Livestock Productivity in China: Data Revision and Total Factor Productivity Decomposition

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Abstract

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 and by employing the random coefficient frontier approach, decompose productivity growth into its technical efficiency and technical progress components. Efforts were made to adjust and augment the available livestock statisitics. 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 was relatively slow.

Keywords: Random coefficient approach, total factor productivity, technical efficiency and progress, China, livestock.

JEL Classification: D240, Q100, Q160.

Productivity in China's Livestock Sub-sectors: Decomposition of Total factor Productivity Growth

Introduction

China's agricultural output has expanded rapidly since the economic reforms of the late 1970s, reflecting both productivity growth and mobilisation of inputs. Over the 1980-2000 period wheat output has doubled and that of maize has risen by about 70%. 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 urbanisation have pushed consumption patterns towards increased consumption of high-value foodstuffs including livestock products. Will China's food output expansion be able to match consumption growth in the future? Urban and rural industrialisation is drawing labour, capital and land away from agricultural employment, and growing environmental awareness could increase pressures to moderate the use of fertilisers and pesticides. Further, the current land tenure system hinders the achievement of scale economies and constrains the expansion of labour-saving agricultural technologies. The above question, along with China's heightened involvement in global food markets as both an importer and exporter, has spurred debate over whether or not China will be able to feed itself, and if not what might be the consequences for global markets?

Perhaps the most (in)famous and pessimistic projection was that of Brown while others (e.g. Fan and Agcaoili-Sombilla) have shed considerable doubt on his scenario of soaring prices and widespread starvation. Nevertheless, several studies have since projected emerging grain deficits in response to population and income growth, urbanisation, a shift in comparative advantage from land-intensive to labour-intensive commodities, and increased demands for livestock feedstuffs. However many of these studies did not specifically include a livestock sector, and could therefore have mis-estimated the derived demand for feedgrains and the impact of enhanced livestock productivity on feedgrain imports. China has been a net exporter (in value terms) of pigmeat and poultry, a net importer of beef, and overall a net exporter of fresh and prepared meats. Is this likely to continue? Rutherford has projected continuing Chinese self-sufficiency in meats, and Delgado *et al*. projected a decline in pork net exports but an increase in the case of poultry by 2020. Both Ehui *et al.* and Rae and Hertel projected China remaining a net exporter of non-ruminant meat in 2005 while Nin-Pratt *et al*. projected a trade deficit in non-ruminant meats by 2010.

Given possible policy and resource constraints, achievement of the Chinese government's goal of food self-sufficiency 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 future grain and meat trade balances. However, the estimation of China's past productivity growth, let alone the formulation of future projections, has 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.

None of the above projections of meats trade for China explicitly incorporated 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. Few studies of livestock TFP have been reported from anywhere, and the majority of those relate to milk production (Forsund and Hjalmarsson; Bravo-Ureta and Rieger; Thomas and Tauer; Ahmad and Bravo-Ureta; Tauer, 1995, 1998; Kumbhakar and Heshmati; Brummer, Glauben and Thijssen.). While several studies have examined China's aggregate agricultural TFP (see Mead for a summary of many of them) to the best of our knowledge no comprehensive livestock TFP studies have been reported for China. We are aware only of Somwaru, Zhang and Tuan's analysis of hog technical efficiency in selected provinces of China, and the work of Jones and Arnade, and Nin *et al*.. that make TFP estimates for the aggregate crops and livestock sectors separately, for a number of countries including China. Therefore one objective of this paper is to make TFP growth estimates for several sub-sectors of the Chinese livestock industry.

Even when TFP growth estimates are available, from a policy point of view it 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 – that is, 'catching-up'). These two TFP components are analytically distinct, can change at different rates, and therefore might have quite different policy implications. For example, should policies be designed to encourage innovation, or the diffusion of existing technologies? Another of our objectives, therefore, is to use the approach of Kalirajan, Obwona and Zhao to provide such a decomposition of livestock TFP in China.

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 Agricultural Statistical Yearbooks of China, 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.[1] To the extent that feeding rations and rates, and other management practices vary across production structures, this information ought to be combined with information on patterns of structural change when making projections of China's livestock production and feedgrain demands. Therefore a third objective of this paper is to derive separate TFP estimates for some of the more important farm types.

In **following** sections we present a brief review of our methodology, followed by discussion of some problems with China's official livestock production and cost data and the adjustments we made to those data. TFP growth results and their decomposition are then presented for four livestock sub-sectors - hogs, eggs, milk, and beef cattle, as well as productivity growth patterns across production structures.

Methodology

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

The stochastic frontier approach (Aigner, Lovell and Schmidt; Meeusen and van den Broeck) has become a popular methodology for studies of agricultural productive efficiency (Kumbhakar, Biswas and Bailey; Bravo-Ureta and Rieger; Fan; Ahmad and Bravo-Ureta; Kumbhakar and Heshmati). While the conventional frontier function approach has been used to decompose productivity growth into technical progress and technical efficiency components, it has some limitations (Kalirajan and Obwona; Kalirajan, Obwona and Zhao) such as the implicit assumption that technical change is neutral and the rate of technical change over time is constant among firms.

These restrictive assumptions can be overcome with the random coefficients regression model of Hildreth and Houck, popularized by Swamy. The slope coefficients of the production function will vary from firm to firm to reflect differences in technical efficiency, the production frontiers shift non-neutrally over time, and the input growth component of output growth (rather than technical change as in more traditional approaches) is computed as the residual. Kalirajan, Obwona and Zhao used this approach to study aggregate agricultural productivity growth in China, and to separately identify the contributions to productivity growth of technical efficiency and technical change. The same procedure is used in this paper.

[1] The text section of the Statistical Yearbook contains speeches and working reports that provide valuable information on livestock production structures. For example, the Agricultural Statistical Yearbook (1981, page 47) and the Livestock Statistical Yearbook (2001, page 1) provide hog production size data for specialized households and commercial enterprises in 1980 and in 1999, respectively.

Assuming a Cobb-Douglas technology and letting the production function parameters describing the production technology be random, the random coefficients model for the *i*-th firm can be written in matrix notation as:

(1) $y_{it} = x_{it}^{'}\beta_{it} + \varepsilon_{it}$

where x_{it} and β_{it} are $K \times 1$ vectors for each firm, *t* indicates time, and output and input data are measured as natural logarithms of the original data. For any time period, each firm's parameter vector, β_i, varies from the mean vector, $\bar{\beta}$, by a vector of random errors, v_i, that is, $\beta_i = \bar{\beta} + v_i$. The related assumptions and solution method for the individual response coefficients, β_{itk}, can be found in Griffiths. The economic assumptions related to (1) are found in Kalirajan, Obwona and Zhao.

