver the final demand of the food and fiber system,
- $(I-A)^{-1}$ = an nxn total requirements matrix,
- Y = an nxl vector of final demand of the food and fiber system identified by sector of origin, 1977 levels in 1977 prices, and
- n = the number of economic sectors, 79 for this analysis

If it is necessary to estimate output of the food and fiber system for a year subsequent to a published table, one must work with less information The only new information required is annual real (constant dollar) estimates of the final demand for the food and fiber system

The disaggregation of the nonfarm component of the output of the food and fiber system is obtained by use of the following procedure

First, partition the technology matrix into farm and nonfarm subsectors.

$$A = \begin{matrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{matrix} \qquad (1)$$

where

- A_{11} represents the 2 by 2 partition of intrafarm-sector direct requirement purchases, sector 1 is livestock, and sector 2 is crops,
- A_{12} is the 2 by 77 partition of nonfarm-sector direct requirement purchases from the farm sector,
- A_{21} is the 77 by 2 partition of farm-sector direct requirement purchases from the nonfarm sector, and

A_{22} is the 77 by 77 partition of intra-nonfarm-sector direct requirement purchases

Then, rewriting the commodity balance equation yields.

$$\begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} + \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} \quad (2)$$

where.

Q_1 = total commodity output of farm sectors 1 and 2,
Q_2 = total commodity output of nonfarm sectors 3, 4, , 79,
Y_1 = final demand for farm commodities 1 and 2, and
Y_2 = final demand for nonfarm commodities 3, 4, , 79.

Second, let the farm sectors be exogenous (let Q_1 be known), then we can solve for nonfarm output (see (*6*) for a more complete explanation of this technique)

$$Q_2 = A_{21} Q_1 + A_{22} Q_2 + Y_2 \quad (3)$$

or

$$Q_2 = (I-A_{22})^{-1} (A_{21} Q_1 + Y_2) \quad (4)$$

Finally, disaggregate equation (4) into BL's or FL's

$$BL = (I-A_{22})^{-1} (A_{21} Q_1) \quad (5)$$
$$FL = (I-A_{22})^{-1} Y_2 \quad (6)$$

Here, BL represents the nonfarm output required to support inputs to the farm sector FL represents nonfarm output required to support delivery to the food and fiber system's final demand by nonfarm sectors

Business Activity Linked to Farm Production

Table 1 presents the BL's and FL's of farm production with the rest of the food and fiber system Thus, the livestock and livestock products and crops industries are excluded because they represent mainly farm production Total nonfarm business activity associated with BL's and FL's was $706 billion in 1977 (column total)

The linkages of the food and fiber system are represented by BL and FL levels and linkage shares For example, $826 million in output of the farm equipment industry (#44) (repair parts, because output related to farm capital expenditures is excluded) was required to support the output of the food and fiber system. Of that total, 91 percent or $754 million, was used to support farm production—the BL About $72 million or 9 percent was used to support the processing and distributing activities of farm output—the FL

Metal containers (#39) provide another example The industry had $6 billion in sales related to the food and fiber system About 8 percent of these sales, or $495 million, were oil cans, metal pesticide cans, and so on, which supported farm production The other 92 percent, or $5 5 billion, were food containers used in processing and distributing farm output.

Although some industries would appear wholly FL's or BL's, that is not usually the case Food processing (#14) is not 100-percent FL's because its output includes manufactured feeds These feeds (processed grain and oilseed products) represent an input to the livestock and livestock products industry and thus represent a BL.

For the United States in 1977, BL's accounted for 11 percent (about $80 billion) of nonfarm business activity of the food and fiber system FL's dominated, accounting for 89 percent ($626 billion)

Implications

The export market for U S cash grains is important to large segments of the farm sector and the farm supply sectors However, domestic PCE of food and fiber products of the U S farm sector dominates the export markets in two ways size of final demand (table 2) and linkage effects (table 1) Thus, policy at the macroeconomic level or farm-specific policy enhancing consumption of U S -processed food products relative to exports of raw farm products will generate greater output effects on the U S economy.

