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Tracking Midwest manufacturing and productivity growth

Philip R. Israelwich, Kenneth N. Kuttner, and Robert H. Schnoorius

After years of lagging economic performance that led to the region's characterization as a "rust belt," Midwest manufacturers have exhibited increasing competitiveness in the last several years, compared with the rest of the nation and with their own earlier performance. Evidence of this strong performance is the fact that the Midwest's output grew faster on average than the nation's, given observed rates of capital and labor usage. A common explanation for this resurgence has been that in the 1980s, Midwest manufacturers undertook aggressive modernization programs in an attempt to reverse their fortunes. This explanation, however, rests largely on anecdotal evidence; data have been hard to come by. With the help of annual production models, the mixed-frequency Midwest Manufacturing Input (MMI) model developed by Israelwich and Kuttner (1993), and annual capital expenditure data from the U.S. Commerce Department, we are beginning to reach a clearer understanding of the region's improvements in productivity and competitiveness as Midwest manufacturers move into the 1990s.

In this article, we explore the reasons for the so-called takeoff in Midwest manufacturing productivity, tracing its growth to significant modernization efforts in several key industries. Investment data and estimates of production models both suggest that productivity gains were higher in the region than in the rest of the nation. We then use the mixed-frequency MMI to assess the quantitative significance of the increased productivity growth for current estimates of Midwest output.

The productivity takeoff identified in this analysis has important implications for the MMI model, which relies on historical rates of productivity growth to account for the divergence of output and employment data, and to compute current estimates of the index. In light of the evidence, we reconsider the assumption of a constant rate of productivity growth for each industry, and suggest a modification to the MMI model that will allow it to capture the technical progress that resulted from modernization of core Midwest industries.

Investment and the productivity takeoff in the Midwest

The key to regional growth is improving competitiveness, and the key to increasing a region's competitiveness is productivity growth relative to other regions. Such productivity gains can be achieved in at least two ways: faster withdrawal of the least productive capital stock (downsizing) than elsewhere, and faster introduction of new, more technologically advanced plant and equipment than elsewhere. While both measures can yield increased output per worker, they have different implications for

*The Midwest is defined here to include the five states in the Federal Reserve District: Illinois, Indiana, Iowa, Michigan, and Wisconsin.

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future growth. If the recent productivity gains in the Midwest were achieved only by shrinking the manufacturing base based on modernizing, the region would be vulnerable to further declines as other regions improve their competitiveness and increase their market share at the Midwest’s expense. However, if Midwest manufacturers were modernizing and closing antiquated facilities, they might offset any reductions in capital stock with productivity gains sufficient to allow output growth relative to the rest of the nation.

In the early 1980s, manufacturers were under severe financial stress, particularly in the Midwest. A relatively deep recession in 1980-82 was followed by an intensification of global competition caused in part by a strong dollar. Many well-known companies such as Caterpillar, USG, and Chrysler were pushed dangerously close to bankruptcy; virtually all manufacturers in the Midwest scrambled to cut costs in order to be as competitive as possible in an increasingly tough global market. As part of that effort, many old or marginally profitable plants were closed under the banner of “rationalization”—a term which in the 1990s would be dubbed “re-engineering.”

Despite these financial problems, many Midwest manufacturers met the increasing competitive pressures of the early 1980s with aggressive capital spending programs. While withdrawing from older capital stock, they also invested in new plants and equipment. The only question was whether these adjustments were occurring at a faster pace in the region than they were elsewhere in the nation.

Before 1980, the Midwest tended to invest at roughly the same rate as the rest of the nation. Investment in the region picked up in the late 1970s but slowed again with the onset of the 1980-82 recession. Thereafter, Midwest investment lagged the rest of the nation until a push resumed in 1985. As figure 1 shows, between 1986 and 1999, average capital expenditure per worker in the Midwest was 9 percent above the amount for the rest of the nation.

The Midwest contains a high proportion of capital-intensive industries, notably auto and steel, yet the difference between investment per worker in the Midwest and in the rest of the nation does not appear due to differences in industrial mix. Indeed, both the auto and steel industries show higher investment per worker in the region than in the rest of the nation. For example, between 1986 and 1990, investment per worker in the transportation industry was 16 percent higher on average in the Midwest than in the rest of the nation: primary metals it was 22 percent higher on average. While these two industries show larger differentials than other industries, they demonstrate that the pattern observed at the aggregate manufacturing level reflects a widespread commitment to modernization among Midwest manufacturers.

