Efficiency gains from regionalization: economic development in China revisited

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Abstract

This paper uses a DEA model of multi-unit efficiency measurement to investigate the gains from regional analysis of efficient economic development. The model is applied to the Chinese city economic development data used by Charnes, Cooper, and Li in a recent issue of this journal to demonstrate the usefulness of alternative DEA-based measures in economic development policy. Assuming that Chinese cities can cooperate within a region reveals that efficiency gains are possible. This may provide additional information to policy makers in terms of how to direct planned investment. Additional information is provided and traditional DEA model results are also explained within this regional development context. Published by Elsevier Science Ltd.

Keywords: Data envelopment analysis; Multi-unit efficiency; Economic development; Measuring gains from regional development; China cities

1. Introduction

Data Envelopment Analysis (DEA) has proven to be an important tool in the analysis of a wide spectrum of policy issues. For example, a recent well-known application, authored by Charnes et al. [1], involves the use of DEA in analyzing the economic development of Chinese cities. Using macroeconomic data on outputs (domestic product measures) and inputs (labor and investment or capital), these authors employed traditional DEA models to compare the economic performance of major cities in China. Suggestions for how this analysis might be

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used to inform economic development policy makers in a planned economy were also provided. This analysis was later extended by Sueyoshi [2]. Macmillan [3,4] provides extensions of DEA to development analysis of multi-regional economic planning in the United States. Applications of DEA to location analysis evaluation include those of Desai and Storbeck [5] and Desai et al. [6]. These studies demonstrate how DEA can be used to determine the efficiency of various spatial configurations.¹

The extension of DEA to economic development policy has motivated this paper. The above examples suggest that economic development may be better evaluated on a regional basis since, as in the case of China, economic development policy often focuses on regional development. However, the DEA models in these studies generally fail to account for regional aspects of economic development. They thus assume the economic performance of each Decision Making Unit (DMU) is independent of other DMUs in the sample. For example, in the Chinese city case, economic development in any given major city is considered independent of any other city’s development. Indeed, some of the cities are located very near each other and are considered to be part of the same “region” in economic development policies. In the current study, we present measures of economic development that allow for analysis of regional, city or individual DMU economic development efficiency.

In order to model regional economic development, two strands of literature that extend DEA models based on the construction of alternative reference technologies are relevant. The first involves DEA analysis of the efficiency of an industry based on the performance of firms in that industry [9,10]. In these models, the approach involves constructing reference technologies using data from individual firms. Further, it allows for hypothetical reallocation of resources across firms to construct an industry reference technology.² The efficiency measures gauged relative to these “industry” reference technologies are compared to the “firm” reference technologies (which do not allow for reallocation of inputs across firms) in order to evaluate the performance of both individual firms and the industry. In this regard, Førsund and Hjalmarsson [9] argue that analysis of industry technologies “can be useful as a kind of description of industrial structure and structural change based on technical relationships, i.e., the distribution of input coefficients and capacity, giving a hypothetically maximum output for given amounts of inputs.”

The second strand of relevant literature involves analysis of firms based on the performance of multi-units owned by the firm. Similar to the industry structure models, these (DEA) formulations construct an “additive technology” to investigate the gains from combining different units within a firm. Modeling the productivity benefits of combining units has allowed for the measurement of efficiency gains in a wide variety of settings, including plants of electric utilities [11] and units in branch banking [12].

The next section contains proposed DEA models and measures for regional economic

¹ For an application of this model to determine candidate sites for regional medical facilities, see Haynes et al. [7]. Balakrishnan et al. [8] use DEA to assess the efficiency of different location covering solutions to a retail outlet network siting problem.

² Førsund and Hjalmarsson [9] present an industry reference technology where all inputs are reallocable. Färe et al. [10] extend this model of industry production where only some of the inputs are reallocable while others are firm-specific (not reallocable) across firms in an industry.
development analysis. They represent a stylized version of structures suggested by Färe and Primont [11]. Interpretation of these models within the context of economic development policy analysis concludes the section. Use of these measures is then investigated in terms of economic development in Chinese cities, using data from Charnes et al. [1]. Results presented in the subsequent section illustrate how regional analysis of economic development can inform policy. The paper ends with a summary of results and suggestions for further research.