Table 1—Proportion of total sectoral food and fiber system business activity attributable to backward and forward linkages, 1977

Sector[1]	Business activity	Backward linkages		Forward linkages	
	Million dollars		*Share*	*Million dollars*	*Share*
3 Forestry and fishery products	2,793 9	145 2	0 05198	2,648 7	0 94801
4 Agricultural, forestry, and fishery services	4,802 3	4,054 3	84425	747 9	15575
5 Iron and ferroalloy ores mining	310 0	70 9	22872	239 1	77128
6 Nonferrous metal ores mining	382 6	129 7	33896	252 9	66104
7 Coal mining	1,721 7	384 4	22328	1,337 3	77672
8 Crude petroleum and natural gas	10,903 0	4,072 5	37351	6,830 6	62649
9 Stone and clay mining and quarrying	578 4	255 9	44253	322 4	55747
10 Chemical and fertilizer mineral mining	313 0	154 1	49247	158 8	50753
11 New construction	0	0	0	0	0
12 Maintenance and repair construction	8,879 5	2,468 0	27794	6,411 6	72206
13 Ordnance and accessories	22 7	2 8	12388	19 9	87612
14 Food and kindred products	180,496 0	12,046 0	06674	168,449 0	93326
15 Tobacco manufactures	10,610 0	2	00003	10,610 0	99997
16 Broad and narrow fabrics, yarn, and thread mills	12,856 0	166 5	01295	12,690 0	98704
17 Miscellaneous textile goods and floor coverings	992 8	184 0	18537	808 8	81463
18 Apparel	34,684 0	24 1	00070	34,660 0	99930
19 Miscellaneous fabricated textile products	786 4	77 0	09800	709 3	90199
20 Lumber and wood products, except containers	2,193 5	379 3	17292	1814 2	82708
21 Wood containers	255 5	152 2	59576	103 3	40424
22 Household furniture	8 7	1 7	19883	7 0	80117
23 Other furniture and fixtures	15 4	3 8	24952	11 6	75048
24 Paper and allied products, except containers	9,839 6	931 8	09470	8,907 8	90529
25 Paperboard containers and boxes	5,824 0	518 9	08911	5,305 1	91089
26 Printing and publishing	3,179 4	307 4	09671	2,871 9	90328
27 Chemicals and selected chemical products	10,505 0	9,311 6	56415	7,193 9	43585
28 Plastics and synthetic materials	5,448 0	435 0	07984	5,013 0	92015
29 Drugs, cleaning and toilet preparations	1,672 3	261 6	15647	1,410 7	84353
30 Paints and allied products	464 0	92 8	19999	371 2	80001
31 Petroleum refining and related industries	12,103 0	4,532 7	37452	7,570 0	62548
32 Rubber and miscellaneous plastic products	6,837 6	1,078 3	15770	5,759 3	84230
33 Leather tanning and finishing	1,151 0	6 3	00553	1,144 6	99447
34 Footwear and other leather products	5,170 3	27 1	00525	5,143 1	99474
35 Glass and glass products	3,422 0	250 1	07308	3,171 9	92691
36 Stone and clay products	1,169 8	297 7	25452	872 0	74548
37 Primary iron and steel manufacturing	4,968 9	932 5	18767	4,036 4	81233
38 Primary nonferrous metals manufacturing	3,481 9	737 3	21175	2,744 6	78825
39 Metal containers	6,019 5	495 4	08231	5,524 0	91769
40 Heating, plumbing, and structural metal products	660 8	188 1	28468	472 7	71532
41 Screw machine products and stampings	1,274 1	174 7	13712	1,099 4	86288
42 Other fabricated metal products	2,284 5	526 7	23055	1,757 8	76945
43 Engines and turbines	382 0	138 3	36203	243 7	63797
44 Farm and garden machinery	825 9	753 5	91233	72 4	08767
45 Construction and mining machinery	269 9	75 7	28071	194 1	71929
46 Materials handling machinery and equipment	128 2	19 2	15000	190 0	85000
47 Metalworking machinery and equipment	408 1	70 1	17199	337 9	82801
48 Special industry machinery and equipment	604 8	100 1	16552	504 7	83448

