Decomposition of Total Factor Productivity Change in the U.S. Hog Industry, 1992-2004

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Abstract. There have been dramatic structural changes in the U.S. hog industry in the last two decades that have coincided with substantial increases in farm productivity. This study used a stochastic frontier analysis to measure TFP growth between 1992 and 2004 and to decompose the TFP growth into four components: technical change and changes in technical efficiency, scale efficiency, and allocative efficiency. The study finds that productivity gains in the twelve year study period are explained almost entirely by technical progress and by improvements in scale efficiency. The study also disaggregates TFP growth in the Southeast and Heartland to better understand the implications of large spatial shifts in production. Results indicate that regional differences in TFP growth in the 1992-1998 and 1998-2004 periods can be explained primarily by changes in scale of production. Results indicate that despite large increases in the scale of production, there remains substantial scope for further scale efficiency gains, particularly in the Heartland where farms operate at a smaller average scale compared to in the Southeast.

Key words: total factor productivity growth, stochastic frontier, technical change, scale efficiency

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1. Introduction

In the last 15 years there have been pronounced structural changes in the U.S. hog sector. Since 1994, production has shifted to larger operations and the number of hog operations has fallen by more than 50 percent (USDA-NASS, various years). In 2001, farms with at least 2000 head accounted for nearly 75 percent of total U.S. hog and pig inventory, double their 1994 share. There has also been a dramatic increase in the use of agricultural contracts: the share of feeder-to-finish hog production under a production contract increased from about 18% in 1990, to 28% in 1995, to almost 60% in 2000 (USDA-ERS). In addition, hog production has become increasingly specialized, with most phases of production (gestation, farrowing, finishing) now occurring on specialized operations (McBride and Key, 2003). Also during this period, production has shifted regionally –with substantial growth in the Southeast and other regions (Onal, Unnevehr, and Bekric, 2000; Roe, Irwin, and Sharp, 2002).

The evolution of the hog industry has had important implications for economic efficiency – the average cost of producing a hog has declined substantially over the last fifteen years and this has contributed to a downward trend in final product prices. The first objective of this study is to measure how much productivity has increased during this period and to better understand the factors that have contributed to this change. The second objective is to examine which farms and regions have experienced the greatest gains in economic efficiency – to obtain a better understanding of the characteristics of farms that have been able to adapt in a rapidly changing environment and to gain insight as to which growers and regions are likely to succeed in the future. To these ends, this study measures how total factor productivity has evolved from 1992 to 2004 for hog farms in different regions and it estimates the degree to which these productivity changes can be attributed to changes in technology, technical efficiency, allocative efficiency, and scale efficiency.

Recent technological progress has been driven by advances in hog genetics, nutrition, equipment, and veterinary medicine. This study estimates the contribution of technological progress in raising total factor productivity. The study also examines the relationship between farm size and productivity. We estimate how returns to scale (scale elasticity) varies by farm size and across regions and estimate how returns to scale have changed over time. We also examine how much the increases in farm size have raised productivity as farms have moved closer to their optimal size.

While technology progress has increased the maximum possible output that can be produced given a set of inputs (the production frontier has shifted outward), not all farms are able to combine inputs in an efficient manner to achieve the maximum possible output (that is, they operate below the production frontier). Over time, some farmers have improved the efficiency with which they use inputs given the technology at their disposal – that is they have improved their technical efficiency. Over time, some farmers may also have become better at selecting their input quantities so as to ensure that the input price ratios equal the ratios of the corresponding marginal products – that is they improved their allocative efficiency. This study examines which regions have had the greatest changes in technical and allocative efficiency.

This study estimates and decomposes TFP for U.S. hog producers between 1992 and 2004. We use the econometric methodology proposed by Orea (2002) to examine the contributions of technical change, and technical, scale, and allocative efficiency change to productivity. To estimate the parameters we assume the technology can be represented by a translog production function and employ the time-varying model for technical inefficiency proposed by Battese and Coelli (1992). Firm inefficiency is assumed to be distributed as a generalized truncated-normal random variable distributed independently of the random errors that are assumed to be drawn from a normal distribution.

