Identifying Sub-Areas that Comprise a Greater Metropolitan Area:

The Criterion of County Relative Efficiency

By

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Abstract

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Data Envelopment Analysis (DEA) is used to measure and rank the relative efficiency of thirty-two counties comprising the Greater Minneapolis-St. Paul Metropolitan Region. This approach supports the notion that the greatest external economies originate in the urban core and decline as one moves toward the transitional areas and the periphery. DEA is a multi-input, multi-output optimization model used to form a frontier of "best practice" counties. By employing the 1993 IMPLAN input-output database and county estimates of three forms of final payments to represent inputs and four categories of final demands to represent outputs, DEA can rank counties which produce a maximum amount of output, while utilizing a minimum amount of inputs. In addition we use a sensitivity analysis introduced by Charnes et al. (1992) and (1996) to determine the robustness of the efficiency classifications. This approach confirms the relative efficiency differences expected between the three groups identified as the metropolitan core, the transitional area and periphery.

157 words

100 words or less needed

I. INTRODUCTION

Past cross comparisons of metropolitan areas of varying sizes (Sveikauskas 1975, Segal 1976, Moomaw 1981, and Henderson 1986) find that productivity increase as cities get larger. This empirical evidence is consistent with the perception that metropolitan areas continue to grow and metropolitan immigration continues to occur. Pred (1975) has argued diffusion of innovative outputs flow in a bicausal direction through the hierarchy of city sizes and across cities of the same size. He also suggests that the hierarchical structure of corporate organizations often influence the diffusion of innovations and consequent growth between various metropolitan areas. Rather than seek explanations for urban growth through cross metropolitan comparisons, we seek explanations through intra regional interactions. Cross county productivities are compared in order to infer the types and nature of intra regional interactions which contribute to the entire region's development.

Wilbur Maki, in his presidential address to the North American Regional Science Association (Maki, 1992), presented a view of the role and productivity of various subareas from the urban center to the hinterlands. Borrowing from labor market definitions of Tolbert and Killian (1987), labor market areas fall into a metropolitan core, a transitional area and the periphery. The urban core represents the "engine" of progress, where the downtown district is the nerve center of trade and commerce. According to Sveikauskas (1979) the percentage of innovation workers increases with SMSA size, suggesting that the largest cities are apt to promote the greatest productivity to meet global competition. Henderson (1986) found strong evidence that the increasing external economies associated with metropolitan size are due primarily to localization economies which occur when a city engages in certain in particular specialized activities. Also within the central city is the dislocation of neighborhoods, limited job opportunities and "...a continuing legacy of racial tensions, crime, poverty, declining tax base, and low educational achievement." Thus the metropolitan core includes the downtown district as well as areas of urban crises.

The transitional area contains an expanding manufacturing base and often experiences the most rapid population and job growth. According to Maki lower site costs, more available land and lower labor costs combine to make this an attractive area for manufacturing and retail sales activities.

The periphery is the source of primary commodities and products from agriculture, forestry and mining. The periphery also exports the outputs of the most routine assembly or production activities. High labor productivity or low wages make the periphery competitive. Land rents are expected to fall and as distance from the center of the city increases. Our working hypothesis anticipates that efficiency will fall as distance from the central core increases towards the peripheral counties.

DEA is an optimization model which can rank the relative efficiencies of particular counties. The most efficient counties form a"a best practice" envelope comprised of counties which produce a maximum amount of outputs, while employing a minimum amount of resources. Counties lying below the efficient frontier are deemed inefficient and their distance to the frontier measures their degree of inefficiency. In addition, a sensitivity analysis introduced by Charnes et al. (1992 and 1996) is used to rank and to measure the degree of county efficiency or inefficiency of the Greater Minneapolis-St. Paul Metropolitan Region.

II. The Model and County Input-Output Data.

Macmillan (1986) suggested using DEA to distinguish between efficient and inefficient industries from the processing sector of an input-output model. Such a model would have formidable data requirements. We rely on the free functional form aspect of DEA to compare the relative county efficiencies of the industries which make up a county's economic base.

Micro IMPLAN (Impact analysis for PLANning) is a microcomputer program that performs interregional input-output analysis. A model can be defined for any county or combination of counties in the United States using secondary data sources which can be purchased from the Minnesota IMPLAN Group, Inc.. Reports can be generated at each stage of the model building process that contain information about the market's structure and industry relationships.

