Decomposition of Total Factor Productivity Change in the U.S. Hog Industry

Nigel Key, William McBride, and Roberto Mosheim

The U.S. hog industry has experienced dramatic structural changes and rapid increases in farm productivity. A stochastic frontier analysis is used to measure hog enterprise total factor productivity (TFP) growth between 1992 and 2004 and to decompose this growth into technical change and changes in technical efficiency, scale efficiency, and allocative efficiency. Productivity gains over the 12-year period are found to be explained almost entirely by technical progress and by improvements in scale efficiency. Differences in TFP growth rates in the Southeast and Heartland regions were found to be explained primarily by differences in farm size growth rates.

Key Words: hog production, scale efficiency, stochastic frontier, technical change, total factor productivity growth

JEL Classifications: D24, Q12

In recent years, the U.S. hog industry has undergone substantial structural changes. Between 1992 and 2004, the share of hogs produced on farms with at least 2,000 head increased from about 30% to 80% (USDA–NASS). Over the same period, the total number of hog operations fell by more than 70%, from over 240,000 to less than 70,000 (USDA–NASS). Hog farming has become increasingly specialized, with most phases of production (gestation, farrowing, finishing) now occurring on separate operations (Key and McBride). This increasing specialization has been facilitated by a rapid growth in contract arrangements between integrators and growers. Between 1992 and 2004, the share of market hogs produced under a production contract increased from 5% to 67% (Key and McBride).

Recent years have also been a period of rapid technological innovation in hog genetics, nutrition, equipment, and veterinary medicine. These technological advances and the structural changes in the hog industry have resulted in substantial increases in farm productivity. Between 1992 and 2004, the average cost of production declined over 40% for feeder pig-to-finish operations, in real terms. The increases in productivity have exerted a downward pressure on hog prices paid by packers, which has contributed to a high exit rate for less efficient hog farmers (USDA–ERS).

Structural changes in the hog sector—particularly the shift in production to large operations—have precipitated controversies over water and air quality, odor nuisances, animal welfare, the integrity of rural communities, and the viability of small- and medium-scale family hog farms. This analysis seeks insights into the future direction of structural change through an examination of the causes of recent productivity growth in the hog sector.

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Specifically, this study uses a stochastic frontier analysis to decompose hog farm total factor productivity growth between 1992 and 2004 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 is 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. Results provide estimates of how economies of scale vary by farm size, how much observed increases in scale contributed to the observed growth in productivity, and whether scale economies have increased over time.

The analysis also disaggregates productivity change in three regions to gain insight into regional differences in productivity change. During the last two decades, the hog industry has undergone significant geographical shifts in production (Onal, Unnevehr, and Bekric; Roe, Irwin, and Sharp). In the early and middle 1990s, production expanded rapidly in the Southeast as large contract operations initiated production. Beginning in the late 1990s, growth in the size of hog farms in the Southeast slowed, likely in part because of a moratorium on hog farm expansion in North Carolina that was enacted in 1997. In contrast, farms in the Heartland grew relatively slowly in the early and middle 1990s but grew relatively rapidly after that. We examine the extent to which differences in productivity between regions can be explained by differences in the scale of production. The results of the regional analysis provide insights into the consequences of policies that would directly or indirectly limit the scale of farm operations.

For the total factor productivity decomposition we use the methodology proposed by Orea, which assumes that technology can be represented by a translog production function. We employ the time-varying model for technical inefficiency proposed by Battese and Coelli. Firm inefficiency is assumed to be distributed as a generalized truncated–normal random variable which is distributed independently of the normally distributed random errors.

Data for the study are drawn from three nationally representative surveys of the hog sector conducted in 1992, 1998, and 2004. The farm-level 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 (e.g., veterinary services and energy).

Some past studies have examined efficiency in hog production in cross-sectional samples. Sharma, Lueng, and Zalenski 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. used a DEA approach to determine the relative measure of technical, allocative, scale, and 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 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 explained differences in efficiency across hog farms at a single point in time, this study is the first that we are aware of to decompose the change in hog farm productivity over time.

The next section reviews the theoretical framework for decomposing changes in total factor productivity over time. The third section provides a detailed description of the data. The fourth section discusses the results of the total factor decomposition and the regional analysis. The final section concludes.

