JRAP (1997) 27, 1: 75-93

The Journal of
Regional
Analysis
& Policy

An efficiency analysis of Minnesota counties: A data envelopment analysis using 1993 IMPLAN input-output analysis

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Abstract. Data envelopment analysis (DEA) is a multi-input, multi-output optimization model used to measure relative efficiency of the best practice counties. The IMPLAN input-output 1993 database and software estimates gross output, final demand, and final payments categories at the county level. The IMPLAN data contain estimates of four forms of final payments. Transfer payments is added as an input but is taken from a separate source. IMPLAN also includes four forms of final demand as outputs. These inputs and outputs form a production frontier of best practice counties. Deviations below the frontier measure the degree of county inefficiency based upon minimizing the use of inputs and maximizing the sale of outputs. Measurement of relative county efficiencies allows comparison between urban core counties, suburban transitional counties, and rural periphery counties. County comparisons of returns to scale verify the existing body of land rent theories. Agglomeration economies measured by DEA efficiency scores and returns to scale measured by DEA frontier intercepts imply that location and urbanization economies are largest in urban core counties and that their effects diminish as distance from the core increases.

1. Introduction

Resource productivity must rise as city size increases. Otherwise, the largest cities would not continue to grow and inmigration would not continue. External economies partially explain this outcome. Past measurements of urban economies have focused on the types and sources of these economies. Sveikauskas (1975), Segal (1976), and Moomaw (1981), using various levels of disaggregation and differing measures of productivity, find significantly higher productivity across larger sized metropolitan areas. Moomaw (1981) finds greater productivity in nonmanufacturing sectors than in manufacturing sectors. Henderson (1986) uses a more flexible form

* The authors wish to thank Jean Jacobson for her editing assistance and Tabitha Schmidt for accomplishing all our computations. Earlier versions of this paper were presented at the 36th annual meeting of the Western Regional Science Association and the Mid-Continent Regional Science Association meeting. We are grateful for comments provided by Charles Lamphear, Wilbur Maki, and David Holland.

translog model (rather than the CES and Cobb-Douglas technologies) and asserts that localization economies are the most prevalent types of external economy (because like industries locate in close proximity), rather than urbanization economies (because unlike industries agglomerate and use common inputs).

We raise a different question: how does productivity vary between counties of the urban-transitional-periphery landscape surrounding metropolitan core areas? Our analysis is based on the arguments of Wilbur Maki in a presidential address to the North American Regional Science Association. Maki's view of the role and efficiency of cities versus rural areas in economic growth and development (Maki 1992) modifies more traditional notions of growth and development policy.

Building on the labor market areas developed by Tolbert and Killian (1987), Maki defines three levels of labor market areas: the metropolitan core, the transitional area, and the periphery. The metropolitan core areas contain the "... world class transportation, telecommunications and distribution centers." The key to information in the core area is the face to face communication required for technology development and for strategic management functions. Efficiencies in transportation and communication and reduction in transaction costs are evident. The education and research function of this area assures its predominance and high levels of technical efficiency. The twin cities of Minneapolis and St. Paul form this type of metropolitan core area.

The transitional area 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-based growth and development. It is not unusual, according to Maki, to find these transitional areas experiencing more rapid economic growth than can be found in the metropolitan core, at least when growth is measured in traditional ways. The periphery exports products subject to the most routine production methods. Either high labor productivity or low wages make the periphery competitive. The periphery is the source of primary products (agriculture, forest, and mines) in addition to routine assembly of manufacturing activities. This view of efficiency implies the traditional concentric circle landscape with rents falling from the metropolitan core. If Maki's description is accurate, we might expect to find the highest data envelopment analysis (DEA) efficiency scores in the urban core and decreasing scores as we move from the core to the periphery.

Unlike Macmillan's (1986) suggestion to use DEA to distinguish efficient and inefficient industries from the processing sector of an input-output model, we propose using the functional free form of DEA to compare relative county efficiencies. Using county data generated from input-output analysis, we measure the relative productivities of various complexes of industries that form the economic base of Minnesota's counties. DEA is a nonparametric method and does not require any explicit assumption about the functional form of the county's production technology.[1] In a similar context Charnes *et al.* (1988) use DEA to analyze the

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[1] Techniques other than the nonparametric DEA approach have been proposed to estimate frontiers, and these techniques have their own limitations. Econometric approaches have been described by Forsund *et al.* (1980). Bauer (1990) describing recent development in the field and noting that

efficiency between inputs and outputs for Chinese cities. Their input-output measures are more aggregated than ours, however.

DEA, unlike input-output analysis, is an optimization technique. DEA measures the relative efficiency of particular decision-making units. A decision-making unit is efficient if, and only if, it is not possible to improve any input or output without worsening some other input or output. A best practice envelope is constructed from the most efficient decision-making units. Decision-making units below the output surface are deemed inefficient, and their distance to the frontier is a measure of the degree of their inefficiency. DEA also is capable of measuring multiple inputs and multiple outputs. In addition, the existence of economies or diseconomies of scale can be determined from our model.

