Livestock In China: Commodity-specific total factor productivity decomposition using new panel data

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Foreword

Studies of total factor productivity in livestock production are rare, but when available provide useful information especially in the context of developing countries such as China where livestock is becoming more important in the domestic agricultural economy. We estimate total factor productivity (TFP) for four major livestock products in China employing the stochastic frontier approach, and decompose productivity growth into its technical efficiency and technical progress components. Efforts are made to adjust and augment the available livestock statistics. The results show that growth in TFP and its components varied between the 1980s and the 1990s as well as over production structures. While there is evidence of considerable technical innovation in China's livestock sector, technical efficiency improvement has been relatively slow.

This research arises from a broader study programme on China's livestock economy that has developed since the appointment of Dr Ma as a Visiting Research Fellow in the Centre, in 2002. Financial support from the Foundation for Research, Science and Technology grant IERX0301, Venture Trust, the National Natural Science Foundation of China (70021001), the Chinese Academy of Science (SW-419), the University of California-Davis and the Giannini Foundation is gratefully acknowledged.

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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 1995; Ma et al. 2004). 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 (1999) has projected continuing Chinese self-sufficiency in meats, and Delgado et al. (1999) projected a decline in pork net exports but an increase in the case of poultry by 2020. Both Ehui et al. (2000) and Rae and Hertel (2000) projected China remaining a net exporter of non-ruminant meat in 2005 while Nin-Pratt et al. (2004) 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 (2003) 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 (2003) analysis of hog technical efficiency in selected provinces of China, and the work of Jones and Arnade (2003) and Nin et al. (2003) 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, this information can be combined with information on structural change patterns when making projections of China's livestock production and feed demands. Therefore another objective is to 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 third 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

A number of methods can be used to make productivity measurements. Traditionally, many studies of productivity growth in agriculture have used index numbers such as the Tornqvist or Fisher to compute productivity as a residual after accounting for input growth. Such approaches interpret the growth in productivity as the contribution of technical progress since these methods assume all firms are technically efficient and therefore operating on their production frontiers and realizing the full potential of the technology. Such methods are inappropriate given our objective of decomposing TFP growth into technical change and efficiency components.[1] The fact is that for various reasons many firms do not operate on their frontiers but somewhere below them, so technical progress may not be the only source of total productivity growth: it may be possible to increase factor productivity through improving the method of application of the given technology – that is, by improving technical efficiency.

Two alternative approaches are commonly used to measure technical change and efficiency effects – nonparametric data envelopment analysis and the stochastic production frontier approach, and neither requires price data. While the former method does not require functional form or distributional assumptions it does, by assuming no sampling error, consider all deviations from the frontier as due to inefficiency. For this reason, and also because it allows us to test hypotheses about the structure of the production technology and the existence of inefficiency, we chose the stochastic frontier approach.

[1] The lack of a complete set of price data also ruled out some index number approaches.

The stochastic frontier production function (Aigner, Lovell, and Schmidt 1977; Meeusen and van den Broeck 1977) has been the subject of considerable recent production efficiency 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 1998; Kumbhakar and Lovell 2000).

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 1999; Henderson 2003). 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 1984). 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.[2] 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.

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

[2] 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.

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 (USDA 1998; Fuller, Hayes and Smith 2000). 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, labour, 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 (2004) 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 (2004) use the 1997 national census of agriculture (National Agricultural Census Office 1999) 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 (2004) assume the production data as published in the Statistical Yearbook to be accurate from 1980-1986. Beyond this date, these 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 (2004). 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 (1974) 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

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[3] Carter, Chen and Chu (2003), 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 obtained on request from the authors.

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 (2004), 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, Labour 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 1996; Tian and Wan 2000; Jin et al. 2002). 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 labour 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, labour 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

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[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.

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 2002). To estimate productivity growth by farm type, our data must be disaggregated to that level. This is not a problem for the feed, labour 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 2003). 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 household production and increasing shares of specialized

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

household 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. Therefore we conduct our analyses for only the specialised household and commercial egg farms for which we have data for 1991-2001. 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) and for any sector and farm type a given province may enter and exit the panel more than once over the time period.

[9] The share sheets may be obtained on request from the authors.

