Livestock in China: Commodity-specific Total Factor Productivity Decomposition Using New Panel Data

Allan N Rae, Hengyun Ma, Jikun Huang and Scott Rozelle

Allan Rae is Director, Center for Applied Economics and Policy Studies, Massey University, New Zealand. Hengyun Ma is Professor, College of Economy and Trade, Henan Agricultural University, Zhengzhou, China and Visiting Research Fellow, Center for Applied Economics and Policy Studies, Massey University, New Zealand. Jikun Huang is Director, Center for Chinese Agricultural Policy, Chinese Academy of Sciences. Scott Rozelle is Professor, Department of Agricultural and Resource Economics, University of California Davis and a member of the Gianinni Foundation.

Email: a.n.rae@massey.ac.nz

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Introduction

China's agricultural output has expanded rapidly since the economic reforms of the late 1970s, reflecting both productivity growth and mobilization of inputs. Among livestock products, output of poultry has increased tenfold, egg output has increased sixfold and that of pork by three times. Over the same period China's rapid economic growth and urbanization have pushed consumption patterns towards increased consumption of high-value foodstuffs including livestock products (Wu, Li and Samual; Ma et al.). These developments have spurred debate over whether or not China will be able to feed itself, and if not what might be the consequences for global markets? China has been a net exporter (in value terms) of pigmeat and poultry, a net importer of beef, and overall a net exporter of fresh and prepared meats. Is this likely to continue? Rutherford has projected continuing Chinese self-sufficiency in meats, and Delgado et al. projected a decline in pork net exports but an increase in the case of poultry by 2020. Both Ehui et al. and Rae and Hertel projected China remaining a net exporter of non-ruminant meat in 2005 while Nin-Pratt et al. projected a trade deficit in non-ruminant meats by 2010.

Given possible policy and resource constraints, achievement of the Chinese government's goal of grain self-sufficiency and continued growth of the livestock sector may have to rely on continuing improvements in agricultural productivity. It follows that the measurement of agricultural productivity will become crucial for estimating the future supply of domestic agricultural commodities and in turn for predictions of the livestock sector's demand for feedgrains and future grain and meat trade balances. However, the estimation of China's past productivity growth as well as the formulation of future projections have also been controversial due in part to considerable doubt over the reliability of the underlying agricultural statistics. Only recently have some researchers made efforts to adjust for discrepancies in existing data series or to access alternative data sources, as do we in this article.

None of the above projections of meats trade for China explicitly incorporate estimates of total factor productivity (TFP) growth in livestock production. Some, instead, used partial measures such as output per animal and livestock feed conversion efficiencies. Such partial productivity measures may be misleading indicators of more general productivity growth. While several studies have examined China's aggregate agricultural TFP (see Mead for a summary) to the best of our knowledge the literature does not contain any comprehensive TFP studies of the livestock sector for China. We are aware only of Somwaru, Zhang and Tuan's analysis of hog technical efficiency in selected provinces of China, and the work of Jones and Arnade, and Nin et al. that make separate TFP estimates for the aggregate crops and livestock sectors for several countries including China. Therefore one objective of this article is to produce TFP growth estimates for several sub-sectors of the Chinese livestock industry.

A feature of China's livestock sector is rapid structural change towards larger and more commercial and intensive production systems. As specialization has developed over the last two decades, the share of backyard livestock production has declined and the shares of specialized households and commercial enterprises have increased. For example, according to the China Agricultural Yearbooks, backyard hog production accounted for more than 91 percent of output in 1980, but its share declined to 76 percent in 1999. Meanwhile the share of specialized households and commercial enterprises rose from less than 9 percent in 1980 to 24 percent in 1999.

To the extent that feeding and management practices vary across production structures, we can combine this information with information on structural change patterns when making projections of China's livestock production and feed demands. Therefore we derive separate TFP estimates for several important farm types.

In addition to having precise estimates of TFP growth, from a policy point of view it also is useful to know whether growth in productivity has been due to technical progress (outward shifts of the production frontier) or improved technical efficiency (producers making more efficient use of available technologies). These two TFP components are analytically distinct, can change at different rates, and likely will have quite different policy implications. For example, should policies be designed to encourage innovation, or the diffusion of existing technologies? Our second objective, therefore, is to provide such a decomposition of livestock TFP in China.

In the following sections we first present a brief review of our methodology. Next, we discuss some problems with China's official livestock production and input data and the adjustments we make to the data. TFP growth results and their decomposition are then presented for four livestock sub-sectors—hogs, eggs, milk and beef cattle. We find productivity growth varies across time periods, sectors and farm types; our data revisions also affect substantially a number of key results.

Methodology

Traditional studies of productivity growth in agriculture have tended to compute productivity as a residual after accounting for input growth, and to interpret the growth in productivity as the contribution of technical progress. Such an interpretation implies that improvements in productivity can arise only from technical progress. However this assumption is valid only if firms are technically efficient, thus operating on their production frontiers and realizing the full potential of the technology. The fact is that for various reasons firms do not operate on their frontiers but somewhere below them, and TFP measured in this way can reflect both technological innovation and changes in efficiency. Therefore technical progress may not be the only source of total productivity growth, and it will be possible to increase factor productivity through improving the method of application of the given technology – that is, by improving technical efficiency.

To study production efficiency, the stochastic frontier production function (Aigner, Lovell and Schmidt; Meeusen and van den Broeck) has been the subject of considerable recent research with regard to both extensions and applications (Battese and Coelli 1995). Stochastic production function analysis postulates the existence of technical inefficiency of production of firms involved in producing a particular output, which reflects the fact that many firms do not operate on their frontiers but somewhere below them. Many theoretical and empirical studies on production efficiency/inefficiency have used stochastic frontier production analysis (e.g., Coelli, Rao and Battese; Kumbhakar and Lovell).