This application of input-output data is aggregated on the county level for the state of Minnesota. By employing disaggregated interregional data across the state of Minnesota, efficient and inefficient counties can be distinguished. Most production analysis identifies inefficiency as a residual from either a theoretical frontier or, as in DEA, an empirical frontier. A major reason for organizing our data set in this way is to identify external economies for those counties in urban areas, suburban enclaves, and rural hinterlands.[2] It is reasonable to expect that DEA-efficient counties may be the counties that have grown in the past and that are likely to grow in the future. Moreover, inefficient counties can be examined in order to identify the sources of inefficiencies in terms of output augmentations or input reductions required for these counties to reach the efficiency frontier.

2. IMPLAN and county input-output data

Micro IMPLAN (Olson, Lindall, Maki) 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 source data that 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 defined region's structure and industry interrelationships.

Micro IMPLAN is used to generate ten sector traditional input-output tables for each Minnesota county. The final payments and final demand components of these tables are identified for each county and are used as inputs and outputs in the DEA model. We also include transfer payments as an input. On the national level transfer

weaknesses of the parametric methods include the imposition of the explicit functional form of the technology and the lack of a known distribution for the inefficiency terms. Comparisons of these two approaches are found in Ferrier and Lovell (1990), Banker *et al.* (1986), and Mensah and Li (1993).

[2] Because our model aggregates across industries into types of incomes as inputs and types of final demands as outputs, we cannot distinguish localization versus general urbanization economies. A county lying below the frontier may be described as having an *external diseconomy*. Henderson (1986) suggests that external economies of scale are largely localization and not urbanization economies.

payments accounted for 17 percent of total personal income in 1993.[3] Transfer payments are an important income component used in the purchase of final outputs.

Including transfer payments, however, results in an unbalanced I/O table.[4] A more efficient county having the same inputs and outputs should have lower transfer payments.

The DEA treatment of taxes is more problematic. IMPLAN includes taxes in the various categories of incomes earned; therefore taxes are implicitly included on the input side of the DEA model. Indirect business taxes also appear implicitly in the prices that are included in final demand or output. Indirect taxes are separated and included as a balancing entry on the input side. IMPLAN gives no indication of where the taxes go, but it can be assumed that the majority leave the county to higher political jurisdictions. We decided to accept IMPLAN's implicit treatment of taxes in the DEA analysis because the IMPLAN database does not allow separation of the tax on incomes. Our DEA treatment therefore implicitly includes taxes on incomes as input and indirect business taxes in the prices of final outputs.

The final payments and transfer payments are:

Inputs:

- Transfer payments
- Employee compensation
- Proprietors income (single proprietors)
- Other proprietary income (dividends, interest, and rental income)
- Total imports.

The final demand components are:

Outputs:

- Household consumption
- Business investment
- Government spending
- Exports.

Based upon these five inputs and four outputs, an efficient frontier is constructed that comprises counties that use as little input as possible while purchasing as much output as possible. A broad notion of county efficiency is implicit in our choice of inputs. By including transfer payments and imports in the model, we have departed form a narrower notion of strict production efficiency.[5] This broader model can

[3] Transfer payments accounted for about 17 percent of total personal income for the United States in 1993. Data for county transfer payment levels were obtained from U.S. Department of Commerce, Bureau of Economic Analysis, *Regional Economic Information System* (REIS) 1969-1994.

[4] Our DEA model includes transfer payments as an input and excludes indirect business taxes that represent a balancing item in the final payments component of the IMPLAN system. These differences yield an unbalanced input-output accounting system. The transfer payments represent an important inefficiency source identified in the DEA model, however, and indirect business taxes already are included implicitly as prices paid for final goods. We opt for the ability to present meaningful explanations over the consistency of using a balanced input-output system.

[5] David W. Holland (36th annual meeting, WRSA, 1997) suggests a three input and four output model. Such a model would describe private sector production efficiency, but would not address public policy questions implied by tax and transfer efficiency at the county level.

address the county as a decision-making unit for the purpose of affecting public sector efficiency. While the county may have little control over externally imposed taxes and subsidies, the efficiencies or inefficiencies attributed to the ways in which these drains and infusions are used by the county to purchase outputs is implicit in this notion of efficiency. In this way, inefficiency in both the private and public sector can be addressed.

Imperfections exist in these measures, however, and do limit the applicability of our results. We justify imports as an input inasmuch as they partially include goods to be used for production. Imported goods to be used as final consumption, however are excluded from the model.[6]

3. Data envelopment analysis

As a linear programming implementation of Farrell's (1957) notion of technical efficiency, DEA is an external approach to efficiency evaluation. The frontier comprises 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) which is 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):

