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THE STABILITY OF INPUT STRUCTURES IN A SUPPLY-DRIVEN INPUT-OUTPUT MODEL: A REGIONAL ANALYSIS

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I. INTRODUCTION

Disruptions in the supply of strategic resources or other crucial factor inputs often present significant problems for planners and policymakers. The problem may be particularly significant at the regional level where higher levels of product specialization mean supply restrictions are more likely to affect leading regional industries. To maintain economic stability in the event of a supply restriction, regional planners may therefore need to evaluate the importance of market versus non-market systems for allocating the remaining supply of the disrupted resource to the region's leading consuming industries.

If allocative efficiency is chosen as the primary goal, planners may choose to allow the market to distribute supplies of the disrupted resource, with higher prices dampening demand. This may lead to problems, however, as the extent of the reduction in demand will depend on user elasticities, and these may be difficult to establish for individual inputs in specific productive uses (Davis and Cherniack (1987), making it very difficult for policy makers to correctly assess the impacts of the restriction. Moreover, in cases where input restrictions are severe, market solutions to input shortages may not be favored if shortages lead to massive disruption in production in key regional industries. In these situations, even if there are alternate regional supplies, local production bottlenecks may arise through capacity constraints and if key industries cannot readily import the balance of their input requirement from outside the region, substantial production cutbacks may occur in the rest of the regional economy. If continued production is to be favored given other objectives, planners may allocate the remaining supplies of the disrupted input in order to maintain existing patterns of distribution of the resource, with users reducing their consumption patterns in proportion to the reduction in supply. Such a policy may be used in regional economies where planning authorities wish to maintain the supply of factors of production to key regional industries.

Input-output analysis has been used to evaluate policies based on distribution patterns reflecting both market and non-market considerations, and can give highly detailed information on both direct and the consequent indirect effects on an economy of a supply restriction. Demand-driven input-output analysis assumes that technology is fixed, there are no capacity

This work was not funded through Argonne National Laboratory

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distributed according to fixed patterns of sales and the economy satisfies its technical requirements in the event of supply constraints through changes in input demand.

The supply-driven approach has also been suggested as suitable for economies experiencing restrictions in supply in situations where there is monopoly control of domestic production and to the situation in many developing and socialist countries where central agencies dominate allocative decision-making (Ghosh 1958). Monopoly control of supplies of a critical resource may be especially relevant in a region where a specialized industrial base is heavily reliant on the continued supply of the disrupted resource from a small number of local suppliers. Regional producers in such a situation may not be able to use alternate sources outside the region to remain in production, at least in the short term, especially if an industry's comparative advantage over other regions producers relies on minimizing input transportation costs, or if transportation services may be provided through long term contractual arrangements.

The supply model was first proposed by Ghosh (1958) and has often been used to model supply restrictions by Giarratani (1976) for petroleum, Chen (1984) for aluminum and Davis and Salkin (1984) for water. The supply model has attracted criticism, however, for its assumption that input coefficients are perfectly elastic, leading to implausibly large changes in input structures (Oosterhaven, 1981, 1988; Giarratani, 1981; Davis and Cherniack 1987). This research evaluates the validity of the supply-driven variant of the conventional input-output framework to establish the extent to which it is applicable to situations where there are input restrictions. The supply-driven input-output model may be a valid framework for the analysis of supply disruptions if severe restrictions can be shown to cause only small average changes in input coefficients. The supply-driven model is tested using regional input-output tables given that larger input coefficient changes might be expected in response to a restriction than in a national economy given the relatively greater levels of specialization and reliance on trade at the regional level.

II. SUPPLY-DRIVEN INPUT-OUTPUT ANALYSIS

II.1. Origins of the Supply-Driven Model

In its original form, Leontief conceived the input-output model as a system of demand driven relationships with whatever final demand required being translated into a series of outputs, with inputs to each sector changing proportionately with changes in sectoral output. Although alternative input combinations may be available to firms in each sector given the absence of resource constraints, the basic input-output model assumes that once a production technology has been chosen, the firm will not substitute among inputs as the level of output increases or decreases. As Ghosh (1958, 1964) points out, however, if alternative input combinations exist, and if scarcities then arise, there may be attempts to ration the factor input in short supply by encouraging its substitution by other scarce factors. There may be market as well as technical factors that determine the equilibrium outcome, these market factors expressing themselves through allocation functions whereby sales from each sector are allocated to purchasing sectors in constant proportion to the level of output of the producing sectors.

The extent to which either demand constraints (production functions) or supply constraints (allocation functions) dominate the input-output system is determined by the degree of competition in input markets. Under competitive conditions with no resource shortages, allocation functions are secondary to production functions in determining the system equilibrium. On the other hand, in a situation where one firm controls supply in one or a number of factor markets, for example, resource scarcity exists and allocation functions will determine choice of production technology and particular input combinations, with production functions playing a secondary role.

Ghosh was critical of the assumption in Leontief's approach that there is excess capacity in most industries, even in the short-run, where changes in final demand do not expose any factor shortages and therefore do not change factor prices and consequently induce factor substitution. In the short run, there is an uneven distribution of excess capacity over all industries that may lead to bottlenecks if excess capacity cannot be easily transferred. This might easily be due to the lack of transportation or social infrastructure provision, for example (Ghosh 1964; p.112). An input-output system should contain, therefore, not only a series of demand constraints on the total output of each industry, but also a series of supply constraints on the distribution of the outputs from one industry to another. Changes in the nature of the final demand schedule may expose bottlenecks in the economy even if it is not beyond the capacity of the various industries impacted to meet the new final demand.

The supply-driven input-output system allows for these rigidities by relaxing the assumption that inputs vary in constant proportion with outputs. Such a system may well describe an economy that relies on significant central control if insufficient resources are available combined with inadequate production capacity to produce a mandated welfare maximizing output schedule. Here input combinations are not a function of the technical requirements of production processes, but of input rationing quotas, any change in which leads to changes in the technical coefficients. In such a case, stability in technical coefficients is highly unlikely for any given change in final demand in this case, and indeed, it may be likely that allocation coefficients are much more stable once central authority has determined the relative contribution to welfare maximizing output of each industry in the economy.