As panel data permit a richer specification of technical change and obviously contain more information about a particular firm than does a cross-section of the data, recent development of techniques for measuring productive efficiency over time has focused on the use of panel data (Kumbhakar, Heshmati and Hjalmarsson; Henderson). Panel data also allow the relaxation of some of the strong assumptions that are related to efficiency measurement in the cross-sectional framework (Schmidt and Sickles). In the rest of the article, we adopt a panel data approach to measure and decompose TFP for several key sub-sectors of China's livestock economy.

We also needed to make an important methodological decision regarding whether to use a single- or multi-product function. In making the decision, this primarily was an issue only for our models of backyard livestock production, since specialised households and commercial operations tend to concentrate on a single livestock type. To understand the importance of modelling two or more livestock types simultaneously, we used the Rural China 2000 Survey, a survey that covers six provinces in China (Hebei, Shaanxi, Liaoning, Zhejiang, Sichuan and Hubei) and 1,199 rural households.[1] The survey data includes detailed, household-level beginning, ending and sales information for various livestock types such as hogs, hens, dairy and beef cattle, sheep and goats. Of the 719 households that had at least one farm animal of any kind at the beginning of the year, nearly two-thirds (64%) raised only a single animal type. Another 30% of those 719 livestock-rearing households raised only hogs and chickens, and 51% of these owned only one or two hogs compared with the average of 4.6 hogs for all households owning hogs. Of the 519 households that farmed hogs with or without other animals, 53% raised only hogs. With so few households truly engaged in intensive production of more than one type of animal, we chose to use separate production functions for each livestock type.

As in Kumbhakar, the stochastic frontier production function for panel data can be expressed as:

$$(1) \quad y_{it} = f(x_{it}, t)\exp(v_{it} - u_{it})$$

where y_{it} is the output of the ith firm ($i = 1, 2, \cdots, N$) in period t ($t = 1, 2, \cdots, T$); $f(\cdot)$ is the production technology; x is a vector of J inputs; t is the time trend variable; v_{it} is assumed to be an iid $N(0, \sigma_v^2)$ random variable, independently distributed of the u_{it}; and u_{it} is a non-negative random variable and output-oriented technical inefficiency term. There are several specifications that make the technical inefficiency term u_{it} time-varying, but most of them have not explicitly formulated a model for these technical inefficiency effects in terms of appropriate explanatory variables.[2] Battese and Coelli (1995) proposed a specification for the technical inefficiency effect in the stochastic frontier production function as:

(2) $u_{it} = z_{it}\delta + w_{it}$

where the random variable w_{it} is defined by the truncation of the normal distribution with zero mean and variance σ^2, such that the point of truncation is $-z_{it}\delta$, i.e., $w_{it} \geq -z_{it}\delta$. As a result, u_{it} is obtained by truncation at zero of the normal distribution with mean $z_{it}\delta$ and variance σ^2. The normal assumption that the $u_{it}s$ and $v_{it}s$ are independently distributed for all $i = 1, 2, \cdots, N$ and $t = 1, 2, \cdots, T$ is obviously a simplifying but restrictive condition.

Technical inefficiency, u_{it}, measures the proportion by which actual output, y_{it}, falls short of maximum possible output or frontier output $f(x,t)$. Therefore technical efficiency (TE) can be defined by:

(3) $TE_{it} = y_{it} / f(x_{it}, t) = \exp(-u_{it}) \leq 1$

Time is included as a regressor in the frontier production function and used to capture trends in productivity change – popularly known as exogenous technical change and is measured by the log derivative of the stochastic frontier production function with respect to time (Kumbhakar). That is, technical change (*TC*) is defined as:

(4) $TC_{it} = \dfrac{\partial \ln f(x_{it}, t)}{\partial t}$

Productivity change can be measured by the change in TFP and is defined as:

(5) $\dot{TFP}_{it} = \dot{y}_{it} - \sum_J S_{jit} \dot{x}_{jit}$

where S_{jit} is the cost-share of the *j*th input for the *i*th firm at time *t*. Kumbhakar has shown that the overall productivity change can be decomposed by differentiating equation (1) totally and using the definition of TFP change in equation (5). This results in a decomposition of the TFP change into 4 components: a scale effect, pure technical change, technical efficiency change and the input price allocative effect.

Data

An ongoing problem for the study of livestock productivity in China is obtaining relevant and accurate data. The majority of published studies of Chinese agricultural productivity have used data published in China's Statistical Yearbook (ZGTJNJ). While this source disaggregates gross value of agricultural output into crops, animal husbandry, forestry, fishing and sideline activities, input use is not disaggregated by sector. A major improvement we introduce is to utilise additional data collected at the farm level that will allow the construction of time-series of input use by livestock farm type.[3] A further problem with livestock data from the official statistical yearbooks is the apparent over-reporting of both livestock product output and livestock numbers (Fuller, Hayes and Smith; ERS). This problem also needs to be addressed if the possibility of biased livestock productivity estimates is to be avoided.