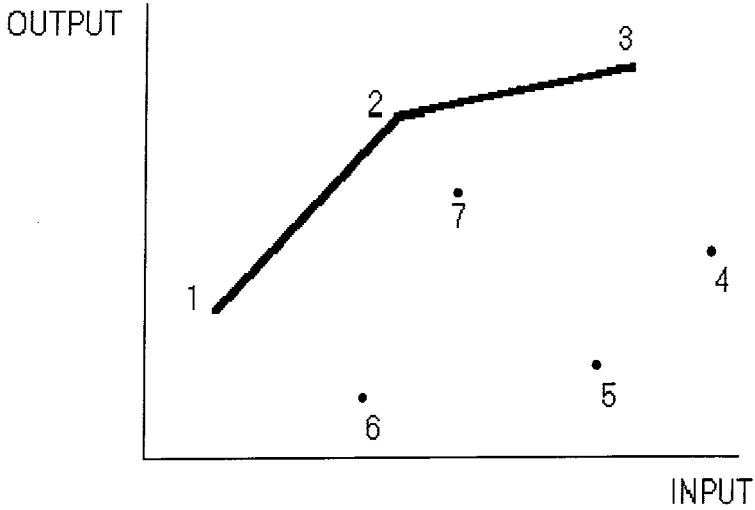
$$PE = \left\{ (Y^T, X^T) = \sum_{j=1}^{n} \mu_j (X_j^T, X_j^T);\ \sum_{j=1}^{n} \mu_j = 1,\ \mu_j \geq 0 \right\}$$

where Y_i and X_i represent the output production and input consumption, respectively, for the jth county, where j = 1, ... , 87.

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 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 dominates, are said to be *technically inefficient*. Figure 1 depicts 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.

[6] We expect that better data collection techniques in the IMPLAN social accounting matrix (SAM) will yield a better notion of public and private financial flows of a test county.

Figure 1. A hypothetical production possibility set and its frontier



Note: Efficient frontier comprises segments $\overline{12}$ and $\overline{23}$

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:

$$\min Z_0 = \sum_{r=1}^{4} - s_r^+ + \sum_{i=1}^{5} - s_i^-$$

$$\text{s.t.} \sum_{j=1}^{87} Y_{rj}\lambda + s_r^+ = Y_{ro},\ r = 1, \ldots, 4 \text{ (outputs for the county)}$$

$$\sum_{j=1}^{87} X_{ij}\lambda + s_i^- = Y_{io},\ i = 1, \ldots, 5 \text{ (inputs for the county)}$$

$$\sum_{j=1}^{87} \lambda_j = 1$$

$$\lambda_j,\ s_r^+,\ s_i^- \geq 0.$$

where Y_{rj} and X_{ij} represent the matrices of output production and input consumption, respectively. The right side values, Y_{ro} and X_{io} represent the component vector for the county being tested, while s_r^+ and s_i^- represent the reference county's shortfall in production and its excess in consumption, respectively. The λ_j vector guarantees a convex combination of the observed decision-making units. A county is deemed efficient when the sum of the slacks is zero:

$$\sum_{r=1}^{4} - s_r^{+*} + \sum_{i=1}^{5} - s^{-*} = Z_o = 0, \text{ (where * denotes an optimum value).}$$

The corresponding pricing or dual model to min Z_o takes the following form:

$$\max \sum_{r=1}^{4} \mu_r y_{ro} - \sum_{i=1}^{5} v_i x_{io} + \varpi$$

$$\text{subject to} \sum_{j=1}^{87} \mu_r y_{rj} - \sum_{i=1}^{5} v_i x_{ij} + \varpi \le 0, \ j = 1, \ldots, 87$$

$$-\mu_r \le -1$$

$$-v_i \le -1$$

$$\varpi \text{ free.}$$

By virtue of the constraints we have

$$\sum_{r=1}^{4} \mu_r^* y_{ro} - \sum_{i=1}^{5} v_i^* x_{io} + \varpi \le 0$$

again where "*" indicates an optimum value. This gives

$$\sum_{r=1}^{4} \mu_r^* y_{ro} + \varpi^* \le \sum_{i=1}^{5} v_i^* x_{io}$$

or

$$0 \le \frac{\sum_{r=1}^{4} \mu_r^* y_{ro} + \varpi^*}{\sum_{i=1}^{5} v_r^* x_{io}} \le 1.$$

The dual depicts a hyperplane that forms a section of the envelopment surface comprising the most efficient counties. The parameters μ and v are the coefficients or multipliers in the dual model. The intercept of a facet on the frontier can be used to indicate whether scale economies or diseconomies exist. Omega, ϖ, identifies returns to scale and is zero if the projected facet goes through the origin of the output scale. If $\varpi < 0$ then the county (or the county's efficient projection) experiences increasing returns to scale. If $\varpi > 0$, the county experiences decreasing returns to scale. v is the marginal effect of input X on the efficiency score, and μ is the marginal effect of output Y on the efficiency score. These models were computed using the standard units model because all inputs and outputs are expressed in the common metric of millions of dollars. This model's application is translation invariant, but not units invariant (Lovell and Pastor 1995). The DEA analysis results are reported in the next section.

4. Empirical results of the DEA

Table 1 describes the DEA efficiency scores for 87 Minnesota counties. For an inefficient county the efficiency score is calculated by measuring the distance from the actual county observation to the projected observation on the frontier. The projected observation is given by the output slacks and the excess inputs. The projected point is defined as:

$$(\hat{Y}_{ro}, \hat{X}_{io}) = (Y_{ro} + s^{+*}, X_{io} - s^{-*}),$$

or alternatively, a projected point can also be defined by the lambda vector as:

$$= (\lambda_{ro}\ Y_{ro}, \Sigma\ \lambda_{io}\ X_{io}).$$

If a county is efficient, then the observed and the projected point will be the same on the frontier, the slacks will be zero, and the efficiency score will be unity. If the county is inefficient, the slacks will be positive, and the distance between the observed and the projected point will be given by the ratio E_j. The efficiency score, for a specific county is given by:

$$E_o = \frac{\text{Virtual Output} + \varpi}{\text{Virtual Input}} = \frac{\mu_{ro} Y_{ro} + \varpi}{v_{io} X_{io}} \quad .$$

Column 1 of Table 1 indicates the efficiency scores such that unity represents a county on the frontier, suggesting that a maximum level of outputs can be purchased from inputs that no other county can exceed. A value less than one indicates that a county lies below the output surface. For example, for Becker County, $E_3 = 0.919$, which suggests that Becker might approach the frontier by proportionately reducing inputs to 91.9 percent of the original level. In addition, in this model one could approach the production surface from below by proportionately augmenting outputs 108.9 percent.

