Available online at www.sciencedirect.com
SCIENCE DIRECT®
Agricultural Economics 31 (2004) 1–16
AGRICULTURAL ECONOMICS
www.elsevier.com/locate/agecon

Productivity growth, catching-up and uncertainty in China's meat trade

Alejandro Nin [a], Thomas W. Hertel [b,*], Kenneth Foster [b], Allan Rae [c]

[a] International Livestock Research Institute (ILRI), P.O. Box 5689, Addis Ababa, Ethiopia
[b] Department of Agricultural Economics, Purdue University, 1145 Krannert Building, West Lafayette, IN 47907-1145, USA
[c] Department of Applied and International Economics, Massey University, Private Bag 11, 222 Palmerston North, New Zealand

Received 7 May 2002; received in revised form 28 July 2002; accepted 26 January 2003

Abstract

The potential role of China as a major importer of agricultural products, and the likely impact on world markets has been a topic of considerable debate over the past decade. In this paper, we focus specifically on the livestock sector and develop a detailed analysis of productivity growth in China's pig and poultry production along with projections of China's likely meat trade in the year 2010. We use a general equilibrium model which permits us to explore the sensitivity of our projections to macro-economic uncertainty as well as uncertainty in livestock productivity growth rates. Our analysis shows that China's net trade position is very sensitive to both of these factors. With high livestock productivity growth and a slow-down in the rest of the economy, China could be a substantial competitor in export markets by 2010. On the other hand, slow productivity growth in livestock production, coupled with a rapidly growing macro-economy could transform China into a major market for future meat exports.

JEL classification: F17; O30; Q17

Keywords: China; General equilibrium; Livestock; Productivity forecasts; Trade

1. Introduction

China's future role in international agricultural trade continues to be a puzzle. Since the 1995 publication of projections by the Worldwatch Institute suggesting massive grain imports by China in the 21st century (Brown, 1995), considerable research effort has been directed at quantifying China's growth in food demand and supply and implications for the world's food trade (Fan and Agcaoili-Sombilla, 1997). However, the bulk of the attention has been devoted to grains. Livestock trade, on the other hand, has received less attention. The purpose of this paper is to provide a rigorous analysis of both the supply and demand determinants underlying China's future net trade position in livestock products.

China has been a significant importer of poultry meat since 1990. Import volume doubled between 1990 and 1994 and again between 1994 and 1996 and 1996 and 1999 (FAO).[1] The most recent FAO

* Corresponding author. Fax: +1-765-496-1224.
E-mail address: hertel@purdue.edu (T.W. Hertel).

[1] We accessed these data for main land China using the Chinese language version of FAOSTAT on 3 January 2003. The disaggregation of Mainland China from Taiwan was not available in the English language options on the web site.

0169-5150/$ – see front matter
doi:10.1016/j.agecon.2003.01.004

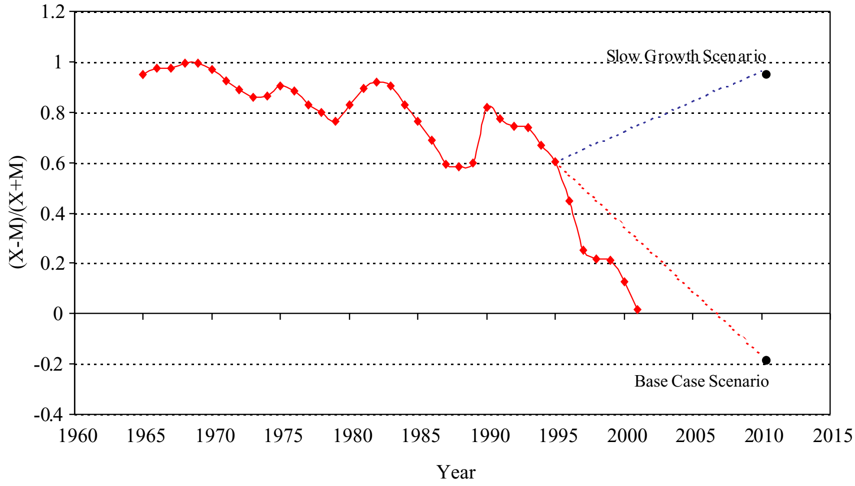


Fig. 1. China's net exports as a portion of total trade ($x+m$) in non-ruminant products (1965–1997) and forecasts to 2010. *Source:* GTAP version 5 data base (Gehlhar, 2002).

statistics place 2001 imports for Mainland China at 707,000 tons. Exports in 2001 were only 580,000 tons, but had a much higher unit value, making Mainland China a net poultry meat exporter *in value terms*. Pig meat is the most important livestock consumption item in China, but imports of this product have only reached a significant level in the past few years, peaking at 136,000 tons in 2000 (FAO). In 1999 and 2000, Mainland China was actually a net importer of pig meat *in volume terms*, although she remained a net exporter when trade is measured in value terms.