Theoretical Framework

This study uses a stochastic frontier analysis to decompose total factor productivity (TFP) growth into four components: technical change, technical efficiency change, scale efficiency change, and allocative efficiency change.[1] Orea shows that if firm i's technology in time t can be represented by the translog output-oriented distance function $D_O(q_{it}, x_{it}, t)$, where q is output, x_{it}, a K-dimensional input vector with elements $(x_{it1} \ldots x_{itk} \ldots x_{itK})$, 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 time periods r and s:

$$\text{(1)} \quad \ln M_{Oi} = EC_i^{rs} + TC_i^{rs} + SC_i^{rs},$$

where

$$\text{(2)} \quad EC_i^{rs} = \ln D_O(q_{is}, x_{is}, s) - \ln D_O(q_{ir}, x_{ir}, r)$$

$$\text{(3)} \quad TC_i^{rs} = -\frac{1}{2}\left[\frac{\partial \ln D_O(q_{is}, x_{is}, s)}{\partial t} + \frac{\partial \ln D_O(q_{ir}, x_{ir}, r)}{\partial t}\right]$$

$$\text{(4)} \quad SC_i^{rs} = \frac{1}{2}\sum_{k=1}^{K}\left[\frac{\varepsilon_{is}-1}{\varepsilon_{is}}\varepsilon_{isk} + \frac{\varepsilon_{ir}-1}{\varepsilon_{ir}}\varepsilon_{irk}\right]\cdot \ln\left(\frac{x_{isk}}{x_{irk}}\right),$$

where for $t = (r, s)$, $\varepsilon_{it} = \Sigma_{k=1}^{K}\, \varepsilon_{itk}$ is the scale elasticity such that $\varepsilon_{itk} = \partial \ln D_O(q_{it}, x_{it}, t)/\partial \ln x_{itk}$.

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

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

where β is a vector of parameters, v_{it} is a normally distributed random error with mean zero and

$$\text{(6)} \quad \begin{aligned} f(\beta, x_{it}, t) = {} & \beta_0 + \sum_{k=1}^{K}\beta_k \ln x_{itk} \\ & + \frac{1}{2}\sum_{k=1}^{K}\sum_{j=1}^{K}\beta_{kj}\ln x_{itk}\ln x_{itj} \\ & + \sum_{k=1}^{K}\beta_{tk} t \ln x_{itk} + \beta_t t + \frac{1}{2}\beta_{tt}t^2. \end{aligned}$$

To account for technical inefficiency, we estimate a stochastic production function model of the form

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

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

$$\text{(8)} \quad \begin{aligned} TE_{it} &= \frac{q_{it}}{\exp(f(\beta, x_{it}, t) + v_{it})} \\ &= \frac{\exp(f(\beta, x_{it}, t) + v_{it} - u_{it})}{\exp(f(\beta, x_{it}, t) + v_{it})} \\ &= \exp(-u_{it}). \end{aligned}$$

By using Equation (7), it can be shown that the technical efficiency factor in Equation (8) equals the distance function in Equation (5):

$$\text{(9)} \quad \begin{aligned} \exp(-u_{it}) &= \exp(\ln q_{it} - f(\beta, x_{it}, t) - v_{it}) \\ &= D_0(q_{it}, x_{it}, t). \end{aligned}$$

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

$$\text{(10)} \quad EC_i^{rs} = E(-u_{is}|e_{is}) - E(-u_{ir}|e_{ir})$$

or

$$\text{(11)} \quad \begin{aligned} \exp\left(EC_i^{rs}\right) = {} & E(\exp(-u_{is}|e_{is})) \\ & \div E(\exp(-u_{ir}|e_{ir})), \end{aligned}$$

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

By using Equations (3), (5), and (6), the technical change index can be derived:

$$\text{(12)} \quad \begin{aligned} TC_i^{rs} = \frac{1}{2}\Bigg[& \sum_{k=1}^{K}\beta_{tk}\ln x_{isk} \\ & + \sum_{k=1}^{K}\beta_{tk}\ln x_{irk} + 2\beta_t + 2\beta_{tt}(r+s)\Bigg]. \end{aligned}$$

[1] This section is based primarily on Coelli et al. (2005), pp. 289–302; Coelli et al. (2003), pp. 25–66; and Orea.