Micro IMPLAN was used to generate ten sector, traditional input-output tables for 32 Minnesota counties. The final payments and final demand components of these tables were identified for each county and were utilized as inputs and outputs in the DEA model.

The final payments and transfer payments to be minimized were:

Inputs:

Employee compensation

Proprietor's income (single proprietors)

Other proprietary income (dividends, interest and rent).

The final demand components to be maximized were:

Outputs:

Household consumption

Business investment

Government spending

Exports.

Based upon these three inputs and four outputs, an efficient frontier is constructed which is composed of those counties which use as little input as possible while purchasing as much output as possible. This production efficiency model measures the private market flows of inputs and outputs. The input-output treatment of tax receipts and tax payments correspond to the production efficiency view of inputs and outputs. For example indirect business taxes are embodied in the prices of the outputs and are considered an allocation of outputs and are properly maximized. The classification of core, transitional and peripheral counties are based of this private sector production efficiency model.

In a previous paper (Raab and Lichty, 1996) a "county efficiency" model is employed using five inputs and four outputs. This approach departs from the narrower notion of strict "production efficiency" and views the county as a decision making unit (DMU) for the purpose of affecting private and public sector efficiency. County efficiency is viewed as having public and private financial flows into and out of the county. Imports into the county were treated as an input to be minimized, however IMPLAN includes a part of imports of goods for final consumption, but these more properly should have been maximized outputs. Similarly transfer payments were treated as an input to be minimized because they represent an important financial flow into the county that can be used to purchase outputs. By including infusions and drains which are used by the county to purchase outputs, the inefficiency of both the private and the public sector can be addressed. However, the IMPLAN accounting system presently limits the applicability of this approach.

The narrower production efficiency model was applied to a definition of Greater Minneapolis-St. Paul Metropolitan Area. The criterion was based upon the population densities of the various counties. Figure 1 outlines the 32 counties which are included in the analysis. The core counties in the center have population densities greater than 250 per square mile. Population densities decrease until the periphery is reached with population densities of less than 25 per square mile. Counties such as Olmstead, including the city of Rochester, and St. Louis, including the city of Duluth, have been explicitly excluded. Thus, we define a frontier comprised of only the metropolitan area and its immediate environs. The county efficiency analysis, performed previously, considered the hierarchical relationships of other second order cities for all 87 Minnesota counties (Raab and Lichty, 1996). The computed values of the stability index will refer to the counties within this immediate area and pick up the efficiency interactions of the core, its transitional areas and the peripheral area of that core.

III. DATA ENVELOPMENT ANALYSIS.

As a linear programming implementation of Farrell's (1957) notion of technical efficiency, DEA is an "extremal" approach to efficiency evaluation. The frontier is comprised of efficient counties, while those counties not of the frontier are deemed inefficient (i.e., enveloped by the more efficient organizations). The original model of DEA, known as the ratio or CCR model (Charnes et al., 1978), has been joined by other DEA models (Charnes et al., 1982 and Banker et al., 1984), including the additive model (Charnes et al., 1984), the model of interest in this paper. In the additive model of DEA, the observed input consumption and output production for a number of counties are measured. The measures of input consumption and output production for a given county are referred to as the county's component vector. The component vectors for all of the counties are combined to form the empirical production possibility set (PE):

$$PE=\{\ (Y^T,\ X^T)\ =\ \sum_{j=1}^{n} \mu_j (Y_j^T,\ X_j^T);\ \sum_{j=1}^{n} \mu_j = 1,\ \mu_j \geq 0.\ \}$$

where Y_j and X_j represent the output production and input consumption, respectively, for the jth county.

The efficiency of each county is determined by comparing its component vector to PE. If no component vector in PE, observed or hypothetical, can be found that strictly dominates the tested county, then the county is said to be technically efficient. Those counties for which a component vector can be found in PE that strictly dominates, are said to be technically inefficient. Figure 3 provides a graphical depiction of a set of counties for a single-input single-output example. From Figure 1, counties #1, #2, and #3 would be technically efficient while counties #4, #5, #6, and #7 would be technically inefficient.