Continued—

Table 1—Proportion of total sectoral food and fiber system business activity attributable to backward and forward linkages, 1977 (Continued)

Sector[1]	Business activity	Backward linkages		Forward linkages	
	Million dollars		*Share*	*Million dollars*	*Share*
49 General industrial machinery and equipment	634 2	196 0	0 30905	438 2	0 69095
50 Miscellaneous machinery, except electrical	901 2	191 3	21234	709 9	78766
51 Office, computing, and accounting machines	162 5	21 7	13370	140 8	86630
52 Service industry machines	488 4	64 2	13149	424 2	86851
53 Electric industrial equipment and apparatus	528 5	135 4	25621	393 1	74379
54 Household appliances	120 2	17 3	14453	102 8	85547
55 Electric lighting and wiring equipment	294 3	62 6	21300	231 6	78700
56 Radio, TV, and communication equipment	248 2	36 2	14591	212 0	85409
57 Electronic components and accessories	385 5	67 5	17517	318 0	82483
58 Miscellaneous electrical machinery and supplies	529 2	380 6	71917	148 6	28083
59 Motor vehicles and equipment	1,296 0	310 1	24115	975 9	75886
60 Aircraft and parts	169 6	28 1	16585	141 5	83415
61 Other transportation equipment	365 6	45 7	12527	319 8	87474
62 Scientific and controlling instruments	198 8	39 0	19641	159 7	80359
63 Optical, ophthalmic, and photographic equipment	394 7	48 6	12336	346 0	87664
64 Miscellaneous manufacturing	1,419 8	70 6	04972	1,349 2	95027
65 Transportation and warehousing	24,278 0	3,539 1	14577	20,739 0	85423
66 Communications, except radio and TV	5,022 3	692 7	13793	4,329 5	86207
67 Radio and TV broadcasting	30 6	3 8	12672	26 7	87328
68 Electric, gas, water, and sanitary services	15,757 0	3,560 0	22593	12,197 0	77407
69 Wholesale and retail trade	142,632 0	6,853 1	04804	135,778 0	95195
70 Finance and insurance	9,625 1	2,733 3	28397	6,891 9	71603
71 Real estate and rental	19,624 0	7,881 7	40163	11,743 0	59837
72 Hotels, personal and repair services (except auto)	2,343 6	304 9	13012	2,038 7	86988
73 Business services	28,601 0	3,589 8	12551	25,011 0	87449
74 Eating and drinking places	72,229 0	489 6	00677	71,739 0	99322
75 Automobile repair and services	4,039 7	636 6	15760	3,403 1	84240
76 Amusements	2,799 1	173 8	06210	2,625 3	93789
77 Health, education and social services and nonprofit organizations	1,089 2	438 2	40231	651 0	59769
78 Federal Government enterprises	2,021 8	222 6	11010	1,799 2	88990
79 State and local government enterprises	354 6	33 9	09576	320 6	90423
Total	706,276 0	79,906 0	11314	626,369 0	88686

[1]See (*11*) for the Standard Industrial Classification for each of the 79 sectors listed

To support this view, we estimate the BL and FL effects of each of the five major components of final demand of the food and fiber system This procedure involves reestimating equations (5) and (6) after substituting Q_1 and Y_2 obtained by using one of the five final demand components—for example, raw farm exports Table 3 shows the results, summed over all sectors

Comparing columns (1) and (2) in table 3 reveals that PCE expenditures and processed food exports generate nonfarm output that is about twice that of corresponding final demands However, raw farm exports and resulting nonfarm output are about equal in magnitude As expected, inspecting col umns (3) and (4) shows that nonfarm sectors which are forward linked to agriculture benefit most from