Empirical Estimation

We define the stochastic frontier production function (Kumbhakar 2000) in translog form:

$$\text{(1)}\quad \ln y_{it} = \alpha_0 + \sum{}_j \beta_j \ln x_{jit} + \beta_t T + \frac{1}{2}\sum{}_j \sum{}_k \beta_{jk} \ln x_{jit} \ln x_{kit}$$

$$+\frac{1}{2}\beta_{tt}T^2 + \sum{}_j \beta_{jt} \ln x_{jit} T - u_{it} + v_{it}$$

where ln denotes the natural logarithm, *i* indexes the provinces, *t* indexes the annual observations over time; y_{it} is total provincial output; the x_js are the inputs, *T* is a time trend to capture trends in productivity change, 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 iid $N^+(m_{it}, \sigma^2_u)$, $m_{it} = z_{it}\delta$ where z_{it} is a vector of explanatory variables. Note that the non-negative inefficiency term u_{it} is obtained by truncation at zero of the normal distribution with mean $z_{it}\delta$ and variance σ^2_u (Battese and Coelli 1995).

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.[10] We define the technical inefficiency function u_{it} as:

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

where D are provincial dummies.

Since there are serious econometric problems with two-stage formulation estimation (Kumbhakar and Lovell 2000, p.264), our study simultaneously estimates the parameters of the stochastic frontier function (1) and the model for the technical inefficiency effects (2). 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 1998, 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 (1996) to estimate the stochastic frontier function and technical inefficiency models simultaneously and this program also permits the use of our unbalanced panel data.

As with any production function estimation, input endogeneity may be an important issue. Another issue that may be relevant to our application is the omission of environmental variables from the production function. Both issues can be considered here, as we believe them to be related in our case. We believe an important reason for considering input endogeneity is that climatic conditions may not only affect output

[10] See Kumbhakar and Lovell (2000, chapter 7) and Cuesta (2000) for a review of recent approaches to the incorporation of exogenous influences on technical inefficiency.

but also may be correlated with input use. In this situation estimated coefficients would be biased unless an appropriate method is used to control for the input endogeneity. While this is a valid concern, our application concerns livestock activities in China. In rural China most households raise hogs, poultry, dairy and beef cattle in penned environments, which in most cases are within or near the proximity of the farmer's home. Hence climate plays a less important role relative to that in crop production, and endogeneity would be less of a problem. For the same reason, we do not think the omission of environmental variables will seriously bias (downwards) our estimates of technical efficiency as they might in an application to crop production (Sherlund, Barrett and Adesina 2002) but we caution the reader to this possibility.

Technical inefficiency (TE) measures the proportion by which actual output falls short of maximum possible output or frontier output. This, along with technical change (TC) is measured as in Kumbhakar (2000) allowing decomposition of TFP into the pure technical change and technical efficiency change components. [11]

Results

To test the appropriateness of our model specification, we first conducted various hypothesis tests before the final stochastic frontier function was chosen. The hypothesis tests show that in each commodity-farm type case the translog stochastic frontier production function was an appropriate functional form when compared with the Cobb-Douglas. We also tested restricted forms of the translog model that assumed either no factor bias or no technical change. Again these hypotheses were rejected in each case (see results in Appendix 1). The null hypothesis of no technical inefficiency effects (γ=0) was also rejected in each case.

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 were excluded from such regional growth rate calculations where we had few observations 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.

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 household farms, but increased in the case of commercial farms. For all

[11] Due to the lack of complete price data, we could not compute the allocative efficiency effect, and we do not think it meaningful to compute the scale effect from our provincial level data. To save space, we do not report the stochastic frontier production parameter estimates but they are available upon request to the authors.

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 household and commercial production. By 1998-2001, the mean level of technical efficiency[12] was 88% for specialist household hog farms and 79% for commercial units, compared with 91% for backyard farms which farm type still predominates in China (its share was 66% in 1998-2001). Annual average growth in TFP on backyard farms 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 household 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 household 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 household and commercial farms increased by over 9% per year during the 1990s; the growth in input use was around half 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 3.8% for specialist household egg production. By 1998-2001, mean technical efficiency had reached 97% for commercial farms, and 93% for specialist production. Some departures from these average results are revealed by the regional disaggregation. On specialist household farms in the Southwest, annual growth in TE was particularly rapid, but the mean level of technical efficiency in this region (82%) was still somewhat below the overall mean for specialist household farms. 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.

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

Milk Production

Annual growth in milk production over the 1990s on specialised household and commercial farms was 8.8% and 5.3% 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 6.6% and 4.6% on specialised household 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 negative growth in technical efficiency in all cases. Average levels of technical efficiency by 1998-2001 were 65% and 57% 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

Growth in beef output over the 1990s (almost 9% annually) was due to equal contributions from growth in productivity and input use (table 5). Our averaged results indicate annual growth in beef TFP of 4.4% over the 1990s, made up almost entirely from technical change with almost no growth in TE. Technical change appears to have been particularly rapid in the West whereas results indicate little if any growth in TE across the regions. By 1998-2001, average technical efficiency was 75%. Despite TFP growth in excess of 4.5% annually in the North, Southwest and West, the poorer 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 household farms producing hogs or milk. 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 all but backyard hog farms. Consequently, average growth in TFP was fastest in hog, egg and beef production, at between 3% and 5% per year, and slowest in milk production. Growth in TFP was poor in the Central region for 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 (2004) 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, labour 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 beef but underestimates for eggs (table 6). 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.