Insert Figure 3 about here

Mathematically, the test for efficiency is achieved by solving the following linear program for each county. The primal or envelopment form of the additive model is:

$$
\begin{array}{llllr}
 & \min\ (-e^{T}s^{+} & -e^{T}s^{-}) & & \\
s.t. & Y\lambda & -s^{+} & & =Y_{j} \\
 & X\lambda & +s^{-} & & =X_{j} \\
 & e^{T}\lambda & & & \leq 1 \\
 & \lambda, & s^{+}, & s^{-} & \geq 0
\end{array}
$$

where Y and X represent the matrices of output production and input consumption, respectively. The right hand side values, Y_j and X_j represent the component vector for county j, while s^+ and s^- represent the shortfall in production and excess in consumption, respectively. The e^T vector is the sum vector, guaranteeing a convex combination of the observed DMUs.

The execution of LP_j serves only to categorize the observed county as technically efficient or technically inefficient. In the proposed analysis, the execution of LP_j does not yield a rank ordering of the counties. To develop a rank ordering of most robustly efficient to most robustly inefficient, one additional linear program must be executed for each county, with the result yielding an • -norm measure of the minimum distance to a Pareto optimum point (efficient frontier).

Charnes et al. (1992 and 1996) developed a sensitivity analysis technique based on the • -norm measure of a vector that defines the necessary simultaneous perturbations to the component vector of a given county to cause it to move to a state of "virtual" efficiency. Virtual efficiency is defined as a point of the efficient frontier where any minuscule detrimental perturbation (increases in inputs and/or decreases in outputs) will cause an efficient county to become inefficient or any minuscule favorable perturbation (decrease in inputs and/or increase in outputs) will cause an inefficient county to become efficient.

For an efficient county, the • -norm measure (herein termed stability index) defines the largest "cell" in which all simultaneous perturbations to the input and output components will not cause a change to the efficiency status from technically efficient to technically inefficient. As such, the larger the stability index, the more robustly efficient the county is said to be. That is, those efficient counties with small stability indices will become technically inefficient with smaller detrimental perturbations than those efficient counties with larger stability indices. Mathematically, the stability index for efficient county j is determined by solving the following linear program:

$$
\begin{aligned}
&\min \quad \theta \\
&s.t. \quad Y^{(E)}\lambda \quad - s^{+} \qquad\qquad + \theta d_0 = Y_j \\
&\qquad\ X^{(E)}\lambda \qquad\qquad + s^{-} \quad - \theta d_I = X_j \\
&\qquad\ e^{T}\lambda \qquad\qquad\qquad\qquad\qquad = 1 \\
&\qquad\quad \lambda, \quad s^{+}, \quad s^{-}, \quad \theta \quad \geq 0
\end{aligned}
$$

where • represents the stability index. The matrix of outputs and inputs are represented by $Y^{(E)}$ and $X^{(E)}$ with the component vector for that efficient county j omitted. Finally d^{T}_{0} and d^{T}_{I} are vectors given by (1, 1, ..., 1). Observe that • simultaneously increases inputs and decreases outputs to arrive at an optimal solution. Figure 2 provides a graphical depiction of the • - norm measure (stability cell) for efficient county #2.

Insert Figure 4 about here

For an inefficient county, the stability index defines the necessary minimum favorable perturbations (decreases in inputs and increases in outputs) that must be undertaken to cause the county to become virtually efficient. Therefore, the larger the stability index for an inefficient county the more robustly inefficient the county would be. That is, an inefficient county with a large stability index rests a greater distance from the efficient frontier than an inefficient county with a smaller stability index. Mathematically, the stability index for inefficient county is determined by solving the following linear program:

$$
\begin{aligned}
&\max \quad \theta \\
&s.t. \quad
\begin{array}{lllll}
Y\lambda & -s^{+} & & -\ \theta d_{0} & = Y_i \\
X\lambda & & +s^{-} & +\ \theta d_{I} & = X_i \\
e^{T}\lambda & & & & = 1 \\
\lambda, & s^{+}, & s^{-}, & \theta & \geq 0
\end{array}
\end{aligned}
$$

where all notations are defined in the prior formulations. Observe that• simultaneously decreases inputs and increases outputs to arrive at an optimal solution. It is customary when establishing the rankings, to negate the stability index values for inefficient counties. Figure 3 provides a graphical depiction of the• -norm measure (stability cell) for inefficient county #7.