A closer look at the auto and steel industries reveals the dual nature of the adjustments that manufacturers made in response to competitive problems. During the 1980s, automakers closed seventeen car and truck assembly plants, of which six were in the Midwest. At the same time, they constructed seventeen plants, seven of them in the Midwest. Some of the new plants were replacements or expansions of existing Big Three plants; for example, Chrysler’s Jefferson Avenue plant in Detroit. But some were entirely new plants built by foreign car companies, often in conjunction with a Big Three producer. Among the foreign-owned plants are the Diamond Star Plant in Illinois (Chrysler and Mitsubishi) and the Flat Rock Plant in Michigan (Ford and Mazda).

A somewhat similar pattern of investment occurred in the Midwest steel industry, where
integrated mills were closed and the remaining mills modernized. Inland Steel, for example, has invested roughly $1 billion since 1985 to modernize its Indiana Harbor Works in East Chicago, Indiana (which included converting it to continuous casting). The company spent another $1 billion on a new mill in Indiana, a joint venture with a Japanese producer. While integrated steel producers were modernizing, they were also opening mini-mills that brought a wholly different production process to U.S. steelmaking.

The result was that both the auto and steel industries saw more productivity gains in the Midwest than in the rest of the nation. These gains made Midwest producers more competitive and allowed industry in the region to grow faster than elsewhere.

Productivity growth in the Midwest: evidence from annual data

The investment patterns noted above suggest that Midwest manufacturers began to modernize aggressively around 1986. What is lacking is some measure of how much efficiency increased as a result. How much has Midwest manufacturing output grown, compared with the growth that would have occurred using pre-1986 technology?

One way to address this question is simply to compare the out-of-sample forecasts from a production function estimated on data from 1973 through 1985 with observed output from 1986 to the present. A natural and intuitive measure of the size of the shock is the difference between the Midwest’s observed output and the model’s prediction: that is, the amount by which actual output exceeds what would have been produced had pre-1986 technology been applied to the actual factor inputs.

A convenient production function for this analysis is the Cobb-Douglas specification,

\[ x = y^\alpha + b(y^\alpha + \nu + \tau), \]

where \( x \) represents output of a given industry measured by the logarithm of real value added (VA), \( y \) the logarithm of payroll employment, and \( \alpha \) is the logarithm of elasticity of capital. For applications such as this, energy consumption is widely interpreted as a proxy for the utilized stock of capital.2 The \( y \) coefficient on the time trend represents the rate of Hicks-neutral technological change (i.e., productivity not embodied in either labor or capital inputs), \( \theta \) and \( \phi \) are the elasticities of output with respect to labor and capital, and \( \eta \) is a random error term. The Cobb-Douglas specification is also consistent with the mixed-frequency AMI introduced subsequently, as well as a variety of other indices discussed in Israelovich et al. (1989).

We first estimated the production function over the sample running from 1973 through 1985, dates chosen on the basis of the Midwest investment patterns discussed above. Using this estimated function, we then projected output for the 1986–90 period on the basis of pre-1986 “old” technology, and compared the projection to the actual VA data, the result of production with “new” technology.

The Midwest versus the nation

Table 1 reports the difference between projected and observed output growth for 15 key manufacturing industries in the Midwest, aggregated into five sectors: transportation, metalworking, machinery, chemicals, and consumer products. Table 2 shows the composition of these sectors and a breakdown of Midwest output by industry. For comparison purposes, similar calculations were done for the rest of the nation. According to these estimates, between 1986 and 1990, Midwest manufacturing sectors improved efficiency by 8 percent more than the corresponding sectors in the rest of the nation.

Given the capital-intensive nature of most Midwest industries and their relative maturity, such a gain is substantial. It would also help explain why output has been growing faster in the region than in the nation since the late 1980s.