Of course there are many different products associated with livestock trade, including live animals, hides and skins, processed products and other by-products. In order to offer a more comprehensive perspective, and in order to view this over time, we turn to the GTAP 5.0 time series trade data on trade in all non-ruminant products[2] (Gehlhar, 2002), which is in turn based on the UN-COMTRADE database. The solid line in Fig. 1 presents the evolution of the dollar value of net exports (exports–imports) of meat as a fraction of total trade on meat (exports + imports) from 1965 to 2001. While this trade specialisation index is highly volatile, the trend is one of gradually diminishing net exports, reflecting a gradual deterioration of China's comparative advantage in pork and poultry production with demand growth out-pacing supply. This begs a further question: Will China eventually become a net importer of livestock products? Resolving this controversy requires examination of the forces underpinning change in consumption patterns in China, as well as the structural changes that have been occurring in China's livestock industry.

Significant research has been conducted into the determinants of meat demand in China and other developing regions as a function of per capita income (e.g. Cai et al., 1998; Rae, 1998; Delgado et al., 1999). Wealthier urban consumers tend to demand a more diverse diet, and expenditures on some food items such as meats, beverages and fruit tend to grow faster than for food staples such as cereals and legumes. Delgado et al. (1999) observe that less than one-quarter of the world's population living in the developed countries presently consume an average of three times the meat per capita compared to the developing countries average. Yet, it is in developing countries where the largest annual increases in the aggregate consumption of animal products are occurring. Delgado et al. (1999) project that aggregate meat consumption in the developing countries will grow by nearly 100 million metric tons (MMT) between the early 1990s and 2020, whereas the corresponding figure for developed countries is 16 MMT. Projected growth rates vary widely

[2] At the farm level, this category includes miscellaneous products, including hides and skins from all animals. This fact will become important when we look at recent developments in China's livestock trade.

among different parts of the developing world, with China leading the way based on a doubling of the total per capita quantity of meat consumed.

While most studies focus on the demand-side determinants of these changes, the supply of food products is also experiencing significant changes and facing new challenges in developing countries, including competition with rapidly growing manufacturing activity for scarce labour and capital, local environmental constraints, innovation in international transportation, policy reforms and relative levels of productivity in livestock production. Coyle et al. (1998) explore the relative importance of supply and demand-side forces in explaining recent changes in the composition of trade. They find that the demand side is relatively more important. However, their analysis abstracts from sector-specific productivity changes and the authors cite this as one of the possible explanations for the large, unexplained residual in their predicted shift from bulk to high value food trade. The particular pattern of livestock productivity growth and the speed at which developing countries are adopting new technologies and potentially converging to productivity values of the most productive regions could also play a central role determining future trends in livestock and food trade.

Several studies explore trade issues related to China's livestock sector using different approaches and models. Studies evaluating China's comparative advantage in livestock production conclude that this country is competitive in livestock production. Tuan and Peng (2001) estimate indicators that incorporate the concepts of domestic resource costs, net social profitability and effective rate of protection to show changes in comparative advantage and trade competitiveness of China's livestock products. According to their results, China's production of hogs, beef cattle and broilers has been competitive in trade and, hence, China had a comparative advantage in producing those products, although hog production has received positive protection while beef cattle and broiler production received negative protection. Hayes and Fuller (1999) used US input–output coefficients and China's current resource endowments in an application of the Heckscher–Ohlin–Vanek, comparative advantage model to get a sense of the degree to which current consumption, production and trade patterns in Chinese agriculture deviate from optimal levels, as determined by US technology. They show that China's capital use today is many times lower than it would be in the presence of US technology, whereas labour use is much higher. If China were to employ US technology, the authors predict that it would be producing cash crops, fruits and vegetables and pork and poultry for export, and importing enormous quantities of land intensive crops as wheat, feed grains and rice.