Table 2—Final demand of food and fiber sector, selected elements, 1977

Input output sector	PCE	Exports	Imports	Sector
	—Million dollars—			*—Type*
1 Livestock	2,511	199	-360	Farm level
2 Other agriculture	7,726	12 523	-1,047	Farm level
14 Food kindred products	113 507	7,308	-8,358	Processing manufacturing
74 Eating drinking	67,477	81	0	Retail trade processing

Source (*11*)

Table 3—Linkage effects of major types of final demand for food and fiber in the United States, 1977

Type	(1) Food and fiber system final demand 1977	(2) Resultant nonfarm total gross output	(3) Nonfarm linkages	(4)
			Backward	Forward
	Billion dollars			
Personal consumption expenditure				
Domestic food	255 9	499 0	60 8	438 2
Other food and fiber	114 4	213 9	10 0	204 0
Exports				
Raw	15 5	15 7	11 2	4 5
processed food	8 2	17 5	2 8	14 7
Imports	-18 1	-39 8	-4 8	-35 0
Total	375 9	706 3	80 0	626 4

processed food exports Nonfarm sectors that are backward linked to agriculture benefit most from raw farm exports One must be careful interpreting a transfer from raw to processed exports For example, a $1-billion reduction in raw exports would decrease nonfarm output less than the increase in nonfarm output from a $1-billion increase in processed exports However, because only a fraction of the reduced raw exports would be needed as input to the food processing industry, raw farm "surplus" would increase An increase of $3-5 billion in processed exports might be required to completely utilize the raw farm export transfer to domestic processing

Expansion of a dollar's worth of processed exports as a substitute for a dollar's worth of raw exports will stimulate forward-linked sectors, depress backward-linked sectors, and reduce the demand for raw farm products Total *nonfarm* output would increase because the FL effects are stronger than the BL effects However, the value of farm sales would fall initially because not all the reduction in raw farm exports would be utilized as input to the food-processing sectors Of course, we are considering only "first-round" effects, general equilibrium effects on prices and outputs are unknown In contrast to this substitution scenario, if processed exports are expanded without reducing raw exports, the linkage effects obtained provide substantially more stimulus to the food and fiber system than export expansion of raw farm products

Expanding domestic PCE for food relative to raw exports of food would have effects like those described when one compares processed exports and raw exports A policy dilemma is evident A $1-dollar expansion of domestic PCE or processed exports will yield more total nonfarm output than will a $1-dollar expansion of raw exports However, both backward-linked nonfarm sectors and the farm sector would produce more from a $1-dollar expansion of raw exports At least in terms of first-round effects, policy that stimulates domestic PCE while dampening foreign demand for raw exports can be expected to have uneven sectoral impacts Farm sectors and backward-linked nonfarm sectors suffer relative to forward-linked nonfarm sectors However, even small growth rates for domestic PCE for food combined with the sheer size of domestic PCE for food (about 17 times as large as raw export demand) could provide the demand stimulus for raw farm products required to offset declining raw farm exports

Although not undertaken here, the identification of sectoral winners and losers under alternative macroeconomic policy scenarios is an important issue and one that economists can conveniently analyze using the linkage framework developed in this article An additional area for research is the identification of processed food items for which the

United States has a comparative advantage There may be few of these items so that FL effects are not available through trade Still, given the nonfarm benefits of increased trade in processed foods, this is another important research area

Finally, there are several limitations to our use of IO analysis in identifying linkages First, there are the usual restrictive assumptions needed with static IO production functions with fixed proportions Second, there is the omission of capital expenditures for farm equipment third, there is the inherent problem of defining what comprises the food and fiber system of the United States

Use of the static IO model is dictated by the lack of a substitute framework that has empirical content for detailed accounting of interindustry flows Furthermore, IO is internally consistent and thus provides reliable, albeit static, insight into interindustry linkages The omission of capital expenditures in the final demand vector understates BL in the U S economy, yet is consistent with earlier efforts at USDA to reflect current account linkages

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