We specify four inputs to livestock production - breeding animal inventories, labor, feed and non-livestock capital. We describe below the construction of data series for these livestock production inputs, as well as our approach to overcoming the over-reporting of animal numbers and outputs.[4]

Livestock Commodity Outputs

Concerns over the accuracy of official published livestock data include an increasing discrepancy over time between supply and consumption figures and a lack of consistency between livestock output data and that on feed availability. Ma, Huang and Rozelle have provided adjusted series for livestock production (and consumption) that are internally consistent by recognizing that the published data do contain valid, albeit somewhat distorted information. In order to adjust the published series, new information from several sources is introduced. Specifically, Ma, Huang and Rozelle use the 1997 national census of agriculture (National Agricultural Census Office) as a baseline to provide an accurate estimate of the size of China’s livestock economy in at least one time period. The census is assumed to provide the most accurate measure of the livestock economy since it covers all rural households and non-household agricultural enterprises. The census also collected information on the number of animal slaughterings (by type of livestock) during the 1996 calendar year. A second source of additional information is the official annual survey of rural household income and expenditure (HIES) that is run by the China National Bureau of Statistics. Information collected in that survey includes the number of livestock slaughtered and the quantity of meat produced for swine, poultry, beef cattle, sheep and goats, and egg production. Ma, Huang and Rozelle assume the production data as published in the Statistical Yearbook to be accurate from 1980-1986. Beyond this date, that data are adjusted to both reflect the annual variation as found in the HIES data and to agree with the Census data for 1996. Further details of the adjustment procedure can be found in Ma, Huang and Rozelle. The adjusted series include provincial data on livestock production, animal inventories and slaughterings. Since dairy cattle are not included in that study, we use a similar approach to adjust data on milk output and dairy cattle inventories.

Animals as Capital Inputs

Following Jarvis we recognize the inventory of breeding animals as a major capital input to livestock production. Thus opening inventories of sows, milking cows, laying hens and female yellow cattle are used as capital inputs in the production functions for pork, milk, eggs and beef respectively. Provincial inventory data for sows, milking cows and female yellow cattle are taken from official sources and adjusted for possible over-reporting as described above.

Additional problems exist with poultry inventories. China's yearbooks and other statistical publications contain poultry inventories aggregated over both layers and broilers. No official statistical sources publish separate data for layers. Ma, Huang and Rozelle, however, provide adjusted data on egg production, and the State Development Planning Commission's agricultural commodity cost and return survey provides estimates of egg yields per hundred birds. Thus layer inventories, at both the national and provincial levels, are calculated by dividing output by yield.[5] A simple test shows that the sum across provinces of our provincial layer inventories is close to our estimate of the national layer inventory in each year.[6]

Feed, Labor and Non-livestock Capital Inputs

Provincial data for these production inputs are obtained directly from the Agricultural Commodity Cost and Return Survey.[7] Thought to be the most comprehensive source of information for agricultural production in China, the data have been used in several other studies (e.g., Huang and Rozelle; Tian and Wan; Jin et al.). Within each province a three-stage random sampling procedure is used to select sample counties, villages and finally individual production units. Samples are stratified by income levels at each stage. The cost and return data collected from individual farms (including traditional backyard households, specialized households, state- and collective-owned farms and other larger commercial operations) are aggregated to the provincial and national level datasets that are published by the State Development Planning Commission.

The survey provides detailed cost items for all major animal commodities, including those covered in this article. These data include labor inputs (days), feed consumption (grain equivalent) and fixed asset depreciation on a 'per animal unit' basis. We deflate the depreciation data using a fixed asset price index. We calculate total feed, labor and non-livestock capital inputs by multiplying the input per animal by animal numbers. For the latter, we use our slaughter numbers for hogs and beef cattle, and the opening inventories for milking cows and layers since these are the 'animal units' used in the cost survey.

Livestock Production Structures

China's livestock sector is experiencing a rapid evolution in production structure, with potentially large performance differences across farm types. For example, traditional backyard producers utilize readily available low-cost feedstuffs, while specialized households and commercial enterprises feed more grain and protein meal. The trend from traditional backyard to specialized household and commercial enterprises in livestock production systems therefore implies an increasing demand for grain feed (Fuller, Tuan and Wailes). To estimate productivity growth by farm type, our data must be disaggregated to that level. This is not a problem for the feed, labor and non-livestock capital variables, since they are recorded by production structure in the cost surveys. However, complete data series on livestock output and animal inventories by farm type do not exist.

Our approach to generating output data by farm type is to first construct provincial 'share sheets' that contain time series data on the share of animal inventories (dairy cows and layers) and slaughterings (hogs) by each farm category (backyard, specialized and commercial).[8] Inventories of sows by farm type are then generated by multiplying the aggregate totals (see earlier section) by the relevant farm-type hog slaughter share. We note that this assumes a constant slaughterings-to-inventory share across farm types for hog production, and therefore assumes away a possible cause of productivity differences in this dimension across farm types. However, it proved impossible to gather further data to address this concern.

To disaggregate our adjusted livestock output data by farm type, it is important to take into account yield differences across production structures. From the cost surveys we obtained provincial time-series data on average production levels per animal (eggs per layer, milk per cow and mean slaughter liveweights for hogs). Such information is then combined with the farm-type data on cow and layer inventories and hog slaughterings to produce total output estimates by farm type that were subject to further adjustment so as to be consistent with the aggregate adjusted output data.