Figure 2 displays the efficiency gains graphically, showing the Midwest’s lead as a function of time. While the gap between observed and

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
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<tbody>
<tr>
<td>Efficiency gains, 1986–90 (percent)</td>
</tr>
<tr>
<td>Sector</td>
</tr>
<tr>
<td>Transportation</td>
</tr>
<tr>
<td>Metalworking</td>
</tr>
<tr>
<td>Machinery</td>
</tr>
<tr>
<td>Chemicals</td>
</tr>
<tr>
<td>Consumer products</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

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TABLE 2
Composition of Midwest manufacturing output, 1990

<table>
<thead>
<tr>
<th>Sector</th>
<th>Share (%)</th>
<th>Industry</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>14</td>
<td>Transportation (SIC 37)</td>
<td>14</td>
</tr>
<tr>
<td>Metalworking</td>
<td>14</td>
<td>Primary metals (SIC 33)</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fabricated metals (SIC 34)</td>
<td>8</td>
</tr>
<tr>
<td>Machinery</td>
<td>36</td>
<td>Nonferrous (SIC 25)</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electrical (SIC 36 and 38)</td>
<td>10</td>
</tr>
<tr>
<td>Chemicals</td>
<td>15</td>
<td>Chemicals (SIC 28)</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Petroleum (SIC 29)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rubber and plastic (SIC 30)</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clay, glass and stone (SIC 32)</td>
<td>1</td>
</tr>
<tr>
<td>Consumer products</td>
<td>22</td>
<td>Food (20)</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lumber and wood (SIC 24)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Furniture and fixtures (SIC 25)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paper products (SIC 26)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Printing and publishing (SIC 27)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Miscellaneous (SIC 39)</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: Industry subtotals may not equal sector totals because of rounding.

predicted output remained positive, it flattened out in 1989 and declined in 1990. Only in 1990 did the rate of improvement in efficiency seem to subside, both in the Midwest and elsewhere. This pattern suggests that the shift in the national economy from a mini-boom in 1988-89 (roughly 4 percent real GDP growth) to virtual stagnation (roughly 1-2 percent real GDP growth) had an impact on efficiency gains. Perhaps the cyclical drop in output growth prior to the 1990-91 recession led to underutilization of labor and capital, which reduced the measure of efficiency gains over the second half of the 1980s. Moreover, the commitment to efficiency gains even in a sluggish economy may help explain why manufacturers have been able to expand output since the 1990-91 recession even though employment growth has been virtually nonexistent.

Comparisons between Midwest industries

The efficiency gains identified in table 1 were clearly not uniform across the Midwest's industries. How widespread were they, and how much of the total gain was due to the industrial structure of the region relative to the rest of the nation? The gains did seem to be concentrated in the region's core manufacturing sectors, transportation and machinery.

The Midwest's transportation sector scored the most impressive gains in efficiency. Output in this sector was 7.9 percent higher than forecasts on the basis of pre-1986 technology, compared to 3.8 percent higher in the rest of the nation.
nation. In the Midwest, the transportation sector is dominated by automobile manufacturers and parts suppliers, both of which were troubled industries throughout the 1980s. Japanese im-
ports and nameplates produced in the U.S. had
been gaining market share for many years, leav-
ing the domestic industry with tremendous over-
capacity. The first wave of restructuring took
place in the early 1980s when Ford and Chrysler
began closing assembly plants. GM began closing assem-
bly plants in the late 1980s and is currently in a
second wave of closings that will extend into
1989. At the same time that Big Three automak-
ers were closing plants, both they and the Japa-
nese were opening state-of-the-art assembly
plants in the Midwest as well as elsewhere.

Over the 1980s, the region’s share of total car
production actually rose from 39 to 44 percent,
although its share of total production declined
from 40 to 28 percent.

The Midwest’s machinery sector also out-
paced the rest of the nation. While in the rest of
the nation machinery was on average 0.9 percent
above its projected level of output over the
1986-90 period, in the Midwest it was 2 percent
higher than projected on the basis of the pre-
1988 technology. The region’s machinery sector is
largely focused on the auto industry and ex-
ports. As suppliers of the new capital, this sector
has been in the forefront of the recent wave of
investment targeted toward global competition.

Machinery producers themselves have faced stiff
competition from foreign competitors, particu-
larly the Japanese. Moreover, some machinery
producers have been bought out by foreign com-
panies, a change that often brings an infusion of
fresh capital that improves productivity. It is
encouraging to see that machinery producers,
especially in the Midwest, have accepted the
challenge of heightened global competition by
increasing capital expenditures rather than by
closing or shifting to other markets.