Now, let β_{t0}^*, β_{t1}^*, β_{t2}^*, …, β_{tK}^* be the estimates of the parameters of the frontier production function that yield the potential output. The frontier production function coefficients, β_{tk}^*'s, are chosen in such a way as to reflect the condition that they represent the production response from following the "best practice" technique. They are obtained from the individual firm response coefficients as:

$\beta_{tk}^* = \max\{\beta_{itk}\},\ k = 0, 1, ..., K \ and \ t = 1, 2, ..., T$. Then the potential frontier output for the *i*-th observation can be calculated by:

(2) $y_{it}^* = x_{it}\beta_t^*$

where x_{it} is the vector of actual inputs (in logarithms) used by the *i*th firm in period *t*, and β_t^* is the vector of best-practice response coefficients. Then it is straightforward to measure technical efficiency (TE) as:

(3) $TE_{it} = Y_{it} / \exp(y_{it}^*)$

where Y_{it} is the actual output level.

Eventually we decompose the output growth (Δy_{it}) into output growth due to input growth (ΔI_{it}) and output growth due to TFP growth (ΔTFP_{it}) and then further we decompose the TFP growth into that due to technical efficiency improvement (ΔTE_{it}) and that due to technical progress (ΔTP_{it}):

(4) $\Delta y_{it} = \Delta I_{it} + \Delta TFP_{it} = \Delta I_{it} + \Delta TE_{it} + \Delta TP_{it}$.

Empirically, we measure (4) in logarithms (see Kalirajan, Obwona and Zhao for additional details of the decomposition procedure).

Data

An ongoing problem for the study of livestock productivity in China is the absence of relevant and accurate data. The majority of published studies of Chinese agricultural productivity have used data published in China's Statistical Yearbook. 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 need therefore is to locate additional data that will allow the construction of time-series of input use by the livestock sector. A further problem with livestock data from the official statistical yearbooks is the apparent over-reporting of both livestock product output and livestock numbers (ERS 1999; 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 three inputs to livestock production, breeding animals, labour and feed, which are the major inputs to livestock production in China. It can also be noted that since the random coefficient method computes the contribution of input growth to the growth of output as the residual, the omission of some input variables from our model specification is not expected to cause serious bias (Kalirajan, Obwona and Zhao 1996). Below, we describe 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.

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 et al. (2004) have provided adjusted series for livestock production (and consumption) that are internally consistent by recognising that the published data do contain valid information but introducing new information from other sources. These comprise, first, the 1997 national census of agriculture, one objective of which was to provide an accurate estimate of the size of China's livestock economy. The census covered all rural households and non-household agricultural enterprises, and collected information included the number of animal slaughterings (by type of livestock) during the 1996 calendar year. The second source of additional information was the official annual survey of rural household income and expenditure. 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 eggs. Ma et al. (2004) assumed the production data as published in the Yearbook to be accurate from 1980-1986. Beyond this date, that data was adjusted to both reflect the annual variation as found in the housed income and expenditure survey data and to agree precisely with the Census data for 1996. Further details of the adjustment procedure can be found in Ma et al. (2004). The adjusted data series included livestock production, animal inventories and slaughterings. Since dairy cattle were not included in that study, we applied a similar procedure to adjust data on milk production and dairy cattle inventories.

Animals as capital inputs

Following Jarvis (1974) we recognise the inventory of breeding animals as a major capital input to livestock production. Thus opening inventories of sows, milking cows, laying hens, breeding broilers and female yellow cattle are used as capital inputs in the production functions for pork, milk, eggs, poultry and beef respectively. Inventory data for sows, milking cows and female yellow cattle were taken from official sources and adjusted for possible over-reporting as described above.

Additional problems existed with regard to poultry inventories. China's yearbooks and other statistical publications present poultry inventories aggregated over both layers and broilers, with none publishing separate data for layers. However Ma et al. (2004) provided adjusted data on egg production, and the State Development Planning Commission's agricultural commodity cost and return survey provided estimates of egg yields per hundred birds. Thus layer inventories, at both the national and provincial levels, were calculated by dividing output by yield[2]. A simple test showed that the sum across provinces of our provincial layer inventories was very close to our estimate of the national layer inventory in each year. 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 obviously severely limits our ability to analyse productivity developments in this sector.

Feed and labour inputs

Data for these production inputs was obtained directly from the Agricultural Commodity Cost and Return Survey.[3] Within each province, a three-stage random sampling procedure was used, to select sample counties, villages and finally individual production units. Samples were 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) were aggregated to the provincial and national level datasets that were issued by the State Development Planning Commission.

The survey provides detailed cost items for all major animal commodities, including those covered in this paper. These data included slaughter liveweight (or commodity output, e.g., milk and eggs) and labour inputs (days) and feed consumption (grain equivalent) on a 'per animal unit' basis. We calculated total feed and labour inputs by multiplying the input per animal by animal numbers. For the latter, we used slaughter numbers for hogs and beef cattle, and the opening inventories for milking cows, layers and broilers since these are the 'animal units' used in the cost survey. It is clear that this procedure, necessitated by the available data, excludes some feed and labour input usage, such as that by other animal categories within the pig and cattle herds.

Appendix Table 1 contains total sample sizes for the cost and return survey, summed over provinces and production structures. Two points can be made. First, the sample size varies from year to year, for example as the survey did not always report feed and labour data for all provinces and each production structure for each year. The second point relates to our objective of identifying 'best practice' and relative technical efficiency in livestock production. In those instances where the sample comprises relatively few counties in some provinces, or few observations per county, the question arises as to how well they will allow 'best practice' to be observed. Close attention to such small-sample instances revealed that they consisted primarily of specialised

[2] The cost and return survey did not contain egg yields for each province for each of the past 15 years. Provincial trend regressions were used to estimate yields in such cases.

[3] This survey was 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 large commercial operations, exactly what is needed to identify 'best practice' if indeed such production structures are more likely to adopt new techniques and advanced management compared with household production systems.

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 utilise 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 and labour 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 does not exist. Our approach to generating these data was to first construct 'share sheets' that contained time series on the share of each livestock output produced by each farm category (backyard, specialized and commercial). We then multiplied both the output and animal inventories data by these shares. We recognize that a given farm type's share of animal inventories need not be the same as its share of output, but it proved impossible to quantify these differences.

Information that allowed estimation of the shares by farm type and province over time came from a wide variety of sources. These included the 1997 agricultural census, a range of published material (such as annual reports, authority speeches and specific livestock surveys) from various published sources, and provincial statistical websites. The census publications provided an accurate picture of the livestock production structure in 1996 (Somwaru, Zhang and Tuan, 2003). However the census defined just two types of livestock farms - rural households and agricultural enterprises (including state- and collective-owned farms). We interpreted the latter as 'commercial' units, but additional information was sourced to disaggregate the rural households into traditional (backyard) and specialized units.

Agricultural Statistical Yearbooks and other published livestock statistics provided data on livestock production structure during the early 1980s, when backyard production and state farms were prevalent. These sources, plus the Animal Husbandry Yearbooks and provincial websites also provided estimates of livestock production shares for various livestock types, provinces and years. When all these data were combined with 1996 values from the census, many missing values still existed. On the assumption that declining backyard production and increasing shares of specialized and commercial operations were a gradual process over the study period, linear interpolations were made to estimate all missing values[4].