Information that allows us to estimate the inventory and slaughter shares by farm type and by province over time comes from a wide variety of sources. These include the 1997 China Agricultural Census, China's Livestock Statistics, a range of published materials (such as annual reports, authority speeches and specific livestock surveys) from various published sources, and provincial statistical websites. The census publications provide an accurate picture of the livestock production structure in 1996 (Somwaru, Zhang and Tuan). However, the census defines just two types of livestock farms - rural households and agricultural enterprises (including state- and collective-owned farms). We interpret the latter as 'commercial' units, but additional information is used to disaggregate the rural households into backyard and specialized units. Agricultural Statistical Yearbooks of China and China's Livestock Husbandry Statistics (Ministry of Agriculture) provide data on livestock production structure during the early 1980s, when backyard production and state farms were prevalent. These sources, plus the Animal Husbandry Yearbooks (Ministry of Agriculture) and provincial statistical websites also provide estimates of livestock shares for various livestock types, provinces and years. When all these data are combined with 1996 values from the census, many missing values still exist. On the assumption that declining backyard production and increasing shares of specialized and commercial operations are gradual processes that evolved over the study period, linear interpolations are made to estimate missing values.[9]

Sample Size

Our panel data are unbalanced since for any livestock and farm type, not all provinces may be present for any year. Selected descriptive statistics that describe our sample sizes are given in table 1. Only for hogs does the data cover both the 1980s and 1990s. Our dataset for backyard egg production include just five years in the 1980s, and the period 1992-96. Even over the latter period, the number of provinces within each year's data are in the range of three to five, and the cost survey stops collecting data for backyard egg production after 1996. While some beef data are available prior to 1989, data on all variables are available only from that date. In contrast to the other livestock types, beef production costs are not available by farm type. Data on milk production covers the 1992-2001 period. The number of provinces for which complete data sets are obtained vary across years, livestock sectors and farm types (table 1).

Empirical Estimation

We define the stochastic frontier production function in translog form:

$$(6)\quad \ln y_{it} = \alpha_0 + \sum{}_j \beta_j \ln x_{jit} + \beta_t t + \frac{1}{2}\sum{}_j \sum{}_k \beta_{jk} \ln x_{jit} \ln x_{kit} + \frac{1}{2}\beta_{tt} t^2 + \sum{}_j \beta_{jt} \ln x_{jit} t - u_{it} + v_{it}$$

where *ln* denotes the natural logarithm, $i = 1, 2, \cdots, N$ indexes the provinces, $t = 1, 2, \cdots, T$ indexes the annual observations over time; y_{it} is total output as defined previously; *j* indicates inputs and *t* is a time trend. The technical inefficiency function u_{it} is defined as:

$$(7)\quad u_{it} = \delta_0 + \delta_1 t + \sum \delta_{2i} D_i$$

where D are provincial dummies.

Since there are serious econometric problems with two-stage formulation estimation (Kumbhakar and Lovell, p.264), our study simultaneously estimates the parameters of the stochastic frontier function (6) and the model for the technical inefficiency effects (7). The likelihood function of the model is presented in the appendix of Battese and Coelli (1993). The likelihood function is expressed in terms of the variance parameters $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma \equiv \sigma_u^2 / \sigma^2$, and γ is an unknown parameter to be estimated. The stochastic frontier function may not be significantly different from the deterministic model if γ is close to 1 (Coelli, Rao and Battese, p.215). On the other hand, if the null hypothesis $\gamma = 0$ is accepted, this would indicate that σ_u^2 is zero and thus the term u_{it} should be removed from the model, leaving a specification with parameters that can be consistently estimated by ordinary least squares. We use the FRONTIER 4.1 computer program developed by Coelli to estimate the stochastic frontier function and technical inefficiency models simultaneously and this program also permits the use of our unbalanced panel data.

To test the appropriateness of our model specification, we conducted various hypothesis tests before the final stochastic frontier function was chosen. The hypothesis tests show that in each case the translog stochastic frontier production function was an appropriate functional form and that livestock production demonstrates significant technological change and factor input biases (Appendix 1).

Results

Due to the unbalanced nature of our panel data, some explanation is required as to the procedures used in constructing tables of results. First, while average productivity growth rates are presented for all livestock types over the 1990s, those over the 1980s could be computed only for hog production. Second, provincial growth rates are averaged to the regional level using output shares as weights. Third, results for any individual province are included in such growth rate calculations provided that at least six observations are available for that province within the relevant time period. Finally, overall average productivity results are obtained by averaging the regional results again using output shares as weights. To encourage appropriate caution in interpreting the latter as national averages, we also indicate the share of national output that is accounted for by such provincial selections.

In the TFP decompositions we do not present the scale effects as they are minor compared with the technical change and efficiency components, and we do not calculate the allocative inefficiency components due to incomplete price data. To save space, we do not report the stochastic frontier production parameter estimates.[10]

Pork Production

Pork production in China increased rapidly during the past 20 years, due to increases in both input levels and TFP (table 2). The rate of increase in both outputs and inputs was smaller over the 1990s compared with the earlier decade for backyard and specialised farms, but increased in the case of commercial farms. For all categories of hog farms, mean TFP growth was slower over the 1990s than over the previous decade. The same can be said for mean TC and TE growth on backyard and commercial farms. TE growth was on average negative on specialist farms over both decades, and was more negative in the 1990s. Improvements in technical efficiency make a relatively small contribution to overall productivity change on each farm type, especially in specialist and commercial production. Hence by 1998-2001, the mean level of technical efficiency was 54% for specialist hog farms and 58% for commercial units compared with 89% for backyard farms.[11] Backyard production of hogs still predominates in China (its share was 66*%* in 1998-2001). Annual growth in TFP declined from 4.8% in the 1980s to 3.7% in the 1990s. Over the latter decade, TE growth averaged 1.0% annually compared with 2.7% annual growth in TC.

The changes in hog farming output and TFP also vary by farm type and region. For backyard farms, TFP and TC growth were also more rapid over the earlier decade on average within each of the regions. Over both decades, the West region showed fastest growth in TC and TFP. The sharpest between-decade declines in both TC and TFP growth occurred in the South and Southwest. Growth in TE was fastest over both decades in the West, North and Central regions, but only in the North was TE growth noticeably faster over the latter decade. In all regions, technical change is the major contributor to TFP growth. On specialist hog farms, growth in both TFP and TC was slower in the 1990s than previously in all regions except for the South. In contrast to backyard operations, TE growth on specialist farms was zero or negative in all regions over both decades. During the 1990s, TFP growth was slower on backyard hog farms than on specialist hog farms in each region, and the West region showed the most rapid growth in TFP for all types of hog farms. The lack of observations for commercial hog farms in the 1980s hinders comparisons across decades, but productivity growth for the North and South regions slowed down over the 1990s.