In the aggregate, the Midwest’s metalwork-
ing sector displayed efficiency gains roughly in
line with the rest of the nation. However, disag-
gragating the sector into its two constituent
industries, fabricated metals and primary metals
(the steel industry in the Midwest) reveals an
interesting contrast. While the pace of technical
change lagged the nation in fabricated metals,
productivity growth in primary metals exceeded
the nation’s— a divergence that also appears in
the MNI results presented later in this article.
Interestingly, the major downsizing in the steel
industry was over by the mid-1980s, leaving the
Midwest the dominant iron and steel-pro-
ducing region. Mid-est firms continued invest-
ing in modernization, and even mini-mills were
expanding in the region. It is the Midwest’s
continued modernization, and perhaps its domi-
nance in the high-quality steel produced by
integrated mills, that allowed the region to out-
pace the rest of the nation in productivity. In
contrast to primary metals, the metal fabrication
industry, which produces finished parts from
raw steel, never experienced any significant
consolidation. The small size of producers in this
fragmented industry may have limited the
adoption of technical advances.

While efficiency gains were clearly wide-
spread in the Midwest, not all the region’s indus-
tries outpaced their counterparts elsewhere in
the nation. The Midwest’s chemical and consumer
products sectors actually lagged the rest of
the nation in efficiency gains over the 1986-90
period. In fact, efficiency in the latter sector was
lower during the period than in previous years.

While these industries are important to the Mid-
west, it is interesting that they are generally
outside the auto-steel-machinery complex that
comprises the heart of the region’s manufactur-
ing. It is perhaps unfortunate that steel in
this “heart” seems not to spill over into other
industries; yet by the same token, it seems that
weakness in some sectors does not result in effi-
ciency gains in other sectors.

The productivity takoff and the MNI

The preceding section discussed measuring
Midwest productivity gains by comparing annu-
al VA data with predictions from estimated
production models. An alternative method is to
apply a similar analysis to predictions generated
by the mixed-frequency MNI, as described in
the appendix. The main advantage of the mixed-
frequency MNI is that it tracks actual VA more
precisely than other purely annual indices, such
as the annual Cobb-Douglas or Adlanti
methods, when projected out of sample. Hence, the MNI
should yield a more accurate assessment of
Midwest efficiency gains than the annual model.

A second reason to use the MNI in this
context is to examine any implications the hy-
pothesized productivity takoff might have for
current estimates of Midwest output. Although
the production model underlying the mixed-
frequency MNI is re-estimated as new, annual
VA data become available, an increase in the

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rates of technical progress may require structural modifications to the model to enable it to track manufacturing output more accurately in the future.

**Out-of-sample comparisons**

To construct a quantitative measure of Midwest efficiency growth, we first estimated the mixed-frequency MMI using annual data from 1973 through 1985. We then used monthly energy, labor, and nationwide production (IP) data to project the MMI forward over the 1986–90 period, in which actual real VA data for the Midwest are available. Comparing the projected series with the actual VA data yields an index of efficiency gains that is comparable to the measures reported earlier. As before, an increase in the rate of productivity growth would imply that the projected MMI would underpredict output growth. This shortfall, therefore, represents the region’s gains expressed in terms of the additional output produced as a result of increased manufacturing productivity.

Table 3 reports these gains, classified by industries and sectors. The results are expressed as the average percentage deviation between observed real VA growth and the annualized growth rate of the projected MMI. In metalworking, for example, the reported 0.6 percent figure signifies that on average, the MMI underpredicted VA growth by 0.6 percent for each year in the 1986–90 period.

The results are broadly similar to those based on the annual estimates reported above. Most striking is the spectacular productivity growth in the transportation sector, which offsets entirely of SIC 37. Here, annual productivity growth over 1986–90 was roughly 9 percent higher than in the preceding 13 years. To restate this in cumulative terms, by the end of 1990, output in the transportation sector was about 40 percent higher than it would have been had firms applied pre-1986 technology to the same labor and energy factor inputs. Such are the quantitative effects of the investment flows and modernization efforts identified earlier.