Insert Figure 5 about here

IV. STABILITY OF THE EFFICIENCY CLASSIFICATIONS OF THE METROPOLITAN COUNTIES

Table 1 indicates the results of the DEA analysis. DEA efficiency scores are not reported for the 32 counties since 24 of the counties appeared of the frontier, while only eight counties fell below the efficiency frontier[1]. It is not possible to rank 24 efficiency unitary scores of the frontier counties. The stability index, however, allows a ranking of all of the counties, both on or below the efficiency frontier. Table 1, column 2 lists the stability index values from the largest value or most robustly efficient, to the largest negative value or most robustly inefficient. Note that only eight counties fell below the frontier, since they have negative stability values. It has been accepted as a DEA convention that the minimum number of DMUs be greater than three times the number of inputs plus outputs (32>3(3+4)).

Three groups were established based upon the magnitude of the index value. Although the boundaries of the index values are quite arbitrary, they yield quite distinct groupings. The first group represented the urban core with stability index values from 250 to 21,904, indicating that these counties are the most robustly efficient. The stability index values were computed from a "standard" units model, since all of the inputs and outputs were using the common metric of millions of dollars.. The urban core counties have the largest populations (from 304,000 to over a million people). They also the highest per capita income ($23,120 to 28,266).

In addition to the raw stability index data, additional criteria were used to determine where to divide the core from the transitional areas. Anoka and Washington counties are primarily outside of the 'beltway', and could be classified as either urban core or transitional counties. Anoka was classed as a transitional area.

By constructing a ratio of consumption to income in each county, we classified "bedroom communities" into the transitional area. Since income is reported in the county where it is earned, but much of consumption likely is taking place in the county of residence, these county will appear as relatively efficient. Based upon this reasoning, Washington, Wright and Sibley counties were treated a bedroom communities and classified as transitional areas (i.e., counties with more than 1.5 standard deviations above the mean ratio of consumption to income). Stability index values for the transitional area range from 7 to 250. These twelve counties have populations from 14,500 and 263,000 incomes that range from $14,998 to $22,394.

The third group comprises 17 peripheral counties and the index values that are under 7. Note that small, absolute positive or negative index values indicate that only very slight perturbations in inputs or outputs would induce the change in the efficiency classification. These peripheral counties apparently have the smallest populations (from 10,500 to 64,900) and the lowest incomes (from $13,338 to $20,373). A general pattern emerges from Figure 2 that as distance from the core increases, population density falls, personal income falls and the robustness of the efficiency classifications falls as well.

V. SUMMARY AND CONCLUSIONS

Much literature has highlighted the continuing importance of the Central City as a driver of regional, and ultimately, national economic growth. Maki (1992) describes the urban core as the innovation leader, the global transportation and communication center and as the"nerve center" of the larger city-region. Others find strong external economies existing in population centers by comparing different sized metropolitan areas.

This paper took another look at these issues by applying DEA to a particular city-region, Minneapolis-St. Paul, to test the efficiency levels of counties both within and outside of the urban core. We found strong support for Maki's and other's views. The core cities in the Minneapolis-St. Paul region evidence the greatest levels of robust efficiency when applying the DEA analysis and efficiency drops along with decreasing population densities and income levels as we move from the urban core. In fact, the results offer stark support for the core, transitional area and periphery description offered by Maki and others.

What does this imply in terms of policy? Maki argues that current drags, such as government regulation or the character of public infrastructure development, hampers productivity and thus stifles both the urban core and the city-region in general. He also asserts that this increase in costs affects the nation's competitive position in the global market place.

Public policies do not have to be associated entirely with additional spending. In fact, in our earlier paper, levels of government spending was only one of the causes of inefficiencies between urban and rural counties. Rather, Maki argues that the organization and structure of urban regions are in need of further investigation. Fragmented government, the loss of higher income citizens, the assignment of property rights and past government expenditures on highways and other infrastructures may, in fact, be the leading causes of loss in efficiency for the city-regions.

Recognizing the crucial role of the central urban core in regional economic development should lead to new relationships between the core and its surrounding areas. Business and government partnerships, regional taxation policies, cooperation between units of local government and between regional governments and state and federal governments could lead to programs that emphasize the expanded viability of the urban core. The global market will require viable metropolitan core areas and, in turn, will generate viable economic regions that can assure future growth and development at the national level.

