LIVESTOCK IN CHINA: COMMODITY-SPECIFIC TOTAL FACTOR PRODUCTIVITY DECOMPOSITION USING NEW PANEL DATA

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Studies of total factor productivity (TFP) 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 TFP for four major livestock products in China employing the stochastic frontier approach, and decompose productivity growth into its technical efficiency (TE) 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, TE improvement has been relatively slow.

Key words: adjusted data, China, decomposition of TFP, livestock, stochastic production frontier.

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 toward 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 pork 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 nonruminant meat in 2005 while Nin-Pratt et al. (2004) projected a trade deficit in nonruminant 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.

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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 (TE) 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 subsectors of the Chinese livestock industry.

A feature of China's livestock sector is rapid structural change toward 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% of output in 1980, but its share declined to 76% in 1999. Meanwhile the share of specialized households and commercial enterprises rose from less than 9% in 1980 to 24% 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 TE (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 subsectors—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 (TC) and TE 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 TE.

Two alternative approaches are commonly used to measure TC and TE 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 sub-ject 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 TC 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 subsectors of China's livestock economy.

We also needed to make an important methodological decision regarding whether to use a single- or multiproduct function. In making the decision, this primarily was an issue only for our models of backyard livestock production, since specialized households and commercial operations tend to concentrate on a single livestock type. To understand the importance of modeling 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 include 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 Yearbooks (ZGTJNJ 1979–2002). 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 utilize 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 (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, labor, feed, and nonlivestock 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

[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.

[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.

consumption figures, and a lack of consistency between livestock output data and those 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 nonhousehold 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 survey (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 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 (1980–2002) 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 Nonlivestock 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 data sets that are published by the State Development Planning Commission (1980–2002).

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

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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 analyze 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.

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 nonlivestock 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 2002). 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 nonlivestock 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 1980–1985, 1990) 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 1999–2002) 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 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

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

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

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
Specialized households	1980–2001	3	25	285
Commercial	1980–2001	2	25	224
Layers				
Specialized households	1991–2001	10	22	160
Commercial	1991–2001	8	16	132
Beef				
Rural households	1989–2001	4	10	97
Milk				
Specialized households	1992–2001	5	16	91
Commercial	1992–2001	10	23	155

statistics that describe our sample sizes are given in table 1. Only for hogs does the data cover both the 1980s and 1990s. Our data set 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 specialized 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 .

Empirical Estimation

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

$$(1)\quad \ln y_{it} = \alpha_0 + \sum_j \beta_j \ln x_{jit} + \beta_1 T + \frac{1}{2}\sum_j\sum_k \beta_{jk} \ln x_{jit} \ln x_{kit} + \frac{1}{2}\beta_{tt}T^2 + \sum_j \beta_{jt} \ln x_{jit} T - u_{it} + v_{it}$$

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_j's are the inputs, T is a time trend to capture trends in productivity change, v_{it} is assumed to be an identically independently distributed (i.i.d) $N(0, \sigma_v^2)$ random variable, independently distributed of the u_{it}; and u_{it} is i.i.d $N^+(m_{it}, \sigma_u^2)$, $m_{it} = z_{it}\delta$ 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_u^2 (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:

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

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

[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.

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 agricultural production function estimation, input endogeneity may be an important issue. One possible source of bias in resulting estimates is from the omission of environmental variables from the production function. Such issues have been addressed in the literature (e.g., Van Soest 1994). Our concern here is that climatic conditions may not only affect output but also may be correlated with input use. In the case of livestock, this means that climatic factors (e.g., excessive cold or heat) could affect feed intake, metabolic rates, and disease incidence that could influence both input use (e.g., the amount of feed given to animals) and the output (independently of the effect of feed on output). In this situation estimated coefficients would be biased unless an appropriate method is used to control for the input endogeneity. The absence of controls for endogeneity could also affect our measures of TE.

Another source of endogeneity bias may be due to management bias. The problem here is that the management ability of the farmer is unknown to the econometrician. Although management ability may be difficult or impossible to measure, the farmer's ability to manage his/her livestock almost certainly affects both input use and livestock output. In the absence of appropriate data to measure managerial ability, the coefficients on the input variables may be biased.

Unfortunately, in our case we do not have any ready means for making corrections for either of these two sources of endogeneity. Either source may affect the estimates of the production function coefficients and the measures of elasticities and TE, and in particular the absence of environmental variables will bias downward our TE estimates. Because of this we need to warn the reader to evaluate the final findings with caution.[11]

Technical inefficiency measures the proportion by which actual output falls short of maximum possible output or frontier output. This, along with TC is measured as in Kumbhakar (2000) allowing decomposition of TFP into the pure TC and TE change components.[12]

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 TC. Again these hypotheses were rejected in each case (see results in Appendix). The null hypothesis of no technical inefficiency effects ($\gamma = 0$) was also rejected in each case. The complete set of estimates are found in a technical appendix (Rae et al. 2006).

