ALTERNATIVE APPROACHES TO THE ESTIMATION OF ECONOMIC IMPACTS RESULTING FROM SUPPLY CONSTRAINTS

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Abstract

The standard Leontief input-output approach to estimating the impacts resulting from changes in final demands is inappropriate to apply to cases in which the gross outputs of particular sectors of the economy are constrained because of conditions such as strikes or natural disasters. In this paper two alternative approaches are presented for estimating the impacts on production resulting from supply-constraints. The first is based on standard interindustry purchase coefficients, the second on sales coefficients. Each model is applied in turn to estimate the impact on the Kern County, California economy of a hypothetical curtailment of State-supplied water to the County's agricultural activities. The empirical results, as well as the underlying assumptions, of each approach are compared and discussed.

I. Introduction

In response to strikes, natural disasters, cartels, trade barriers, and various other sources of resource shortages in recent years, there has been expanding interest in the application of regional input-output models for the estimation of economic impacts of exogenous changes originating from the supply side of the market. To deal with the problems of supply-side constraints, some analysts have turned their attention toward the construction of interindustry models based on sales coefficients rather than the customary purchase coefficients (6, 2).

In this paper alternative approaches, using purchase and sales coefficients, to the estimation of regional economic impacts emanating from supply constraints are reviewed and the underlying sets of assumptions are compared. In contrast to the conventional procedure of estimating changes in sector outputs resulting from changes in final demands (using the purchase coefficients model) and changes in final payments (using the sales coefficients model), the approach herein is to estimate changes in the outputs of unconstrained sectors, given the reduced outputs of the supply-constrained sectors.

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Each of the approaches is then applied to the problem of a constrained water supply to agricultural production in Kern County, California and the differences in results are discussed.

II. A Supply-Constrained I-O Model Based on Purchase Coefficients

For estimating the economic impacts resulting from a reduction in the productive capacity of one or more industries, the basic, orthodox input-output model is inappropriate since, as mentioned, it is designed to trace the implications of exogenous changes in the final demand categories. The task of estimating the impacts of supply-constrained sectors on the rest of the economy can be directly addressed, however, if the direct requirements matrix, and the vectors of gross outputs and final demands of the standard I-O model are first partitioned as follows (11, 98-99):

$$\begin{vmatrix} qr \\ qs \end{vmatrix} = \begin{vmatrix} Arr & Ars \\ Asr & Ass \end{vmatrix} \begin{vmatrix} qr \\ qs \end{vmatrix} + \begin{vmatrix} fr \\ fs \end{vmatrix} \quad (1)$$

where gr, gs = the output of the constrained and unconstrained industries, respectively;

Arr = the direct requirements matrix of transactions between the r constrained industries;

Ars = the direct requirements matrix of coefficients of inputs by the s unconstrained industries of the r constrained industries' outputs;

Asr = the direct requirements matrix of coefficients of inputs by the r constrained industries of outputs by the s unconstrained industries;

Ass = the direct requirements matrix of transactions between the s unconstrained industries; and

fr,fs= the vectors of final demands for the production of the r constrained industries and the s unconstrained industries, respectively.

Given values for the outputs qr of the constrained sectors and for the final demands fs of the unconstrained sectors, one may solve for the outputs qs of the unconstrained sectors and the final demands fr of the constrained sectors in equation (1) as follows:

$$qs = (I\text{-}Ass)^{-1}(Asrqr + fs) \quad (2)$$
$$fr = (I\text{-}Arr)qr - Arsqs \quad (3)$$

For purposes of comparison with the sales-coefficient model developed in the next section, the underlying assumptions of the above model are:

1) an unchanged matrix A of purchase coefficients;
2) an unchanged vector of final demands for the production of unconstrained sectors;
3) an altered vector of final demands for the production of constrained sectors.

III. A Supply-Constrained I-O Model Based on Sales Coefficients

An approach to the estimation of the impacts of resources constraints, alternative to that of the preceding section is based on a sales-coefficient model first developed by Ghosh (3). Designed to trace the economic implications of changes in the final payments sector, the model is based on the set of sales coefficients B = (bij).

$$bij = xij/xi \qquad (4)$$

where xij = sales from sector i to sector j and xi = total sales (output) of sector i. The sales-coefficient model may now be partitioned in a fashion similar to the partitioning of the purchase-coefficient model in equation (1).

$$|qr\,|qs| = |qr\,|qs| \begin{vmatrix} Bss & Brs \\ Bsr & Bss \end{vmatrix} + |pr\,|ps| \qquad (5)$$

where pr, ps = vectors of final payments of the r constrained industries and s unconstrained industries, respectively.