Only 22 of the 87 counties have E_js less than one and are deemed inefficient. Figure 2 shows the inefficient counties by cross-hatching. A weak pattern emerges that indicates that these counties are rural, while urban counties display efficient scores of unity. Weak groupings of inefficient county complexes also appear.

The shaded area in Figure 2 also shows the Twin Cities metropolitan area that surrounds the cities of Minneapolis and St. Paul. We define the metropolitan area in terms of population density (Figure 3) to include 13 counties. All of these counties have E_js of unity and therefore help to form part of the efficiency frontier.

A different classification scheme based on counties with populations over 100,000 (column 3, Table 1) identifies eight counties: Anoka, Dakota, Hennepin,

Table 1. DEA results

Area name	Efficiency scores (E_j)	Returns to scale (ω)	Population (1,000s)	Personal income per capita ($s)
Aitkin	1.000	D	12.9	14027
Anoka	1.000	I	263.6	18556
Becker	0.919	I	28.5	14385
Beltrami	1.000	I	36.5	14198
Benton	0.919	I	32.2	15915
Big Stone	1.000	D	6.0	14336
Blue Earth	1.000	I	53.7	17517
Brown	1.000	I	27.1	17377
Carlton	0.930	I	30.0	15845
Carver	1.000	I	54.1	22218
Cass	1.000	I	23.5	14655
Chippewa	0.954	I	13.1	16063
Chisago	1.000	D	33.9	16802
Clay	1.000	I	51.6	15280
Clearwater	1.000	I	8.3	12850
Cook	1.000	I	4.3	18911
Cottonwood	1.000	D	12.5	14955
Crow Wing	1.000	I	47.8	16691
Dakota	1.000	I	304.4	23120
Dodge	1.000	I	16.5	16373
Douglas	0.988	I	29.7	15881
Faribault	0.908	I	16.6	16117
Fillmore	1.000	D	20.7	15037
Freeborn	1.000	D	32.6	16194
Goodhue	0.948	I	41.8	18698
Grant	0.967	D	6.1	17234
Hennepin	1.000	I	1045.7	28266
Houston	1.000	D	19.0	16641
Hubbard	1.000	D	15.6	14165
Isanti	1.000	I	27.5	16354
Itasca	1.000	I	42.3	15050
Jackson	1.000	I	11.7	14364
Kanabec	1.000	D	13.2	14814
Kandiyohi	1.000	I	40.1	16773
Kittson	1.000	D	5.5	16157
Koochiching	0.912	D	16.2	15140
Lac Qui Parle	1.000	D	8.6	14786
Lake	1.000	D	10.5	15776
Lake of the Woods	1.000	D	4.3	15468
Le Sueur	1.000	I	23.8	17129
Lincoln	1.000	D	6.9	13232
Lyon	1.000	I	24.8	18093
Mcleod	1.000	I	32.8	18314
Mahnomen	1.000	D	5.1	12344
Marshall	1.000	D	10.7	13470
Martin	0.950	D	22.7	16752
Meeker	1.000	I	20.9	15633
Mille Lacs	1.000	I	19.4	14911
Morrison	0.999	I	29.9	13873
Mower	1.000	I	37.5	18929

Table 1. DEA results (cont.)

Area name	Efficiency scores (E_j)	Returns to scale (ω)	Population (1,000s)	Personal income per capita ($s)
Murray	1.000	D	9.6	14349
Nicollet	0.943	D	29.4	17121
Nobles	1.000	I	20.3	16686
Norman	1.000	D	7.8	15815
Olmsted	1.000	D	112.5	22347
Otter Tail	1.000	I	52.0	15785
Pennington	0.973	D	13.4	16220
Pine	1.000	D	22.4	14084
Pipestone	0.989	D	10.4	15095
Polk	0.984	I	32.7	16041
Pope	1.000	D	10.9	14229
Ramsey	1.000	I	484.8	23826
Red Lake	1.000	D	4.4	12681
Redwood	0.948	I	17.2	16006
Renville	0.945	I	17.4	15642
Rice	1.000	I	51.0	16847
Rock	1.000	D	9.8	16192
Roseau	1.000	I	15.6	15556
St. Louis	1.000	D	198.7	17872
Scott	1.000	I	64.9	20376
Sherburne	1.000	I	48.2	16302
Sibley	1.000	D	14.5	14998
Stearns	1.000	I	123.1	16335
Steele	1.000	D	31.2	18744
Stevens	1.000	I	10.4	15156
Swift	0.990	D	10.5	15226
Todd	1.000	D	23.6	13338
Traverse	1.000	D	4.3	17232
Wabasha	0.983	D	20.2	17635
Wadena	1.000	I	12.9	13686
Waseca	1.000	D	18.1	15616
Washington	1.000	I	166.0	22394
Watonwan	1.000	I	11.7	15885
Wilkin	0.983	D	7.4	15693
Winona	0.989	D	48.2	17759
Wright	1.000	D	74.4	17631
Yellow Medicine	0.983	D	11.6	15231

Olmstead, Ramsey, Stearns, St. Louis, and Washington. Two of the eight counties, Olmstead and St. Louis, are outside the Twin Cities metropolitan area. Table 2 identifies the urban areas associated with these counties. All of these counties also have E_js of unity.