Egg Production

Egg production on both specialised and commercial farms increased by over 9% per year during the 1990s; the growth in input use was around 50% that rate (table 3). Growth in TC averaged close to 3.5% on both farm types. However, growth in TE was more rapid on commercial farms, resulting in a somewhat higher rate of TFP growth (4.8%) compared with 3.5% for specialist egg production. By 1998-2001, technical efficiency had reached 98% for commercial farms, and 91% for specialist production. Some departures from these average results are revealed by the regional disaggregation. On specialist farms in the Southwest, annual growth in TE was particularly rapid, but farms in this region were still producing well below the frontier as the average level of technical efficiency reached only 45% by 1998-2001. Technical change, however, was almost stagnant on specialist farms in this region. Commercial egg farms in the North region showed poor productivity performance over the 1990s. Growth in both TE and TC averaged less than 1% annually, well below that of commercial farms in the other regions. Growth in TC for these farms was also well below that achieved by specialised egg producers in the same region.

Milk Production

Annual growth in milk production over the 1990s on specialised and commercial farms was around 9% and 5% per year, but was dominated by growth in input use rather than TFP growth (table 4). Compared with other livestock production, that of milk showed the highest growth rates of TC but the lowest growth in TFP. Annual growth in TC averaged around 6.5% and 4.5% on specialised and commercial farms. TC growth was particularly rapid in the South and Southwest, and slowest in the West. However within many provinces, productivity improvements have not kept up with these technical advances, and averaged results for each region revealed declining growth in technical efficiency in all cases. Average levels of technical efficiency by 1998-2001 were 68% and 78% on specialised and commercial farms respectively. Hence on average there appeared to be very little improvement in TFP on specialised milk production farms during the 1990s, and only a 1.3% annual growth in TFP in commercial production. However due to rapid TC growth on commercial farms, and a relatively slow decline in technical efficiency, TFP growth averaged in excess of 6% on these farms in the South and Southwest.

Beef Production

As in the case of milk production, growth in beef output over the 1990s (almost 10% annually) was due primarily to increased input use (table 5). Our averaged results indicate annual growth in beef TFP of 2.2% over the 1990s, made up from a 3.9% annual growth in TC but a decline of 1.7% per year in TE. Technical change appears to have been particularly rapid in the West, but less than 1% per year in the Central region. As we found with milk production, average regional results indicate that production has been increasingly falling below potential in each region. By 1998-2001, average technical efficiency was 82%, but only 36% and 43% in the South and West respectively. Despite TFP growth in excess of 4% annually in the North, Southwest and West, the poor productivity performance in the Central region (the two provinces of which accounted for 29% of national production in 1998-2001) dragged down the overall average growth in beef TFP.

In summary, positive technical progress occurred over the 1990s for all livestock sectors studied. Such progress was on average slowest on backyard hog farms at just under 3% per year, and ranged up to over 6% per year on specialist hog and milk farms. In comparison, growth in technical efficiency has been slow or negative. Based on the mean results, production has been falling further behind the advancing production frontier especially in milk production, but also on beef farms and all but backyard hog farms. Consequently, average growth in TFP was fastest in hog and egg production, at between 3% and 5% per year, and slowest in milk production. Growth in TFP was poor in the Central region for both beef and milk production and in the case of milk we estimated a large performance difference between the North and Central regions (low or negative growth in TFP) and the higher-performing South and Southwest regions. Differences in productivity growth across regions were less obvious in hog and egg production.

Comparison with TFP Growth Estimated Using Official Data

Having made considerable efforts to adjust the official data on livestock production and animal numbers, to what extent is this reflected in our results? Ma, Huang and Rozelle have already shown significant differences between their production data series and the official production statistics, so here we restrict attention to the differences in TFP and its decomposition. We recalculated all our data series using the official series on output, animal inventories and slaughterings in place of our adjusted data. Note that this also changed our feed, labor and non-livestock capital input series since these were computed as the products of inputs per animal and total animal numbers or slaughterings.

The period since 1990 is of particular interest, since our adjustments to official data were made from the late 1980s onwards. Over-reporting of output and animal numbers in the official statistics could result in over-reporting of output growth and/or input growth. Thus TFP growth could be biased in either direction. We found that output growth over the 1990s was overestimated for all products based on official data, and that use of the latter data provided overestimates of input growth for hogs and eggs but underestimates for beef. TFP growth rates over the 1990s were biased upwards for all farm types producing eggs, milk and beef, but were biased downwards in the case of hogs, when official data were used. For example, the mean TFP annual growth rates for hogs, based on official data, were 10%, 41% and 103% below those based on our adjusted data for backyard, specialised and commercial farms respectively. For eggs the overestimations were 49% and 83% for specialised and commercial farms, respectively.

Discussion and Conclusions

In this article we described our efforts to incorporate recently-revised data with other data that have been little-used in studies of China’s agricultural productivity. The resulting panel data are viewed as an improvement on previously-existing data series. The core of the article uses the data within the stochastic production frontier framework to measure and decompose productivity growth in China’s major livestock sectors.