From Equation (6), the scale elasticity is:

$$\varepsilon_{it} = \sum_{k=1}^{K} \varepsilon_{itk}, \quad \text{where } \varepsilon_{itk} = \beta_k + \frac{1}{2}\sum_{j=1}^{K} \beta_{kj} \ln x_{itj} + \beta_{tk} t. \tag{13}$$

This can be used to compute the scale efficiency change index shown in Equation (4).

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

$$\ln TFP_i^{rs} = \ln q_{is} - \ln q_{ir} - \frac{1}{2}\sum_{k=1}^{K} [(\sigma_{isk} + \sigma_{irk}) \cdot (\ln x_{isk} - \ln x_{irk})] \tag{14}$$

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

$$AC_i^{rs} = \frac{1}{2}\sum_{k=1}^{K} \left[\left(\left(\frac{\varepsilon_{isk}}{\varepsilon_{sk}} - \sigma_{isk} \right) + \left(\frac{\varepsilon_{irk}}{\varepsilon_{rk}} - \sigma_{irk} \right) \right) \times (\ln x_{isk} - \ln x_{irk}) \right]. \tag{15}$$

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" (Iowa, Illinois, Indiana, Kentucky, Missouri, and Ohio) and the "Southeast" (Alabama, Arkansas, Georgia, North Carolina, South Carolina, and Virginia). Producers located in the remaining surveyed states (Colorado, Kansas, Michigan, Minnesota, Nebraska, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, Utah, and Wisconsin) were placed in the "Other" 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 tenfold.[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 pro-

[2] Feeder-to-finish operations are those on which feeder pigs (weighing 30–80 pounds) are purchased or placed, finished, and then sold or removed for slaughter (weighing 225–300 pounds).

[3] Output is measured in hundredweight gain (cwt.)—the weight added to purchased/placed hogs and existing hog inventory in the calendar year. Each head produced represents approximately 2 cwt. (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 6,000 cwt. produces approximately 3,000 head per year. Assuming three hog cycles per year, annual production of 6,000 cwt. could be produced by an operation with an inventory of 1,000 head.

Table 1. Descriptive Statistics by Region and Farm Size

	1992	1998	2004
Share of feeder-to-finish farms (%)			
Heartland	54.7	55.9	48.9
Southeast	15.2	9.6	10.7
Other	30.1	34.5	40.4
Share of feeder-to-finish output (%)			
Heartland	57.9	35.4	45.2
Southeast	20.1	32.3	24.7
Other	22.0	32.3	30.0
Mean farm output (cwt. gain)			
Heartland	1,649	3,763	9,671
Southeast	2,062	20,050	24,216
Other	1,142	5,563	7,767
Share of feeder-to-finish output (%)			
Output $<$ 1,000	14.7	1.9	0.5
1,000 $\leq$ Output $<$ 2,500	35.0	6.7	3.0
2,500 $\leq$ Output $<$ 10,000	41.0	26.5	16.7
10,000 $\leq$ Output $<$ 25,000	9.3	29.2	36.3
25,000 $\leq$ Output	0.0	35.7	43.4
Observations			
Heartland	88	147	191
Southeast	50	178	131
Other	73	167	156

Source: 1992, 1998, and 2004 USDA ARMS.

portional 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 part from the moratorium in North Carolina on new hog farm construction. In the ARMS surveys, feeder to finish farms in North Carolina accounted for 78%, 92%, and 93% of finished hog output in the Southeast region in 1992, 1998, and 2004, respectively. In 1997, North Carolina passed House Bill 515, The Clean Water Responsibility and Environmentally Sound Policy Act, which 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] 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 measures of output such as "number of head removed," accounts for changes in inventory and for variation in the weight of feeder and finished pigs. Feed is defined as the total weight of feed applied.[5] The labor input is a Tornqvist quantity index comprised of

[4] For full text of the bill see: http://ssl.csg.org/dockets/99bscbills/2499b01nchb515cleanswine.html

[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.