While an economic system that relies on predetermined industry outputs with resource shortages and or capacity shortages is more common to socialist countries, the use of allocation systems in market economies may be as equally valid if one considers periods of resource rather than capacity shortages. Situations where there is resource scarcity may arise for various reasons, particularly in situations where the production and or the marketing of the scarce resource are in the hands of one firm. In such a situation the producer may wish to maintain its market rather than alter its sales distribution pattern by selling for the highest return. Clearly here, especially if control of output distribution is transferred to central authority, the supply-driven model can provide useful information to planners in their design of policies to offset the impact of resource shortages given the objectives of regional development strategies.

II.2. Supply-Side and Demand-Side Input-Output Models

Input-output analysis is based on the two accounting identities which equate the value of each sectors output to the value of its inputs. thus:

$$\begin{aligned} & x = Zi + y \\ \text{and} \quad & x = Z'i + v \end{aligned}$$

where Z is a matrix of transactions from sector i to sector j , Z' being a transpose of Z .

y is a vector of final use (final demand)

v is a vector of primary inputs (value added)

x is a vector of gross outputs

i is the unit vector

Demand driven input-output models are built on the behavioral relationship:

$$z_{ij} = a_{ij}x_j \quad i,j,\dots,n.$$

which is the linear demand relationship giving the direct input technical coefficients.

Supply driven input-output models are built on the behavioral relationship:

$$z_{ij} = s_{ij}x_i$$

which shows that interindustry flows are proportional to the output (sales) of the producing industries, giving the allocation functions. Both models are written in matrix notation, thus:

$$\begin{aligned} X &= AX + Y \\ \text{and} \quad X' &= V + X'S \end{aligned}$$

where X is a column vector of sectoral outputs, x_i

X' is a row vector of sectoral inputs, x_j

A is a matrix of direct input technical coefficients,

a_{ij}

S is a matrix of direct output sales coefficients, s_{ij}

Y is a column vector of final demands, y_i

V is a row vector of final payments (value added), v_j

Base year sectoral outputs, x_i , are equal to base year sectoral inputs, x_i , because profits are defined as residuals. National (regional) product therefore equals national (regional) income. Both models are solved for X , and X' by:

$$\begin{aligned} X &= (I - A)^{-1} Y \\ \text{and} \quad X' &= V (I - S)^{-1} \end{aligned}$$

conditional on Z_{ij} , and therefore $(I - A)^{-1}$, and $(I - S)^{-1}$ being non-negative, with Y and V given.

The matrix $(I - A)^{-1} ((I - S)^{-1})$ therefore represents the sensitivity of sectoral outputs (inputs) to changes in final demands (value-added).

II.3. The Validity of the Supply-Driven Model

The theoretical validity of the supply-driven model has been the subject of some debate since the work of Ghosh in the 1950s, with majority of this work focusing on the evaluation of the consistency of supply-driven models with their demand-driven counterparts (for example, Bon 1988; Dietzenbacher 1989; Deman, 1988). Additional attempts have also been made to extend the basic supply-driven model to include both demand driven and supply-driven elements (Cronin 1984).

The empirical reliability of the supply-driven model has been tested by establishing the extent to which the allocation coefficients are stable over time compared to production coefficients, and the extent to which short run forecasts using allocation coefficients differ from those using production coefficients. Using the U.K. national tables, Ghosh (1964), found that over time production coefficients gave more accurate predictions than allocation coefficients compared to observed data for gross output. Augustinovics (1970) compared coefficient stability in both simple (direct coefficient matrices) and complex input-output forms (inverse coefficient matrices) and final structure matrices (primary input structure and final allocation structure), comparing structural changes within the Hungarian economy over time, and between Hungary and other countries. Changes in input structures over time were generally smaller than those in the output structure, although on some occasions output structures were more stable than input structures.

Giarratani (1980) compared structural change within both a supply and demand constrained framework for the US economy for both direct and indirect matrices for groups of primary, secondary and tertiary industries. Changes in the coefficients computed from the inverse matrices were found to be smaller than those in the technical coefficients matrix, indicating that structural changes in the demand driven model were of a similar magnitude to changes in the supply driven model. Giarratani also found only small differences in the predictive capabilities between the models, both in terms of the relative accuracy of their forecasts and the sectoral distribution and standard deviations of the error terms. A similar exercise was conducted by Bon (1986) for six U.S. input-output models. He found that the demand model performed marginally better than the supply model in forecasting gross outputs, the supply model produced superior results for a larger number of sectors.

II.4. Applications of the Supply-Driven Model to Supply Restrictions.

The supply-driven model has been used to examine the impact of natural resource shortages on national and regional economic growth. Giarratani (1976), for example, examined the strength of supply linkages between extractive industries and intermediate production in order to identify the energy sectors which have the most potential to restrict national output. He found that the total supply multipliers of the energy fabrication sector were relatively large, but only

slightly larger than those of the extractive energy sectors. High values for the supply multipliers indicate the potential each supplying industry had to disrupt output from the three energy sectors. In the event of a natural resource restriction, there may be intervention in the sector where the shortage occurs, meaning that in the context of an input-output system these sectors become exogenous rather than endogenous to the model. Giarratani therefore recalculates the direct and indirect matrices with the three energy sectors deleted from the original matrix S , and added to the primary input vector to show the effect on gross output of distributing supplies according to the patterns of sales before the shortage existed. The results show how authorities would be able to evaluate the contribution to welfare maximizing gross output of this and alternate allocation programs.

Changes in output due to supply restrictions are likely to affect primary inputs by more than the amount of the restriction itself, there being additional direct and indirect forward production effects than those captured using Giarratani's simulation procedure. Oosterhaven (1988) proposes a set of 'processing coefficients' that modify the new level of output to allow for these additional forward effects. While these coefficients are used in the context of the demand-driven model, they can be modified for the supply-driven model if it can be assumed that excess supplies are assumed to exist from all sectors except the one subject to the restriction, allowing direct and first round indirect effects as these input stocks are used up. In this special case, therefore, production is subject to supply factors, but changes in output do not violate the notion of fixed coefficients because of the existence of excess supplies. Total forward production effects resulting from a supply restriction cannot be measured using the demand-driven model as the latter assumes that there will be no changes in input coefficients. Total effects can be measured, however, in the context of the supply-driven model which allows the assumption of fixed coefficients to be relaxed.