Results

Following the procedure of Griffiths, we estimated random coefficients year-by-year for each livestock type and production structure. The Breusch-Pagan LM tests demonstrated that the production function parameters did vary randomly across regions. While the production functions were estimated from provincial data, we report here only the results for national average data. Indices for the various components of (4) were derived as follows. First, exponentials of, for example, Δy_{it} were taken to derive the series K_{it} of actual levels relative to those of the previous year. Then we constructed a series K_{it}^{0}, where K_{i1}^{0}=1 and $K_{it}^{0} = K_{it} \times K_{i,t-1}^{0}$ for remaining terms. Finally, we derived $K_{it}^{1} = K_{it}^{0} / K_{i,2001}^{0}$ to base the series on the 2001 value. It is these values, K_{it}^{1}, that are presented in Tables 1 to 4 and Figures 1 to 6.

Growth in TFP and its Components

Pork production in China increased rapidly during the past 20 years, due to increases in both input levels and TFP. Hog production increased more rapidly in the 1980s, however, than over the following decade (Table 1). While annual growth in inputs was similar across both decades, the contribution of TFP growth was greater during the earlier period. The decline in TFP growth from 5.0% per year over the 1980s to 2.3% in the 1990s reflected almost no growth in technical efficiency over the latter period and somewhat slower technical progress.

Growth in egg production (Table 2) had been even more rapid than that for hogs, but output growth had also slowed somewhat during the 1990s. But unlike hogs, TFP growth dominated input growth in contributing to these outcomes (especially during the 1980s) and growth in TFP was much more rapid than that for hogs over both time periods. During the 1980s, average annual TFP growth in egg production exceeded 8.0%, entirely due to technical progress. Such progress increased at a slower rate of about 4.4% during the 1990s, almost as did TFP growth, and technical efficiency continued to decline.

Data for milk and beef (Tables 3 and 4) covered only the 1990s, during which output grew at annual rates of 10% and 8% respectively. For milk, output growth was dominated by input growth, but beef output growth was largely attributable to growth in productivity. Beef TFP growth averaged 5.5% per year over the 1990s, with growth in technical efficiency somewhat a little bit slower than that of technical progress. For milk, however, technical efficiency declined markedly so that technological progress was responsible for the annual 0.44% growth in TFP. Thus technical efficiency growth in

[4] All share sheets may be requested from the authors.

beef production clearly exceeded that for milk production, while the growth of technological change did not. This could be due to the fact that traditional household-based structure dominates beef cattle production, which may face fewer possibilities for adopting new technologies compared with specialized or commercial dairy farms.[5]

Trends in technical efficiency over the 1990s, as measured by (3), are compared across livestock types in Table 5. At the national average level, actual outputs reached around 90% of the frontier levels for both eggs and milk by the mid-1990s. Since then the gap between actual outputs and the frontier has widened, especially in the case of milk, for which the ratio of actual to frontier output was only 20% by 2001. While the technical efficiency ratios trended downwards over 1992-2001 for eggs and milk, those for hog production increased by almost 1.3% per year, and averaged 60% of frontier output over the entire period. Growth in technical efficiency since 1993 was most rapid in the case of beef, at 4% per year, and by the years 2000 and 2001 national average performance had almost reached the frontier.[6]

Productivity Growth Across Production Structures

Several differences were found in TFP growth, and the relative contribution of its components, across production structures (Figures 1 to 6). In hog production (Figures 1 and 2), TFP tended to remain static from the mid-1980s to the early 1990s for specialized households and commercial operations, before growing at over 10% per year to 2001. In contrast, backyard production TFP declined from the 1980s to the 1990s, before showing modest growth of less than 1% per year. Although it is unclear why many rural households exited from hog production in the 1990s, declining productivity may be one of more important reasons.[7] While technical efficiency improved marginally at about the same rate over the 1990s for each structure, it was differences in technical change that explained the inferior productivity performance of backyard operations. These differences were revealed as static or declining technical progress in backyard production, compared with annual growth of around 10% in the specialized household and commercial operations.

Egg productivity developments across production structures were found to be rather similar to those in hog production (Figures 3 and 4). TFP grew steadily throughout the 1990s on specialized household and commercial structures, but declined in backyard production over the latter half of the decade. These trends reflected similar trends in technical change across the production structures, as all experienced similar trends in technical efficiency. As with hog production, the growth in input levels was similar

[5] Unspecialized households own around 90% of all cattle in China, each typically raising 1-2 cows on a predominantly straw-based diet (Longworth, Brown and Waldron).

[6] From our limited data set for broilers, technical efficiency ratios were computed as 46% for specialized households and 54% for commercial enterprises for 1998-2001. These ratios are somewhat lower than for hogs and eggs, but greater than those for milk production.

[7] In 2000, the Center for Chinese Agricultural Policy (Chinese Academy of Sciences) and the Department of Agricultural and Resource Economics (University of California-Davis) conducted a rural household survey that covered more than 1000 traditional rural households. It was found that in 1990, only 0.4 percent of households exited from hog production, but more than 8 percent of households did so in 2000.

across structures.

In Figures 5 and 6, milk productivity comparisons are presented for specialized households and commercial structures. Input growth was much more rapid during the 1990s on commercial than specialized household structures, and was the major driver of output on the former production units. TFP was increasing over the decade on specialized household farms however, compared with declining TFP on the commercial operations. A similar pattern was found for technical progress, as both types of structure showed similar declining trends in technical efficiency. Just why the commercial enterprises did not perform as well as specialized households is beyond the scope of this paper. Based on our knowledge of China's milk production enterprises, however, a possible explanation is the existence of some old state-owned milk production enterprises in the data sample, which may not have the advantage of adopting new technologies and management. In fact, in some provinces where state-owned dairy farms accounted for a large share of milk production, the decline in TFP was even worse than the national average.

The Impact of Policy and Technology on TFP

Correlating the TFP with some certain changes of livestock policies and technologies historically to observe their impact is already beyond scope of this study. However, the evolution of livestock TFP was closely correlated with both exogenous and endogenous variables. In studying China's hog production structure and efficiency, Sowaru, Zhang and Tuan (2003) have pointed out that China's hog industry is adjusting to capture the benefits of specialization, a conclusion almost the same as ours that large hog farms are efficient. Chen and Rozelle (2003) have linked the rise and fall of backyard hog production to the emergence of grain and labor markets, upon which households maximize their utilities by efficiently allocating their economic resources.

Generally, the livestock markets in China might operate more efficiently than the grain markets (Chen and Rozelle, 2003), and therefore policies might not have much thing to do with improving TFP, but technologies could be major driving force. For example, during the 1980s, concerns that livestock production would not be sufficient to feed its citizens led to a series of government-initialized programs, most of which sought to encourage the establishment of large commercialized livestock operations in suburban regions (Pan, 2000). By the late 1990s, however, many of operations went bankrupt (Chen and Rozelle, 2003).