Table 2. Summary Statistics for Production Variables by Region

	Heartland	Southeast	Other
Output (cwt. gain)	4,557	12,853	4,925
	(63,650)	(93,909)	(116,737)
Feed (cwt.)	12,174	27,106	13,780
	(163,170)	(193,659)	(316,029)
Labor (Tornqvist index[a])	2.9	5.8	2.1
	(59.2)	(61.9)	(34.2)
Capital (dollar[b])	29,597	70,934	29,124
	(284,255)	(422,608)	(1,099,257)
Other inputs (dollar[c])	12,856	37,256	12,261
	(169,263)	(481,801)	(262,583)
Observations	426	359	396

Note: Standard deviations are in parentheses.
Source: 1992, 1998, and 2004 USDA ARMS.
[a] The Tornqvist index combines paid labor plus unpaid farm household labor used in the hog enterprise. Labor expenditure shares for paid and unpaid labor are used as weights, and expenditures for unpaid labor are imputed.
[b] Capital is the "capital recovery cost"—the estimated cost of replacing the existing capital equipment (barns, feeding equipment, etc.).
[c] Other inputs are defined as expenditures on veterinary services, bedding, marketing, custom work, energy, and repairs.

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 (e.g., barns and feeding equipment). "Other inputs" is defined as expenditures on veterinary services, bedding, marketing, custom work, energy, and repairs. 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 Producer Price Index (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. However, this pattern masks substantial differences between the Heartland and the Southeast during the two intervening 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.

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 elastic-

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

Table 3. Partial Factor Productivity by Region and Year

	Partial Factor Productivity			
	1992	1998	2004	1992–2004 Average Annual Growth Rate
Feed productivity (cwt. gain per cwt. feed)				
Heartland	0.286	0.314	0.764	8.5
Southeast	0.281	0.443	0.629	6.9
Other	0.243	0.313	0.625	8.2
Labor productivity (cwt. gain per unit[a])				
Heartland	2070	3019	6187	9.6
Southeast	2237	6151	6918	9.9
Other	2584	2919	5373	6.3
Capital productivity (cwt. gain per dollar[b])				
Heartland	0.091	0.097	0.238	8.3
Southeast	0.099	0.156	0.252	8.1
Other	0.075	0.111	0.234	9.9
Other inputs productivity (cwt. gain per dollar[c])				
Heartland	0.327	0.491	0.541	4.3
Southeast	0.456	0.359	0.485	0.5
Other	0.248	0.491	0.49	5.8

Source: 1992, 1998, and 2004 USDA ARMS.

[a] Hog enterprise labor is measured using a Tornqvist index that aggregates paid labor and unpaid farm household labor using labor expenditure shares as weights. Expenditures for unpaid labor are imputed.

[b] Capital is the "capital recovery cost"—the estimated cost of replacing the existing capital equipment (e.g., barns and feeding equipment).

[c] Other inputs are defined expenditures on veterinary services, bedding, marketing, custom work, energy, and repairs.

ities 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). Labor, particularly unpaid family 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.

Technical efficiency scores are disaggregated by region and farm size in Table 5. Technical efficiency measures the extent to which farms are able to combine inputs in an efficient manner to achieve the maximum possible output (i.e., proximity to the production frontier). 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 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, and manure management practices). Unfortunately, estimating a model that allows for technological differences across production regions is limited by the number of observations in the sample.

Table 5 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

Table 4. Stochastic Production Function Parameter Estimates

Parameter	Coefficient	SE	t-statistic
β_0 constant	0.377	0.0385	9.8
β_1 feed	0.473	0.0214	22.2
β_2 labor	0.045	0.0119	3.8
β_3 capital	0.319	0.0258	12.4
β_4 other inputs	0.280	0.0193	14.5
β_{11}	0.101	0.0323	3.1
β_{22}	−0.028	0.0148	−1.9
β_{33}	0.092	0.0609	1.5
β_{44}	0.081	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
$\sigma^2 \ (=\sigma_v^2+\sigma_u^2)$	0.355	0.0300	11.8
$\gamma \ (=\sigma_u^2/\sigma_v^2+\sigma_u^2)$	0.725	0.0536	13.5
Observations	1,181		

Source: Authors' calculations using data from the 1992, 1998, and 2004 USDA ARMS.