Davis and Salkin (1984) model the effects of a water shortage on the agricultural production of a small region, using an ad hoc formulation of both a demand and supply constrained model which estimates changes in outputs from the unconstrained sectors with reduced outputs from the sectors where the shortage has occurred. The two models were found to give substantially different results due to the relative size of the forward and backward linkages of the agricultural sectors most affected by the water shortage. Impacts described by the demand model emphasize the important links agriculture had with the largest industries in the region, whereas the supply model describes a reduced pattern of output based on allocation coefficients, with input shortfalls being made up by imports from outside the region.

An alternative formulation of the supply-driven input-output model to situations where there is a supply disruption is presented by Oosterhaven (1988), based on earlier work by Isard and Kuenne (1953). The model uses exogenous primary inputs and regional output coefficients and combines them with technical coefficients from a regional attraction model (Klaassen 1967) to estimate the forward production effects on intermediate output. This overcomes the problem of double counting the output of the restricted sector with forward production effects and changes in regional technical coefficients being treated separately making the new input coefficients endogenous.

III. THE STABILITY OF INPUT STRUCTURES IN THE SUPPLY-DRIVEN MODEL

III.1. Introduction

In the supply-driven input-output model, the proportion of gross outputs of each industry being sold to other industries remains constant and a change in supply from one or a number of sectors to the remainder of the economy necessarily means that producers have to adjust their production technology to allow for changes in the availability of inputs. Exogenous changes are facilitated through adjustments in input structure i.e. substitution between inputs, either away from an input in short supply or towards an input in excess supply. The most important criticism of the supply-driven model is that changes in output, lead to changes in factor inputs which are economically and/or technically infeasible, implying that it is not possible to define a unique cost minimizing input function for the production of a good. This is the case particularly in situations where there is a supply restriction and output changes are highly uneven across sectors. Although small changes in inputs may be possible if one assumes a certain level of sub-optimality by firms in their combinations of input purchases, clearly there are only a limited number of technologies and input combinations to produce a given product. If it can be shown however, that large changes in the output of any part of the economy, such as would be the case with a supply disruption, do not cause more than minor changes in the resulting input coefficients, then the supply model remains a valuable tool for impact analysis.

The issue of technological consistency of input structures in the supply-driven model has received little attention in the literature. The supply model has often been accepted as legitimate purely on an empirical basis if it can be shown that allocation coefficients and supply multipliers show similar levels of stability over time as their demand model counterparts. Only the work of Gruver (1989) has so far contributed to an understanding of the response of firms to changes in supply. He has shown that small changes in input coefficients can be interpreted as firms making small adjustments in their input mixes to achieve a local approximation to a cost minimizing solution, based on linearization of the production function, with the assumption that relative prices do not change. Although Gruver's analysis is a significant development, it is still not possible to determine, a priori, whether or not the adjustments in input structure required to meet new levels of inputs will be consistent with the substitution possibilities available in the economy.

There is clearly a need, therefore, to explore the relationship between production and allocation coefficients to provide more rigorous support for the supply constrained model. While there may be a range of substitution possibilities open to most producers given the increasing scarcity or lack of one or a number of its inputs, assuming high levels of elasticity of substitution may oversimplify reality. As Chen and Rose (1986) point out, supply constrained models are often used to assess the impact of large scale supply restrictions on economic activity in the short term, and clearly adjustments to production technology given changes in input availability may not be feasible in the short run. Moreover, there are clearly a limited number of input substitution possibilities available for the production of a given commodity. Achieving or maintaining certain gross output levels may therefore be either technologically infeasible or at least inefficient compared to input combinations at lower levels of gross output.

III.2. Joint Stability

Chen (1984) and Chen and Rose (1986) have attempted to develop a theoretical linkage between production and allocation coefficients in order to ensure that changes in gross outputs in the supply constrained model can be supported by the range of substitution possibilities available to producers in an economy. They have suggested that the stability of input coefficients in the supply constrained model with fixed allocation coefficients, referred to as 'joint stability', can be seen as a function of the ratio of relative changes in the gross outputs of the sectors whose production technology is required to change in response to the supply disruption.

Given their framework Chen and Rose are able to suggest that the stability of input combinations from an exogenous supply disruption with fixed allocation coefficients depends on the size of the multipliers for each sector. If sectoral multipliers that consist largely of direct effects (those that describe proportional changes in the distribution of a factors across all sectors) dominate the model, with relatively insignificant indirect and induced effects, then the solution is more likely to tend towards equiproportional output changes than is a model where indirect and induced effects are more important.

Chen and Rose tested their formulation of stability relationships for a simulated 50% reduction in the supply of aluminum in the Taiwan economy. They found that even given the size of the disruption in supply to a material that has few substitutes, absolute percentage changes in nearly all production coefficients were found to be less than one per cent in most of the largest aluminum using sectors, and substantially less than that in other sectors.

III.3. The Joint Stability Relationship

Given that a reduction in the supply of a primary factor leads to necessary adjustments in the direct input technical coefficients (a_{ij}) when applying the supply driven model, following Chen and Rose (1986), changes in the matrix A can be defined thus:

$$da_{ij} = a_{ij} - a_{ij}^* = (X_{ij}/X_j) - (X_{ij}^*/X_j^*)$$

where a_{ij} (a_{ij}^*) are the original (new) direct input technical coefficients,
 Z_{ij}^* is the new amount purchased by sector j as input from sector i,
 X_j^* is the new output level in sector j.

Given that operation of the supply driven model assumes sales, or allocation coefficients are constant:

$$s_{ij} = Z_{ij}/X_i \quad s_{ij}^* = Z_{ij}^*/X_i^*$$

$$\text{and} \quad s_{ij} = s_{ij}^*$$

Therefore:
$$da_{ij} = s_{ij}X_i/X_j - s_{ij}^*X_i^*/X_j^*$$

Define: $e_i = X_i^*/X_i$

for each individual element, and in matrix form:

$$E = (X^*)(X)^{-1}$$

where E is a diagonal matrix, the i th element of which is X_i^*/X_i .