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.

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 the slowing down in *aggregate agricultural* TFP growth found in several other studies (including those summarized in Mead 2003) following the immediate post-reform period of the late-1970s to the mid-1980s. Despite the slowing of hog sector productivity growth, it should be noted that mean growth in TFP for all livestock sectors 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, egg and beef production, at between 3% and 5% per year. 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 of milk is TFP growth low, at between 0.5% and 1.3% on average across regions. 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.[13]

The low TFP of milk is almost certainly 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 rapidly-

[13] For example livestock and crop TFP growth, averaged over the 51 countries in Nin et al's (2003) study, were 0.5% and 0.6% respectively during 1965-94, while Nin, Arndt and Preckel (2003) estimate mean agricultural TFP growth of around 1% for their sample of 20 developing countries during 1961-1994.

increasing input use, a lot of experimentation and perhaps mistakes by producers in the search for new technologies 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% on specialist hog and milk farms. Although this rate of growth is far above the growth of China's population, it is less than the demand growth for livestock products which will rise by around 5% annually in the coming decade (Huang, Rozelle and Rosegrant 1999). While the rate of technical change is high, there appears to be room for further growth. Of China's total investment into research in the agricultural sector in 1999, only 9% is directed to livestock (Huang et al. 2000), 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 for the sector's products, they should expand research investment into livestock. There is also room to reduce technical barriers to importing technology (CCICED 2004).

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 our empirical work is that growth in technical efficiency, or the rate of 'catching-up' to best practice, has been relatively slow or even negative in comparison to technical change. Mean technical efficiency levels by 1998-2001 were around 90% or more for egg production and backyard hog production. Over the same time period, production of milk was less than 65% of potential output given input levels, and was around 75% in the case of beef. Thus mean technical efficiency was lowest in ruminant animal production. Attention to the use of best practice techniques for given technologies, and diffusion of existing technology, would appear to be even higher priorities in Chinese livestock management than the encouragement of technical change.

Although further research is needed to pinpoint the source of efficiency decline, a large part of the fall is almost certainly due to the deterioration of the extension system (CCICED 2004; Nyberg and Rozelle 1999). 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, structural factors. It is probably inevitable that as farm households increasingly focus their attention on the off-farm sector they will pay less attention to, 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 2002), 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 and household-based egg production, the levels of TFP increase are relatively low (around 3 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 and structural change away from backyard production will be contributing to increased productivity growth for the sector as a whole. 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 2002), 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, comparisons that are possible suggest the importance of working with data only after care has been taken to ensure their quality. For example, both Nin et al. (2003) and Jones and Arnade (2003) used FAO data (which draws on official national sources) to compute both crop and aggregate livestock TFP for many countries.[14] 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 (2003) calculated TFP growth at 10.8% during 1991-99, while Nin et al.'s (2003) graphed results imply annual growth in livestock TFP of around 8.5% over the 1989-94 period. 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.

Finally, the dataset we have assembled and the results of our analysis should be of value to other research that addresses China's agriculture. For example we raised some research questions in the introductory section that others have begun to address with the aid of partial or general equilibrium models. The representations of China's agricultural sector, and the livestock production sub-sector in particular, in these models could well be enhanced with our data and the analyses they offer. Apart from the need to accurately project China's productivity growth in these sectors, biases in technical change such as towards feed-saving technologies, along with differences in productivity across farm types, could be critical in projecting China's trade in feedgrains and meats.

[14] Nin et al. (2003) and Jones and Arnade (2003) used directional distance functions and Malmquist indices.

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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	97
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

Note: In tables 2-5, input growth can be calculated as output growth – TFP growth.

[a] **1990s**: 1) Backyard: North (Jilin, Shanxi, Mongolia, Heilongjiang and Liaoning), Central (Shandong,Henan and Hubei), South (Zhejiang, Fujian, Guangdong, Jiangsu, Anhui, Jiangxi and Hunan), Southwest (Guizhou, Guangxi, Yunnan and Sichuan), West (Ningxia, Qinghai, Gansu, and Shaanxi); 2) Specialised: North (Tianjin, Jilin, Shanxi, Mongolia, Heilongjiang and Liaoning), Central (Hebei, Shandong,Henan and Hubei), South (Zhejiang, Fujian, Guangdong, Jiangsu, Jiangxi and Hunan), Southwest (Guizhou, Guangxi, Yunnan and Sichuan), West (Ningxia, Qinghai, Gansu, and Xinjiang); 3) Commercial: North (Beijing, Tianjin, Jilin, Shanxi, and Liaoning), Central (Shandong,Henan and Hubei), South (Zhejiang, Fujian, Guangdong, Jiangsu, Anhui, and Jiangxi), Southwest (Guangxi, Yunnan and Sichuan), W (Ningxia, Gansu, and Xinjiang).