Given the value of the outputs qr of the constrained sectors and for the final payments ps of the unconstrained sectors, one may solve for the outputs qs of the unconstrained sectors and the final payments pr of the constrained sectors in equation (5) as follows:

$$qs = (qrBrs + ps)\,(I\text{-}Bss)^{-1} \qquad (6)$$

$$pr = qr(I\text{-}Brr) - qsBsr \qquad (7)$$

The underlying assumptions of the model are:

1) an unchanged matrix B of sales coefficients;
2) an unchanged vector of final payments for the unconstrained sectors;
3) an altered vector of final payments for the constrained sector.

The model rests principally, of course, on the assumption of an unaltered matrix of sales coefficients over the period of analysis. To date, defense of the validity of this assumption has rested more on empirical investigations (e.g., (1, 5) of the actual stability of these coefficients compared with that of purchase coefficients rather than upon the weight of theoretical argument.[1]

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[1]Objections to the second assumption of an unchanged vector of final payments of the unconstrained sectors may be raised on the basis that there is little or no reason to assume that final payments of a particular sector will be unaltered if its total sales are ultimately decreased. This restrictive assumption, which occurs only among the unconstrained sectors in the model, may be relaxed by substituting into equation (6) the following relationship:

$$ps = qs \cdot \hat{a}s \qquad (8)$$

where âs is a diagonal s x s matrix of final payments coefficients derived from the purchase coefficients (direct requirements) model of section II. Final payments, ps, of the unconstrained sectors are now expressed as a function of total sales, qs. Under this assumption, equation (6) would be rewritten as:

$$qs = qrBrs(I\text{-}Bss\text{-}\hat{a}s)^{-1} \qquad (9)$$

IV. Empirical Application of the Models to Kern County, California

Kern County, California is situated at the southern end of the San Joaquin Valley. The county is California's third largest, with about 30% of its area consisting of valley floor. Currently, Kern is the nation's third most productive county in terms of agricultural output. Agriculture and oil provide the underpinnings for local manufacturing and services. In 1980 the County's population slightly exceeded 400,000. In the same year the County's per capita income (PCI) was $9112 (1980 Calf. PCI = $10,929; 1980 U.S. PCI = $9511) (12).

Within the county, the Kern County Water Agency purchases and distributes water from the California state aqueduct to a number of irrigation districts. While there are other sources of surface and ground water in parts of the county, the Agency distributes a substantial amount of irrigation water to agricultural users in the western areas where no alternative supplies exist. Either these areas are without underlying usable aquifers, or pumping depths preclude application of available water to a range of crops typically grown in these areas.

As part of an overall analysis regarding the dependence of the region on state-supplied water, it is of interest to estimate the impacts on the region that might be expected if the flow of this water were to be curtailed. Through employment by the County of a model (10) which incorporates agricultural production functions for various crops and takes full account of the fact that the county receives water from other sources as well as from the State, the County estimated that the cut-off of State water would directly result in a $190 million reduction in the $1.2 billion aggregate output of the agricultural sectors of Cotton, Food Feed Grains; Fruits & Tree Nuts; Vegetables, Sugar & Misc. Crops; and Oil Bearing Crops because no alternative sources of water are available for the affected areas (8). The estimated distribution of the reductions are as shown in Table 1. The results of these constraints upon the County's agricultural production can now be estimated by each of the alternative supply-constrained models (see equations (2) and (6)).

TABLE 1

ESTIMATED DIRECT REDUCTIONS IN 1980 KERN COUNTY AGRICULTURAL PRODUCTION WHICH WOULD RESULT FROM CURTAILMENT OF STATE-SUPPLIED WATER

Sector	Gross Output ($$10^6$)	Change in Gross Output ($ 10^6)
Dairy Farm Products	38.24	---
Poultry & Eggs	2.51	---
Meat Animals	53.48	---
Cotton	306.13	48.98
Food and Feed Grains	61.40	5.08
Fruits and Tree Nuts	464.59	104.25
Vegetables, Sugar & Misc. Crops	173.01	24.49
Oil Bearing Crops	48.82	7.46
Total	1148.18	190.26

The Purchase-Coefficient Model

The total reduction in gross outputs resulting from the reduction of $190M in agricultural production is shown in Table 2 as $89.50M. Of the 60 sectors in the open version of the model, there is recorded in the Table the 10 sectors with the greatest absolute declines in total sales (gross outputs). When the model is closed with respect to households--i.e. the column vector of household consumption and a corresponding row vector of wages and salaries are incorporated into the processing matrix in order to account for the Keynesian rounds of consumer spending—the increased output of the 53 sectors totals $249.64M.