Rae and Hertel (2000) test for convergence in livestock productivity among the Asia-Pacific economies. They find evidence of recent convergence in productivity levels for pig and poultry production, but generally not in ruminant production. For China, significant 'catch-up' to North American levels was demonstrated in poultry and pigs, and for non-ruminant production the speed with which the technology gap has been closing was greatest for China. Rae and Hertel (2000) then proceed to draw out the potential implications for trade in livestock and grains. However, an important limitation of their study is that their productivity projections are simple extrapolations of past trends. Clearly, there is a limit to the amount of 'catching-up' that can occur, and this needs to be taken into account when making such projections.

Studies that make projections of the Chinese economy to future years show contrasting results and in many cases suggest that China's present advantage in livestock production might change in the future. The Rosegrant et al. (2001) projections of world agriculture using the IMPACT model show that China will experience the largest projected rise in meat imports, from near trade balance in 1997 to 4 million tons of imports in 2020. They predict that poultry and pork products will drive this increase, with poultry imports rising from virtually zero in 1997 to 2 million tons in 2020 and pork imports rising 1 million tons from a trade surplus in 1997 to a trade deficit of 1 million tons in 2020. Huang et al. (2000), use a partial equilibrium model for China' s food demand, supply and trade analysis, to make projections to 2005 with alternative scenarios. They find that, with no policy changes, the supply of most animal products in China will meet the increase in the domestic demand for these commodities and the change in net trade over the period of 2000–2005 will be marginal. They also find that trade liberalisation will tend to increase the prices of animal products in China's domestic market. Consequently, there will be an expansion in the production of animal products particularly the production of pork. Delgado et al. (1999) make projections for 2020, and compared with 1993 they see net exports declining for pork but increasing in the case of poultry. Rutherford (1999) forecasts self-sufficiency of meat in several Asian countries to the year 2010 using forecasts of the likely future balances between domestic production and consumption of meat. He concludes that China, together with Pakistan and amongst others Vietnam, are likely to be self-sufficient with respect to ruminant meat and project an improvement in the long-term, non-ruminant self-sufficiency estimates in China. OECD (2002) projects declining exports of pork and increasing net imports of poultry meat to 2007.

Also relevant to the issue of China's trade in livestock products is the literature about China's recent accession to the WTO. Analysing policy changes in China due to WTO accession and projecting the economy to 2020, Huang and Chen (1999) predict that, as a result of accession, China will become a major exporter of pork and poultry (and an importer of corn). In contrast with these results, Fuller et al. (2001) using a multi-market world agricultural model predict large meat imports as a result of China's entry to WTO. They argue that their results are consistent with the fact that it is currently 3.9 times more costly to ship grain in its raw form than an equivalent quantity of grain shipped as animal protein. The study by Huang and Rozelle (2002) uses a partial equilibrium model of Chinese agriculture to analyse the impact of China's WTO accession with projections to 2005. Their baseline projections, without policy changes, show that the livestock sector will still be a net exporter, but the level of net exports will be minimal due to higher feed prices that result from limited access of producers to grain imports. Their trade liberalisation scenario results predict an increase in the price of livestock products and a decrease in the price of feed, stimulating increased production, reduced consumption and expanding increased net exports.

The results from the literature presented above are by no means conclusive concerning the future role of China in international livestock markets. In fact, many of these studies seem to contradict one another. Part of the reason for this is due to the fact that each one emphasises a different aspect of the problem. In addition, it must be recognised that any such projections are fraught with uncertainty and ideally the uncertainty would be formally acknowledged and systematically incorporated into the analysis. In this paper, we seek to address these divergent predictions by building on previous work (Nin et al., 2002) to improve on the Rae/Hertel effort in two ways. First, we provide a detailed analysis of productivity growth in China's pig and poultry production and we decompose historical productivity growth, as well as forecasts for future growth, into two parts: an underlying trend in the technical frontier and individual countries' movement towards that frontier. In addition, we formally introduce uncertainty into the analysis by generating a distribution of productivity forecasts that allow us to derive confidence intervals on our projections for the trade balance of livestock products.

The paper is organised as follows. The next section presents a historical analysis of non-ruminant livestock productivity growth world-wide, with a special emphasis on China. We decompose historical productivity growth into catching-up and technical change components. The third section presents the productivity forecasts for China. This is followed in the fourth section by a discussion of the macroeconomic scenarios for the year 2010. Section 5 presents an analysis of China's trade in livestock products in the face of supply uncertainty, while Section 6 analyses the impact of China's macro-economic growth on meat trade balances. The last section presents conclusions and highlights findings from this study.