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% per year. The overwhelming portion of this growth resulted from technical progress (expanding at an average rate of 3.0% per year) and increases in scale efficiency (3.4% per year). The rate of change in TFP appears to be relatively constant over the two periods—increasing by 45.1% from 1992–1998 and by 44.1% 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% increase in productivity between 1992 and 1998, and a 25.6% increase between 1998 and 2004. In contrast, the scale effect appears to have diminished: while changes in scale efficiency contributed to a 30.6% increase in productivity between 1992 and 1998, scale effects only raised productivity by 13.8% 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

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	0.67	0.68	0.70
Finished hog output (cwt. gain)			
Output $<$ 1,000	0.67	0.64	0.61
1,000 $\leq$ Output $<$ 2,500	0.74	0.64	0.69
2,500 $\leq$ Output $<$ 10,000	0.73	0.72	0.69
10,000 $\leq$ Output $<$ 25,000	0.79	0.76	0.74
25,000 $\leq$ Output	NA	0.76	0.74
All farms	0.70	0.70	0.69

Source: Authors' calculations using data from the 1992, 1998, and 2004 USDA ARMS.

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

	Percent Change		Average Annual Growth Rate
	1992–1998	1998–2004	1992–2004
Heartland			
Technical efficiency 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 efficiency change	5.8	3.4	0.8
Total factor productivity change	36.3	59.6	6.7
Southeast			
Technical efficiency 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 efficiency change	8.7	−3.9	0.4
Total factor productivity change	91.7	35.9	8.3
Other			
Technical efficiency 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 efficiency change	−4.2	6.7	0.2
Total factor productivity change	47.8	23.9	5.2
All farms			
Technical efficiency 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 efficiency change	2.6	3.9	0.5
Total factor productivity change	45.1	44.1	6.3

Source: Authors' calculations using data from the 1992, 1998, and 2004 USDA ARMS.

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).

Over time, some farmers may have improved their allocative efficiency—that is, they may have become better at selecting input quantities to equate input price ratios with the ratios of the corresponding marginal products. However, allocative efficiency change appears to have 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 changes in technical efficiency were minimal.

The regional changes in TFP are consistent with changes in partial factor productivity shown in Table 3 and discussed previously. 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%). 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 later).

In the 1998–2004 period, productivity in the Heartland rebounded—increasing by al-

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
$1{,}000 \leq$ Output $< 2{,}500$	1.13	1.16	1.22
$2{,}500 \leq$ Output $< 10{,}000$	1.08	1.12	1.17
$10{,}000 \leq$ Output $< 25{,}000$	1.07	1.09	1.12
$25{,}000 \leq$ Output	NA	1.03	1.05
All farms	1.16	1.12	1.14

Source: Authors' calculations using data from the 1992, 1998, and 2004 USDA ARMS.

most 60%, compared with only 36% 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% increase in TFP compared to only a 13.8% 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 twelve-year period and seem to have been important in determining productivity growth at the regional level within the two subperiods, it is worth examining in more detail. Table 7 displays the average scale elasticity by region and 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.

Table 7 shows that for all output categories, returns to scale increased between 1992 and 1998 and between 1998 and 2004. This implies that holding output constant (output is approximately constant within each scale category) returns to scale increased steadily over the study period. However, because the scale elasticity declines with farm size and average farm size increased substantially over the study period (as shown in Table 1), the average scale elasticity showed little change over time.

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 remains a substantial scope for efficiency gains in the sector as a whole from further increases in scale. This is particularly true in the Heartland (and the "Other" region), where the average farm output is substantially smaller than it is in the Southeast.

Limitations of the Analysis

There are some limitations in the methodological approach that are worth highlighting. First, this study did not account for the fact that manure is an output produced jointly with hogs. Manure is an unusual output in that it can have either a positive or negative value, depending on a number of factors. In general, manure is more valuable in regions where the demand for manure nutrients is relatively high (in regions with abundant cropland, where environmental regulations are less stringent, and where hog production is less concentrated). By not considering manure as an output, the study underestimates hog farm output in regions where manure has positive value and overestimates output in regions where manure has negative value. As a consequence, the analysis likely underestimates productivity in the Heartland and overestimates productivity in the Southeast.[7] In addition, for many farms, it is likely that the shadow value of manure declined between 1992 and 2004, as nutrient application limits and other regulations became more stringent and binding. If so, the analysis overestimates the increases in farm productivity between 1992 and 2004. Hence, not including manure as an output biases to some degree the estimates of the changes in total factor productivity, scale efficiency, technical efficiency, technical change, and allocative efficiency.