2. DEA models of gains from regionalization

In our efforts to compute potential gains from considering regionalization, we employ the DEA models proposed by Färe and Primont [11]. Essentially, these models construct three distinct reference technologies and gauge the efficiency of each DMU relative to each technology. In terms of notation, assume there are $R$ regions, numbered $r = 1, \ldots, R$. Each region has $J_r$ cities numbered, $j = 1, \ldots, J_r$. A multiple input, multiple output economic development model is assumed with $N$ inputs and $M$ outputs for each city in each region. Thus, $x_{jr} = (x_{jr1}, \ldots, x_{jrn})$ is the vector of observed quantities of inputs, $x_{jrm}$, used by city $j$ in region $r$ for each input $n = 1, \ldots, N$. Likewise, $y_{jr} = (y_{jr1}, \ldots, y_{jrm})$ is the vector of observed quantities of outputs, $y_{jrm}$, used by city $j$ in region $r$ for each output, $m = 1, \ldots, M$.

The first measure of efficiency for each city is based on what Färe and Primont [11] call the “Afriat” technology, a variable returns technology for each region. The measure of efficiency relative to the Afriat technology is the ratio of maximum potential output relative to the variable returns to scale technology constructed for the observed cities in a region. This measure is computed for each city, denoted $j_r$ in region $r^*$, by solving the following linear programming problem:

$$F^A(x^{r^*}, y^{r^*}) = \text{maximum } \theta \text{ subject to:}$$

$$\sum_{j=1}^{J_r} z_j y_{jr^*m} \geq \theta y_{j^r*r^*m}, \quad m = 1, \ldots, M$$

$$\sum_{j=1}^{J_r} z_j x_{jr^*n} \leq x_{j^r*r^*n}, \quad n = 1, \ldots, N$$

$$\sum_{j=1}^{J_r} z_j = 1, \quad z_j \geq 0, \quad j = 1, \ldots, J_r$$

(1)

---

3 For a clear discussion of the information associated with defining measures of efficiency relative to alternative reference technologies, see Grosskopf [13].

4 This technology was named for Afrait, who originally suggested this variable returns technology restriction [14].
where, \( z_j \)s are the usual DEA intensity variables. Notice that we compute a measure for each city relative to cities in the same region. Thus, \( F^A \) gives the ratio of maximum output to actual output, where maximum output is determined by efficient cities within a region. The value, \( 1 - 1/F^A \), gives the amount by which outputs could be increased if the city were as efficient as the efficient cities in its region.

The second proposed measure assumes that each city can cooperate with other cities in its region. The reference technology thus is assumed to represent an additive technology for cities within a region. Following Färe and Primont [11], this technology is referred to as the “Koopmans” technology and represents the additive hull of the observed regional level data.\(^5\)

The Koopmans measure for city \( j^* \) is an output-based DEA model of the following form:

\[
F^K(x_{jr^*}, y_{jr^*}) = \text{maximum } \theta \text{ subject to:}
\]

\[
\sum_{j=1}^{J_r} z_j y_{jr^*m} \geq \theta y_{jr^*m}, \quad m = 1, \ldots, M
\]

\[
\sum_{j=1}^{J_r} z_j x_{jr^*n} \leq x_{jr^*n}, \quad n = 1, \ldots, N
\]

\[
0 \leq z_j \leq 1, \quad j = 1, \ldots, J_r
\]

Comparing Eqs. (1) and (2), it is clear that for each city \( j^* \) in region \( r^* \), \( F^A(x_{jr^*}, y_{jr^*}) \leq F^K(x_{jr^*}, y_{jr^*}) \). This allows us to define the potential gain from regional cooperation for city \( j^* \) with the following measure:

\[
\text{GMR}(x_{jr^*}, y_{jr^*}) = \frac{F^K(x_{jr^*}, y_{jr^*})}{F^A(x_{jr^*}, y_{jr^*})}
\]

The third and final measure developed here is computed relative to the regional technology. Each region is assumed to be an economic development unit. The free disposal convex hull of these units is then constructed. The DEA measures of efficiency for city \( j^* \) relative to this technology are computed by solving the following linear programming problem:

\[
F^{Ak}(x_{jr^*}, y_{jr^*}) = \text{maximum } \theta \text{ subject to:}
\]

\[
\sum_{r=1}^{R} \sum_{j=1}^{J_r} z_{jr} y_{jr^*m} \geq \theta y_{jr^*m}, \quad m = 1, \ldots, M
\]