2. Productivity growth 1961–1997

2.1. Technical change and 'catching-up'

As discussed in the previous section, our focus on the livestock sector is of special interest in light of the changing consumption patterns in China. In this context, it is interesting to examine; how fast China has been catching-up to productivity levels in developed countries?

The technological catch-up effect discussed by Abramovitz (1986) is based on the possibility of imitating technologies developed elsewhere at low cost, allowing poor countries to grow faster than rich ones, other things being equal. This is because countries with low levels of productivity (followers) are able to bring into production a large backlog of unexploited technology and have then the opportunity to 'catch up' to the frontier. The further away from the frontier a country finds itself, the greater the potential for such catch-up. According to Abramovitz, productivity growth in the leading region is governed and limited by technical change. The larger the technological and, therefore, the productivity gap between leader and follower, the stronger the follower's potential for growth in productivity; and, other things being equal, the faster one expects the follower's growth rate to be. On the other hand, the catch-up process is inherently self-limiting because as a follower catches up, the rate of productivity growth declines. The present study utilises this idea about the diffusion of new technologies from leaders to followers.

Data on the global livestock sector are drawn from FAOSTAT (2000), the statistical database of the Food and Agriculture Organisation of the United Nations (FAO). Because we do not have a complete inventory of inputs allocated to livestock production, we use the same partial factor productivity measure used by others, namely "output per head of livestock". From this point on, we will refer to our measure of partial factor productivity simply as 'productivity'. However, it should be borne in mind that this measure is fundamentally limited and will be inaccurate in the face of substantial factor substitution (Capalbo and Vo, 1988) and jointness in production. In a related paper, Nin et al. (2003) show that the simple output per head measure appears to result in an overestimate of China's historical livestock productivity growth. This is due to the fact that it fails to take into account the increased feed, labour and capital per animal required in the modern livestock production systems.

Constant returns to scale are assumed in the production function for each country, implying that the scale effect of productivity growth, relevant at the firm level (Oude Lansink et al., 2000), vanishes at the industry level. In defence of this assumption, we appeal to the work of Diewert (1981), who shows that if there is free entry and exit into an industry in which producers competitively minimise cost, and if the output level at which minimum average cost is reached is small relative to total industry output, then the industry cost function will be approximated by a cost function linear that is in output, and therefore dual to a constant returns to scale production function.

Following Färe et al. (1994) we decompose our measure of historical productivity growth into two parts: an underlying trend in the technical frontier and individual countries' movements toward that frontier (catching-up). With a single input x (animal stock) producing a single output y (meat), the technology is represented in Fig. 2 by the production frontier S_t for period t and by the frontier S_{t+1} for period $t+1$. The frontier is the boundary of technology in each year and is defined as the maximum feasible output given a quantity of input x. Fig. 2 also shows two production points representing animal stock and production for a specific country in period t (x_t, y_t) and $t+1$ (x_{t+1}, y_{t+1}). A partial factor productivity (PFP) measure in period t and $t+1$ for this country can be defined respectively as: $\text{PFP}_t = y_t/x_t$ and $\text{PFP}_{t+1} = y_{t+1}/x_{t+1}$. Similarly, productivity on the frontier in period t and $t+1$ for the same amount of input used in this country is defined as $F_t = y_t^*/x_t$ and $F_{t+1} = y_{t+1}^*/x_{t+1}$. Using these productivity estimates, a simple index of productivity growth between period t and $t+1$ for our problem country is estimated as: $\text{PGI}_{t,t+1} = \text{PFP}_{t+1}/\text{PFP}_t$. This index takes values greater than one if productivity between t and $t+1$ is growing and values less than one if productivity is shrinking. Productivity growth as measured by this index can be decomposed in a catching-up (efficiency) and a technical change effect by simply multiplying the right hand side of the previous equation by $(F_{t+1}/F_t)(F_t/F_{t+1}) = 1$ with F be-