When comparing the results of our TFP analysis across commodities, farm types and regions, there are some regularities that demonstrate the nature of China's livestock economy. Results for hog production revealed a slowing down of TFP growth over the 1990s compared with the earlier decade. This is a similar trend to that found in several other studies (including those summarized in Mead) of a slowing down in *aggregate agricultural* TFP growth since the immediate post-reform period of the late-1970s to the mid-1980s. Despite the slowing of growth in hog sector productivity, it should be noted that for all livestock sectors mean growth in TFP was still positive. Despite differences in the rate of growth of the source of TFP (that is, either TC or TE) for the various commodities in our study, the rate of TFP growth is fairly healthy for all of the major livestock activities, except for milk. Over the 1990s we found that average growth in TFP was fastest in hog and egg production, at between 3% and 5% per year. TFP growth in the beef sector was estimated at around 2% per year. It was slowest in the milk production (less than 1% on specialised household farms). Thus the growth rates of TFP for hogs, beef and eggs are all greater than 2 percent and about 4 percent on average. The differences among these major commodities vary little. Only in the case milk, is TFP growth low (in fact, it is negative in some regions). It also should be noted that in many respects these rates of TFP growth are not considered too poor. At a weighted average of around 3-4%, livestock TFP growth is far above the rate of population growth. Moreover, internationally, a 4% rate of TFP growth is not low.[12]

The low TFP of milk almost certainly is due to the fact that milk production, while still relatively small, has been expanding rapidly in recent years. Certainly in such an environment where there is the emergence of new production bases (and the use of inputs may be rising fast), a lot of experimentation in the search by producers for new technologies (so there may be mistakes being made) and some slow-adopters of new technologies, wide regional discrepancies among TFP, TC and TE growth rates and slow overall TFP growth should not be too surprising.

Decomposition of TFP growth into its technical efficiency and technical progress components revealed differences among livestock types. One of our major findings is that technical progress occurred over the 1990s for all livestock sectors. Annual growth rates varied from under 3% on backyard hog farms to over 6% per year on specialist hog and milk farms. Although this rate of growth is far above the growth of China's population, it is considerably less than the demand growth for livestock products. Overall livestock demand in China in the coming decade will rise by around 5% annually (Huang, Rozelle and Rosegrant). While the rate of technical change is high, there appears to be room for growth. Of China's total investment into research in the agricultural sector in 1999, only 9% is directed to livestock (Huang et al.), a rate far below its sectoral share of output value for the same year (nearly 30% - ZGNYNJ, 2000). Hence, if leaders want the technology to continue to drive increases in output that can help meet the rising demand of the sector, they should expand research investment into livestock. There is also room to reduce technical barriers to importing technology (CCICED).

There appears to be even more room for improving the livestock sector's performance by improving the efficiency of producers. One of the most regular findings of the empirical work is that growth in technical efficiency, or the rate of 'catching-up' to best practice, has in comparison been relatively slow or even negative. Mean technical efficiency levels by 1998-2001 were around 90% for egg production and backyard hog production. Over the same time period, production of milk was less than 80% of potential output given input levels, and was just over 80% in the case of beef. Mean technical efficiency was lowest in specialist and commercial hog production, at between 54% and 58%. Therefore attention to the use of best practice techniques for given technologies, and diffusion of existing technology, would appear to be high priorities in Chinese livestock management. Although further research is needed to pinpoint the source of efficiency decline, almost certainly a big part of the fall is due to the deterioration of the extension system (CCICED; Nyberg and Rozelle). There is a great need to radically reform the system and invest large sums of money into its revival. But, the low levels of efficiency of traditional sectors may be due to other, more structural factors. It is probably inevitable that as farm households increasingly focus their attention on the off-farm sector they will pay less attention and have less time to carefully manage their small-scale livestock operations. Instead of trying to revive the traditional sector that will eventually disappear, as it has in all modern societies (Chen), it may be better to develop a set of policies that will allow specialized households and large commercial units to operate more efficiently. Policies, such as measures to create an extension system that focuses on large operators and legal changes that will allow specialized households to organize into cooperatives and farmer associations, can advance the sector and could lead to gains of efficiency in the coming years.

Although modest, there are systematic differences among farm types for the major commodities (ignoring milk due to the recent nature of its expansion). In particular, in the case of backyard hogs, household-based egg production and beef production (which is produced mostly by backyard/household-level producers), the levels of TFP increase are relatively low (around 2 percent). In contrast, the TFP growth of commercial hog producers and commercial egg producers is higher - more than 4 percent. Clearly, the productivity of those enterprises with access to more financial resources and information is expanding relatively fast. The one exception is hog production by specialized households where the rise of TFP rivals that of commercial operations. This exception is almost certainly due to several breakthroughs in small-scale hog production that have been pushed by public extension agents and private salesmen/technicians associated with the hog feed industry.

Another observation from our analysis is the relative homogeneity of TFP growth rates for hog production across regions of the country. While not being able to identify the exact reason for such a finding, it could be that the rise of nationwide firms supplying feed and other inputs may be making similar technologies available for most producers. In such competitive markets as those that characterize China's agricultural economy (Chen), producers in all regions are being forced to search for the best available technology and their actions are resulting in similar rates of growth of TFP across China.

Because of the paucity of previous studies of livestock productivity in China, comparisons with other findings are limited. However, when we compare our results with the other studies that do exist (and if we compare estimates with those using similar methods but with unadjusted data), our results show the importance of working with data only after care has been taken to ensure their quality. For example, Mead’s results for the aggregate of grains, other crops and livestock imply average annual TFP growth rates of 1.9% during 1989-96, and 0.2% during 1996-99. Both Nin et al. and Jones and Arnade used FAO data (which draws on official national sources) to compute both crop and aggregate livestock TFP for many countries. In each study, China’s TFP growth over the 1990s was estimated as more rapid in the livestock than the crops sector. For livestock, Jones and Arnade calculated TFP growth at 10.8% during 1991-99, while Nin et al.’s graphed results imply annual growth in livestock TFP of around 8.5% over the 1989-94 period. We have shown in the results section of the paper that both of these growth rates for the aggregate livestock sector are well above our own estimates and quite possibly these are over-estimates that have been caused by the use of official, unadjusted data. If the use of official data does lead to systematically incorrect results, sectoral officials who certainly need accurate information on the state of their sector should begin to take steps to overhaul the system that collects livestock data.