\(^5\) This technology was named for Koopmans, who originally suggested this variable returns technology restriction [15].
\[
\sum_{r=1}^{R} \sum_{j=1}^{J_r} \xi_{j,r} x_{j,m} \leq x_{j,r}^* R_r, \quad n = 1, \ldots, N
\]

\[
0 \leq \xi_{j,r} \leq z_r, \quad j = 1, \ldots, J_r, \quad \sum_{r=1}^{J_r} z_r = 1.
\] (4)

In problem (4), the \( \xi_{j,r} \) and \( z_r \) represent an Afriat technology constructed from the \( R \) Koopmans technologies. Comparing Eqs. (2) and (4), it can be shown that \( F^A(x_{j,r}^*, y_{j,r}^*) \leq F^A K(x_{j,r}^*, y_{j,r}^*) \). This allows us to define a measure of a region’s efficiency relative to all other regions for each city \( j^* \):

\[
\text{REG}(x_{j^*,r}^*, y_{j^*,r}^*) = \frac{F^A K(x_{j^*,r}^*, y_{j^*,r}^*)}{F^A K(x_{j^*,r}^*, y_{j^*,r}^*)}
\] (5)

To illustrate these measures of regional economic development efficiency, assume the existence of four cities and two regions. The cities are denoted \( R1, R2, S1, \) and \( S2 \). The first region, \( R \), contains cities \( R1 \) and \( R2 \) while the second region, \( S \), contains cities \( S1 \) and \( S2 \). In computing the measures of efficiency, five technologies are constructed. Their efficient points (or boundaries) are given in Table 1 and illustrated in Fig. 1. For each region, two Afriat technologies, two Koopmans technologies, and one regional technology are constructed. For each city, we compute three measures of efficiency. The first, the city measure or \( F^d \) is computed relative to the separate regional Afriat technologies. Referring to Fig. 1, the city measures for \( R1 \) and \( S1 \) are unity since these cities are efficient (on their respective regional frontiers). Both \( R2 \) and \( S2 \) are inefficient in the sense that they could have produced more output relative to the efficient cities in their region. The maximal output for city \( R2 \) is defined by the line segment \( R1e \). For city \( S2 \), the maximal output is the line segment \( S1f \).

The second measure computed is the gains from regionalization or GMR (see Eq. 3). It compares the outputs produced relative to the Afriat and Koopmans technologies. Cities \( S1 \) and \( R1 \) have a GMR measure equal to unity, since both cities are on the Afriat and Koopmans technologies. These cities are thus efficient within their region \( S \) relative to the technologies if cities within their region cooperated. For city \( R2 \), there are gains from regionalization. GMR is inefficient, since the measure for \( R2 \) relative to \( R1e \) is smaller than is the measure relative to the line segment for region \( R \) Koopmans technology, \( R1R \). For city \( S2 \),

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example reference technologies and efficient points</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reference technology</th>
<th>Efficient points</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T^A \text{Region} R )</td>
<td>( R1, e )</td>
</tr>
<tr>
<td>( T^A \text{Region} S )</td>
<td>( S1, f )</td>
</tr>
<tr>
<td>( T^k \text{Region} R )</td>
<td>( R1, R \ (= R1 + R2) )</td>
</tr>
<tr>
<td>( T^k \text{Region} S )</td>
<td>( S1, S \ (= S1 + S2) )</td>
</tr>
<tr>
<td>( T^A K )</td>
<td>( S1, R )</td>
</tr>
</tbody>
</table>
there are gains from GMR since the measure computed relative to $S1f$ is smaller than that computed relative to the Koopmans technology ($S1 S$).

The final measure, the *regional* or REG measure (see Eq. 4), compares the efficiency of each city within a region based on the cities’ regional technology. That is, it compares the $T^{AK}$ technology to the Koopmans technologies. For these measures, only city $S1$ is efficient. City $R1$ is inefficient because the output produced is less than the output measures along the line segment $S1R$. Cities $R2$ and $S2$ are also inefficient since their measure of efficiency relative to the Koopmans technologies is less than the measure relative to the $T^{AK}$ technology. It should be clear that these measures of efficiency are related because the technologies in which efficiency is gauged are nested. Specifically, for each city we have the following relationship:

$$F^{AK}(x^{r^e}, y^{r^e}) = \text{REG}(x^{r^e}, y^{r^e}) \cdot F^{A}(x^{r^e}, y^{r^e}) \cdot \text{GMR}(x^{r^e}, y^{r^e})$$