By contrast, 22 inefficient counties are shown in Figure 2 and are aggregated in Table 3. The DEA-efficient Minneapolis-St. Paul counties are urban, containing a large average population of 202,600 with a high personal income per capita of $20,203 (Table 2). By stark contrast, inefficient counties in Table 4 are rural, con-

Figure 2. 22 inefficient counties: $E_j < 1$ (cross-hatched); 13 metropolitan counties (shaded)

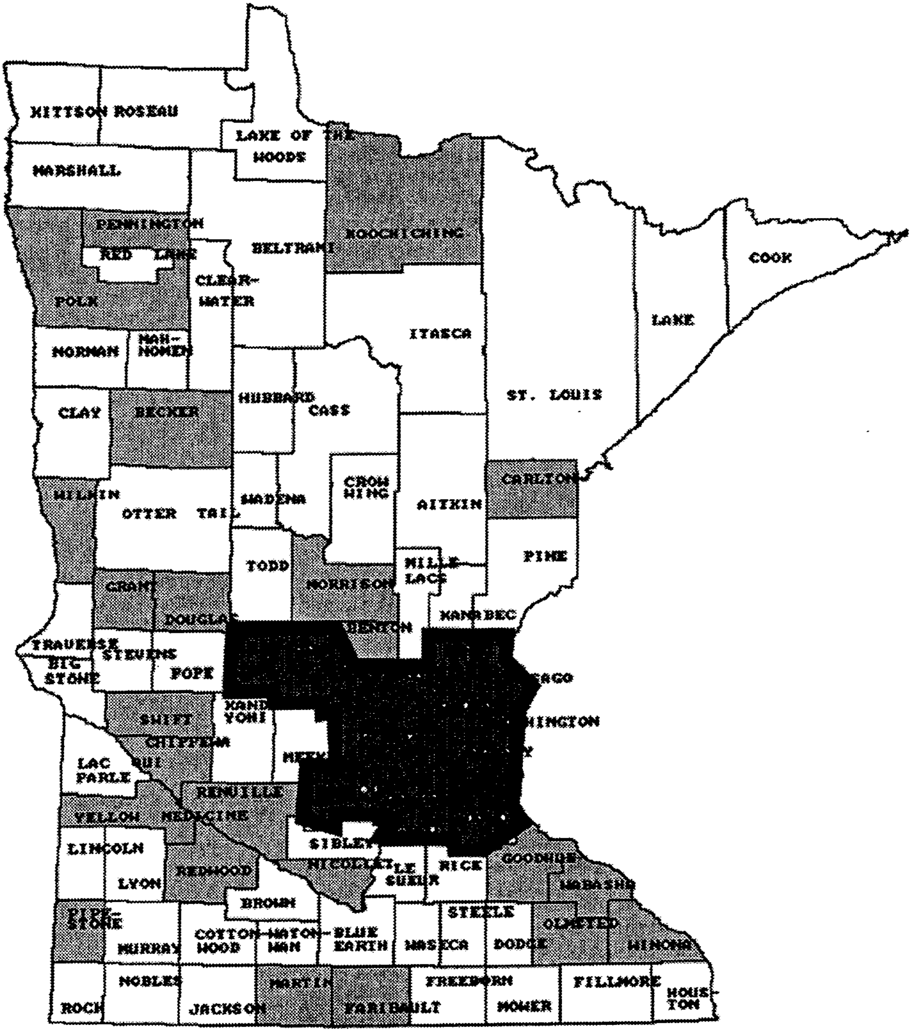


Figure 3. Population density by county

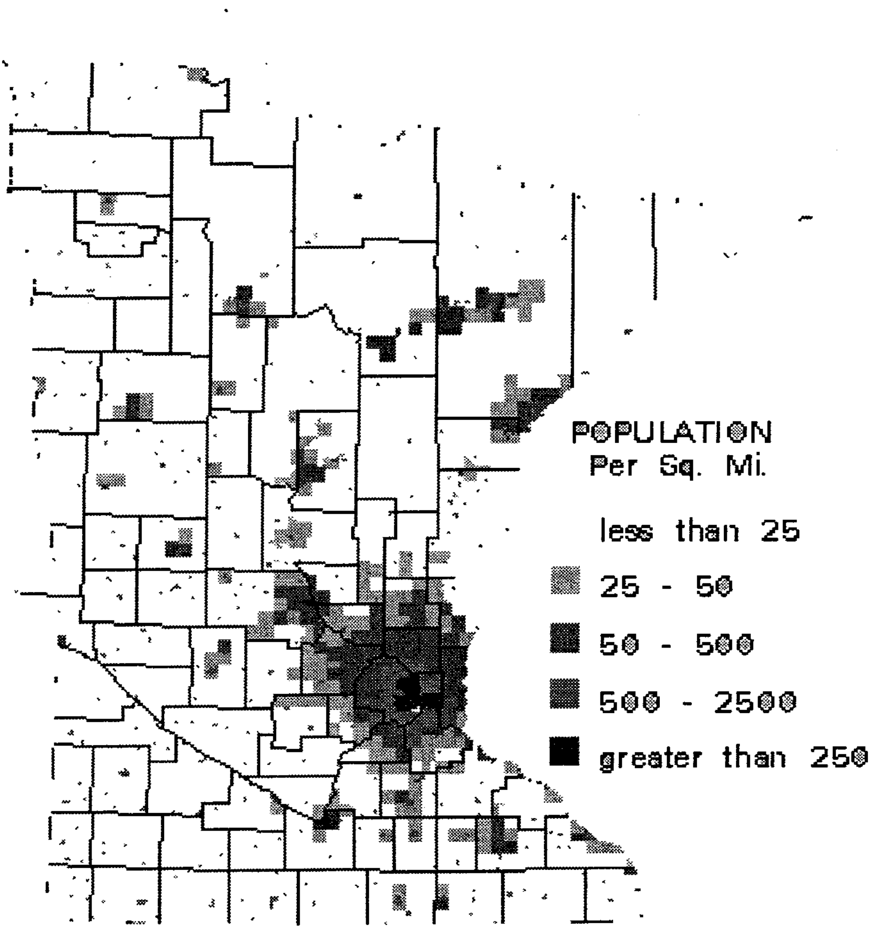


Table 2. Counties with population greater than 100,000 and urban areas within

Anoka County
- Coon Rapids city
- Blaine city
- Fridley city

Dakota County
- Burnsville city
- Eagan city
- Apple Valley city

Hennepin County
- Minneapolis city
- Bloomington city
- Brooklyn Park city

Olmsted County
- Rochester city
- Marion township
- Stewartville city

Ramsey County
- St. Paul city
- Roseville city
- Maplewood city

Stearns County
- St. Cloud city
- St. Cloud township
- Waite Park city

St. Louis County
- Duluth city
- Hibbing city
- Virginia city

Washington County
- Cottage Grove city
- Woodbury city
- Oakdale city

Table 3. DEA results for Minneapolis-St. Paul metropolitan counties

Area name	Efficiency scores (E_j)	Returns to scale (ω)	Population (1,000s)	Personal income per capita ($s)
Anoka	1.000	I	263.6	18556
Carver	1.000	I	54.1	22218
Chisago	1.000	D	33.9	16802
Dakota	1.000	I	304.4	23120
Hennepin	1.000	I	1045.7	28266
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Ramsey	1.000	I	484.8	23826
Scott	1.000	I	64.9	20376
Sherburne	1.000	I	48.2	16302
Stearns	1.000	I	123.1	16335
Washington	1.000	I	166.0	22394
Wright	1.000	D	74.4	17631
			202.6	20,203