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Table 1

Productive Efficiency Results (32 Counties)

		Stability Index ($m)	Population (1,000s)	Per Capita Income ($)
	Urban core			
1	Hennepin	21904.49	1045.7	28266
2	Dakota	461.24	304.4	23120
3	Ramsey	262.16	484.8	23826
	Transitional			
4	Anoka	187.08	263.6	18556
5	Washington	102.53	166	22394
6	Stearns	65.14	123.1	16335
7	McLeod	55.43	32.8	18314
8	Kandiyohi	24.07	40.1	16773
9	Rice	15.78	51	16847
10	Nicollet	15.51	29.4	17121
11	Carver	10.18	54.1	22218
12	LeSuer	9.43	23.8	17129
13	Chisago	8.07	33.9	16802
14	Wright	7.98	74.4	17631
15	Sibley	7.16	14.5	14998
	Peripheral			
16	Todd	3.68	23.6	13338
17	Isanti	3.33	27.5	16354
18	Renville	2.99	17.4	15642
19	Swift	2.84	10.5	15226
20	Pine	2.57	22.4	1484
21	Morrison	1.74	29.9	13873
22	Wabasha	1.29	20.2	17635
23	Kanabec	1.03	13.2	14814
24	Meeker	0.95	20.9	15633
25	Pope	-0.03	10.9	14229
26	Douglas	-1.36	29.7	15881
27	Chippewa	-1.88	13.1	1663
28	Benton	-2.16	32.2	15915
29	Mille Lacs	-2.61	19.4	14911
30	Scott	-4.04	64.9	20373
31	Sherburn	-5.61	48.2	16302
32	Goodhue	-8.51	41.8	18698