1980s: 1) Backyard: North (Tianjin, Jilin, Shanxi, Heilongjiang and Liaoning), Central (Hebei, Shandong,Henan and Hubei), South (Zhejiang, Fujian, Guangdong, Jiangsu, Anhui, Jiangxi and Hunan), Southwest (Guizhou, Guangxi and Sichuan), West (Ningxia, Gansu, and Shaanxi); 2) Specialised: North (Liaoning), Central (Hubei), South (Zhejiang, Anhui, Jiangxi), Southwest (Sichuan); 3) Commercial: North (Beijing, Tianjin), South (Shanghai, Fujian, Jiangsu, Jiangxi).

In total these provinces accounted for 95%, 95% and 81% of backyard, specialized household and commercial farm output respectively in 1999-2001; and 91%, 36% and 15% in 1989-91.

n.a. = data unavailable.

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	3.63	-0.03	3.66	12.47	1.57	0.77	0.80
Central	9.01	4.77	1.05	3.72	10.47	6.84	1.96	4.88
South	2.68	1.92	-0.87	2.79	4.11	4.39	1.07	3.32
Southwest	0.85	5.70	5.28	0.42	n.a.	n.a.	n.a.	n.a.
West	11.63	3.15	0.22	2.93	0.82	5.65	2.44	3.21
Mean	9.15	3.78	0.32	3.46	9.47	4.83	1.44	3.39

[a] Specialized households: North: Shanxi, Mongolia, Liaoning, Jilin and Heilongjiang; Central: Hebei, Shandong, Henan, Hubei; South: Jiangsu, Zhejiang, Anhui and Jiangxi; Southwest: Yunnan; West: Shaanxi, Gansu and Xinjiang.
Commercial: North: Beijing Tianjin, Liaoning and Jilin; Central: Shandong, Henan and Hubei; South: Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hunan and Guangdong; West: Gansu and Xinjiang.
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]Specialized households: North: Tianjin, Mongolia, Liaoning, Jilin and Heilongjiang; Central: Hebei, Shandong and Henan; South: Anhui and Fujian; West: Shaanxi and Xinjiang.
Commercial operations: North: Beijing, Tianjin, Mongolia, Liaoning and Jilin; Central: Hebei, Shandong, Henan and Hubei; South: Shanghai, Jiangsu, Anhui, 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 (TFP) and Decomposition into Technical Efficiency (TE) and Technical Change (TC)

Region [a]	Output	TFP	TE	TC
1990s:				
North	8.53	5.35	0.00	5.35
Central	9.77	3.10	0.00	3.10
South	n.a.	n.a.	n.a.	n.a.
Southwest	5.47	4.58	0.06	4.52
West	7.37	6.54	0.02	6.52
Mean	8.84	4.41	0.01	4.40

[a] North: Shanxi, Mongolia, Liaoning, Jilin and Heilongjiang; Central: Shandong and Henan; Southwest: Guizhou and Yunnan; West: Shaanxi, Ningxia, and Xinjiang.
In total, these provinces accounted for 62% of national beef production in 1999-2001.
n.a.=data unavailable.

Table 6. Mean Annual Growth (%) of Total Factor Productivity (TFP) and Decomposition into Technical Efficiency (TE) and Technical Change (TC) Using the Official Data

Commodity	Backyard Production				Specialized Households				Commercial Operations			
	Output	TFP	TE	TC	Output	TFP	TE	TC	Output	TFP	TE	TC
1990s:												
Pork	3.60	3.36	1.33	2.04	13.14	3.14	-4.45	7.59	13.98	-0.27	-2.83	2.57
Eggs	n.a.	n.a.	n.a.	n.a.	11.39	6.11	0.07	6.04	12.41	9.52	5.89	3.63
Milk	n.a.	n.a.	n.a.	n.a.	16.99	11.33	16.65	-5.32	23.77	6.80	2.21	4.59
Beef [a]	11.70	5.68	-5.40	11.08					n.a.	n.a.	n.a.	n.a.

Note: Means calculated over the same provinces and regions as explained in footnotes to tables 2-5.
[a] Rural households, including rural backyard and specialized households.
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	109.4	165.6	15	112.2***
2. No factor bias	118.7	165.6	4	93.6***
3. No technical change	125.4	165.6	6	80.2***

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% significance levels.