Of all, livestock feeding technique might be the most important that drives China's livestock TFP increase. The contribution of feeding techniques to the TFP may be more easily seen from the declining feed-meat conversion coefficients. For example, feed consumptions (grain equivalent) per unit hog gain have decreased by 29 percent for backyards, 23 percent for specialized households and 32 percent for commercial operations from 1985 to 2001. Likewise, they have declined by 24 percent for specialized households and 36 percent for commercial operations in the 1990s.

Furthermore, the declining feed-meat conversion coefficients obviously implies the increasing technological components in the variety of animals and feed nutritious techniques, which is due to the fact that much of technological change can be embodied in feedstuff and variety of animals and in turn causes cost structure to change over time. In fact, it is obvious that cost shares of feedstuff and pup animals have been increasing. For example, hog cost shares of pup animals for specialized households and commercial operations doubled from 1980 to 2001, which might lead to steadily increasing of TFP indices (see Figure 2, B). In contrast, piglet cost share only rose by 24 percent, the result was that backyard enjoyed very flat TFP indices (see Figure 2, B). Another negative example can be found from egg production where cost share of pup laying hen for backyard decreased in the 1990s, and as a result the TFP indices declined in the late 1990s (see Figure 3, B).

Conclusions

In this paper we have applied the varying coefficients production frontier framework to the empirical measurement and decomposition of productivity growth in China's livestock sectors. It can be viewed as a further development of Kalirajan, Obwona and Zhao's research into productivity growth in Chinese agriculture (the aggregate of crop, livestock and fisheries production) by focusing specifically on livestock production. While provincial data was used in our empirical estimation, the results reported here were obtained using national average input and output levels.

Our results for hog and egg production reveal a slowing down of TFP growth over the 1990s compared with the earlier decade, from 5.0% to 2.3% growth per year for hogs, and from 8.5% to 4.4% for egg production. This could be viewed as a continuation of the trend observed by Kalirajan, Obwona and Zhao for the agricultural sector as a whole, of slower TFP growth over the 1984-87 post-reform period compared with the reform period of 1978-84. For ruminant livestock production over the 1990s, the only period for which data were available, TFP in beef cattle production averaged 5.5% per year, compared with 0.4% for milk production. While these rates of productivity improvement exceeded those in the hog sector, they were considerably below productivity gains achieved by egg producers.??????

Decomposition of TFP growth into its technical efficiency and technical progress components also revealed differences among livestock types. In hog production, both sources of productivity growth were important during the 1980s. Over the 1990s, however, technical efficiency was static and, combined with a slower rate of technical progress, gave rise to the lower TFP growth. Egg production was noticeable for its extremely high rates of technical progress, with annual growth of more than 11% in the 1980s and 5% over the following decade. Technical efficiency declined moderately over both decades, however, so that TFP grew somewhat more slowly than the rate of technical change. For both hog and egg production, we found that growth in TFP and technical progress over the 1990s was superior on specialized household and commercial production units than in traditional backyard production. The results for milk production indicated a rapid decline in technical efficiency over the 1990s, of almost 11% per year. However, this product showed the most rapid growth in technical progress over the 1990s of all livestock types, of 12% per year. In contrast to the situation on specialized households, both TFP and technical progress declined on commercial milk enterprises. In noting this difference, we observed that state-owned dairy farms have a large share of total output in some regions of China, which farms may have been slower in adopting new technologies than other farm types. Beef cattle productivity growth differed from other livestock types in that both technical efficiency and technical progress contributed to the observed growth in total factor productivity during the 1990s, with the greater contribution due to efficiency gains.

During the 1990s, growth in technical efficiency was either low or negative for all livestock types studied with the exception of beef cattle and on average, production was 40% to 85% of potential output for given levels of inputs. Therefore attention to the use of best practice techniques for given technologies, and diffusion of existing technology, would appear to be a high priority in Chinese livestock management, especially in milk production, and across all production structures. Traditional backyard production, despite the growth of other structures, still accounts for a large share of China's livestock production. Our results suggest there may also be a need to encourage research into the development and adoption of new technologies designed for backyard producers of hogs, eggs and beef, so as to drive increased productivity overall.

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Table 1. Output, Input and TFP Indices: Hog Production

Year	Output	Input	TFP	Technical Efficiency	Technical Progress
1981	0.3493	0.5677	0.6153	0.8850	0.6953
1982	0.3738	0.6740	0.5546	0.7711	0.7193
1983	0.3868	0.4894	0.7905	1.0505	0.7524
1984	0.4246	0.6535	0.6498	0.8382	0.7752
1985	0.4864	0.5868	0.8289	1.0119	0.8191
1986	0.5279	0.6991	0.7551	0.8133	0.9284
1987	0.5534	0.6678	0.8287	0.9282	0.8928
1988	0.5857	0.6814	0.8594	0.9398	0.9145
1989	0.5896	0.6232	0.9460	1.1180	0.8461
1990	0.6176	0.6952	0.8884	1.0630	0.8358
1991	0.6930	0.8538	0.8116	0.9485	0.8557
1992	0.7181	1.0503	0.6837	0.7878	0.8679
1993	0.7520	0.9242	0.8136	0.9572	0.8500
1994	0.7635	0.7737	0.9869	0.9992	0.9877
1995	0.7816	0.7296	1.0713	1.1023	0.9718
1996	0.8405	0.8078	1.0406	1.0608	0.9809
1997	0.8744	0.8653	1.0105	0.9462	1.0681
1998	0.8766	1.0852	0.8077	0.7995	1.0103
1999	0.9408	0.8721	1.0788	1.1029	0.9781
2000	0.9681	0.9704	0.9976	1.0348	0.9641
2001	1.0000	1.0000	1.0000	1.0000	1.0000
Annual Growth (%): [a]					
1981-1990	7.07	1.94	5.03	2.32	2.65
1990-2001	4.08	1.80	2.25	0.48	1.76
1981-2001	5.32	2.91	2.34	0.67	1.66

Note: Based on official production data, annual growth rates of output and TFP indices are 5.78 percent and 3.66 percent for 1990-2001 and 7.04 percent and 4.26 percent for 1982-01. Indices are based on 2001.

[a] Using semilog regression averages at 1% significant level.