Then:

$$\begin{aligned} da_{ij} &= s_{ij} (X_i/X_j - e_i X_i/e_j X_j) \\ &= s_{ij} (X_i/X_j (1 - (e_i/e_j))) \\ &= Z_{ij}/X_j (1 - (e_i/e_j)) \\ &= a_{ij} (1 - (e_i/e_j)) \end{aligned}$$

The relationship between a_{ij} and a_{ij}^* can be written as:

$$da_{ij}/a_{ij} = 1 - (e_i/e_j)$$

or: $a_{ij}^* = a_{ij} (e_i/e_j)$

or: $a_{ij}^* = a^{ij} (X_i^*/X_i)/(X_j^*/X_j)$

or: $A = EAE^{-1}$

The stability of input combinations assuming constant allocation coefficients is therefore dependent on the ratio of relative changes of corresponding sectoral gross outputs. Percentage changes in production coefficients are computed from relative, or weighted, changes in sectoral gross outputs with the initial impact being spread equi-proportionately across all sectors by the allocation functions. Divergence from direct proportional increases or decreases resulting from the exogenous change reflects indirect and induced supply side effects. The extent to which allocation and technical coefficients exhibit 'joint stability' will vary inversely with the size of sectoral multipliers in the allocation model. This is because multipliers are a combination of direct (where changes are equi-proportional across all sectors) and higher order effects. The more dominant the direct effects are the closer changes in input coefficients are likely to be to equiproportional change.

Joint stability in an absolute sense is an ideal property of the input-output model whereby "production and allocation coefficients remain constant after an application of either the production or allocation version of the model" (Rose and Allison 1989, p. 453). Clearly such a condition may only be satisfied where all percentage changes in either supply increases/restrictions, or demand increases/decreases are equal. Although absolute joint stability may not be attainable, however, it is possible that coefficient changes will be relatively small

and within tolerable limits of accuracy in many cases. In such cases relative joint stability may exist if "production and allocation coefficients approximate their original value after an application of either the production or allocation version of the model" (op cit. p. 453).

The concept of relative joint stability is adopted by this research to evaluate the applicability of the supply-driven input-output model. The evaluation is made in the context of a regional economy where the stability of input structures may be less attainable in the event of a supply restriction, given the reliance of regions on external trade for the inputs required to meet production schedules.

IV. TESTING THE STABILITY OF INPUT STRUCTURES IN THE SUPPLY-DRIVEN INPUT-OUTPUT MODEL: THE CASE OF WASHINGTON STATE

IV.1. Introduction

Research examining the reliability of the supply driven input-output model and its plausibility for evaluating economic impacts has been undertaken entirely using national input-output data. National economies tend to be relatively self-contained units where the flows of goods and services to meet intermediate and final demand schedules within the economy tend to significantly overshadow those traded with foreign countries. Even though many regional economies exhibit high levels of diversification, most tend to be more specialized than the national economies of which they are a part and tend to be more reliant on trade with other regions.

Given the levels of specialization among regions and the consequent importance of interregional trade in goods and services, regional economies tend to be highly responsive to short run changes in supply and demand both from within the region itself or from elsewhere in the economy. The speed at which regional economies can respond to these changes may depend on a variety of factors. Among these may be the amount of regional excess capacity, the ability to attract factors of production in the short run, differing lag times in making input and output adjustments, and the ability of firms to direct their products to new markets. Failure in any one of these areas may lead to losses in regional production as imported supplies replace output produced within the region. The region may be able to offset these losses in the long term with various changes in regional technology. These may include changes in sectoral product mix, variations in relative prices, input substitution, technical change (adoption of 'best practice' techniques) and import substitution as with the expansion of regional production.

As Beyers (1972) has shown for the Washington economy, substantial changes in supply or demand in the short run, in this case due to rapid economic growth, is more likely to lead to changes in trading patterns than to changes in technology. Exhaustion of regional excess capacity led the major growth industries to draw on sources of input supply from outside the region to allow them to meet their demand schedules. Thus, as Table 4.1 shows, short run growth in Washington State is reflected in changes in the ratio of imported inputs to total inputs during years when the state's economy was growing. In the growth year 1967, imported intermediate input exceeded or equalled the proportion of intermediate input supplied from

within the region. In 1963 and 1972, when growth was more sluggish, imported intermediate inputs fell below those supplied locally.

Evaluating the stability of input coefficients in a regional context may therefore provide a useful test of the supply model because of the likelihood that changes in supply will have the potential to cause more significant short term disruptions in factor input markets. Regional economies tend to specialize in their production of goods and services, with a relatively large proportion of their sectors involved in a small number of industries, often meaning that regional producers have to rely on trade outside the region for their inputs to production. Regional economies are therefore more vulnerable to supply restrictions if significant proportions of input requirements cannot be met from within the region. The importance of trade is therefore an essential part of the evaluation of the impacts of supply restrictions in a regional context.

The Washington State economy was chosen for the stability simulations because of its highly open nature with significant trade in most sectors being undertaken with industries outside the region. The Washington State economy is also a reasonably representative region with no extreme conditions relating to size, diversification and self-sufficiency which may allow some general conclusions to be drawn from the simulation results. Additionally, four survey-based tables are available for the State, three of which give details of both regional and total direct input requirements.

The next section describes the data and sectors chosen for the simulations, Section 3 describes the methodology for evaluating the impact of a factor input restriction, on both a closed and open version of the Washington state economy. Section 4 presents and discusses the simulation results, and Section 5 evaluates the significance of the Oosterhaven measure of forward production effects.

IV.2. Data and Sectors Simulated

Data for the simulations were taken from the four input-output data bases for the state of Washington produced by the University of Washington Graduate School of Business Studies (Bourque and Weeks, 1969; Beyers et. al., 1970; Bourque and Conway, 1977; and Bourque, 1987).

The sectors chosen for the input restriction simulations were selected from those that were selling to at least five common sectors in each of the input-output years (i.e., five or more cell entries in each row). Many of the sectors in the Washington economy could not meet this criterion, partly due to the substantial structural change throughout the period and partly due to the slump in the regional economy in 1972 substantially cut down the level of regional activity in many of the sectors. Six sectors were chosen for the restriction simulations: Other Food Products, Sawmills, Other Wood Products, Plywood, Petroleum and Aluminum.