Thus, for each city we can measure economic development efficiency based on the region, $F^{AK}$, and decompose that measure into efficiency from regional cooperation, REG, a measure of economic development of the city relative to other cities in the region, $F^{A}$, and a measure of the gains to that city of cooperating with other cities in their region, GMR. This decomposition can provide useful information for economic development analysis. For example, analysis of economic growth data within a region can reveal the potential for additional gains in economic development by combining areas. Information on the gains from pooling resources across geographic areas may also prove useful for policy that targets investment in infrastructure and capital. This is of particular importance to planned economies such as China, where investment is targeted to specific areas.\(^6\)

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\(^6\)Local governments in the US are certainly involved in economic development policy and thus could also benefit from such information. Other considerations, such as political factors and the cost of delivering services, would also be relevant to decisions involving cooperation. See Carey et al. [16] for a model of municipal consolidation.
3. Data and results

To demonstrate the regional economic development measures proposed herein, we use data from the development of Chinese cities in 1983 and 1984; in particular, macroeconomic data for 28 Chinese cities in Charnes et al. [1]. Descriptive statistics of the variables used in the model are provided in Table 2. One output of the model in [4] is used, the value gross industrial output (GIOV), which is measured in 10,000s of rmb, the Chinese monetary unit.7 As seen from Table 2, there is considerable variation in GIOV across cities. Further, GIOV grew from more than 103 trillion rmb to over 115 trillion rmb, on average, for each city. Total growth in GIOV for all 28 cities between 1983 and 1984 was 12.5%.

Two inputs are specified by the model: a measure of the size of the labor force in each city, LABOR, measured in 10,000 persons; and a measure of the level of investment (or capital) in each city, INVEST, which is measured in 10,000s rmb. Table 2 reveals considerable variation in both labor and capital across cities. Also, on average, both labor and capital increased between 1983 and 1984. As Charnes et al. [1] discuss, the increase in capital in certain cities was part of China’s economic development planning policy. Differences in the sizes of investment in each city will be analyzed below.

In this analysis, we demonstrate the gains from regionalization within the Chinese context of [1]. We specify four regions: Shanghai, Beijing, Guangzhou, and Lanzhou. Fig. 2 is a map of these regions showing the cities therein. A list of the cities in each region is given in the Appendix. Two of the regions are based on the two largest economic centers in China: Shanghai and Beijing. The third region, Guangzhou, is a focus of Chinese economic development policy because it is close to Hong Kong. The fourth region, called Lanzhou, has a

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Table 2
Descriptive statistics of variables by year

<table>
<thead>
<tr>
<th>Variable/Year</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIOV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1983</td>
<td>1,030,288.93</td>
<td>1,240,964.39</td>
<td>145,792.00</td>
<td>6,785,798.00</td>
</tr>
<tr>
<td>1984</td>
<td>1,159,102.46</td>
<td>1,359,289.90</td>
<td>162,454.00</td>
<td>7,443,700.00</td>
</tr>
<tr>
<td>LABOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1983</td>
<td>131.12</td>
<td>101.46</td>
<td>20.09</td>
<td>483.01</td>
</tr>
<tr>
<td>1984</td>
<td>132.71</td>
<td>102.91</td>
<td>20.07</td>
<td>487.44</td>
</tr>
<tr>
<td>INVEST</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1983</td>
<td>112,961.86</td>
<td>129,571.72</td>
<td>28,112.00</td>
<td>616,961.00</td>
</tr>
<tr>
<td>1984</td>
<td>125,667.57</td>
<td>163,559.28</td>
<td>1,847.00</td>
<td>718,953.00</td>
</tr>
</tbody>
</table>

* Source: Statistics compiled by the authors using data from Charnes et al. [1].

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7 Charnes et al. [1] specify three outputs. We specify one because, with few observations, our regional analysis is more limited.
more sparse population and a very different economic development focus. We point out that our efficiency results are specific to these regions. A different specification of regional development would thus most likely yield different results. Also, over time, different regions would likely produce different patterns of efficiency.