The practice of "petroleum farming" in the County is evidenced by the ranking of the Petroleum Products sector. The output of this sector constitutes a quarter (24.9%) of the combined local purchases of the eight agricultural sectors. Since in accordance witht he purchase-coefficient model, reductions in the purchases of the constrained sectors result in corresponding reductions in the purchases of these sectors, the Petroleum sector is significantly affected by the decreases in agricultural production. The Mining sector is ranked second, according to the magnitude of the absolute decline in total output, not because of its importance as a direct supplier to the agricultural sectors but because of its strong technical linkages to Petroleum. The combined eight agricultural sectors purchase less than one-half of one per cent of their domestically supplied inputs from Mining, while the Petroleum Products sector secures 81% of its domestic inputs (viz. crude petroleum) from the Mining sector.

TABLE 2

ESTIMATED REDUCTIONS IN GROSS OUTPUTS IN SELECTED SECTORS RESULTING FROM PRODUCTION CONSTRAINTS EASED ON THE PURCHASE COEFFICIENT MODEL, KERN COUNTY, CALIFORNIA 1980

Sector	Open Model		Closed Model	
	Gross Output Reduction ($\$10^6$)	% Red	Gross Output Reduction ($\$10^6$)	% Red.
1. Petroleum Products	23.22	1.0	32.59	1.4
2. Mining	17.68	0.4	30.66	0.6
3. Agric. Forestry & Fishery Services	13.64	13.0	13.78	13.1
4. Wholesale Trade	8.40	2.4	15.29	4.4
5. Finance, Insurance & Real Estate	5.25	0.9	20.79	3.5
6. Services	4.43	0.5	29.16	3.4
7. Transportation	3.02	1.5	6.13	3.0
8. Nitrogenous & Phosphatic Fertilizers	2.78	18.5	2.78	18.5
9. Construction	2.61	0.2	5.61	0.5
10. Forest, Greenhouse & Nursery Prod.	1.93	5.6	2.10	6.1
:	:	:	:	:
52. Cookies and Crackers	0.00	0.04	0.19	3.2
Total	89.50		249.64	

The Agricultural, Forestry and Fishing Services sector, the Nitrogenous and Phosphatic Fertilizer sector and the Forest, Greenhouse and Nursery sector rank among the top ten sectors most affected by the agricultural constraints because of their roles as direct suppliers to the agricultural sectors. The remaining sectors in the first ten rank high because of their strong links to the Petroleum Products and Mining sectors and thus their indirect links to agriculture. (Together, the Petroleum Products and Mining sectors constitute 57% of the total sales of the 60 productive sectors.)

The Sales Coefficient Model

The results of estimating the impact of the reduction in agricultural production on the rest of Kern County regional economy by means of the sales coefficient model is shown in Table 3. The total impact of the activities by the open model is approximately 1/9 that estimated by the purchase coefficient model. There is, of course, nothing inherent in the sales coefficient model that would lead to a smaller overall impact estimate. The lower impact estimate in this case results from the fact that the agricultural sectors with the largest absolute reductions in output have very weak forward linkages compared with their backward linkages. This can be seen by comparing the proportions (ID/X) of intermediate to total sales with the proportions (IO/X) of intermediate to total purchases.

	ID/X	IO/X
Cotton	9.6%	41.4%
Fruits & Tree Nuts	1.8%	28.6%
Veg., Sugar & Misc. Crops	3.8%	23.5%

TABLE 3

ESTIMATED REDUCTIONS IN GROSS OUTPUTS IN SELECTED SECTORS RESULTING FROM PRODUCTION CONSTRAINTS IN AGRICULTURE BASED ON THE SALE COEFFICIENT MODEL KERN COUNTY, CALIFORNIA 1980