Table 2. Output, Input and TFP Indices: Egg Production

Year	Output	Input	TFP	Technical Efficiency	Technical Progress
1982	0.1561	0.4058	0.3846	1.2781	0.3010
1983	0.1758	0.4497	0.3908	1.2554	0.3113
1984	0.2079	0.7894	0.2634	1.1520	0.2286
1985	0.2700	0.6114	0.4417	1.1137	0.3966
1986	0.3345	0.5640	0.5932	1.1576	0.5124
1987	0.3473	0.7032	0.4938	1.0690	0.4619
1988	0.3839	0.7888	0.4867	0.9785	0.4974
1989	0.4327	0.7709	0.5613	1.0303	0.5448
1990	0.4632	0.6531	0.7093	1.2152	0.5837
1991	0.5002	0.8464	0.5910	0.9188	0.6432
1992	0.5448	0.7675	0.7099	1.0270	0.6912
1993	0.5799	0.6996	0.8290	1.1275	0.7352
1994	0.6128	0.7940	0.7718	1.1334	0.6810
1995	0.6624	0.7989	0.8291	1.1450	0.7241
1996	0.7104	0.8493	0.8365	1.0830	0.7724
1997	0.7666	0.8062	0.9509	1.1697	0.8130
1998	0.8325	0.8403	0.9907	1.1459	0.8645
1999	0.8921	0.8878	1.0048	1.0846	0.9264
2000	0.9524	0.9622	0.9898	1.0197	0.9707
2001	1.0000	1.0000	1.0000	1.0000	1.0000
Annual Growth (%): [a]					
1982-1990	15.28	6.29	8.46	-1.92	10.58
1990-2001	7.34	2.79	4.42	-0.25	4.68
1982-2001	9.64	3.20	6.24	-0.53	6.80

Note: Based on official production data, annual growth rates of output and TFP indices are 10.66 percent and 8.18 percent for 1990-2001 and 13.16 percent and 9.78 percent for 1982-2001. Indices are based on 2001.

[a] Using semilog regression averages at 1% significant level.

Table 3. Output, Input and TFP Indices: Milk Production

Year	Output	Input	TFP	Technical Efficiency	Technical Progress
1993	0.4668	0.5681	0.8216	2.2817	0.3601
1994	0.5105	0.9202	0.5548	1.0998	0.5045
1995	0.5732	0.2476	2.3149	4.3647	0.5304
1996	0.6363	0.3532	1.8016	3.3777	0.5334
1997	0.6540	0.7851	0.8331	1.4039	0.5934
1998	0.7452	0.3876	1.9229	2.7769	0.6924
1999	0.8366	1.3607	0.6149	0.7776	0.7907
2000	0.9201	0.8338	1.1035	1.2101	0.9119
2001	1.0000	1.0000	1.0000	1.0000	1.0000
Annual Growth Rate (%): [a]					
1993 -2001	10.02	9.54	0.44	-10.50	12.23

Note: Based on official production data, annual growth rates of output and TFP indices at the same period are 7.48 percent and –10.84 percent. Indices are based on 2001.

[a] Using semilog regression averages.

Table 4. Output, Input and TFP Indices: Beef Production

Year	Output	Input	TFP	Technical Efficiency	Technical Progress
1990	0.4398	0.9951	0.4420	0.7444	0.5937
1991	0.4866	0.7541	0.6453	1.0590	0.6094
1992	0.5367	0.9457	0.5675	0.7834	0.7244
1993	0.5240	1.2790	0.4097	0.5511	0.7434
1994	0.5542	0.7467	0.7422	0.7017	1.0578
1995	0.6242	0.7348	0.8495	0.8705	0.9758
1996	0.7349	0.7721	0.9519	1.0866	0.8760
1997	0.7905	1.3008	0.6077	0.6597	0.9212
1998	0.8868	1.3236	0.6700	0.8435	0.7943
1999	0.9402	1.2072	0.7789	0.8321	0.9360
2000	0.9470	1.1465	0.8259	1.0544	0.7834
2001	1.0000	1.0000	1.0000	1.0000	1.0000
Annual Growth Rate (%): [b]					
1990-2001	8.30	2.63	5.53	2.05	3.41

Note: Based on official production data, annual growth rates of output and TFP indices at the same period are 14.73 percent and 11.76 percent. Indices are based on 2001.

[a] Traditional household (backyard) operations only, since this is the predominant beef cattle production structure in China.

[b] Using semilog regression average.

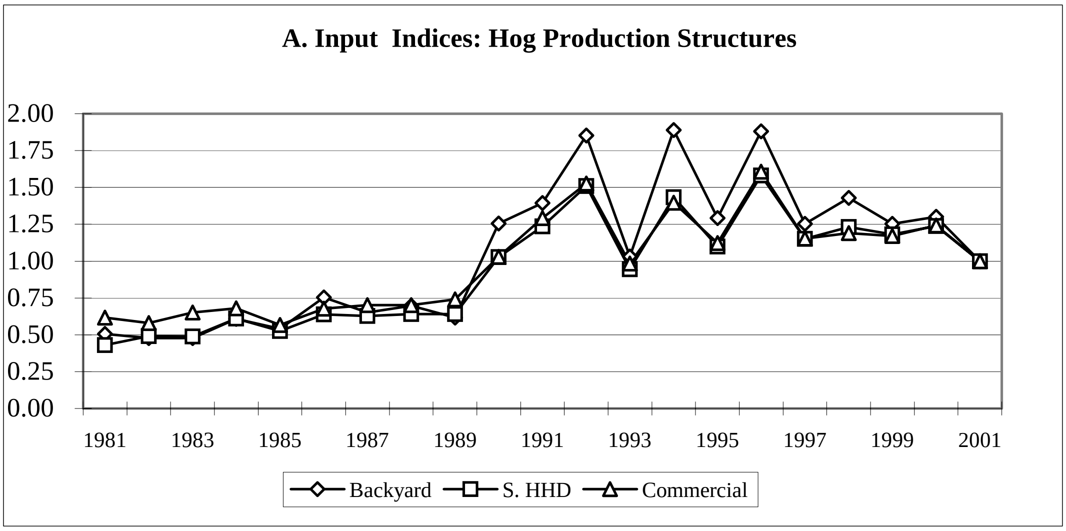
Table 5. Technical Efficiency across Livestock Products: 1992-2001 [a]

Year	Hogs	Eggs	Milk	Beef Cattle
1992	0.4897	0.8036	0.4687	0.6997
1993	0.5951	0.8822	0.4678	0.4922
1994	0.6212	0.8868	0.2255	0.6266
1995	0.6853	0.8959	0.8949	0.7774
1996	0.6595	0.8473	0.6926	0.9704
1997	0.5882	0.9152	0.2878	0.5891
1998	0.4970	0.8966	0.5694	0.7533
1999	0.6857	0.8486	0.1594	0.7431
2000	0.6433	0.7978	0.2481	0.9416
2001	0.6217	0.7824	0.2050	0.8931
1992-2001	0.6087	0.8556	0.4219	0.7487
Annual growth:				
1992-2001 [b]	1.29	-0.66	-9.16	4.33

Note: Based on official production data, the 1992-2001 technical efficiencies for hogs, eggs, milk and beef cattle are 0.6075, 0.8613, 0.4710 and 0.6780; correspondingly, the 1992-2001 annual growth rates are -0.14, 0.08, -12.16 and 1.48 percent.

[a] Calculated as in equation 3 (actual output divided by the frontier output).

[b] Using semilog regression average.