taining a small average population of 22,100 with a low personal income per capita of $16,071. This comparison seems uniform; the only exceptions are several metro counties in Table 3 (Chisago, Isanti, and Sherburne) that have relatively small populations and low income, but also lie on the efficient frontier. These counties may be described as *bedroom communities*. They appear as efficient because their high personal incomes are earned in the urban community outside the county, but these incomes are used within the county to purchase high levels of output (i.e., final demand).

The additive DEA model, unlike input-oriented or output-oriented models, can show both the input reductions (Table 5), and output augmentations (Table 6) necessary to reach the efficient frontier. The most prominent input reduction involves transfer payments which are the most overutilized resource relative to the level of output purchases in 20 of the 22 inefficient counties. The movement toward effi-

Table 4. DEA results of inefficient counties only

Area name	Efficiency scores (E_j)	Returns to scale (ω)	Population (1,000s)	Personal income per capita ($s)
Becker	0.919	I	28.5	14385
Benton	0.919	I	32.2	15915
Carlton	0.930	I	30.0	15845
Chippewa	0.954	I	13.1	16063
Douglas	0.988	I	29.7	15881
Faribault	0.908	I	16.6	16117
Goodhue	0.948	I	41.8	18698
Grant	0.967	D	6.1	17234
Koochiching	0.912	D	16.2	15140
Martin	0.950	D	22.7	16752
Morrison	0.999	I	29.9	13873
Nicollet	0.943	D	29.4	17121
Pennington	0.973	D	13.4	16220
Pipestone	0.989	D	10.4	15095
Polk	0.984	I	32.7	16041
Redwood	0.948	I	17.2	16006
Renville	0.945	I	17.4	15642
Swift	0.990	D	10.5	15226
Wabasha	0.983	D	20.2	17635
Wilkin	0.983	D	7.4	15693
Winona	0.989	D	48.2	17759
Yellow Medicine	0.983	D	11.6	15231
Means			22.1	16,071