Some past studies have examined efficiency in hog production in cross sectional samples. Sharma, Lueng, and Zalenski (1997) examined the scale and technical efficiency of swine producers in Hawaii using a stochastic frontier production function and an output-oriented data envelopment analysis (DEA) model. Rowland, et al. (1998) used a DEA approach to determine the relative measure of technical, allocative, scale, economic and overall efficiency for a sample of 43 Kansas hog farms. Their study used three consecutive years of data, but the short time frame and small sample size did not permit a decomposition of efficiency change over time. Tonsor and Featherstone (2005) also used a DEA model to evaluate the components of efficiency by hog farm specialization type using a 1998 survey of the hog sector. Unlike past studies that have focus on explaining differences in efficiency across hog farms at a single point in time, our study is the first that we are aware of to decompose the change in hog farm productivity over time.

Data for the study are drawn from three nationally representative surveys of the hog sector conducted in 1992, 1998, and 2004. The USDA-ARMS data permit a detailed analysis of productivity change by farm size category and region. Data include quantity and expenditure information on labor (operator and hired), capital (detailed information based on depreciation of productive assets), feed, and other inputs (medical services, etc.).

Results focus on regional differences between the Southeast and Heartland hog producing regions. We find that farms in the Southeast experienced a relatively large increase in total factor productivity between 1992 and 1998, while farms in the Heartland had a larger increase between 1998 and 2004. Differences in productivity gains can be explained primarily by scale effects. While both regions experienced similar changes in technical efficiency during this period, farms in the Southeast experienced greater increases in scale efficiency during 1992-1998, while farms in the Heartland had greater gains in scale efficiency during 1998-2004. Estimates of scale economies by region suggest a greater scope for future scale efficiency gains in the Heartland.

2. Theoretical Framework

This study uses a stochastic frontier analysis to decompose TFP growth into four components: 1) technical change, which is the increase in the maximum output that can be produced from a given level of inputs (a shift in the production frontier); 2) technical efficiency change, which is the change in a firm's ability to achieve maximum output given its set of inputs (how close it is to the production frontier); 3) scale efficiency change, which is the change in the degree to which a firm is optimizing the scale of its operations; and 4) allocative efficiency change, which the change in a firm's ability to select a level of inputs so as to ensure that the input price ratios equal the ratios of the corresponding marginal products.[1]

Orea (2002) shows that if a firm's technology can be represented by the translog output-oriented distance function $D_O\left(q^t, x^t, t\right)$, then the logarithm of a generalized output-oriented Malmquist productivity index $\ln M_O$ can be decomposed into changes in technical efficiency (EC), technical change (TC), and scale efficiency change (SC), between period *s* and *t*:

(1) $$\ln M_O = EC^{st} + TC^{st} + SC^{st}$$

where

(2) $$EC^{st} = \ln D_O(q_t, x_t, t) - \ln D_O(q_s, x_s, s)$$

(3) $$TC^{st} = -\frac{1}{2}\left[\frac{\partial \ln D_O(q_t, x_t, t)}{\partial t} + \frac{\partial \ln D_O(q_s, x_s, s)}{\partial t}\right]$$

(4) $$SC^{st} = \frac{1}{2}\sum_{k=1}^{n}\left[\frac{\varepsilon_t - 1}{\varepsilon_t}\varepsilon_{kt} + \frac{\varepsilon_s - 1}{\varepsilon_s}\varepsilon_{ks}\right]\cdot \ln\left(\frac{x_{kt}}{x_{ks}}\right)$$

where the scale elasticity, $\varepsilon_t = \sum_{k=1}^{n}\varepsilon_{kt}$, where $\varepsilon_{kt} = \partial \ln D_O(q_t, x_t, t)/\partial \ln x_k$, and k and t are indices for inputs, and time, respectively.