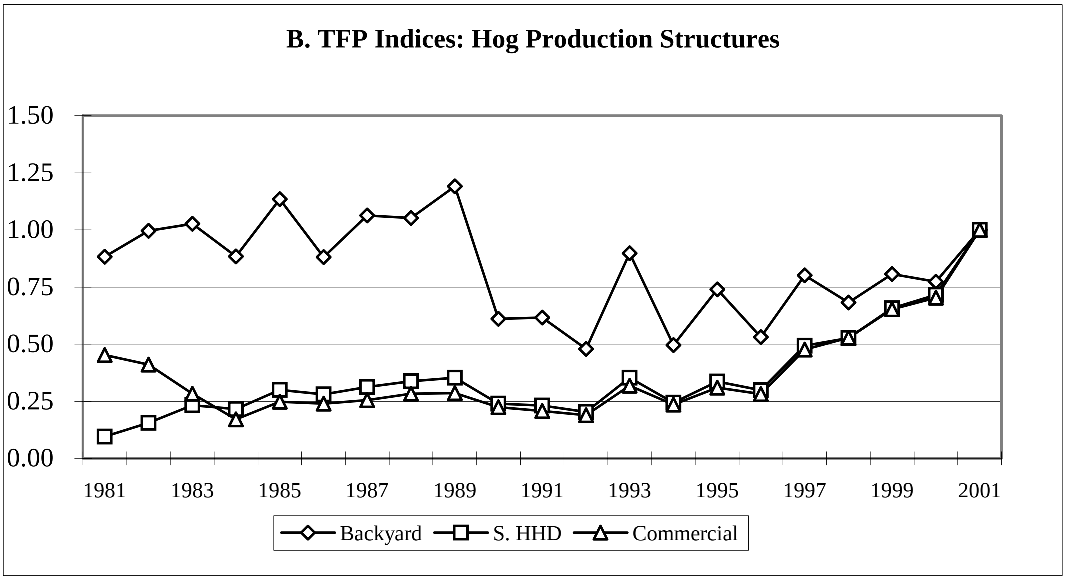


Figure 1. Input and TFP indices by hog production structure

Note: In Figures 1 to 6, Backyard is traditional household production; S.HHD is specialized household production (defined as household-based production with more than 50 percent of household labor employed in, and income earned from, production of the relevant livestock enterprise) and Commercial is market-oriented enterprises.

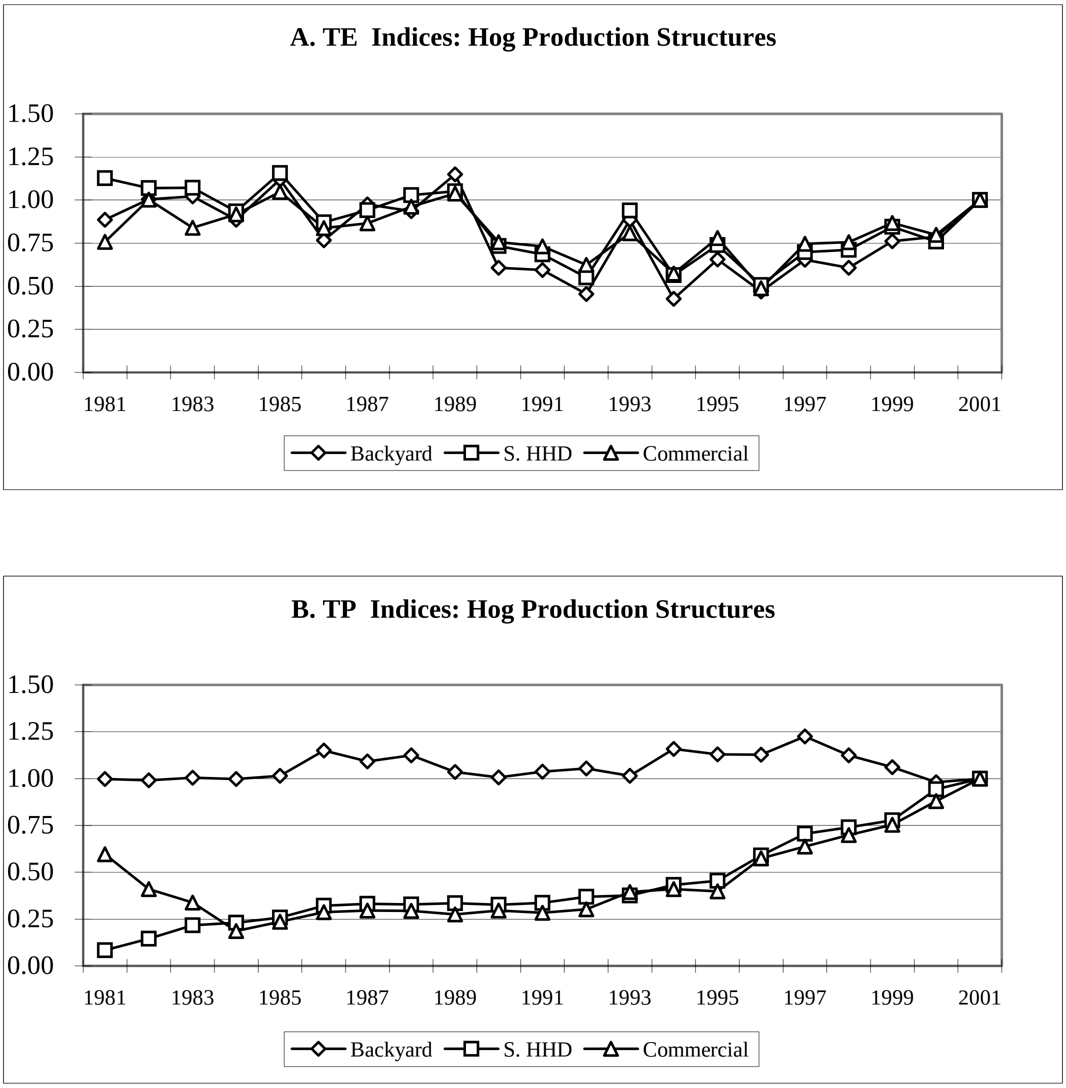
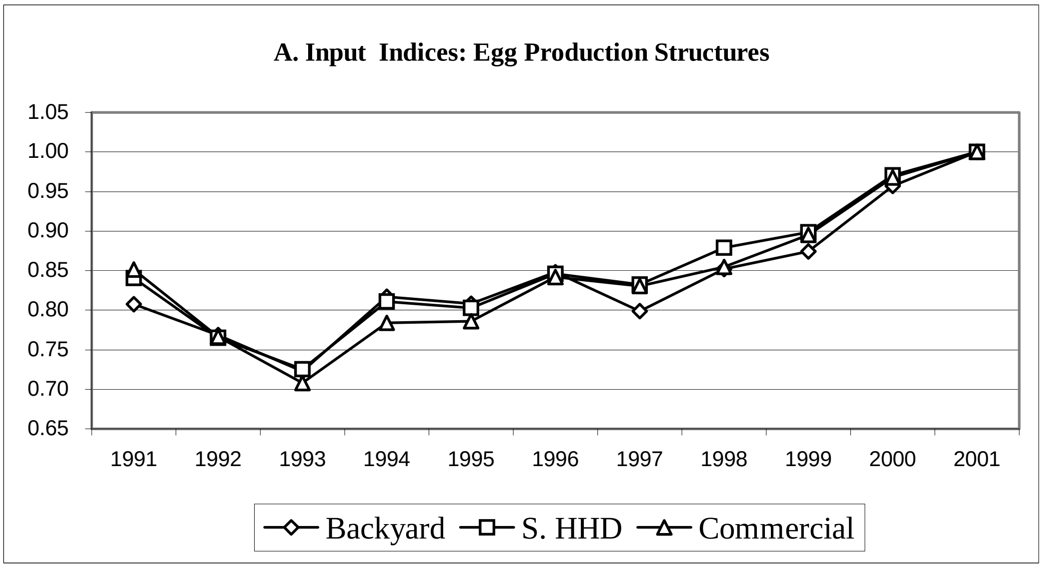