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Table 1. Sample Sizes

	Time periods covered	Minimum no. of provinces per year	Maximum no. of provinces per year	Total sample size
Hogs				
Backyard households	1980-2001	15	27	491
Specialised Households	1980-2001	3	25	285
Commercial	1980-2001	2	25	224
Layers				
Specialised Households	1991-2001	10	22	160
Commercial	1991-2001	8	16	132
Beef				
Rural Households	1989-2001	4	10	88
Milk				
Specialised Households	1992-2001	5	16	91
Commercial	1992-2001	10	23	155

Table 2. Annual Growth (%) of Hog Total Factor Productivity (TFP) and Decomposition into Technical Efficiency (TE) and Technical Change (TC)

Region [a]	Backyard Production				Specialized Households				Commercial Operations			
	Output	TFP	TE	TC	Output	TFP	TE	TC	Output	TFP	TE	TC
In the 1990s:												
North	0.80	4.52	1.97	2.55	10.14	5.35	-0.96	6.31	12.30	4.08	-0.67	4.75
Central	-0.34	4.55	1.60	2.95	4.90	5.80	-0.67	6.47	2.34	4.73	-0.01	4.74
South	0.46	3.12	0.52	2.60	9.79	5.46	-0.57	6.03	12.72	4.16	-0.60	4.75
Southwest	1.28	3.44	0.82	2.62	8.21	4.57	-0.78	5.36	20.32	4.46	-0.43	4.89
West	3.04	5.28	1.84	3.44	-1.11	5.99	-1.22	7.21	22.95	6.81	2.19	4.62
Mean	0.70	3.72	1.01	2.72	8.30	5.35	-0.72	6.07	11.97	4.40	-0.38	4.78
In the 1980s:												
North	1.54	4.75	1.71	3.04	20.48	7.83	-0.10	7.94	-5.82	6.31	0.68	5.63
Central	7.99	5.26	1.86	3.41	27.74	6.41	-1.10	7.51	n.a.	n.a.	n.a.	n.a.
South	7.39	4.63	1.08	3.54	7.69	3.24	0.00	3.24	7.88	4.94	-0.58	5.52
Southwest	7.18	4.47	0.76	3.71	21.41	7.35	0.00	7.35	n.a.	n.a.	n.a.	n.a.
West	6.69	5.90	2.03	3.87	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Mean	7.02	4.80	1.26	3.54	15.98	5.58	-0.14	5.72	0.63	5.67	0.09	5.58

[a] North: Beijing, Tianjin, Shanxi, Mongolia, Liaoning, Jilin, and Heilongjiang; Central: Hebei, Shandong, Henan, and Hubei; South: Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Hunan and Guangdong; Southwest: Guangxi, Sichuan, Guizhou, and Yunnan; West: Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.

In total, these provinces accounted for 95%, 95% and 81% of backyard, specialized household and commercial output in 1999-2001.

n.a. = data unavailable.

In Tables 2-5, input growth can be calculated as output growth – TFP growth.

Table 3. Annual Growth (%) in Egg Total Factor Productivity (TFP) and Decomposition into Technical Efficiency (TE) and Technical Change (TC)

Region [a]	Specialized Households				Commercial Operations			
	Output	TFP	TE	TC	Output	TFP	TE	TC
1990s:								
North	11.29	3.20	-0.03	3.66	12.47	1.56	0.77	0.80
Central	9.01	4.51	1.05	3.72	10.47	6.79	1.96	4.88
South	2.68	2.19	-0.87	2.79	4.11	4.38	1.07	3.32
Southwest	0.85	5.62	5.28	0.42	n.a.	n.a.	n.a.	n.a.
West	11.63	2.69	0.22	2.93	0.82	5.76	2.44	3.21
Mean	9.15	3.51	0.32	3.46	9.47	4.80	1.44	3.39

[a] For specialized households: North: Beijing, Shanxi, Mongolia, Liaoning, Jilin and Heilongjiang; Central: Hebei, Shandong and Henan; South: Shanghai, Anhui, Jiangxi, Hunan, Fujian, Guangdong and Hainan; Southwest: Yunnan; West: Shaanxi, Qinghai and Ningxia.

For commercial operations: North: Tianjin, Mongolia, Liaoning, Jilin and Heilongjiang; Central: Hebei and Hubei; South: Zhejiang, Anhui, Jiangxi, Hunan, Fujian, Guangdong and Hainan; West: Shaanxi and Ningxia.

In total, these provinces accounted for 87% and 75% of specialized households and commercial operations output in 1999-2001.
n.a. = data unavailable.

Table 4. Annual Growth (%) in Milk Total Factor Productivity (TFP) and Decomposition into Technical Efficiency (TE) and Technical Change (TC)

Region [a]	Specialized Households				Commercial Operations			
	Output	TFP	TE	TC	Output	TFP	TE	TC
1990s:								
North	4.75	2.87	-5.25	8.13	2.84	-0.60	-5.60	5.01
Central	14.82	0.02	-7.31	7.33	12.18	-0.87	-6.99	6.12
South	-4.55	8.93	-7.99	16.92	-1.99	6.37	-0.58	6.96
Southwest	n.a.	n.a.	n.a.	n.a.	-2.73	9.05	-8.83	17.88
West	11.48	-2.50	-6.45	3.95	10.47	1.15	-0.35	1.50
Mean	8.81	0.48	-6.09	6.58	5.25	1.31	-3.26	4.57

[a] For specialized households: North: Tianjin, Mongolia, Liaoning, Jilin and Heilongjiang; Central: Hebei, Shandong and Henan; South: Anhui and Fujian; West: Shaanxi and Xinjiang.