IV.3. Simulation Proceedure

Regional input-output models often give information on technical and regional coefficients. The matrix of intermediate flows, (Z_{ij}) , represents the sum of imports, (m_{ij}) , and the regional inputs, (r_{ij}) . The stability of regional and technical coefficients for the Washington state economy for each input-output year were calculated given a 50% percent reduction in the output of each chosen sector (X_e) , in the following manner. The matrix of allocation coefficients, S , is computed from the matrix of interindustry flows, Z , thus:

$$S_i = Z_i/X_i$$

with each element being defined thus:

$$s_{ij} = z_{ij}/x_i$$

$$\text{where } z_{ij} = r_{ij} + m_{ij}$$

The matrix of technical coefficients, A , is calculated from the matrix of interindustry flows, Z , thus:

$$A_j = Z_j/X_j$$

with each element being defined thus:

$$a_{ij} = z_{ij}/x_j$$

The matrix of intermediate flows, Z , is modified to include the production restriction to give Z^* , defined thus:

$$Z^* = Z - X_e$$

where X_e is the vector of inputs to industrial sectors from the sector whose production has been curtailed. The matrix of allocation coefficients, S , is adjusted to include the production restriction to give S^* , defined thus:

$$S^* = S - Ze_j/X_e$$

where Ze_j is the coefficient corresponding to X_e . The reduction in input is then incorporated into the vector of primary inputs, V , thus:

$$V^* = V + X_e$$

The inverse matrix is computed from the new matrix of allocation coefficients, S^* , thus:

$$(I - S^*)^{-1}$$

The model is solved for the new gross outputs in the economy to reflect the reduction in the output from the relevant sector and the consequent indirect and induced effects, thus:

$$V^* (I - S')^{-1} = X^*$$

where $V^* = V - 0.5X_c$, for example, to reflect a 50% reduction in the output of X_c . The extent to which industries have modified their input requirements can be examined using the new matrix of interindustry flows, Z'' , calculated thus:

$$X^* S' = Z''$$

The new matrix of technical requirements, A^* , is calculated using the new gross output totals, thus:

$$A^* = Z_{ij}'' / X_j^*$$

with each individual element defined thus:

$$a_{ij}^* = z_{ij}'' / x_j^*$$

Chen and Rose then calculated stability measures from the original and new technical requirements matrices, thus:

$$(|A' - A|/A)100$$

The procedure is then repeated for the regional coefficients, where $z_{ij} = r_{ij}$.

IV.4. Simulation Results

Tables 1 to 6 summarize the results of the simulations for the six sectors chosen from the four Washington data bases. Each table presents percentage differences in input coefficients due to a 50% reduction in the output of the sector listed at the top of each table, with the sectors impacted by the shortage shown on the left. Each table gives average absolute percentage differences and their respective standard deviations. Percentage changes in the sector whose output has been restricted is not included in the tables of absolute differences. Results for the years 1963, 1967 and 1972 list percentage differences for both the pure regional model, with its coefficients representing interregional transactions, and the total requirements model, which adds imports to the intraregional flows. Results for 1982 show only the regional coefficients with no data available for that year for import coefficients.

Table 1 shows the impact of a 50% reduction in the output of Other Foods. An output restriction in this sector seems to cause only minor disruptions to the six sectors purchasing its outputs directly, with 35 of a possible 42 average coefficient differences falling between zero and +1%. The most significant input coefficient changes were found in the Beverages sector with average absolute differences of +1.5% for the total requirements model in 1967 and 1972,

and close to +1.0% for the regional model in both years rising to almost +2.5% in 1982. Larger coefficient changes were found for Livestock and Products, Meat Products and Dairy Products between 1963 to 1972, with smaller changes in 1982. Average coefficient differences peaked in 1967 for the Canning and Preserving sector, with changes of +1.1% in the regional model, and +2.3% in the total requirements model.

A restriction in the output of the Plywood sector (Table 2) is primarily felt within the wood and paper products industry grouping. coefficient changes were the most significant for Other Wood Products, with coefficient differences rising to +1.7% for the pure regional model in 1982, for Pulp Mills, with coefficients in 1972 changing by +1.7% in the regional model and by +1.7% in both models and for Furniture and Fixtures in the first two input-output years.

The effects of a 50% output curtailment in the Other Wood Products sector is evaluated for its seven direct purchasers (Table 3). A restriction in this sector does not seem to substantially effect input coefficients with no coefficients changing by more than +1.0%. Small peaks in coefficient changes are found in 1967 for Other Manufacturing, and 1972 for Furniture and Fixtures. A number of coefficient changes have standard deviations which are somewhat large, reflecting the fact that the majority of sectors seem to have responded to the shortage in the output of other Wood Products by increasing their inputs from one sector, Construction.

The effect of an output restriction in the Paperboard Mill Products sectors was evaluated for ten sectors in the states economy (Table 4). Coefficient changes seem to be larger for those sectors in the food and food processing industry group than they are for the remaining sectors. In the food sectors the largest coefficient change is +2.57% with the majority of coefficient difference falling between +1.0% and +2.0%. For the second group of industries the largest coefficient change is +4.07%, with all but eight of a possible 35 coefficient differences falling between zero and +1.0%. Coefficient changes for the 1967 data were generally smaller than those for the other three years and those for 1963 larger than in all succeeding years. Somewhat large values for the standard deviations, notably for the chemicals, glass, metals and aerospace industries show that these sectors adjusted their input coefficients from one or a small number of sectors by substantially more than the mean change. In this instance these sectors were significantly increasing their inputs from the service industries, primarily trade, in response to the output restriction from Paperboard Mills.

Coefficient changes in response to a 50% reduction in petroleum supply are shown for the ten major consumers in Table 5. A Petroleum output restriction would seem to have been least significant for the majority of its major purchasers in 1972. Coefficient changes in the event of the reduction declined over the period 1963 to 1972, and increased for all sectors in 1982. Largest coefficient changes were found in 1982. The three food and food processing sectors were affected most severely in 1982, and to a lesser extent in 1967. The five wood pulp and paper mill sectors were also most affected by the restriction in at the end of the period, with coefficient changes as high as +5.2% for Pulp Mills in the regional model. Relatively large standard deviations for some coefficient changes reflect larger than average increases in consumption of transportation services in response to the loss of petroleum inputs.

Table 6 shows coefficient changes given a 50% reduction in the output of the aluminum

sector. Percentage differences are small in each year for the majority of the sectors. Only 11 of the 49 coefficient changes exceed +1.0% and changes in excess of +2% appear in only five cases: Structural Metal Products 1967, 1972 and 1982 in both the regional and total requirements model, and in Aerospace in 1963 in the total requirements model and in 1967 in both models. Structural Metal Products, Other Fabricated Metals, Non-Electrical Industrial Machinery and Ship and Boat Building are least affected by the aluminum restriction in 1963, with the three remaining sectors Electrical Machinery, Aerospace and Other Manufacturing least affected in 1972. Largest coefficient changes were found in 1982 in all but two sectors, Structural Metal Products and Aerospace, which both appeared to be most significantly affected by aluminum shortages in 1967.