Figure 2. Technical efficiency (TE) and technical progress (TP) by hog production structure



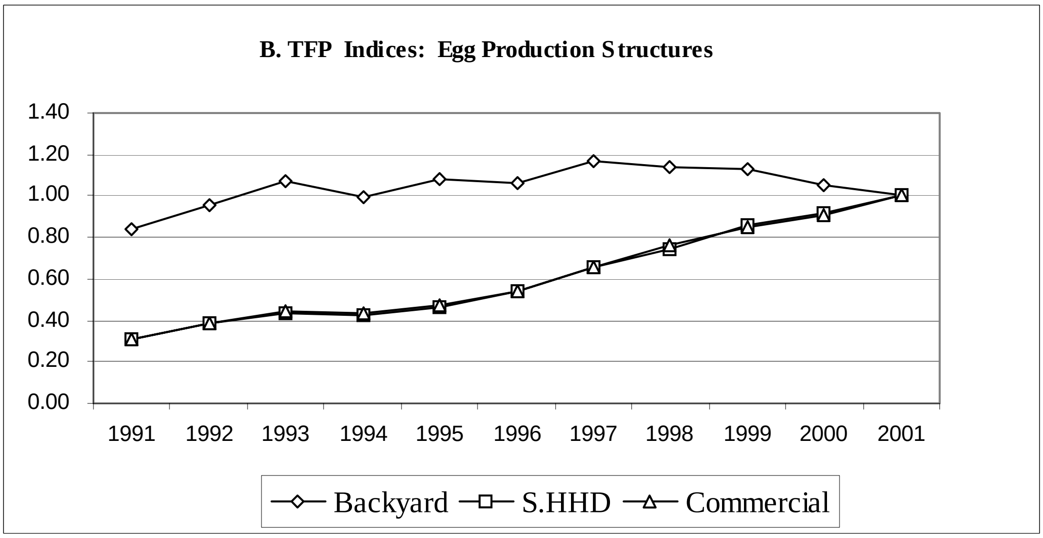


Figure 3. Input and TFP indices by egg production structure

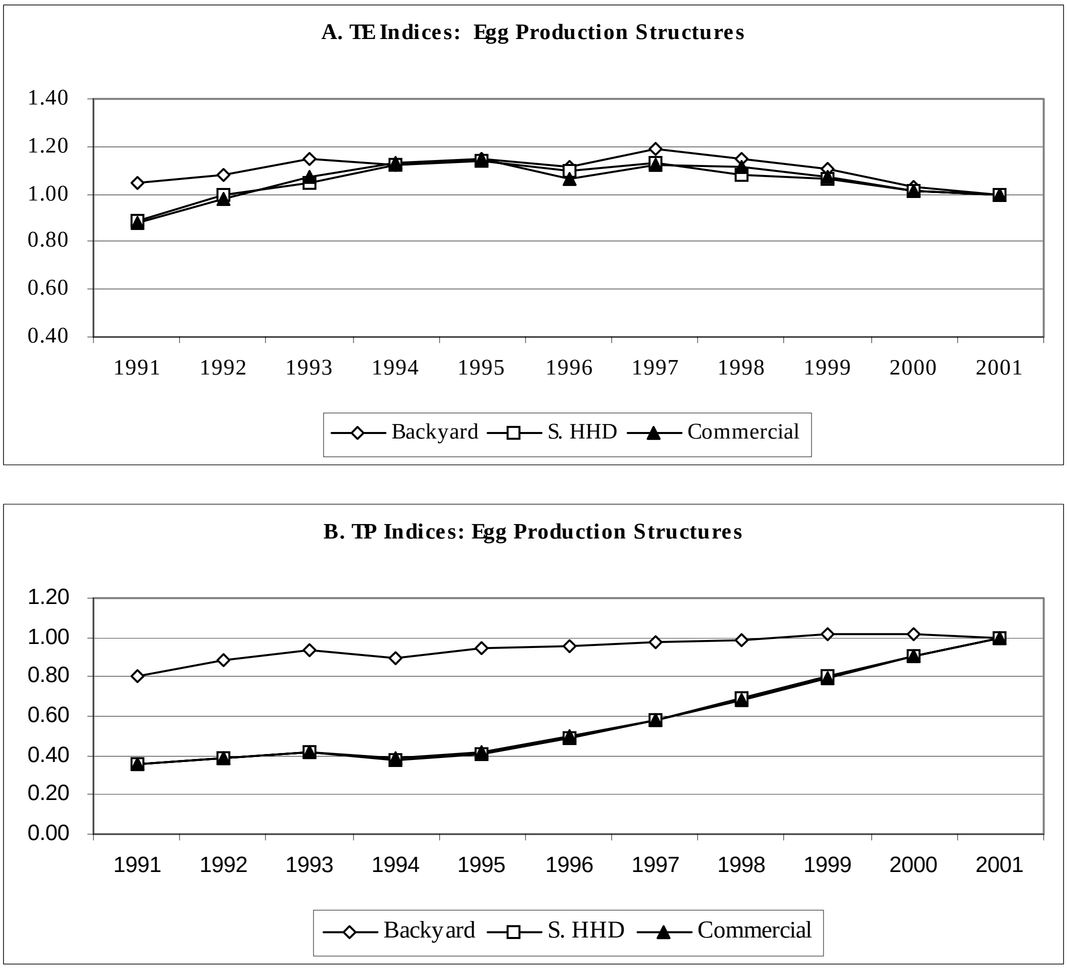
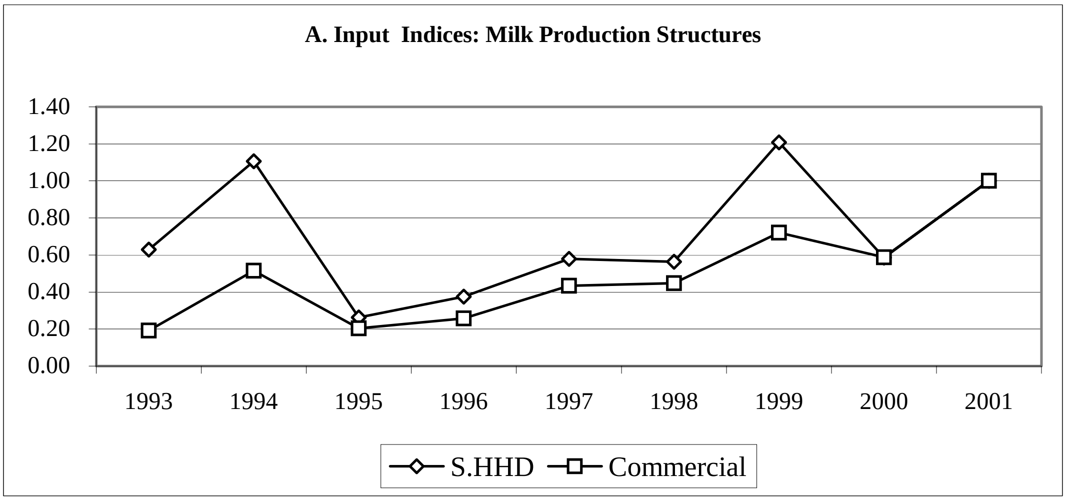