Fig. 3 gives the total output (GIOV) of all cities in each region for 1983 and 1984. In both years, Shanghai was the largest region, as measured by GIOV, followed by Beijing, Lanzhou, and Guangzhou. Lanzhou is the largest region in terms of area. Note that the differential rates of growth in GIOV between 1983 and 1984 across regions is small. The growth in output was largest in Lanzhou (13.2%), followed by Shanghai (13.0%), Beijing (11.9%), and Guangzhou (11.6%).

There are also differences in the total amount of investment across regions, as well as changes in level between 1983 and 1984. Fig. 4 illustrates these differences. Beijing had the highest level of investment in both years and the largest growth in investment (in excess of 17.7%). In contrast, Shanghai had a higher level of output compared to Beijing in both years, as shown in Fig. 3, but had a net decrease in level of investment (by approximately 3.5%). As Charnes et al. [1] observe, the level of investment by city has been influenced by economic development policies. For example, given its proximity to Hong Kong, planners increased investment in the city of Guangzhou between 1983 and 1984 by almost 5%. Also, development in the more rural western province, Lanzhou, has been of particular interest as investment increased there by more than 16.5% between 1983 and 1984.

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8 Our regions roughly coincide with the three "economic belts" specified in China’s Seventh Five-Year Plan (1986–1990): the eastern coastal region, the central region, and the western region. We specify a fourth region that roughly splits the eastern coastal region in order to distinguish the area on the coast near Hong Kong. See Hansen and Zhang [17] for further discussion.
We now analyze the economic development gains in efficiency from regionalization for each of the regions and cities studied in [1] for years 1983 and 1984. Table 3 provides the average and standard deviation for each measure/region/year combination. Table 4 compares the number and percentage of cities gauged efficient for each measure by city and year. The city measures compare cities within a region. Note that in both years the cities in the Shanghai region had the lowest level of efficiency, on average, with the lowest percentage of efficient cities. The four cities in the Guangzhou region were all efficient relative to each other in both 1983 and 1984. On average, output could be increased by almost 8% in the Beijing region’s cities and by more than 4% in the cities of the Lanzhou region in 1983. Similar to the findings of Charnes et al. [1], Beijing’s cities realized relative increases in efficiency.

Recall that GMR measures how much each city could gain from cooperation with other cities in its region. That is, if each city were efficient within its region, GMR shows how much output would be increased relative to the additive technology. Interestingly, the gains from
regionalization fall, on average, between years 1983 and 1984. However, the gains are small in both years, ranging from 5% in the Beijing region in 1983 to 1% in the Shanghai region in 1984.

The overall region measure indicates that the cities in the Shanghai region dominate those in the other regions (see Table 4). Indeed, in both years, all cities in the Shanghai region are efficient relative to this frontier. Lanzhou is gauged the most inefficient region, on average. The percentage of Lanzhou cities found efficient relative to the region reference technology is also low, as it is for the cities in the Beijing region. For both the Lanzhou and Beijing regions, region efficiency fell, on average, between 1983 and 1984. Cities in the Beijing region were, on average, 42% inefficient 1983 and 59% inefficient in 1984. While there was a decrease in efficiency in the Lanzhou region between 1983 and 1984, the decrease was smaller than in

Table 3
DEA model results by region and year\(^a\)

<table>
<thead>
<tr>
<th>Year/Measure</th>
<th>Shanghai ((n = 9))</th>
<th>Beijing ((n = 9))</th>
<th>Guangzhou ((n = 4))</th>
<th>Lanzhou ((n = 6))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983 CITY ((F^*F))</td>
<td>0.877 (0.148)</td>
<td>0.924 (0.126)</td>
<td>1.000 (0.000)</td>
<td>0.958 (0.065)</td>
</tr>
<tr>
<td>GMR ((F^*F))</td>
<td>0.955 (0.062)</td>
<td>0.951 (0.066)</td>
<td>0.983 (0.033)</td>
<td>0.963 (0.062)</td>
</tr>
<tr>
<td>REGION ((F^*F))</td>
<td>1.000 (0.000)</td>
<td>0.580 (0.016)</td>
<td>0.518 (0.027)</td>
<td>0.468 (0.024)</td>
</tr>
<tr>
<td>1984 CITY ((F^*F))</td>
<td>0.865 (0.191)</td>
<td>0.954 (0.085)</td>
<td>1.000 (0.000)</td>
<td>0.944 (0.087)</td>
</tr>
<tr>
<td>GMR ((F^*F))</td>
<td>0.990 (0.201)</td>
<td>0.969 (0.051)</td>
<td>0.986 (0.011)</td>
<td>0.969 (0.059)</td>
</tr>
<tr>
<td>REGION ((F^*F))</td>
<td>1.000 (0.000)</td>
<td>0.488 (0.069)</td>
<td>0.721 (0.290)</td>
<td>0.432 (0.027)</td>
</tr>
</tbody>
</table>

\(^a\) Source: Computed by the authors.