IV.5. Additional Forward Effects

Conventional Ghoshian impact formulas may not completely capture the effects of a production restriction. Oosterhaven (1988), for example, suggests that there are subsequent forward production effects resulting from the operation of the supply model, which are not measured by standard allocation framework. Oosterhaven considers an extreme case of highly uneven sectoral growth whereby only the primary input of one sector is restricted. Such a situation may occur where there is a bottleneck in the production of a single primary input and excess supply of all other factor inputs necessary for production. Changes in the level of output on the economy are therefore a function of the extent to which this bottleneck can be overcome.

In such a situation there are likely to be forward production effects which arise from changes in the severity of the bottleneck. Oosterhaven suggests, however, that these effects are limited to a direct and a first round indirect effect. The direct effect is equal to the change in production of the industry directly subject to the bottleneck, thus:

$$V^{**direct} = V^* (1/v_{ij}^*)$$

where v_{ij}^* is the element of the value added coefficient matrix corresponding to the bottleneck input and the sector whose output is restricted.

Measuring only direct forward production effects, however, underestimates the size of these effects. Oosterhaven suggests that a first round indirect effect, corresponding to the change in production by the remaining sectors in response to the production effect in the first sector, should be calculated, thus:

$$V^{***first\ round} = V^{**direct} s_{ij} (1/a_{ij}) \text{ (for } j = 1 \text{)}$$

Oosterhaven's special case provides a framework for measuring Ghoshian forward production effects in a Leontief context. No additional inputs required because there are excess supplies, and these supplies also allow him to meet the requirement of the Ghoshian system that backward effects are zero. Indirect effects are assumed to finish after the first round, however, because further production changes would mean additional output increases, violating the Leontief assumptions of Oosterhaven's framework.

There are likely to be additional forward production effects in subsequent rounds of the operation of the model that can be measured in Oosterhaven's framework, however. These effects can be fully measured with a Ghoshian approach where it is no longer necessary for input coefficients to remain constant, with changes in value added therefore becomes:

$$V^{\text{total}} = (V^{\text{direct}} + V^{\text{first round}}) (I - S)^{-1}$$

Value added adjustments from changes on supply in the Ghoshian framework can also be considered by closing the model to include households (Davis and Salkin, 1984). Here changes in output lead to changes in income which affects output levels through historical spending patterns (allocation coefficient), which in turn leads to output and employment increases and additional changes in output levels.

Comparisons of unadjusted absolute average percentage differences and those including Oosterhaven's formula for measuring direct and indirect forward production effects were undertaken for each of the six sectors simulated. Results are reported for the aluminum sector for 1972. Table 7 shows the effect of an output restriction in the aluminum sector for 1972 with and without Oosterhaven's adjustments to the simulation procedure to include additional forward production effects which occur with the loss in output. Shown are the percentage differences for the regional and total requirements models before and after the inclusion of the processing coefficients in the two models. Coefficient changes including the Oosterhaven formula are slightly larger than the changes from the unadjusted formula, but generally by less than +0.5% for this particular simulation. The impact of the adjusted formula was examined for each of the six sectors subjected to the simulated output restrictions and was also found to produce little substantive difference from those produced by the original simulation model.

IV.6. Discussion

Results of the simulation for each of the six sectors show that, in the majority of cases for both regional and technical coefficients, in each of the four years, relative joint stability existed in the supply-driven model, even with substantial input reductions. Additional forward production effects incorporated through Oosterhaven's processing coefficients did not seem to produce markedly different levels of stability than were found with the unaugmented simulation procedure.

In each of the simulations, the technical coefficients showed slightly larger degrees of instability in response to the supply shocks than did the regional coefficients. Clearly this is an unexpected result if one considers the relative vulnerability of an economy to supply disruptions in situations where the region can trade for replacement inputs (although not possible in a strictly Ghoshian framework) and situations where it cannot. However, if one considers the relative sizes of the technical and regional coefficients one might expect larger changes in the former with consequently larger adjustments needed to offset the output restriction.

One might expect patterns of input coefficient change over time for the six chosen sectors to be reflective of developments in the economy of Washington State as a whole. Substantial

capacity restrictions arose in the state's economy over the period 1963-1967, indicated by increased capital spending and a historically low unemployment rate of 4.3% in 1967 (Conway, 1980), and led to the increased use of imported factor supplies. In the early 1970s there was a slowdown in the State's economy followed by increasing diversification towards services in the early 1980s.

The effects of supply disruptions for the six sectors chosen do not clearly reflect patterns of growth and stagnation in the Washington economy. As one might expect, a production restriction in aluminum in 1967 would have led to higher levels of coefficient instability than in other years, which may reflect the capacity shortages associated with the boom in aerospace markets. Similarly restrictions in 1967 also led to the highest levels instability for restrictions in Other Foods, instability that persisted in 1972. Of the four remaining sectors, production restrictions would seem to have had the greatest impact in 1963 for Plywood, Paperboard Mills and Petroleum, which may be indicative of the capacity restrictions that were to emerge in 1967. Higher levels of coefficient instability for a number of sectors purchasing Plywood and Paperboard Mill Products may reflect the fact that even by 1972 capacity had not expanded sufficiently from the 1967 boom to better compensate for input disruptions. Between 1967 and 1972 industries may still have continued to import additional factor inputs with only limited expansion in their production within the state. Restricted Petroleum and Aluminum supplies seemed to lead to the most significant coefficient instability in 1982.

V. CONCLUSIONS

This research has evaluated the supply-driven input-output model as a tool for analyzing the economic impact of supply restrictions. The model was originally conceived by Ghosh as a framework of analysis applicable to centrally planned economies and situations in less developed countries where government agencies are involved in administering the supply of factors of production to key industries. The model may be similarly applicable in developed economies where production of factor inputs tends to be monopolistic or where there are severe capacity restrictions which limit the response of production to changes in factor demand.