For commercial operations: North: Beijing, Tianjin, Mongolia, Liaoning and Jilin; Central: Hebei, Shandong, Henan and Hubei; South: Shanghai, Jiangsu, Anhui, Fujian, Hunan, Guangdong; Southwest: Guangxi and Chongqing; West: Shaanxi, Gansu and Xinjiang.

In total, these provinces accounted for 59% and 57% of specialized household and commercial farm output in 1999-2001.
n.a. = data unavailable.

Table 5. Annual Growth (%) of Beef Total Factor Productivity and Decomposition into Technical Efficiency (TE) and Technical Change (TC)

Region [a]	Output	TFP	TE	TC
1990s:				
North	9.19	4.65	-1.56	6.21
Central	9.77	-0.93	-1.72	0.80
South	n.a.	n.a.	n.a.	n.a.
Southwest	12.00	4.07	-2.99	7.06
West	11.10	8.92	-1.40	10.32
Mean	9.73	2.21	-1.70	3.90

[a] North: Shanxi, Mongolia, Liaoning, Jilin and Heilongjiang; Central: Shandong and Henan; Southwest: Guizhou and Yunnan; West: Shaanxi and Ningxia.
In total, these provinces accounted for 59% of national beef production in 1999-2001.
n.a. = data unavailable.

Appendix 1. Maximum Likelihood Ratio Tests for Stochastic Frontier Production Function Using Adjusted Datasets

Restricted Function	Likelihood Function		# of Restrictions	χ^2 Statistics
	Restricted	Unrestricted		
Hog Production:				
Backyard:				
1. C-D function	281.2	395.0	15	227.7***
2. No factor bias	370.5	395.0	4	49.0***
3. No technical change	369.6	395.0	6	50.7***
Specialised Household:				
1. C-D function	131.9	190.6	15	117.4***
2. No factor bias	152.3	190.6	4	76.6***
3. No technical change	101.0	190.6	6	179.3***
Commercial:				
1. C-D function	92.7	140.5	15	95.6***
2. No factor bias	109.1	140.5	4	62.8***
3. No technical change	117.0	140.5	6	46.9***
Eggs Production:				
Specialised Household:				
1. C-D function	205.4	232.9	15	55.0***
2. No factor bias	222.0	232.9	4	21.8***
3. No technical change	205.8	232.9	6	54.2***
Commercial:				
1. C-D function	151.0	186.9	15	71.7***
2. No factor bias	180.3	186.9	4	13.1**
3. No technical change	163.2	186.9	6	47.2***
Milk Production:				
Specialised Household:				
1. C-D function	105.2	160.9	15	111.4***
2. No factor bias	116.7	160.9	4	88.3***
3. No technical change	96.3	160.9	6	129.3***
Commercial:				
1. C-D function	109.3	174.3	15	130.0***
2. No factor bias	149.0	174.3	4	50.6***
3. No technical change	122.4	174.3	6	103.8***
Beef Production:				
1. C-D function	19.2	78.5	15	118.5***
2. No factor bias	69.7	78.5	4	17.7***
3. No technical change	47.2	78.5	6	62.7***

Note: The unrestricted function is translog stochastic frontier production function; Critical values at 1% significant level are 30.6, 16.8 and 13.3 for the hypotheses of C-D function, no technical change and no factor biases; *** and ** stand for 1% and 5% significant levels.

Footnotes

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[1] Conducted in November and December 2000 by a team comprising the Centre for Chinese Agricultural Policy of the Chinese Academy of Sciences, the Department of Agricultural and Resource Economics of the University of California, Davis, and the Department of Economics of the University of Toronto.

[2] See Kumbhakar and Lovell (chapter 7), and Cuesta for a review of recent approaches to the incorporation of exogenous influences on technical inefficiency.

[3] Carter, Chen and Chu, in studying aggregate agricultural TFP growth in Jiangsu province, compared results based on provincial aggregate data with sectorally-disaggregated household data. They found that use of the former provided implausibly high TFP growth over the 1988-96 period.

[4] Our complete adjusted data set can be downloaded from the website http://econ.massey.ac.nz/caps.

[5] The cost and return survey did not contain egg yields for every province for each of the years in our sample. Provincial trend regressions were used to estimate yields in such cases.

[6] Data on inventories of breeding broilers are available only from 1998, and we could not discover any way of deriving earlier data from the available poultry statistics. This severely limited our ability to analyse productivity developments in this sector.

[7] This survey is conducted through a joint effort of the State Development Planning Commission, the State Economic and Trade Commission, the Ministry of Agriculture, the State Forestry Administration, the State Light Industry Administration, the State Tobacco Administration and the State Supply and Marketing Incorporation.

[8] We did not disaggregate beef data by farm type, since the cost survey presented beef information for just a single category – rural households.

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[9] The share sheets may be downloaded from. the website http://econ.massey.ac.nz/caps.

[10] They are available upon request to the authors.

[11] The complete set of estimated technical efficiency levels are not presented here, but may be obtained from the authors.

[12] For example livestock and crop TFP growth, averaged over the 51 countries in Nin et al's study, were 0.5% and 0.6% respectively during 1965-94, while Nin, Arndt and Preckel estimate mean agricultural TFP growth of around 1% for their sample of 20 developing countries during 1961-1994.