With one output q, a translog distance function can be defined:

(5) $$\ln D_O(q_{it}, x_{it}, t) = \ln q_{it} - f(\beta, x_{it}) - v_{it}$$

where i is an index for firms, and

(6) $$f(\beta, x_{it}) = \beta_0 + \sum_{k=1}^{N}\beta_k \ln x_{kit} + \frac{1}{2}\sum_{k=1}^{N}\sum_{j=1}^{N}\beta_{kj}\ln x_{kit}\ln x_{jit} + \sum_{k=1}^{N}\beta_{tk} t \ln x_{kit} + \beta_t t + \frac{1}{2}\beta_{tt} t^2,$$

[1] This section is based primarily on Orea (2002); Coelli, Rao, O'Donnell, and Battese (2005), pp289-302; and

and where v_{it} is a normally distributed random error with mean zero. To account for technical inefficiency, we estimate a stochastic production function model of the form:

$$\ln q_{it} = f(\beta, x_{it}) + v_{it} - u_{it} \tag{7}$$

where u_{it}, a non-negative random variable associated with technical inefficiency, is drawn from a truncated normal distribution (Battese and Coelli, 1992). An output-oriented measure of technical efficiency is the ratio of observed output to the corresponding stochastic frontier output:

$$TE_{it} = \frac{q_{it}}{\exp(f(\beta, x_{it}) + v_{it})} = \frac{\exp(f(\beta, x_{it}) + v_{it} - u_{it})}{\exp(f(\beta, x_{it}) + v_{it})} = \exp(-u_{it}) \tag{8}$$

Note that the technical efficiency factor is the distance function from (5):

$$\exp(-u_{it}) = \exp(\ln q_{it} - f(\beta, x_{it}) - v_{it}) = D_0(q_{it}, x_{it}, t). \tag{9}$$

The technical efficiency measure (8) can be estimated conditional on $e_{it} = v_{it} - u_{it}$. It follows from (2) and (8) that the efficiency change can be estimated:

$$EC_i^{st} = E(-u_{it} | e_{it}) - E(-u_{is} | e_{is}) \tag{10}$$

Coelli, Estache, Perelman, and Trujillo (2003), pp25-66.

or

(11) $$\exp\left(EC_i^{st}\right) = E\left(\exp\left(-u_{it} \mid e_{it}\right)\right) / E\left(\exp\left(-u_{is} \mid e_{is}\right)\right),$$

where the numerator and denominator in (11) are the estimated technical efficiency scores in periods *t* and *s*, respectively, which have values between zero and one.

Using (3), (5), and (6) the technical change index can be derived:

(12) $$TC_i^{st} = \frac{1}{2}\left[\sum_{k=1}^{K} \beta_{tk} \ln x_{kit} + \sum_{k=1}^{K} \beta_{sk} \ln x_{kis} + 2\beta_t + 2\beta_{tt}(s+t)\right].$$

From (4), (5), and (6) the scale efficiency change index is given:

(13) $$SC_i^{st} = \frac{1}{2}\sum_{k=1}^{K}\left[\frac{\varepsilon_{it}-1}{\varepsilon_{it}}\varepsilon_{kit} + \frac{\varepsilon_{is}-1}{\varepsilon_{is}}\varepsilon_{kis}\right] \cdot \ln\left(\frac{x_{kit}}{x_{kis}}\right)$$

where $\varepsilon_{it} = \sum_{k=1}^{n} \varepsilon_{kit}$ and $\varepsilon_{kit} = \beta_k + \frac{1}{2}\sum_{j=1}^{N} \beta_{kj} x_{jit} + \beta_{tk}$.

To estimate allocative efficiency change, we compare the Malmquist TFP index (1) to the logarithm of the Tornqvist TFP change index (with one output):

(14) $$\ln TFP_i^{st} = y_{it} - y_{is} - \frac{1}{2}\sum_{k=1}^{K}\left[\left(s_{kit} + s_{kis}\right) \cdot \left(x_{kit} - x_{kis}\right)\right]$$

where s_{kit} are the input cost shares. Any difference between the Tornqvist TFP change calculated in (14) and the Malmquist TFP index calculated in (1) must be due to allocative efficiency change. Hence, it can shown that the allocative efficiency change (AC) is:

(15) $$AC_{it} = \frac{1}{2}\sum_{k=1}^{K}\left[\left(\left(\frac{\varepsilon_{kit}}{\varepsilon_{kt}} - s_{kit}\right) + \left(\frac{\varepsilon_{kis}}{\varepsilon_{ks}} - s_{kis}\right)\right)\cdot\left(x_{kit} - x_{kis}\right)\right]$$

3. Data

Data used in this study are from the 1992, 1998, and 2004 USDA Agricultural Resource Management Survey (ARMS) of the hog sector. Because of broad differences in production techniques among various types of hog operations, we limit the sample to feeder pig-to-finish hog operations.[2] Over the period of this study, hog operations have become more specialized, with production shifting from farrow-to-finish operations to separate farrowing, nursery, and finishing operations. This study does not capture efficiency gains resulting from this specialization, but instead captures gains in efficiency within the feeder-to-finish product cycle.

The analysis focuses on two major hog producing regions: the “Heartland” (IA, IL, IN, KY, MO, OH) and the “Southeast” (AL, AR, GA, NC, SC, VA). Producers located in the remaining surveyed states (CO, KS, MI, MN, NE, OK, PA, SD, TN, TX, UT, WI) were placed in the “Other regions” category. Table 1 lists the distribution of observations, farms, and output by region and farm size for the three survey years. The 1992 to 1998 period is characterized by a shift in production from the Heartland to the Southeast and Other regions. Over this period, the share of output produced by farms in the Southeast increased by 12.2 percentage points, even though the share of feeder-to-finish operations located in this region declined by 5.6 percentage points. This increase in output despite a relative decline in farm numbers is explained by a large increase in scale of production: average farm size in the Southeast increased almost ten-fold.[3] Farms in the Heartland, while representing roughly half of all feeder-to-finish hog farms in both 1992 and 1998, experienced a relatively small proportional increase in average farm output over this period, and consequently suffered a 22.5 percentage points decline in output share.

The 1998 to 2004 period is characterized by a rebound of output share in the Heartland region and a decline in output share in the Southeast. From 1998 to 2004, Heartland farms doubled in size while farms in the Southeast experienced a much smaller proportional increase (though starting from a larger average size). As a result, farms in the Heartland increased their share of output by 10.2 percentage points over this period, and the share of output produced in Southeast declined by 7.6 percentage points.

The relative decline in output and growth in average farm size in the Southeast during 1998-2004 likely resulted in large part from the moratorium in North Carolina on new hog farm construction (averaging over the three survey periods, farms in North Carolina produced about 92% of the total output in the Southeast region). In 1997, North Carolina passed House Bill 515, The Clean Water Responsibility and Environmentally Sound Policy Act, which among other things imposed a moratorium on the construction of new and expanded hog operations with 250 or more hogs. There were several exceptions to this moratorium, including for new construction using "innovative animal waste management systems that do not employ an anaerobic lagoon."[4]

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[2] Feeder pit-to-finish operations are those on which feeder pigs (weighing 30-80 pounds) are purchased/placed, finished and then sold/removed for slaughter (weighing 200-260 pounds).
[3] Output is measured in hundredweight gain - the weight added to purchased/placed hogs and existing hog inventory in the calendar year. Each head represents approximately 2 hundredweight gain (250 pounds for a typical finished market hog minus 50 pounds for a typical feeder pig). Hence, ignoring losses due to animal mortality, a farm with an output of 10,000 hundredweight gain produces approximately 5000 head per year.
[4] For full text of the bill see: http://ssl.csg.org/dockets/99bscbills/2499b01nchb515cleanswine.html

The moratorium, which was originally to expire in 1999, was extended several times in modified form through 2007.