The supply model has been used on a number of occasions as a forecasting tool and has compared favorably with the demand-driven model in the accuracy of its predictions. The model has not, however, found a wider market in impact analysis where supply factors are predominant. This is partly due to the interpretation of the role of supply factors and their importance in developed in economies, and partly because there are a number of theoretical aspects of the model that are still somewhat contentious. The most important of these is the extent to which input structures remain stable given significant changes in supply.

As the polar opposite of the demand model the supply model assumes that input coefficients adjust to changes in output given fixed patterns of distribution. Changes in output in the economy are met through industries modifying their input mixes, implying that more than a limited number of input combinations and production technology exist for any given product. This is clearly contentious if one considers more than limited flexibility in input structures. Small changes in input coefficients in response to short run changes in supply can, however, be

empirically justified if they are within tolerable limits of accuracy (Rose and Allison, 1989). Small changes can also be theoretically interpreted as firms moving toward cost minimizing input mixes which are in close proximity to their original input structure given unchanging relative prices (Gruver, 1989). These changes may therefore merely represent substitutions associated with a linear approximation of the relevant production function.

^{paper reports on}
This research ^{that} has attempted to show that large short term changes on the supply side do not lead to substantial changes in input coefficients and do not therefore mean the abandonment of the concept of the production function as has been suggested (Oosterhaven, 1988). The supply-driven model was tested for six sectors of the economy of Washington State and found to yield new input coefficients whose values were in most cases close approximations of their original values, even with substantial changes in supply. Average coefficient changes from a 50% output reduction in these six sectors were in the vast majority of cases (297 from a total of 315) less than +2.0% of their original values, excluding coefficient changes for the restricted input. Given these small changes, the most important issue for the validity of the supply-driven input-output model may therefore be the empirical question of the extent to which these coefficient changes are acceptable as being within the limits of approximation.

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**Table 1: Sectoral Average Absolute Percentage Differences in Input Coefficients
Due to a Fifty Percent Production Restriction in Other Foods.**

Sector	1963		1967		1972		1982
	rij	aij	rij	aij	rij	aij	rij
Livestock and Products	0.207 0.081	0.263 0.089	0.314 0.085	0.356 0.096	0.557 0.193	0.648 0.216	0.682 0.024
Meat Products	0.173 0.116	0.331 0.242	0.131 0.118	0.290 0.101	0.391 0.115	0.626 0.231	0.064 0.026
Dairy Products	0.420 0.212	0.456 0.232	0.434 0.139	0.584 0.213	0.556 0.243	0.825 0.299	0.176 0.055
Canning and Pres- erving	0.835 0.297	0.842 0.315	1.109 0.293	2.310 0.648	0.586 0.252	0.718 0.313	0.285 0.081
Grain Mill Products	0.362 0.151	0.364 0.196	0.619 0.169	0.709 0.307	0.508 0.219	0.586 0.237	0.157 0.020
Beverages	0.426 0.123	0.502 0.139	1.070 0.262	1.524 0.354	1.060 0.234	1.523 0.327	2.475 0.583

Notes: Table gives average absolute percentage differences with their respective standard deviations shown below.

Percentage differences do not include coefficients for sector subject to the restriction, nor coefficients with zero values.

**Table 2: Sectoral Average Absolute Percentage Differences in Input Coefficients
Due to a Fifty Percent Production Restriction in Plywood.**

Sector	1963		1967		1972		1982
	rij	aij	rij	aij	rij	aij	rij
Other Wood Products	1.227 0.326	1.209 0.331	0.585 0.173	0.645 0.222	1.605 0.385	2.436 0.514	1.718 0.372
Furniture and Fixtures	1.163 0.554	1.419 0.589	0.786 0.249	1.657 0.437	0.270 0.315	0.383 0.451	0.339 0.290
Pulp Mills	0.281 0.217	0.276 0.199	0.104 0.194	0.170 0.281	1.710 0.424	1.772 0.408	0.691 0.078
Aerospace	0.152 0.397	0.169 0.410	0.095 0.209	0.167 0.291	0.115 0.325	0.138 0.421	0.087 0.329
Ship and Boat Building	0.187 0.338	0.201 0.365	0.103 0.212	0.234 0.366	0.184 0.268	0.251 0.384	0.120 0.303

Notes: Table gives average absolute percentage differences with their respective standard deviations shown below.

Percentage differences do not include coefficients for sector subject to the restriction, nor coefficients with zero values.

Table 3: Sectoral Average Absolute Percentage Differences in Input Coefficients
Due to a Fifty Percent Production Restriction in Other Wood Products.

Sector	1963		1967		1972		1982
	rij	aij	rij	aij	rij	aij	rij
Vegetables and Fruits	0.333 0.068	0.296 0.066	0.171 0.073	0.196 0.153	0.132 0.101	0.322 0.136	0.292 0.093
Furniture and Fixtures	0.772 0.265	0.887 0.288	0.242 0.104	0.557 0.213	0.576 0.253	0.667 0.260	0.259 0.096
Paper Mills	0.035 0.049	0.047 0.036	0.093 0.120	0.169 0.173	0.086 0.172	0.130 0.214	0.064 0.085
Aluminum	0.049 0.047	0.088 0.041	0.088 0.131	0.172 0.210	0.060 0.132	0.101 0.211	0.059 0.094
Aerospace	0.083 0.192	0.074 0.199	0.082 0.154	0.130 0.240	0.091 0.199	0.135 0.232	0.047 0.107
Ship and Boat Building	0.084 0.163	0.164 0.148	0.068 0.115	0.148 0.236	0.091 0.191	0.143 0.236	0.161 0.051
Other Manufacturing	0.090 0.040	0.083 0.044	0.503 0.170	0.652 0.240	0.089 0.159	0.211 0.163	0.058 0.078

Notes: Table gives average absolute percentage differences with their respective standard deviations shown below.

Percentage differences do not include coefficients for sector subject to the restriction, nor coefficients with zero values.

Table 4: Sectoral Average Absolute Percentage Differences in Input Coefficients
Due to a Fifty Percent Production Restriction in Paperboard Mill Products.