Although there are a few bright spots, none of the other sectors showed the kind of spectacular growth detected in transportation. Echoing the earlier annual results, within metalworking, primary metals (SIC 33) did well, turning in a robust average 2.8 percent per year increase in

<table>
<thead>
<tr>
<th>Sector</th>
<th>Gain (%)</th>
<th>Industry</th>
<th>Gain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>9.0</td>
<td>Transportation (SIC 37)</td>
<td>9.0</td>
</tr>
<tr>
<td>Metalworking</td>
<td>0.6</td>
<td>Primary metals (SIC 33)</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fabricated metals (SIC 34)</td>
<td>-0.8</td>
</tr>
<tr>
<td>Machine plants</td>
<td>-0.8</td>
<td>Nonelectrical (SIC 35)</td>
<td>-0.9</td>
</tr>
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<td></td>
<td></td>
<td>Electrical (SIC 36 and 38)</td>
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<td>Chemicals</td>
<td>-0.9</td>
<td>Chemicals (SIC 28)</td>
<td>-0.3</td>
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<td>Petroleum (SIC 29)</td>
<td>-5.7</td>
</tr>
<tr>
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<td></td>
<td>Rubber and plastic (SIC 30)</td>
<td>0.4</td>
</tr>
<tr>
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<td></td>
<td>Clay, glass and stone (SIC 32)</td>
<td>-4.0</td>
</tr>
<tr>
<td>Consumer products</td>
<td>-1.6</td>
<td>Food (SIC 20)</td>
<td>-0.1</td>
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<td>Lumber and wood (SIC 24)</td>
<td>5.3</td>
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<td></td>
<td>Furniture and fixtures (SIC 25)</td>
<td>-3.7</td>
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<td></td>
<td>Paper products (SIC 28)</td>
<td>-4.0</td>
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<td></td>
<td></td>
<td>Printing and publishing (SIC 27)</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Miscellaneous (SIC 39)</td>
<td>-9.6</td>
</tr>
</tbody>
</table>
its rate of productivity growth. The slight deterioration in fabricated metals (SIC 34) partly offset this gain, however, resulting in a modest overall gain for metalworking of only 0.6 percent.

Neither machinery nor chemicals displayed any significant evidence of a productivity acceleration. The small improvement in machinery sector productivity evident in the annual results is not apparent in the MML. The rates of technical change in both non-electrical (SIC 35) and electrical machinery (SICs 36 and 38) remained close to pre-1986 levels. The rate of technical change also appeared stable in the chemical sector, with chemicals (SIC 28) and rubber and plastics (SIC 30) indices tracking VA quite closely. The exceptions were petroleum (SIC 29) and clay, glass and stone (SIC 32), whose performance appeared to deteriorate significantly. However, given the poor quality of the data and the very small size of these industries in the Midwest (each only about 1 percent of 1990 VA), little weight should be given to these results.

Performance within the consumer products sector was rather disappointing overall. All industries showed some diminution in their rate of technical change, with the exception of lumber and wood (SIC 24). Since this industry currently accounts for only 1 percent of the Midwest’s output, its impact on the region is small.

**Modeling the productivity takeoff**

How important are these results statistically? How might the mixed-frequency MML model be extended to allow a changing rate of productivity growth? What is the impact of more rapid techni
cal change on current estimates of the MML? To address these three issues, we re-estimate the MML for the transportation and primary metals industries—the two industries that show significant acceleration in the region—allowing a shift in the productivity growth rate in 1986. The significance of this shift can then be evaluated statistically.

The results of this exercise, as reported in table 4, generally support the out-of-sample findings. Again, the evidence for a productivity takeoff is strongest for transportation, which experienced a statistically significant increase in annual productivity growth of 10 percent relative to the 1973-85 period. If this more rapid growth were extrapolated into 1991, then with the same inputs, output (measured by VA) would be roughly 70 percent higher than it would have been using 1973-85 technology.

The results for primary metals also provide some evidence for a higher productivity growth rate, although the statistical significance is weaker. While the estimated shift coefficient implies an increase in annual productivity growth of 4 percent, it is not statistically significant at the traditional 0.05 level.

**Extending the MML**

These findings have potentially important implications for current appraisals of Midwest output. One of the purposes of the MML is to assess the level of manufacturing activity prior to the release of VA data, which become available after a two- to three-year lag. Contemporaneous estimates of the growth of industry output incorporate a weighted average of energy and labor inputs, plus the rate of productivity growth relevant for that industry. Updates of the MML, therefore, depend critically on whether this rate of productivity growth is stable. Projections that did not take account of productivity acceleration might as a result seriously underestimate current output levels.

To assess the consequences on the MML, we perform one final exercise, comparing post-1990 MML projections with and without a shift in productivity growth in 1986. Rather than re-estimate the model for every industry, we again concentrate on the two showing some evidence of a productivity takeoff: primary metals (SIC 33) and transportation (SIC 37). The results appear in figure 3.