Table 5. Extent of input reductions to reach the frontier

County	Transfer payments	Employee compensation	Proprietor income	Other income	Imports
1 Becker	-51.72	0.00	-2.47	0.00	0.00
2 Benton	-28.89	0.00	-2.99	0.00	-29.22
3 Carlton	-18.53	-25.78	0.00	-10.86	-15.77
4 Chippewa	-11.93	-3.79	-2.25	-8.70	-2.06
5 Douglas	-19.11	0.00	-2.25	0.00	0.00
6 Faribault	-24.58	-0.93	-0.16	-14.37	-1.37
7 Goodhue	-24.77	-22.33	0.00	-22.70	0.00
8 Grant	-3.28	0.00	0.00	-1.89	-0.19
9 Koochiching	-17.09	-12.73	0.00	0.00	-1.97
10 Martin	-20.80	0.00	0.00	-1.64	-10.06
11 Morrison	-3.09	0.00	0.00	0.00	0.00
12 Nicollet	0.00	-24.73	0.00	0.00	-8.87
13 Pennington	0.00	0.00	0.00	0.00	-0.22
14 Pipestone	-5.08	0.00	0.00	0.00	0.00
15 Polk	-20.58	0.00	0.00	0.00	0.00
16 Redwood	-11.22	0.00	-1.46	-11.59	0.00
17 Renville	-17.82	0.00	-2.41	-10.12	0.00
18 Swift	-2.27	-0.00	-0.01	-8.04	0.00
19 Wabasha	-6.88	0.00	-2.75	0.00	-1.49
20 Wilkin	-4.48	0.00	0.00	-4.38	-0.02
21 Winona	-11.60	0.00	0.00	0.00	0.00
22 Yellow Medicine	-1.17	0.00	-0.66	-5.73	0.00

Table 6. Extent of output (final demand) augmentations to reach the frontier

County	Consumption	Government purchases	Investment	Exports
1 Becker	0.00	0.00	6.31	27.73
2 Benton	0.00	23.05	3.49	0.00
3 Carlton	9.13	0.00	2.74	0.00
4 Chippewa	0.00	0.00	1.41	0.00
5 Douglas	0.00	0.00	0.00	0.00
6 Faribault	0.00	0.00	18.56	0.00
7 Goodhue	0.00	11.81	62.34	0.00
8 Grant	0.00	0.00	4.13	0.00
9 Koochiching	0.00	1.21	29.34	0.00
10 Martin	0.00	7.08	8.56	0.00
11 Morrison	0.00	0.00	3.86	0.00
12 Nicollet	0.00	0.00	30.74	0.00
13 Pennington	0.00	0.00	21.19	0.00
14 Pipestone	0.00	0.00	7.60	0.00
15 Redwood	0.00	0.00	12.07	0.00
16 Polk	0.00	0.00	17.78	0.00
17 Renville	0.00	0.00	10.23	0.00
18 Swift	0.00	0.00	0.00	0.00
19 Wabasha	0.00	0.00	5.01	0.00
20 Wilkin	0.00	2.46	5.80	0.00
21 Winona	0.00	7.00	36.40	0.00
22 Yellow Medicine	0.00	0.00	8.65	0.00

ciency requires that transfer payments be reduced an average of $15.2 million. Other required resource reductions include proprietors income, other incomes, and imports, which appear in approximately half of the inefficient counties. (The magnitude of the adjustment is small compared to transfer payments.)

Employee compensation appears as an excess input in only six of the inefficient counties. Output augmentations may need to be made. For the 22 inefficient counties, 20 evidenced either insufficient government purchases, or insufficient investment purchases, or both. The lack of purchases for social and private infrastructure may prevent these counties from participating in future economic growth. In terms of development policy, however, it is not evident from the analysis whether these deficient purchases are due to their low expected productivity or low levels of entrepreneurial initiative.

An important aspect of this approach is a discussion of returns to scale (RTS). In the dual or pricing model form of the additive model, the unconstrained variable ϖ represents the projected intercept of a facet on the frontier. If this intercept has a positive sign in two space, the projected production relationship to the vertical output axis has little slope, implying low average productivity, and evidencing decreasing returns to scale (DRS). If the intercept is zero, then the projected facet of the efficient decision-making units goes through the origin and exhibits constant scale returns (CRS). A negatively signed projected intercept would be steeply sloped, would have high productivity, and would evidence increasing scale returns (IRS). The returns to scale of an inefficient decision-making unit that uses the same facet as its reference set would be classified as the same returns to scale as the particular reference set.

For Minnesota the proportion of counties exhibiting increasing returns is evenly split (Table 1: 46 of 87 counties). For the 22 inefficient counties, increasing returns to scale are also evenly split (Table 4: 11 of 22). For the urban counties in Table 2, however, 11 of 13 urban counties exhibit increasing returns to scale. This is remarkable, as these are the most heavily populated counties with the highest per capita incomes. Apparently these counties are in the first stage of production exhibiting increasing returns to scale and have not reached the second stage of production where decreasing returns to scale begin. If metropolitan counties primarily exhibited increasing returns to scale, then peripheral counties exhibited decreasing returns to scale. Figure 4 identifies the 41 counties with positive intercepts ($\varpi > 0$, indicating a flat facet with low average productivity) which primarily lie in the hinterlands.