Sector	1963		1967		1972		1982
	rij	aij	rij	aij	rij	aij	rij
Meat Products	0.483	0.562	0.423	0.798	0.580	0.874	1.621
	0.443	0.405	0.156	0.329	0.416	0.614	0.547
Dairy Products	1.111	1.391	0.186	0.511	1.647	2.573	1.356
	0.655	0.727	0.242	0.328	0.599	0.969	0.563
Canning and Preserving	1.409	1.670	0.915	1.319	0.974	1.685	1.083
	0.768	0.856	0.331	0.560	0.353	0.566	0.388
Beverages	1.853	1.941	1.532	1.786	1.318	2.083	1.143
	0.905	0.927	0.464	0.715	0.364	0.627	0.366
Other Foods	1.355	1.267	0.748	1.243	0.850	1.722	0.769
	0.724	1.984	0.290	0.568	0.378	0.660	0.246
Paper Mills	0.554	1.465	0.516	0.819	1.026	2.316	0.209
	0.227	0.543	0.149	0.255	0.236	0.493	0.080
Industrial Chemicals	0.210	0.329	0.151	0.331	0.404	0.604	0.279
	0.346	0.538	0.249	0.523	0.481	0.737	0.381
Glass Products	3.347	2.910	0.672	0.796	2.842	4.407	1.878
	0.548	1.314	0.283	0.291	0.070	0.138	0.683
Other Fabricated Metals	0.649	0.749	0.137	0.188	0.115	0.179	0.293
	0.939	0.839	0.147	0.196	0.061	0.090	0.117
Aerospace	0.406	0.468	0.109	0.247	0.200	0.514	0.095
	0.826	0.845	0.180	0.394	0.339	0.936	0.126

Notes: Table gives average absolute percentage differences with their respective standard deviations shown below.

Percentage differences do not include coefficients for sector subject to the restriction, nor coefficients with zero values.

**Table 5: Sectoral Average Absolute Percentage Differences in Input Coefficients
Due to a Fifty Percent Production Restriction in Petroleum.**

Sector	1963		1967		1972		1982
	rij	aij	rij	aij	rij	aij	rij
Field and Seed Crops	1.007 0.447	1.987 0.947	1.107 0.390	1.753 0.681	0.347 0.238	0.840 0.391	1.261 1.169
Vegetables and Fruits	0.233 0.183	0.444 0.365	0.751 0.363	0.756 0.602	0.294 0.356	0.484 0.580	1.124 1.114
Livestock and Produce	0.385 0.260	1.320 0.689	0.633 0.447	1.718 0.827	0.348 0.240	0.827 0.432	1.179 1.068
Logging	0.171 0.092	0.339 0.199	0.489 0.390	0.715 0.560	0.213 0.289	0.253 0.442	1.567 1.035
Sawmills	0.418 0.641	0.454 0.664	0.390 0.400	0.833 0.587	0.188 0.292	0.221 0.444	1.288 1.265
Pulp Mills	0.521 0.405	0.875 0.390	0.442 0.412	0.983 0.578	1.621 0.531	1.836 0.640	5.239 1.524
Paper Mills	0.394 0.453	0.578 0.405	0.378 0.395	0.558 0.525	0.742 0.247	0.964 0.362	1.876 1.053
Paperboard Mills	0.350 0.223	0.523 0.424	0.318 0.374	0.539 0.527	0.324 0.411	0.433 0.477	1.770 1.152
Cement, Stone and Clay	2.111 0.673	2.119 0.707	0.780 0.307	0.839 0.530	0.458 0.202	0.525 0.318	4.721 1.912
Aerospace	0.325 0.553	0.421 0.546	0.289 0.465	0.581 0.774	0.207 0.333	0.402 0.591	1.005 1.536

Notes: Table gives average absolute percentage differences with their respective standard deviations shown below.

Percentage differences do not include coefficients for sector subject to the restriction, nor coefficients with zero values.

Table 6: Sectoral Average Absolute Percentage Differences in Input Coefficients
Due to a Fifty Percent Production Restriction in Aluminum.

Sector	1963		1967		1972		1982
	rij	aij	rij	aij	rij	aij	rij
Structural Metal Products	0.304	1.604	2.434	2.410	1.838	1.969	2.000
	0.139	0.786	0.656	0.623	0.588	0.810	1.067
Other Fabricated Metals	0.102	0.422	0.495	0.586	0.725	1.441	3.741
	0.092	0.633	0.406	0.354	0.229	0.458	0.958
Non-Electrical Industrial Equipment	0.170	0.675	0.905	1.187	0.533	0.834	0.888
	0.262	0.432	0.309	0.392	0.258	0.361	1.866
Electrical Machinery	0.486	1.192	0.573	0.796	0.325	0.684	0.679
	0.222	0.598	0.440	0.331	0.354	0.428	1.772
Aerospace	0.142	0.941	0.409	0.880	0.140	0.481	0.491
	0.197	0.390	0.380	0.365	0.389	0.393	1.574
Ship and Boat Building	0.139	0.433	0.224	0.405	0.173	0.413	0.489
	0.210	0.516	0.549	0.583	0.418	0.507	1.540
Other Manufacturing	0.805	1.466	0.345	0.397	0.165	0.497	0.761
	0.287	0.645	0.443	0.386	0.232	0.349	1.391

Notes: Table gives average absolute percentage differences with their respective standard deviations shown below.

Percentage differences do not include coefficients for sector subject to the restriction, nor coefficients with zero values.

Table 7: Sectoral Average Absolute Percentage Differences in Input Coefficients
Due to a Fifty Percent Aluminum Production Restriction, including and
excluding the Oosterhaven Adjustment

Sector	rij		aij	
	Unadjusted	Adjusted	Unadjusted	Adjusted
Structural Metal Products	1.838 0.588	2.516 0.797	1.969 0.810	2.650 1.173
Other Fabricated Metals	0.725 0.229	0.913 0.395	1.441 0.458	1.894 0.616
Non-Electrical Industrial Equipment	0.533 0.258	0.694 0.365	0.834 0.361	1.190 0.516
Electrical Machinery	0.325 0.354	0.448 0.494	0.684 0.428	1.040 0.633
Aerospace	0.140 0.389	0.224 0.532	0.481 0.393	1.624 0.505
Ship and Boat Building	0.173 0.418	0.248 0.563	0.413 0.507	0.652 0.779
Other Manufacturing	0.165 0.232	0.245 0.290	0.497 0.349	0.814 0.564

Notes: Table gives average absolute percentage differences with their respective standard deviations shown below.

Percentage differences do not include coefficients for sector subject to the restriction, nor coefficients with zero values.

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