The top panel shows the impact of this change on the aggregate MML. The effect is small but perceivable. The cumulative discrepancy relative to the unadjusted index was

<table>
<thead>
<tr>
<th>TABLE 4</th>
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</thead>
<tbody>
<tr>
<td><strong>Estimated shift in Midwest rate of productivity growth</strong> (annualized percentage)</td>
</tr>
<tr>
<td>1973-85</td>
</tr>
<tr>
<td>Transportation (SIC 37)</td>
</tr>
<tr>
<td>Primary metals (SIC 33)</td>
</tr>
</tbody>
</table>

* significant at the .05 level.
These results demonstrate that if the productivity acceleration had continued from 1990 to the present, it may have had a noticeable impact on the (MMI); accordingly, the existing MMI would have understated the Midwest’s actual output from 1991 to 1993. Should the index then be modified to incorporate higher rates of productivity growth in certain industries? Clearly, the answer depends on recent productivity developments. For example, if we assumed that the 1986–90 rate of change had continued into 1993 but it had actually leveled off, then modifying the MMI would introduce an upward bias into it. For this reason, the appropriate incorporation of changes to the MMI model requires an ongoing, disaggregated examination of the structure of the economy.

Conclusion
Despite falling levels of employment, Midwest manufacturing output expanded rapidly during the 1980s. This growth, which surpassed national output growth over the period, suggests improved competitiveness among the region’s manufacturers. The evidence confirms this impression. Comparing the predictions of production models applied to annual Midwest data with similar predictions for the rest of the nation showed that the region’s brisk expansion was due in large part to strong productivity growth. The main cause of this growth appears to have been the aggregate modernization efforts of Midwest manufacturers, as reflected in the region’s higher rate of investment per worker relative to the national average.

Using the MMI to evaluate the size and scope of the productivity gains, we found that they were largely confined to a few key industries, particularly transportation and primary metals. However, given the prominence of these industries in the Midwest, their impact on overall manufacturing output is substantial, possibly easing current...
estimates in excess of 2 percent if the productivity growth observed from 1986 through 1990 continued into 1993. This finding underlines the importance of incorporating higher rates of technical change for certain industries into future updates of the MMI to reflect the continuing modernization of Midwest manufacturing.

APPENDIX

Tracking Midwest manufacturing with the mixed-frequency MMI

A useful tool for analyzing Midwest manufacturing is the mixed-frequency Midwest Manufacturing Index (MMI) developed by Hirsch and Kunter (1993). While this technique uses the Cobb-Douglas production function employed in the annual results, it differs from this specification in its use of a monthly production model. At the same time, it constrains the estimated monthly production series in such a way as to be consistent with the observed annual value added (VA) data; hence the "mixed-frequency" designation.

Incorporating monthly data yields two significant advantages over annual models. First, it makes it possible to track high-frequency fluctuations in Midwest output. Second, the mixed-frequency MMI has been shown to provide more accurate out-of-sample projections of manufacturing activity than pure annual models. Since annual VA data are not yet available for the Midwest, this benefit is particularly useful for assessing the effects of accelerated technical change on the current output of the region's manufacturing sector.

The foundation of the mixed-frequency MMI is a Cobb-Douglas production equation applied to monthly data. Expressed as first differences of natural logarithms, the monthly change in the real output of any Midwest industry, \( \Delta_y^M \), is the weighted sum of the change in employment hours, \( \Delta h^e \), and energy usage, \( \Delta E_t^u \):

\[
\Delta y^M_t = \gamma + 0.3\Delta h^e_t + 0.7\Delta E_t^u + \eta_t,
\]

As in the annual model, \( \gamma \) is the (constant) rate of Hicks-Neutral technical change, \( \delta > 0 \) represents the elasticity of output with respect to labor and capital (energy), and \( \eta_t \) is a stochastic error term. The superscript \( T \) is used to denote Midwest data. Note that with the shift to monthly data, each variable now carries two subscripts. The first, \( t \), denotes the year, while the second, \( s \), represents the month within that year. Thus the change in output between the second and third months of the 13th year of the sample would be denoted \( \Delta y_{13}^M \).