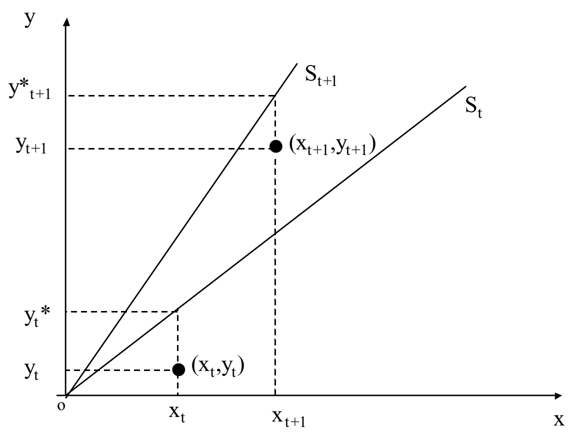


Fig. 2. Partial factor productivity growth and decomposition.

ing productivity at the frontier as defined above. Rearranging terms we obtain:

$$\mathrm{PGI}_{t,t+1} = \left[\frac{\mathrm{PFP}_{t+1}/F_{t+1}}{\mathrm{PFP}_t/F_t}\right]\left[\frac{F_{t+1}}{F_t}\right]. \qquad (1)$$

The first term on the right hand side of Eq. (1) is an index measuring catching-up as the rate at which the problem country is approaching or moving away from the frontier. This is the case because the ratios PFP_t/F_t and $\mathrm{PFP}_{t+1}/F_{t+1}$ measure how far the country is from the frontier in period t and $t+1$, respectively. If the country is catching up to the frontier, this index will exceed one. The second term of Eq. (1) is an index of technical change, measuring productivity growth in the frontier between t and $t+1$. Values greater than one for this index imply that the sector is experiencing technical progress.

2.2. Productivity growth and its components 1961–1997

We use production and animal stock data from FAOSTAT for ten regions over the 1961–1997 period in our historic analysis to construct the productivity indexes for China, Korea, South East Asia, Latin America, Sub-Saharan Africa, Australia, New Zealand, US–Canada, European Union (EU-15) and Japan. It should be noted that the credibility of official Chinese livestock data has been called into question as reported in USDA/FAS (1998) and Fuller et al. (2000). Given that there are no corrected data for the relevant period considered here, we use the FAOSTAT data derived from official Chinese statistics, implying that this will likely result in overestimates of the productivity projections to 2010.

Table 1 reports the average annual rate of productivity growth and its components over the sample period, for each country/sector pair in the sample, reported as a ratio of productivity in the year $t+1$ and t. The contrast between productivity growth in pig and poultry production is noteworthy. Productivity in poultry production has been growing at an average rate of 2.7% a year during 1961–1997 compared with only 1.7% in the case of pig production. There is also a significant contrast in the contribution of technical change and catching-up to productivity growth in these sectors. Movement in the frontier has dominated productivity growth in poultry production over the past three decades, while catching-up has been the driver of productivity growth in pig production, world-wide. The rate of technical change in poultry production for 1961–1997 has been, on average, 2.4%, increasing to 3% over the 1991–1997 period. This contrasts with pig production, where technical change was only 0.7% per year over the 1961–1997 period, slowing to 0.5% in the 1990s.

Set in this global context, China's productivity performance has been nothing short of remarkable. China

Table 1
Average annual productivity growth rate (%)

	Pigs				Poultry			
	Productivity		Catching-up		Productivity		Catching-up	
	1991–1997	1961–1997	1991–1997[a]	1961–1997[b]	1991–1997	1961–1997	1991–1997[a]	1961–1997[b]
China	3.0	4.2	2.6	3.7	11.8	2.9	8.6	0.5
Korea	0.2	2.5	−0.2	1.8	2.8	3.1	−0.2	0.7
South East Asia	0.7	2.0	0.3	1.2	0.0	1.3	−2.9	−1.1
Latin America	2.5	1.2	2.0	0.4	1.9	3.2	−1.0	0.8
Sub-Saharan Africa	0.7	0.2	0.2	−0.5	0.2	0.9	−2.7	−1.4
Australia	0.8	1.6	−0.3	0.9	1.0	3.0	−1.9	0.6
New Zealand	1.0	1.9	0.5	1.1	2.1	5.0	−0.9	2.5
US–Canada	0.9	1.0	0.5	0.2	3.0	2.1	0.0	0.0
EU-15	0.9	0.8	0.4	0.0	2.1	2.9	−0.9	0.6
Japan	−0.1	1.6	−0.5	0.8	−0.4	2.2	−3.3	−0.2
Mean	1.1	1.7	0.5	0.9	2.4	2.7	−0.7	0.3

[a] The annual average rate of technical change for the period 1961–1997 was 0.5% for pigs and 3.0% for poultry.
[b] The annual average rate of technical change for the period 1961–1997 was 0.7% for pigs and 2.4% for poultry.