Table 2 provides summary statistics for the output and input variables by region. Output is defined as "hog weight gain" – the weight added to purchased/placed hogs and existing hog inventory in the calendar year prior to the year of the survey. Hog weight gain, unlike the alternative measure of output "number of head removed," accounts for changes in inventory and differences in weights of feeder and finished pigs between operations. Feed is defined as the total weight of feed applied.[5] The labor input is a Tornqvist quantity index comprised of paid labor and unpaid farm household labor using the labor expenditure shares for paid and unpaid labor as weights.[6] Capital is the "capital recovery cost" – the estimated cost of replacing the existing capital equipment (barns, feeding equipment, etc.). "Other inputs" is defined as expenditures on veterinary services, bedding, marketing, custom work, energy, and repairs. Price indices from official statistics are used when price information is not directly available from the farm survey. Labor wages are deflated using the Bureau of Labor Statistics (BLS) Blue Collar Total Compensation index; feed prices are deflated using a weighted average of the BLS corn and soybean PPI; Capital is deflated using the BLS farm machinery PPI, and other inputs are deflated using the CPI. In the estimation we rescale all logged values of the variables as deviations from the sample mean to facilitate interpretation of the coefficients.

Table 3 provides an overview of the advances in factor productivity during the study period for the three regions. Except for "other inputs" in the Southeast, all partial factor productivity measures increased at roughly the same annual rates between 1992 and 2004.

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[5] It is not possible to disaggregate feed into components because many operations, particularly those that contract, did not report the composition of feed used.

However, this pattern masks substantial differences between the Heartland and the Southeast during the two sub-periods. While all regions began in 1992 with approximately the same levels of factor productivity, from 1992 to 1998 farms in the Southeast experienced much larger increases in feed, labor, and capital productivity than did farms in the Heartland. Between 1998 and 2004, this pattern is reversed, with farms in the Heartland increasing their feed, labor and capital productivity at a much more rapid rate than farms in the Southeast. The next section examines whether these shifts in productivity were caused mainly by changes in the scale of production, which was illustrated in table 1, or whether the shifts were caused by differences in rates of technological change, allocative efficiency change, or technical efficiency change.

4. Empirical Results

Table 4 presents the estimated coefficients of the stochastic production function. Because the variables are expressed as deviations from their means, the first-order parameters of the translog function can be directly interpreted as estimates of production elasticities evaluated at the sample means. The production elasticities with respect to feed, capital, and other inputs have plausible values and are statistically significant. The estimated elasticity of output with respect to labor is quite low, but this finding is consistent with other studies that also found low labor elasticities (e.g., Brummer, Glauben, and Thijssen, 2002). Labor, particularly unpaid labor, is difficult to quantify and value using a survey instrument and the resulting low elasticity and relatively low statistical significance level for labor could reflect these empirical challenges.

Because a common production function is estimated for all three regions, efficiency scores can be interpreted as an estimate of the productive efficiency in each region assuming all

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[6] The labor expenditures for paid labor are observed. Labor expenditures for unpaid labor are estimated using an imputed wage for unpaid labor.

farms had access to the same technology. It is possible that regional differences in climate and geology impose some difference in hog farm technology (allowing for different livestock facilities, feed, manure management practices, etc.) Future research could test for technological differences between regions.

The average technical efficiency score for the sample is 0.697 with a standard deviation of 0.129. The low average technical efficiency score and the level of variation in the score suggest substantial scope for improvement for many farms. Future work could try to identify the farm and operator characteristics associated with high technical efficiency scores. Technical efficiency scores are disaggregated by region and farm size in table 5. The table shows limited variation in average technical efficiency across regions and over time. However, there is a subtle pattern that seems consistent with our earlier observations about factor productivity: technical efficiency declines in the Heartland between 1992 and 1998 and then rebounds by 2004. In the Southeast, technical efficiency increases slightly between 1992 and 1998 and then declines between 1998 and 2004. The table shows a stronger relationship between efficiency and farm output – with larger operations being, on average, more technically efficient than smaller ones. This result suggests greater scope for improving technical efficiency through enhanced adoption of best practice techniques for smaller scale operations.