Sector	Open Model Gross Output Reduction ($\$10^6$)	Open Model % Red.	Closed Model Gross Output Reduction ($\$10^6$)	Closed Model % Red.
1. Cottonseed Oil Mills	4.39	11.03	4.65	11.7
2. Wines, Brandy & Brandy Spirits	1.70	2.3	2.58	3.5
3. Petroleum Products	0.80	0.0	26.63	1.1
4. Services	0.67	0.1	14.35	1.7
5. Mining	0.52	0.0	28.59	0.6
6. Prepared Foods, N.E.C.	0.27	2.2	0.41	3.3
7. Construction	0.21	0.0	17.40	1.7
8. Agric, Forestry & Fishery Serv.	0.11	0.1	1.81	1.7
9. Finance, Insurance & Real Est.	0.10	0.0	4.38	0.8
10. Wholesale Trade	0.08	0.0	5.86	1.7
:	:	:	:	:
52. Scrap, Used & Second Hand Goods	0.00	0.01	0.14	2.4
Total	9.88		176.63	

Given that the agricultural sectors in the County export about three-quarters (72.3%) of their total output, it is primarily these export flows that are reduced by the model, in accordance with the assumption of unchanged sales distribution patterns. The reduction in total output ($176.63M) in the closed model is markedly larger since in each round of decreased spending household consumption expenditures are reduced.

The sector most affected by the agricultural reduction, the Cottonseed Oil Mills sector, accounts for 79.8% of the Cotton sector's domestic sales. Similarly, the second ranked sector, Wines, Brandy and Brandy Spirits, accounts for 84.1% of the local sales of the Fruits & Tree Nuts sector. Food Feed Grains also ranks high in the Table because of its backward linkages to agriculture. The remaining sectors appear in the top rankings because of their general predominance in the Kern County economy.

V. Purchase-Coefficient vs. Sales-Coefficient Models

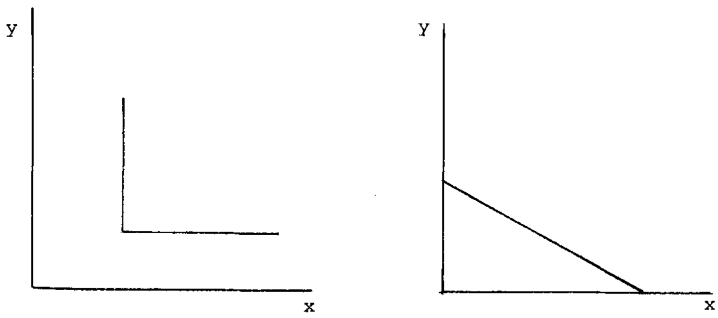
Application of the purchase-coefficient model to the initial reduction of $190 million in Kern County agriculture resulting from the curtailment of State-supplied water produced an estimated reduction in gross output in the rest of the County economy of $250 million, compared to the estimate of $177 million yielded by the sales-coefficient model. The difference in the two estimates is attributable to the weak internal sales linkages of the County's agricultural sectors relative to their purchase linkages, and to the nature of the assumptions of the two models.

The purchase-coefficient model implies a set of producers totally oriented to their factor markets. Each producer acts in such a way to minimize changes in his input structure. Substitution between externally and locally supplied inputs, or between locally supplied factors is precluded. The producer is motivated to preserve an unaltered pattern of locally supplied inputs and passively accepts the resulting changes in the distribution of his outputs. The sales-coefficient model implies significantly different producer behavior. In this model each producer is assumed to act to preserve a stable sales distribution. While minimizing disruptions to sales patterns, producers in this model readily accept changes in input patterns.

In contrast to the purchase-coefficient model which allows <u>no</u> substitution between inputs, the sales-coefficient model implies in theory <u>unlimited</u> substitution in each sector between the sector's various inputs. Given two inputs x and y, these two extremes in production functions can be represented by Figure 1.

On the national level the production function of the purchase coefficient model is the more readily acceptable of the two formulations in light of the considerable existing research that has been undertaken on the stability of individual sector technologies. On the regional level, however, the case is not so easily made. Regional purchase coefficients reflecting patterns of inputs from local producers represent departures from sector technological patterns since imported inputs are not represented in the matrix. In other words, the more sparse the transactions matrix of the regional economy, the weaker is the case for the relative appeal of the purchase-coefficient matrix based on fixed sector technologies. It is quite conceivable that a producer, particularly one heavily dependent on imports, may act in such a manner to preserve the stability of his distribution pattern while remaining relatively unconcerned about the origin of the inputs he purchases from one or more wholesalers.

Figure 1. Production Functions of the Purchase and Sales Coefficients Models



To date, however, a relatively limited amount of work, as mentioned, has been directed toward the stability of sales coefficients. In particular, studies focusing on the nature and magnitudes of substitutions between sector inputs resulting from the assumption of stable sales coefficients in the face of constrained production levels has yet to be undertaken.