A difficulty with this approach is that while monthly energy and labor data are available for the Midwest, no monthly output measure exists. The only available measure of region's production is the real value added (VA) data used in the annual results. In light of this data limitation, estimating the monthly model might appear to be a lost cause, since traditional regression techniques require the observations on the left-hand variable to be available at the same frequency as those for the right-hand variables. Using regression methods, therefore, requires that energy and labor be aggregated to an annual frequency. This is the approach used earlier to compare productivity growth in the Midwest and in the rest of the nation.

Fortunately, there are ways around this obstacle. Techniques exist to combine data of differing frequencies into a single model. For the mixed-frequency MMI, we use a state-space econometric model that treats Midwest output growth as a latent variable. Given some additional relationships between the unsolved \( \Delta y^M \), and other data series, the monthly model can be estimated even in the absence of direct information on Midwest output.

One key link between \( \Delta y^M \) and something observable is the "adding up" relationship between the monthly growth of output and the annual growth of the real VA data. Because the annual VA observations correspond to the sum of the output produced in each month, the year-to-year change in real VA is actually a weighted average of the monthly output growth as the current year preceding 23 months. Thus, constraining the monthly growth rates to produce an annual pattern consistent with the VA data implies that

\[
\ln(VA_{t+1}) - \ln(VA_t) = \frac{1}{12} \sum_{s=1}^{12} \Delta y_{t+s}^M.
\]

Imposing this equation enforces consistency between the estimated MMI and the annual VA data. This relationship alone is not enough for the monthly approach to yield any dividends, since all the available information is still coming at an annual frequency. In order to make inferences about fluctuations within the year, we need an additional source of monthly information. One source of such information is the monthly index of industrial production (IP) prepared by the Federal Reserve Board. Besides the energy and labor inputs used as inputs to the MMI, the IP typically incorporates some information on actual output, such as the dollar value or physical quantity of goods shipped. Thus the IP index con-
tains information on industry output not captured by energy and labor inputs alone. However, the information in the IP index pertains to the nation, not to the Midwest. Therefore we cannot simply use IP to compute Δy_m. Instead, we relate national to regional fluctuations by using an equation to describe the co-movement of the two series:

\[ Δy_m = \beta \Delta y_p + \epsilon \]

As before, Δy_m represents the growth in Midwest output, Δy_p is the growth of national output in the same industry as measured by industrial production. The coefficient \( \beta \) relates the magnitude of the national fluctuations to those of the region, and \( \epsilon \) is random "noise" in the relationship.

Unlike the production model introduced earlier, this equation does not describe any fundamental economic or structural relationship between the region and the nation. Neither is the national IP in any way a determinant of regional output in the same way that regional labor and energy inputs are. Rather, this equation describes how Midwest economic fluctuations have historically been correlated by movements on a national scale.

Clearly, the fact that Midwest industry comprises a portion of the national total implies a positive correlation between the region and the nation, represented by a positive value of \( \beta \). But to the extent that industries within and outside the region are subject to similar demand conditions, one might expect the correlation to be even greater than suggested by the industry's share in total output. It is unlikely, however, that \( \beta \) would exceed 1, since many regional fluctuations will be dampened by offsetting fluctuations in the rest of the nation. While the \( \beta \) parameter picks up the relative magnitudes of industrial fluctuations, the standard deviation of \( \epsilon \) captures the amount of "noise," or unpredictable variation, in the link between regional and national output.

Table 5 shows the results from estimating the mixed-frequency MNI model for one representative industry: primary metals (SIC 33). The estimates of the production function's \( \alpha \) and \( \theta \) parameters fall within the range of economically reasonable values, although the sum of \( \alpha \) and \( \theta \) imply increasing returns to scale. The estimate of \( \gamma \) which is constant throughout the sample suggests only very modest productivity growth of 1.4 percent per year. The very small estimate of \( \phi \) indicates that output has grown at roughly the same rate in the Midwest as in the nation. The estimated \( \beta \) of 0.54, however, suggests that IP fluctuations in the nation are approximately half the magnitude of fluctuations in the Midwest.

FOOTNOTES
1Estimates of Midwest capital expenditures for the years 1979-81 are not available in the Commerce Department's Annual Survey of Manufactures (ASM). Values were calculated by first computing a sample of 480 Midwest firms with 100 or more employees, taken from the Longitudinal Research Data (LRD) base for the years 1985-88, with the reported ASM data for those years and, second, applying the average proportions to the LRD base to generate ASM-equivalent data.

2Moody (1994) discusses the use of entropy as a proxy for capital services.


REFERENCES