Decomposing TFP Change

Table 6 presents the average results of the TFP decomposition for every region and for all farms. In aggregate, TFP increased at an average rate of 6.3 percent per year. The overwhelming portion of this growth resulted from technical progress (expanding at an average rate of 3.0 percent per year) and increases in scale efficiency (3.4 percent per year). The rate of change in

TFP appears to be relatively constant over the two periods – increasing by 45.1 percent from 1992-1998 and by 44.1 percent from 1998-2004. Interestingly, the contribution of technological change to increasing productivity appears to have increased substantially over the two periods – technical change contributed to a 13.5 percent increase in productivity between 1992 and 1998, and a 25.6 percent increase between 1998 and 2004. In contrast, the scale effect appears to have diminished: while changes in scale efficiency contributed to a 30.6 percent increase in productivity between 1992 and 1998, scale effects only raised productivity by 13.8 percent in between 1998 and 2004. Since, as we discuss later, scale elasticity increased somewhat between the two periods (holding farm size constant) as the production technology evolved, the reduction in the contribution of the scale efficiency to TFP can be attributed to a slowdown in the growth of average farm output (which was shown in table 1).

Notably, there was essentially no change in average technical efficiency over the twelve-year period of study. The minimal change in technical efficiency may have resulted from the fact that the pooled cross-section sample used in this study includes a constantly evolving set of farmers – that is new farms continuously entered as older farms exited. Over time, older more experienced farmers, who might be more technically efficient because of learning by doing, exit and are replaced by younger less experienced and consequently less technically efficient farmers. In contrast, with balanced panel data sets farmers remain in the sample and gain experience, which could explain why other studies have found technical efficiency gains over time. Allocative efficiency change also played a relatively small role in TFP change – increasing at an annual rate of only 0.5%. With constantly changing factor prices and turnover in the sample of farmers, it is possible that improvements in allocative efficiency were minimal for the same reasons that technical efficiency change was minimal.

The regional changes in TFP are consistent with changes in partial factor productivity shown in table 3 and discussed above. Between 1992 and 1998, TFP almost doubled in the Southeast. In contrast, productivity increased by only about a third in the Heartland over the same six-year period. Between 1992 and 1998, technical progress contributed roughly equal amounts to the growth in TFP for farms in both the Heartland and Southeast regions. However, the contribution of scale efficiency to TFP was much greater in the Southeast than the Heartland (67.7 versus 19.9 percent). The large increase in scale efficiency in the Southeast resulted from the region's rapid increase in the scale of production (see table 1), given the increasing returns to scale of the production technology (which we discuss below).

In the 1998-2004 period, productivity in the Heartland rebounded – increasing by almost 60 percent, compared to only 36 percent in the Southeast. This "catching up" in the Heartland in the second period was also driven by increases in scale efficiency – in the Heartland, scale efficiency contributed to a 29.3 percent increase in TFP compared to only a 13.8 percent increase in TFP in the Southeast. The Heartland actually lagged slightly behind the Southeast in technological progress during this period.

Since increases in scale efficiency played such an important role in contributing to productivity gains over the 12 year period, and seems to have been important in determining productivity growth at the regional level within the two sub-periods, it is worth examining in more detail. Table 7 displays the average scale elasticity by region and output scale category for the three survey years. The average scale elasticity for all farms, ranging between 1.12 and 1.16, indicates substantial returns to scale in the production technology in all periods. Since the production technology is assumed to be the same across regions, regional differences in scale efficiency can be attributed to differences in size: returns to scale are greater for smaller operations, and farms in the Heartland (and "Other region") are smaller, on average, than farms in the Southeast.

Holding output constant, returns to scale appear to have increased steadily over the study period. For all output categories returns to scale increased between 1992 and 1998 and between 1998 and 2004. However, because average farm size increased substantially over the study period, the average scale elasticity at the regional level showed little change. Hence, while the potential for efficiency gains from further increases in scale may be limited for large farms (farms producing more than 25,000 cwt had an average scale elasticity of 1.05) there seems to remain substantial scope for efficiency gains in the sector as a whole from further increases in scale. This is particularly true in the Heartland (and "Other regions") as average farm output is substantially smaller there compared to in the Southeast.

5. Conclusions

There have been dramatic structural changes in the hog industry in the last two decades: farms have increased in scale and become more specialized, the use of production contracts has increased, and production has shifted regionally. These changes have coincided with a substantial increase in productivity – TFP increased at an average annual rate of over 6 percent between 1992 and 1998. This study used a stochastic frontier analysis to decompose the TFP growth into four components: technical change and changes in technical efficiency, scale efficiency, and allocative efficiency. The study found that the productivity gains in the twelve year study period were explained almost entirely by technical progress and improvements in scale efficiency. There were minimal changes in average allocative or technical efficiency, though estimates of technical efficiency indicate substantial scope for improvement, especially for smaller-scale operations.