exhibits the highest rate of productivity growth over the entire period for pig production, with most of this rapid productivity growth due to 'catching-up' which proceeded at an average annual rate of 3.7% between 1961 and 1997. As can be seen from the 1991–1997 figures for pig productivity in Table 1, the growth rate for China, as with the world as a whole, moderated somewhat in the last decade. This contrasts sharply with the experience of China's poultry sector. Here we see an average annual rate of productivity growth over the 1961–1997 period which mirrors the global average, with catching-up contributing relatively little to the total 2.8% annual productivity growth rate. However, when we focus just on the 1991–1997 period, we find an astounding 11.8% average annual productivity growth rate for poultry, of which the lion's share (8.6%) is due to catching up.

In addition to looking at long run averages, it is also instructive to examine the time path of cumulative indexes calculated as the sequential multiplicative products of the annual index defined in Eq. (1). Fig. 3 displays these charts for pig and poultry production in China. In pig production, shown in Fig. 3a, the curve representing the catching-up index is above the technical change curve showing that productivity growth since 1961 is largely due to 'catching-up'. After an initial period of catching-up between 1961 and 1965, we see that China fell away from the frontier during 1966–1978, the years of the Cultural Revolution. The catching-up process in pig production was resumed with the de-collectivisation beginning in the late 1970s and early 1980s (Lin, 1992).

The time paths of indexes for poultry production are shown in Fig. 3b. Here, we see the technical change curve lying above the catching-up curve until the decade of the 1990s. During this period, technical change was the driving force behind growth in poultry productivity. However, since 1990, poultry production in China has been catching-up at a remarkable pace. This is shown by the sharp upturn in the catching-up curve at the beginning of the 1990s resulting in an increasing importance of this component in explaining productivity growth. The process of productivity growth in poultry production is quite different from that of pigs, and appears to be related to the second part of the rural reforms that began in the late 1980s and 1990s (De Brauw et al., 2000).

In summary, our historical analysis suggests that significant modernisation of the pig sector in China commenced around a decade earlier than was the case for poultry. In practice, much of this productivity growth derived from changes in the structure of pork production, where output has gradually shifted from individual farm households using traditional technology (95% of output in the mid-1980s versus 80% in 1996) to specialised livestock-producing households and commercial firms applying modern technology (USDA/ERS, 1998). Feed use and efficiency has also changed dramatically for both pig and poultry production in China. As recently as the early 1980s,

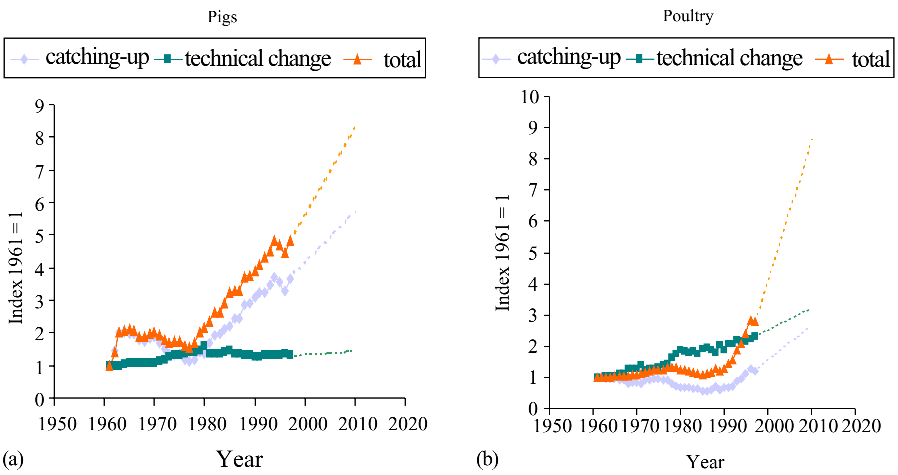


Fig. 3. Cumulative productivity growth rates in China.

most of China's domestic animals were fed in the backyards of farm households and, depending on the type of animal, feed ingredients generally included low-quality grains, table scraps, tubers and other crop by-products and residues. With government reforms in the mid-1980s, large amounts of feed grains, as well as soybean and rapeseed meal began to be used in animal feed (Tuan and Peng, 2001). This too, has contributed to the remarkable productivity record in recent years.