Figure 4. Technical efficiency (TE) and technical progress (TP) by egg production structure



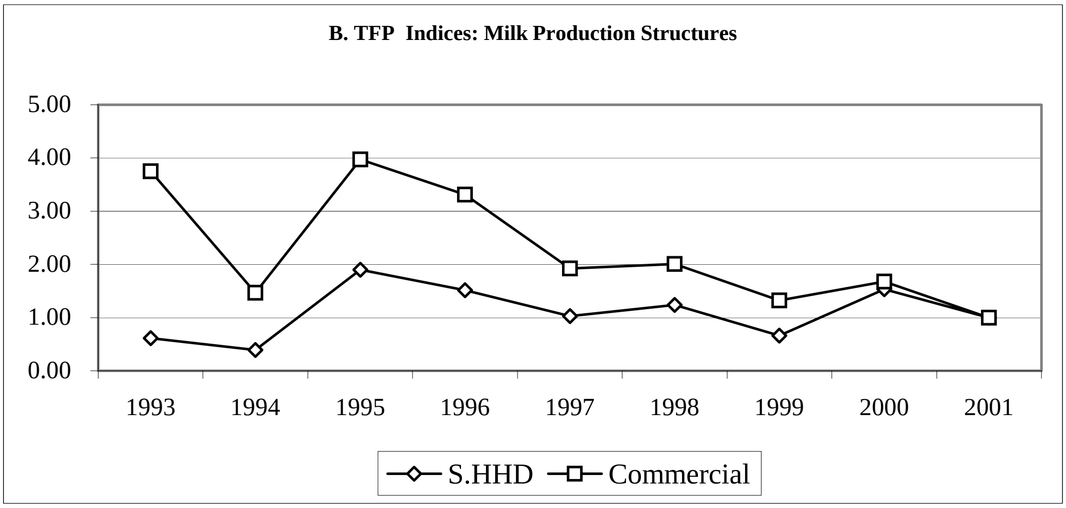
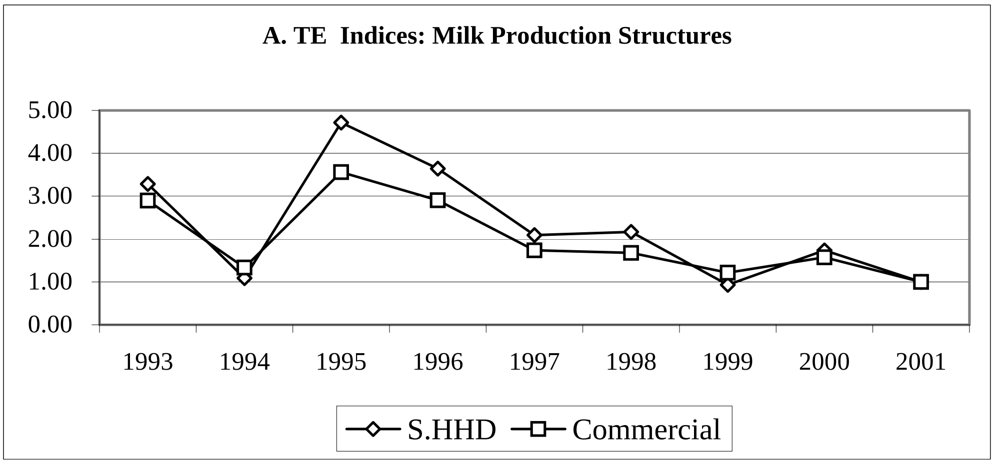


Figure 5. Input and TFP indices by milk production structure



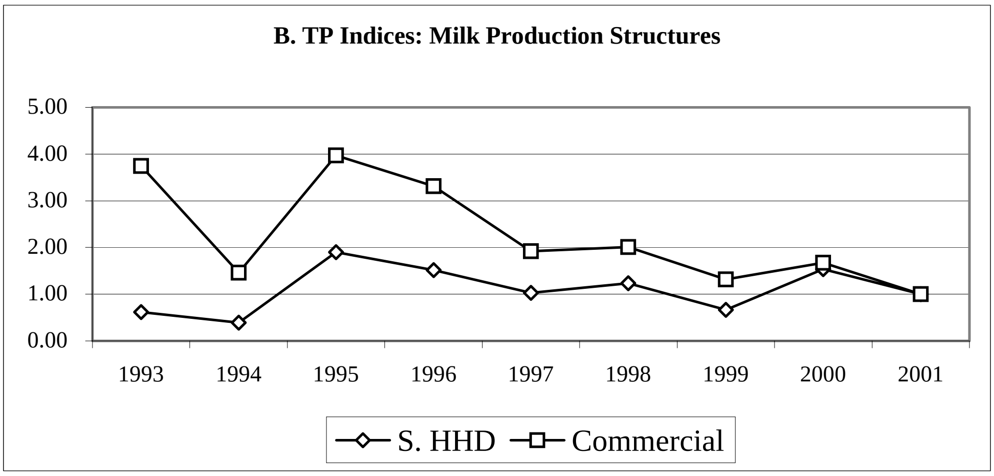


Figure 6. Technical efficiency (TE) and technical progress (TP) by milk production structure

Appendix Table 1.   Sample Size

Year	Hog	Eggs	Beef Cattle	Milk	Broiler
1980	29	–	–	–	–
1981	37	8	-	–	–
1982	35	8	-	–	–
1983	25	10	-	–	–
1984	40	12	-	–	–
1985	32	13	-	–	–
1986	40	19	-	–	–
1987	41	16	-	–	–
1988	42	17	-	–	–
1989	32	19	10	–	–
1990	51	21	6	–	–
1991	59	23	6	–	–
1992	57	36	8	25	-
1993	49	33	7	23	-
1994	54	31	6	20	-
1995	56	25	8	18	-
1996	52	33	9	24	-
1997	57	27	10	25	-
1998	61	33	10	27	18
1999	56	32	10	27	25
2000	67	41	10	36	25
2001	74	42	11	41	28

Source: China's Agricultural Production Cost and Return Survey Collection, various years. Observations were counted by province and production structures (traditional backyard household, specialized household and commercialized enterprise).