Figure 1

Definition of Greater Metropolitan Region

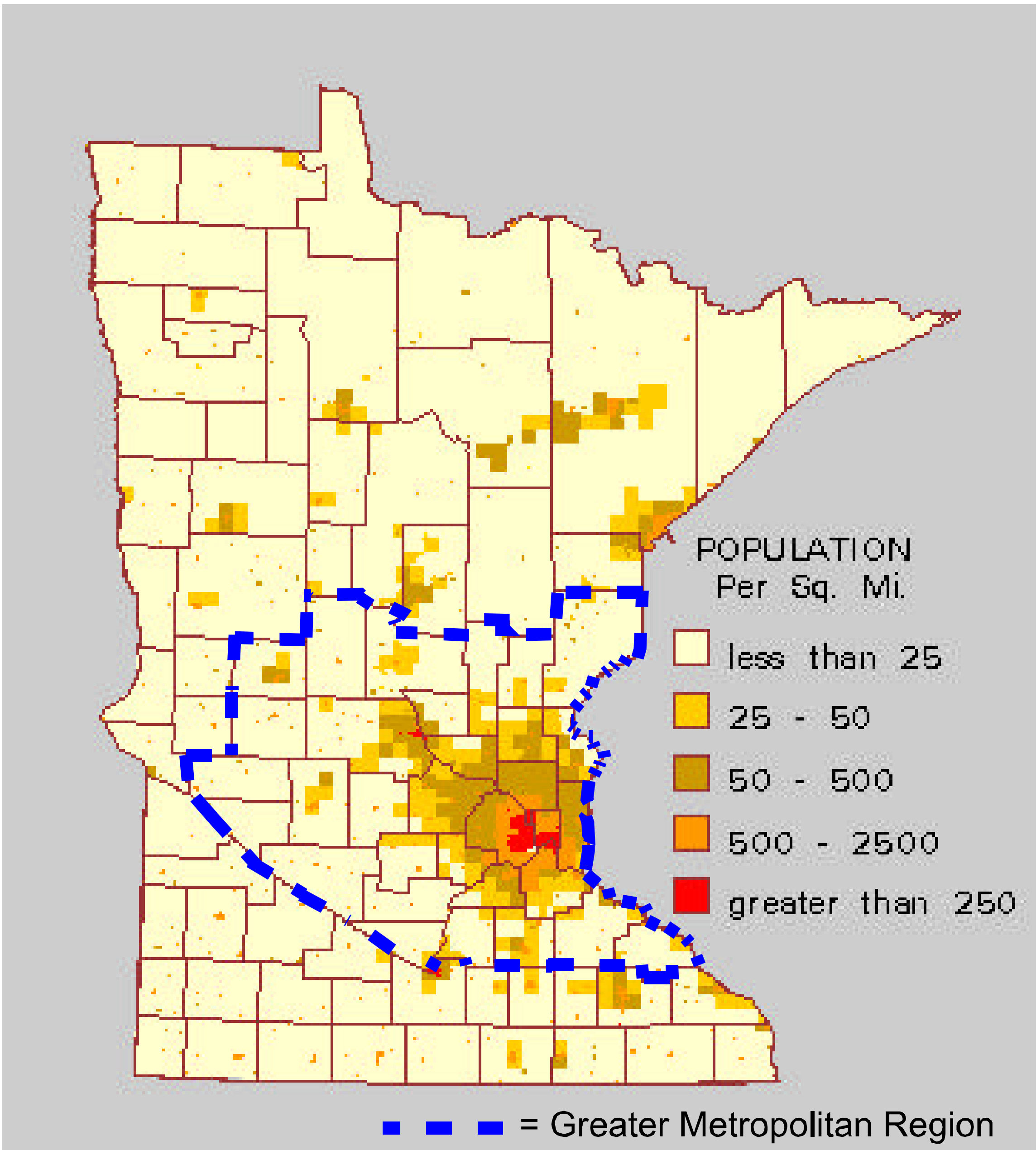


Figure 2
Stability Index (assigned ranges)

Periphery -9 <-->5

Transitional 5 <--> 250 (shaded)

Urban Core 250 <--> 21905 (cross-hatched)

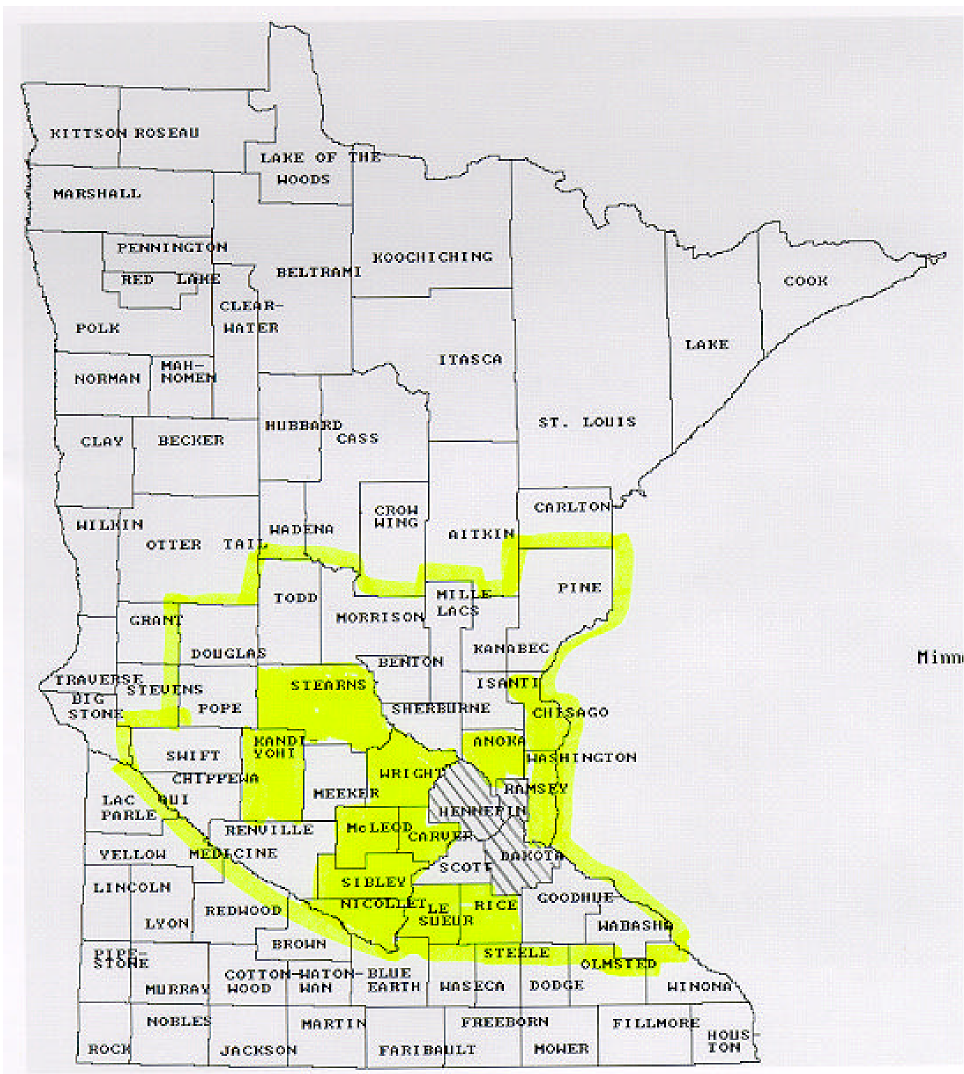
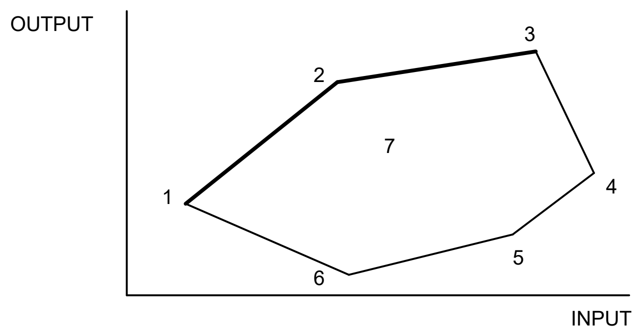