To account for manure as an output in a TFP decomposition would require information about the quantity of manure produced (and its nutrient content) and the shadow value of the manure (or its nutrients). The ARMS survey provides no direct information about the quantity of manure produced, or its value to the farmer.[8] Estimating the quantity and shadow price of manure or manure nutrients with the data available would require making a set of assumptions that would likely introduce substantial error into the analysis. Consequently, an accounting of hog farm output that includes manure is left for future research.

A second limitation of this study is that it did not account for output quality. Hog (pork) quality has changed over time to reflect consumer preferences. For example, hogs have generally become leaner during the period of this study. It is plausible that a typical hog produced in 2004 would command a higher price per pound than a typical hog produced in 1992, if they were both sold in 2004. In other words, hogs produced in 2004 probably better reflect consumer preferences and are therefore "higher quality". Because higher-quality hogs command a higher price, this study underestimates output, and therefore productivity, for operations producing higher-quality livestock. To the extent that contract operations are better able to raise high-quality hogs, the study could have underestimated productivity gains in the Southeast, where contracting is more prevalent. In addition, it is likely that the study underestimated productivity gains over time as quality improved. Because the surveys used in this study did not provide any information about hog quality attributes, efforts to control for product quality are left for future research.

[7] In the Southeast, the demand for manure nutrients is generally lower because there is relatively less land available for spreading manure and there is a denser concentration of animal feeding operations (Kellogg et al.). Environmental regulations limit the allowable nutrient application on land, so many farmers in the Southeast have an incentive to treat manure in lagoons in order to lower the nutrient content of the manure (Aillery et al.; Kaplan, Johansson, and Peters; Ribaudo et al.). In contrast, in the Heartland, the value of manure is greater because there is relatively more land available on which to apply the manure, so fewer farmers use storage facilities designed to lower the nutrient content of the manure.

[8] The ARMS survey provides no direct information about the quantity and price of manure sold. Estimating the shadow price of manure would require detailed information about how much manure is produced and its nutrient content (both of which may have changed substantially over time, with improvements in feed efficiency). It would also require information about how the manure is used—whether it is applied on farm or off farm, the rate at which it is applied, the rate chemical fertilizers are applied along with the manure, the yields on the crops on which manure is applied, and the costs associated with transporting and applying the manure. Most of this information is not available from the ARMS survey.

Conclusions

There have been pronounced 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% between 1992 and 2004. 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 12-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. Likely in part as a result of a state 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 productivity: TFP 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 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 of this study suggest there could be substantial economic costs to policies that limit the size or growth of hog farm enterprises. To the extent that the moratorium on hog farm expansion in North Carolina limited the growth in farm size in the Southeast region, farm productivity was lower than it would have been without the moratorium. Decision-makers will have to weigh these efficiency costs against environmental and other benefits to society from size-restricting policies. The North Carolina moratorium had the objective of temporarily slowing the growth of hog production in the state to allow for studies and legislation to address environmental problems associated with nutrient runoff from lagoons and fields.[9] In addition to providing time for studies and legislation, the moratorium likely had the effect of limiting the growth of hog output and thereby limiting the amount of manure produced in the state. With less manure production there was likely a lower risk of nutrient runoff from lagoons into surface water, a reduction in nitrogen and phosphorus loads in nutrient-sensitive waterways, and reductions in odor and ammonia emissions.[10] Estimating the value of these or other potential benefits is beyond the scope of this study.

The study also found that despite the large increases in the scale of production that have occurred over the past decades, 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. This finding suggests we are likely to observe further increases in the scale of hog production in the coming decade.

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[9] See Section 1.1, Part I of the Clean Water Responsibility and Environmentally Sound Policy Act, referenced in Footnote 4.

[10] Aillery et al. discusses some of the environmental impacts associated with livestock production, and provides some empirical research relating livestock production to environmental outcomes.

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