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

[11] While the effect of climate on the nature of our estimated coefficients is valid, in our application—livestock activities in China—the effect may be less severe than when examining livestock activities in nations in which livestock activities are mostly in range or unpenned environments. 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 somewhat less important role relative to other livestock systems. That is not to say the climate-induced endogeneity will not be present (many factors will also affect animals in penned environments). The point we want to make, however, is that we do not think the omission of environmental variables would be as serious as in other applications including cropping (Sherlund, Barrett, and Adesina 2002).

[12] Due to the lack of complete price data, we could not compute the allocative efficiency effect. To save space, we do not report the stochastic frontier production parameter estimates nor the complete sets of TE ratios and output elasticities. These are available as a technical appendix in Rae et al. (2006).

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

	Backyard Production				Specialized Households				Commercial Operations			
Region[a]	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) Specialized: 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), West (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) Specialized: North (Liaoning), Central (Hubei), South (Zhejiang, Anhui, and Jiangxi), Southwest (Sichuan); (3) Commercial: North (Beijing and Tianjin), South (Shanghai, Fujian, Jiangsu, and 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. indicates data unavailable.

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 specialized household 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 TE 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 TE 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, TC is the major contributor to TFP growth. On specialist household

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

	Specialized Households				Commercial Operations			
Region[a]	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, and 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. indicates data unavailable.

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 specialized 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 TE 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 TE in this region (82%) was still somewhat below the overall mean for specialist household farms. TC, 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 specialized egg producers in the same region.

Milk Production

Annual growth in milk production over the 1990s on specialized household and commercial farms was 8.8% and 5.3% per year, respectively, 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 specialized household and commercial farms, respectively. 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 TE in all cases. Average levels of TE by 1998–2001 were 65% and 57% on specialized and commercial farms, respectively. Hence on average there appeared to be very little improvement in TFP on specialized 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 TE, TFP growth averaged in excess of 6% on these farms in the South and Southwest.

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

	Specialized Households				Commercial Operations			
Region[a]	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, and 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. indicates 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. indicates data unavailable.

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 TC with almost no growth in TE. TC 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 TE 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 TE has been slow or negative. Based on the mean results, production has been falling further behind the advancing production frontier especially in milk production, and 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.

For each livestock type, returns to scale are indicated by the sum of the output elasticities with respect to all inputs. We computed these at the sample means of the data and then took average values over the period 1999–2001. The results suggest constant returns to scale in egg production, with coefficients of 0.97 for specialized household systems and 1.00 for commercial production. Decreasing returns to scale are indicated for all other livestock types, and quite sharply decreasing returns in the case of beef production. The elasticity totals range

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

	Backyard Production				Specialized Households				Commercial Operations			
Commodity	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. indicates data unavailable.

between 0.74 and 0.79 for the hog production systems, and between 0.67 and 0.85 for milk production. For beef, this coefficient is substantially lower at 0.48. We should point out that one reason for the estimated output elasticity totals being less than unity is the omission of some inputs from the estimated production function. In our case, some inputs were omitted due to their very small share of total costs, but in the case of ruminants a more substantive input omission was fodder consumption, due to data unavailability. The fodder cost-share for the 1999–2001 period was between 15% and 20% in the case of milk, and just under 15% for beef. In contrast, it was 2–4% in hog production and close to zero for eggs.

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, labor, and nonlivestock 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 onward. Overreporting of output and animal numbers in the official statistics could result in overreporting 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 upward for all farm types producing eggs, milk, and beef, but were biased downward 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 used little 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 (i.e., 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% and about 4% 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 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 TE 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 TC 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 TE, or the rate of "catching-up" to best practice, has been relatively slow or even negative in comparison to TC. Mean TE 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 TE was lowest in ruminant animal production. Part of this result may be due to the inability to control for climatic factors and the resulting downward bias that could occur in our TE estimates. This would be consistent with our findings since cattle often are thought to be more affected by climatic factors than poultry or hogs, which would result in more unexplained variation and higher levels of technical inefficiency. Provided our results did indeed capture some of the underlying nature of the true inefficiencies, attention to the use of best practice techniques for given technologies, and diffusion of existing technology, could be even higher priorities in Chinese livestock management than the encouragement of TC.

Although further research is needed to pinpoint the source of efficiency decline, one possibility is that part of the fall is due to the deterioration of the extension system (CCICED 2004; Nyberg and Rozelle 1999). 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. For example, 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, might aid the development of 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

[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 1961–94.

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%). In contrast, the TFP growth of commercial hog producers and commercial egg producers is higher—more than 4%. 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 draw 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 overestimates 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.

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

Finally, the data set 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 subsector 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 TC such as toward feed-saving technologies, along with differences in productivity across farm types, could be critical in projecting China's trade in feedgrains and meats.

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Appendix

Table A. Maximum Likelihood Ratio Tests for Stochastic Frontier Production Function Using Adjusted Data Sets

	Likelihood Function			
Restricted Function	Restricted	Unrestricted	# of Restrictions	χ^2 Statistics
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***
Specialized 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				
Specialized household				
1. C-D function	205.4	232.9	15	55.0***

(Continued)

Table A. *(Continued)*

Restricted Function	Likelihood Function: Restricted	Likelihood Function: Unrestricted	# of Restrictions	χ^2 Statistics
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				
Specialized 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 factor bias and no technical change; (***) and (**) asterisks stand for 1% and 5% significance levels.