Figure 3

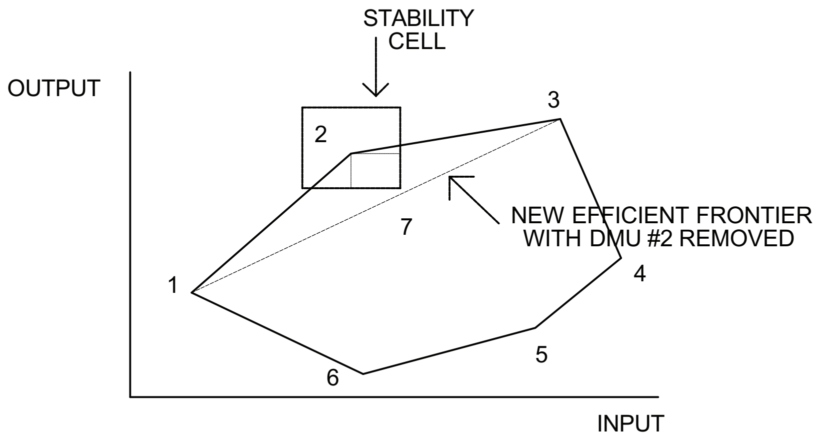
Production Possibility Set



Note: Efficient frontier comprised of segments $\overline{12}$ and $\overline{23}$.

Figure 4

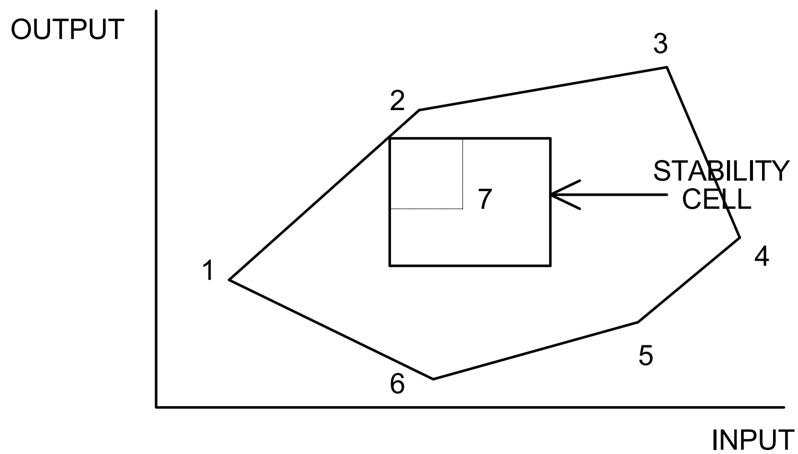
Stability Measure for Efficient County



Note: • depicted as dotted line segment when county #2 is removed. That is, the largest increase in inputs and decrease in outputs which will allow county #7 to remain efficient.

Figure 5

Stability Index Measure for Inefficient County #7



Note: • depicted as dotted line segment when cell around county #7 is enlarged until it barely touches the frontier. That is, the maximum simultaneous decrease in inputs and increase in outputs which will cause county #7 to remain inefficient.

Footnote

1. In a previous DEA for the whole state of Minnesota (comprised of 87 counties), Raab and Lichty (1966) found: (1) using the additive model, 65 counties formed the frontier with only 22 inefficient counties: (2) using the CCR formulation (Charnes, Cooper and Rhodes 1978) of the ratio model, 61 counties formed the frontier with only 26 inefficient counties. In short, most counties appear on the frontier, especially if they are found in the greater metropolitan area.