Between 1992 and 1998 farms in the Southeast (mainly in North Carolina) increased their share of finished hog output while farms in the Heartland (mainly Iowa, Illinois, and Ohio) decreased their share. Probably as a result of a moratorium on large hog farm construction in North Carolina, this trend was later reversed between 1998 and 2004: average farm size and output share grew faster in the Heartland relative to the Southeast. The trends in output were mirrored by the trend in TFP: productivity increased more in the Southeast between 1992 and 1998, and later increased more in the Heartland between 1998 and 2004.

Average farm size growth and the resulting in improvements in scale efficiency appear to explain most of the differences in productivity growth between the Heartland and Southeast since 1992. Farms in both regions had similar rates of technical advance over the study period. However, in the Southeast, relatively rapid growth in average farm output during 1992-1998 resulted in relatively large gains in scale efficiency in that period. From 1998 to 2004, farms grew faster in the Heartland, leading to greater productivity growth in that region.

Results indicate that despite large increases in the scale of production, there remains substantial scope for further scale efficiency gains, particularly in the Heartland where farms operate at a smaller average scale than do farms in the Southeast.

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Table 1. Summary Statistics by Region

	1992	1998	2004
Number of observations			
Heartland	88	147	191
Southeast	50	178	131
Other regions	73	167	156
Share of feeder-to-finish farms			
Heartland	54.7	55.9	48.9
Southeast	15.2	9.6	10.7
Other regions	30.1	34.5	40.4
Mean farm output			
Heartland	1,716	5,399	11,313
Southeast	2,333	20,771	25,074
Other regions	1,097	10,516	12,933
Share of feeder-to-finish output			
Heartland	57.9	35.4	45.2
Southeast	20.1	32.3	24.7
Other regions	22.0	32.3	30.0
Share of feeder-to-finish output			
Output < 1,000	14.7	1.9	0.5
1,000 < Output < 2,500	35.0	6.7	3.0
2,500 < Output < 10,000	41.0	26.5	16.7
10,000 < Output < 25,000	9.3	29.2	36.3
25,000 < Output	0.0	35.7	43.4

Table 2. Sample Summary Statistics

	Units	Mean	Std. Dev.
Heartland (N=426)			
Hog output	Cwt. gain	7,290	12,037
Feed	Cwt.	18,069	30,556
Labor	Tornqvist index	4.72	11.26
Capital	Dollars	42,443	56,476
Other inputs	Dollars	19,219	30,198
Southeast (N=359)			
Hog output	Cwt. gain	19,773	27,327
Feed	Cwt.	39,995	57,106
Labor	Tornqvist index	8.30	18.86
Capital	Dollars	99,424	117,244
Other inputs	Dollars	59,540	150,973
Other regions (N=396)			
Hog output	Cwt. gain	9,732	34,089
Feed	Cwt.	27,541	95,139
Labor	Tornqvist index	3.90	8.13
Capital	Dollars	59,670	360,325
Other inputs	Dollars	22,029	77,287

Table 3. Partial Factor Productivity by Region and Year

Input – Region	Partial Factor Productivity			
	1992	1998	2004	Annual growth rate 1992-2004
Feed (cwt)				
Heartland	0.286	0.314	0.764	8.5
Southeast	0.281	0.443	0.629	6.9
Other regions	0.243	0.313	0.625	8.2
Labor (Tornqvist index)				
Heartland	2070	3019	6187	9.6
Southeast	2237	6151	6918	9.9
Other regions	2584	2919	5373	6.3
Capital (dollars)				
Heartland	0.091	0.097	0.238	8.3
Southeast	0.099	0.156	0.252	8.1
Other regions	0.075	0.111	0.234	9.9
Other Inputs (dollars)				
Heartland	0.327	0.491	0.541	4.3
Southeast	0.456	0.359	0.485	0.5
Other regions	0.248	0.491	0.49	5.8