Table 4
Efficient cities by measure, region and year\(^a\)

<table>
<thead>
<tr>
<th>Year/Measure</th>
<th>Shanghai ((n = 9))</th>
<th>Beijing ((n = 9))</th>
<th>Guangzhou ((n = 4))</th>
<th>Lanzhou ((n = 6))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983 CITY</td>
<td>4 (44.4)</td>
<td>6 (66.7)</td>
<td>4 (100.0)</td>
<td>4 (66.7)</td>
</tr>
<tr>
<td>GMR</td>
<td>5 (55.6)</td>
<td>4 (44.4)</td>
<td>3 (75.0)</td>
<td>2 (33.3)</td>
</tr>
<tr>
<td>REGION</td>
<td>9 (100.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>1984 CITY</td>
<td>5(55.6)</td>
<td>5(55.6)</td>
<td>4(100.0)</td>
<td>4(66.7)</td>
</tr>
<tr>
<td>GMR</td>
<td>3 (33.3)</td>
<td>4 (44.4)</td>
<td>1 (25.0)</td>
<td>2 (33.3)</td>
</tr>
<tr>
<td>REGION</td>
<td>9 (100.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
</tbody>
</table>

\(^a\) Source: Computed by the authors.
Beijing, from 53%, on average, to 57% in 1984. For Guangzhou, region efficiency increased from 48% output loss to 28% output loss in 1984.

It is interesting to compare our DEA results to the more traditional measure of economic development, growth in gross domestic output (GIOV), as well as with the investment policy of Chinese regional development. Table 5 thus shows the percentage change in regional output (GIOV) and investment (INVEST) between 1983 and 1984 along with changes in each of our efficiency measures. Shanghai, with its high growth rate in output and, despite the negative growth rate in investment, is the dominant region in both years. Note that no city experienced change in the REG measure. Beijing, on the other hand, had a high rate of investment, but all cities fell further from the region frontier. Gains from regionalization increased the most for the Lanzhou cities. These results are generally consistent with the results of Charnes et al. [1].

4. Conclusion

This paper applies the models of multi-unit DEA analysis to regional economic development policy. Data from an earlier study of 28 Chinese cities were used here. We found that, in general, cooperation among cities within a region produces gains in efficiency. This may be instructive for policy makers in terms of how to direct planned investment. Additional information about regional development is provided, with traditional DEA model results also explained within this context.

We believe that our proposed models and measures are useful in the analysis of economic development policy, especially within a spatial context. In fact, our models can be related to the modifiable areal unit problem (MAUP), long-studied in regional economics, geography,
and regional science [18]. Much of the work in MAUP is concerned with overcoming the arbitrariness of existing regional subdivisions and with distinguishing between the spatial impacts of individual and area level relationships [19]. Within the framework of productivity, our models successfully distinguish such effects.

Although the regions we proposed here were based simply on a minimum distance criterion measured to an arbitrarily defined ‘center’, other regions are possible and probably desirable. One might, for example, designate regions based on the spatial autocorrelation of variable important to the production process. Such an approach might motivate the cooperation of cities in a region. Arbitrary regions aside, our analysis constructs a model for measuring the extent of potential gains in productivity from regional coordination. Future research by the authors will be designed to improve our framework by revealing more effective principles for constructing regions pertinent to the production process.

Appendix A

A1. Chinese city locations and region definitions (Source: Compiled by the authors)

<table>
<thead>
<tr>
<th>Region/City</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shanghai</td>
<td>120.45</td>
<td>31.39</td>
</tr>
<tr>
<td>Changzhou</td>
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9 Spatial autocorrelation is the notion that the presence of some quality at some point in space makes its presence in some neighboring locations more or less likely. Geographers have long been interested in such relationships. For an early example of such work, see Cliff and Ord [20].
### References