The geographic patterns of efficiency and returns to scale are dominated by the metropolitan counties and radiate outward, just as predicted by Maki's version of land use and land rent theories. Yet from a policy perspective, even though nearly half the counties have decreasing returns to scale (41 of 87), all of the counties were at their optimal scale. This result is derived by comparing the additive, variable returns to scale (VRS) model to the Charnes-Cooper-Rhodes (CCR) ratio model which exhibits constant returns to scale. Our additive VRS model frontier depicts only pure technical efficiency, while the ratio constant returns to scale model frontier measures both technical and scale inefficiencies. The two frontiers are identical, even though different metrics are implied by the two models' distinctive objective functions. A direct comparison between the two models does not allow a direct measure of scale inefficiency. The only exceptions are four counties that are technically efficient (according to the VRS additive model), but fall below the ratio model frontier, implying they are not scale efficient. All but four counties of 65 that are technically efficient are also scale efficient. Thus, 61 counties are both technically and scale efficient in 1993.

5. Conclusion and policy implications

DEA analysis shows promise for evaluating the efficiency levels of counties associated with metropolitan core areas as compared to transitional and peripheral regions. When applied to the counties in Minnesota, a pattern emerges that is similar to that proposed by Wilbur Maki in his presidential speech to the North American Regional Science Association. The core counties associated with Minneapolis and St. Paul are uniformity efficient with increasing returns to scale compared to the rest of the state. Efficiency scores decrease from that core as counties are located nearer to the periphery, with many of these counties showing the highest incidence of inefficiency and decreasing returns to scale.

Deviations from optimal scale of the county economic base are relatively unimportant. Even though the peripheral counties have low population and low income, there appears to be little productivity to be gained by altering the scale of the local economic base (except for four of 65 technically efficient counties who could raise their productivity by altering their scale). Many peripheral counties are on the fron-

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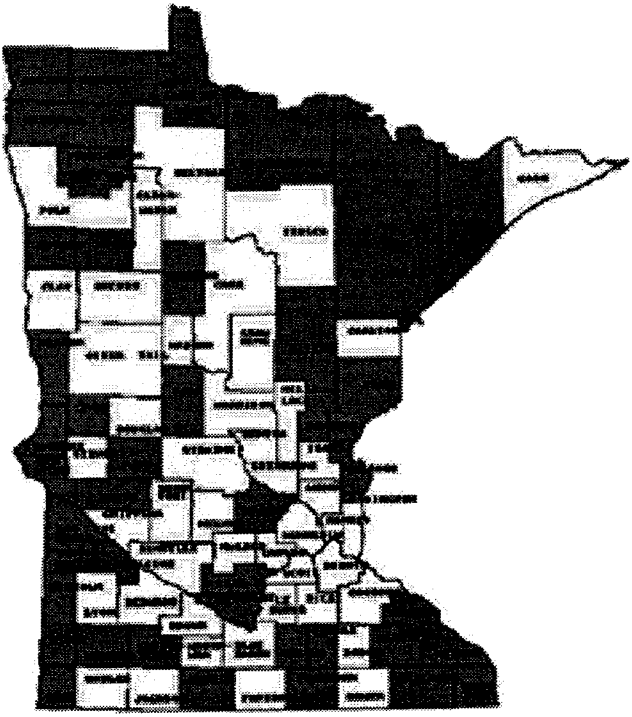
Figure 4. 41 shaded counties exhibiting DRS ($\omega > 0$)



tier, even with a small scale economic base and low levels of economic productivity, while fewer other small scale counties fall below this particular facet and are deemed inefficient.

Enhancing the efficiency of the 22 inefficient counties almost uniformly requires transfer payments to be reduced in order to move toward the frontier. In these counties the levels of transfers do not justify the existing levels of purchases. Hence, public decisions that determine who is to receive transfer payments and that influence where these individuals or groups reside will be a major determinant of the efficiency status of the county. Where peripheral counties are inefficient due to private transfers, i.e., retired individuals moving to rural areas to take advantage of amenities from rural living, public policy inconsequentially improves efficiency.

In addition, we identify inadequate investment and government purchases relative to the levels of input utilization as major sources of output inefficiencies. This lack of public and private expenditures into the economic base and infrastructure will lead to poor economic consequences for the inefficient counties.

The general perspective from the Maki view and our confirmation in terms of relative efficiency differences between the core metropolitan area, the transitional area, and the periphery lead to a heretical view of economic development efforts. If the metropolitan core remains as the innovative, export-creating, and import-replacing center, it will promote the growth and development of the remaining region(s) within the state. Professor Maki asserts that governmental subsidies of transportation and of suburban housing have weakened the efficiency of the urban core by separating place of residence from place of work and have relegated the core as a depository for low income, high service requirement populations. Educational subsidies, housing subsidies, and transportation subsidies long directed toward the transitional and peripheral areas should be redirected toward the central city. The problems of providing adequate education, fighting crime, and others currently faced by central cities too often are addressed by allocating scarce public resources toward ex-suburbia and rural areas while denying the central city needed resources. This view suggests that subsidies should flow toward those regions that hold the greatest promise for realizing positive outcomes, namely the central core, as it promises to be the engine of growth for the large regions. Of course, this is a policy implication when efficiency is the goal. There are equity considerations that may negate this policy implication.

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