Table 4. Stochastic Production Function Parameter Estimates

Parameter		Coefficient	Standard Error	t-statistic
β_0	constant	0.3774	0.0385	9.8
β_1	feed	0.4734	0.0214	22.2
β_2	labor	0.0453	0.0119	3.8
β_3	capital	0.3189	0.0258	12.4
β_4	other inputs	0.2797	0.0193	14.5
β_{11}		0.1012	0.0323	3.1
β_{22}		-0.0279	0.0148	-1.9
β_{33}		0.0920	0.0609	1.5
β_{44}		0.0808	0.0337	2.4
β_{12}		-0.0055	0.0188	-0.3
β_{13}		-0.0791	0.0383	-2.1
β_{14}		-0.0738	0.0268	-2.8
β_{23}		0.0060	0.0207	0.3
β_{24}		-0.0183	0.0174	-1.1
β_{34}		0.0226	0.0366	0.6
β_t	time	0.0619	0.0034	18.2
β_{tt}	time-squared	0.0046	0.0017	2.7
β_{t1}		-0.0257	0.0045	-5.7
β_{t2}		0.0012	0.0029	0.4
β_{t3}		0.0065	0.0058	1.1
β_{t4}		0.0212	0.0043	4.9
σ^2	$\left(=\sigma_v^2+\sigma_u^2\right)$	0.3549	0.0300	11.8
γ	$\left(=\sigma_u^2/\sigma_v^2+\sigma_u^2\right)$	0.7247	0.0536	13.5

Note: There were 1,181 observations.

Table 5. Technical Efficiency by Farm Output Category, Region and Year

	Technical Efficiency Index		
	1992	1998	2004
Region			
Heartland	0.72	0.68	0.70
Southeast	0.73	0.74	0.69
Other regions	0.67	0.68	0.70
Finished hog output (cwt. gain)			
Output < 1,000	0.67	0.64	0.61
1,000 < Output < 2,500	0.74	0.64	0.69
2,500 < Output < 10,000	0.73	0.72	0.69
10,000 < Output < 25,000	0.79	0.76	0.74
25,000 < Output	na	0.76	0.74
All farms	0.70	0.70	0.69

Table 6. Decomposition of Total Factor Productivity Change, 1992-2004

	Percent Change		Annual Growth Rate
	1992-1998	1998-2004	1992-2004
Heartland			
Technical eff. change	-3.1	1.3	-0.2
Technical change	13.7	25.6	3.0
Scale efficiency change	19.9	29.3	3.7
Allocative eff. change	5.8	3.4	0.8
Total factor prod. change	36.3	59.6	6.7
Southeast			
Technical eff. change	0.6	-3.6	-0.3
Technical change	14.7	29.6	3.4
Scale efficiency change	67.7	13.8	5.5
Allocative eff. change	8.7	-3.9	0.4
Total factor prod. change	91.7	35.9	8.3
Other regions			
Technical eff. change	0.6	1.1	0.1
Technical change	13.1	24.6	2.9
Scale efficiency change	38.3	-8.5	2.0
Allocative eff. change	-4.2	6.7	0.2
Total factor prod. change	47.8	23.9	5.2
All farms			
Technical eff. change	-1.7	0.8	-0.1
Technical change	13.5	25.6	3.0
Scale efficiency change	30.6	13.8	3.4
Allocative eff. change	2.6	3.9	0.5
Total factor prod. change	45.1	44.1	6.3

Table 7. Scale Elasticity by Farm Output Category, Region and Year

	Scale elasticity		
	1992	1998	2004
Region			
Heartland	1.14	1.17	1.16
Southeast	1.13	1.11	1.11
Other regions	1.18	1.15	1.19
Finished hog output (cwt. gain)			
Output < 1,000	1.20	1.24	1.27
1,000 < Output < 2,500	1.13	1.16	1.22
2,500 < Output < 10,000	1.08	1.12	1.17
10,000 < Output < 25,000	1.07	1.09	1.12
25,000 < Output	na	1.03	1.05
All farms	1.16	1.12	1.14