> As we come to understand the nature of forces (economic and otherwise) bearing on the staility of supply patterns, we begin to lay a scientific basis for this model. It may be that the actions of economic agents in periods of market disruptions exert pressure that influences supply channels. In an attempt to impose stability (security) in markets where little exists, these forces may lead firms to satisfy requests for their products or services on the basis of previous distribution patterns. Casual evidence would seem to support this hypothesis. A rigorous understanding of the behavioral processes that might generate this pattern of sales, however, constitutes a central element in the scientific basis for attributing explanatory power to this model (4).

With respect to both models it should be emphasized that each is based on the assumption of constant coefficients. Circumstances may thus dictate that neither model described above be employed in unmodified form. For example, if the sectors in the Kern County economy which rely on agricultural inputs replace the domestic with imported supplies, or modify their input mixes in light of the factor scarcities, the assumption of fixed input proportions of the purchase-coefficient model of equation (2) is directly violated. Alternatively, if any one of the County's producing sectors (agricultural or non-agricultural) should alter the proportions in which it distributes its outputs among the non-agricultural sectors, the fixed coefficients of the sales-coefficient model of equation (6) would be invalid.

Further, if the response of the County's agricultural sectors to the water curtailment is solely to reduce production for the export market, neither of the above models would be relevant since the problem is no longer one of local supply constraints. Under these conditions the impact on the rest of the County's economy results directly from reduced agricultural exports and the economic implications can be appropriately estimated by application of the traditionally formulated regional input-output model to a change in final demands (exports).

In the final analysis, the appropriate model for the estimation of the economic impacts resulting from constrained factor supplies is that model which most closely reflects the anticipated economic responses of the producers in the economy. With further research in the area, it may be found that the choice is to some extent a function of the relative density of the I-O transactions matrix.

VI. Summary and Conclusions

In order to estimate the overall effects of supply constraints on specific sectors of an economy, an input-output approach based on purchase coefficients was formulated in which the gross outputs of the constrained sectors and the final demands of the unconstrained sectors are held fixed. A second, alternative interindustry model based on sales coefficients was then formulated in which the gross outputs of the constrained sectors were again set at fixed levels and the final payments sectors of the unconstrained sectors were assumed unchanged. Given its respective assumptions, each model yields estimates of the outputs of the unconstrained sectors.

Both models were then applied to the task of estimating the impacts on the regional economy of Kern County, California of a hypothetical curtailment of State-supplied water. The two models yielded quite different results. The variations in results arise from two sources: the differences in assumptions between the models and the difference between the strengths of the backward and forward linkages of the particular agricultural sectors in the models most affected by the water curtailment.

The purchase-coefficient model assumes for each sector a fixed pattern of inputs. Since the agricultural sectors in the County have strong direct purchase links (refined petroleum) to the Petroleum Products sector which in turn has strong backward links (crude petroleum) to the Mining sector, any reduction in the output of agriculture necessarily has marked implications in the model for the petroleum sectors. As the petroleum sectors (Petroleum Products and Mining) are the largest sectors in the 60-sector model in terms of total outputs, the impact on the economy estimated by this approach is quite significant.

By way of contrast, the total impact on the economy yielded by the open model version of the sales coefficient model is relatively small. The sales coefficient model assumes for each sector a fixed pattern of sales and hence that any reduction in a sector's output will cause the sector to reduce its sales proportionately among its various established markets. If, additionally, an unchanged technology is assumed, it is implied that the regional producer who finds his locally supplied inputs reduced will make up the shortfall with comparable imports. The application of this approach to the Kern County water curtailment situation resulted in a comparatively limited impact on the economy since the sales linkages of the agricultural sectors with the rest of the County economy are relatively minimal. The reduction in agricultural outputs was accounted for by the model almost entirely in terms of reduced exports.

For most applications the more orthodox purchase coefficient model perhaps remains the most attractive of the two approaches, given the appeal of the assumption of fixed sector purchase patterns relative to that of fixed sector sales distributions. However, the purpose of this paper is less to argue the relative merits of either approach than to emphasize the opportunity to choose between alternative approaches to the estimation of impacts resulting from supply constraints and the circumstances under which each alterntive might be appropriately considered. With additional research on the stability of sales coefficients and on the underlying rationale for such stability, the sales coefficient model, applied alone or possibly in conjunction with the purchase coefficient model, may prove a significant contribution to our capabilities in the area of regional economic impact analysis.

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