3. Productivity forecasts

By decomposing productivity growth into the technical change and catching-up components, we are able to refine our forecasts of future productivity growth in the pig and poultry sectors. As is seen from the pig productivity growth rates in Table 1 and Fig. 3a, a simple, trend-based extrapolation of past growth rates is likely to be too optimistic given the tendency of catching-up to diminish as a country approaches the frontier. We now turn to the two distinct approaches we have for projecting these two components of productivity growth.

3.1. Modelling catching-up and technical change

In the case of catching-up, we assume that the observable growth in productivity can be modelled as a diffusion process of new technologies. Previous studies have shown (Griliches, 1957; Jarvis, 1981) that the cumulative adoption path follows an S-shaped curve. Initially, productivity changes slowly because new innovations take some time to be adopted—usually, it is necessary to adapt the new technologies to different local conditions. After this, a period of rapid growth is expected as the risk of applying the new technology is reduced. Finally, productivity growth slows when the bulk of the producers who will find the technology profitable have adopted it, and the process reaches a stable ceiling. We specify the following logistic function to represent the catching up process for each of the regions in the sample:

$$Z_{it} = \frac{K_t}{1 + \mathrm{e}^{-\alpha - \beta t}}. \tag{2}$$

In this equation, Z_{it} corresponds to the productivity value of country i on period t. The parameters α and β determine the shape of the logistic relationship for each region. A positive and significant β will be taken as evidence that this particular region is catching-up to the frontier. A high positive value of β indicates that it will take a shorter time to get to the frontier while a low value of β implies a longer period of adjustment. The parameter K_t determines the ceiling, or maximum productivity level, to which the region in question is expected to converge. The ceiling in our case is not constant over time but varies with technical change. In estimating the logistic relationship, we use observed values for K_t. These are computed as the maximum productivity value for each sector across all countries in the sample in year t. Nonetheless, while we are able to use actual observations on the frontier in estimating the logistic function, when it comes to forecasting, we need some way of predicting the evolution of this productivity ceiling. We choose to make this a simple exponential function of time, as follows: $K_t = \mathrm{e}^{\mu + \gamma t}$. If a region is not catching-up, the logistic model is likely not a good representation of the pattern of productivity growth. In these cases, a simple exponential function is used to model productivity growth over time (either growth or decay).

3.2. Data and econometric results

Data used are from FAOSTAT as described in the previous section. Results from estimation of the logistic functional form for China are provided in Table 2. We identify two structural change points in the pig productivity series (1965 and 1979) and one structural change point in the poultry series (1989). These indicate the existence of different periods of catching-up and productivity growth as shown by the productivity index in our historical analysis. Note once again the relatively earlier beginning of the catching-up process in pig production with higher relative productivity values than in poultry production. The estimated parameters of the logistic curves for pig and poultry productivity also indicate a slower rate of catching-up in pig production under current conditions. Whereas it would take 50 years to increase pig productivity from 10 to 90% of the frontier value under the current diffusion process, the comparable figure for poultry is just 36

Table 2
Parameters[a] and regression statistics for China's non-ruminant productivity assuming a logistic diffusion process

	R^2	α	*t*-statistic	β	*t*-statistic	Period[b]
Pig production	0.83	−1.73	−7.34	0.23	3.21	1961–1965
		−0.41	−5.12	−0.06	−10.02	1966–1978
		−2.90	−12.41	0.09	11.12	1979–1997
Poultry production	0.93	−1.07	−22.87	−0.02	−8.59	1961–1988
		−5.49	−16.74	0.13	12.79	1989–1997

[a] The parameters of the logistic function are estimated using the following transformation: $Y_{it} = \log[Z_{it}/(K_t - Z_{it})] = \alpha + \beta t$.
[b] Structural change with breaking points in 1966 and 1979 for pig production and 1989 for poultry production.

years. Table 3 shows the results of the estimation procedure for the productivity frontier for pigs and poultry. The frontier in pig production is defined by Japan during most of the historic period, but this country shows a negative growth in output per head from our 1995 base. Projecting productivity of the frontier regions (Japan, US–Canada and the EU-15) we find that the EU-15 becomes the most productive region and defines the frontier in 2010, with productivity levels similar to those in US–Canada. This implies a slight acceleration of technical change in the coming years, as compared with the historical values. In poultry production, US–Canada, New Zealand and Australia have been producing at the frontier for the last two decades. We project a slow-down in Australia's productivity growth, and consequently the frontier in the future will be set by US–Canada and New Zealand.

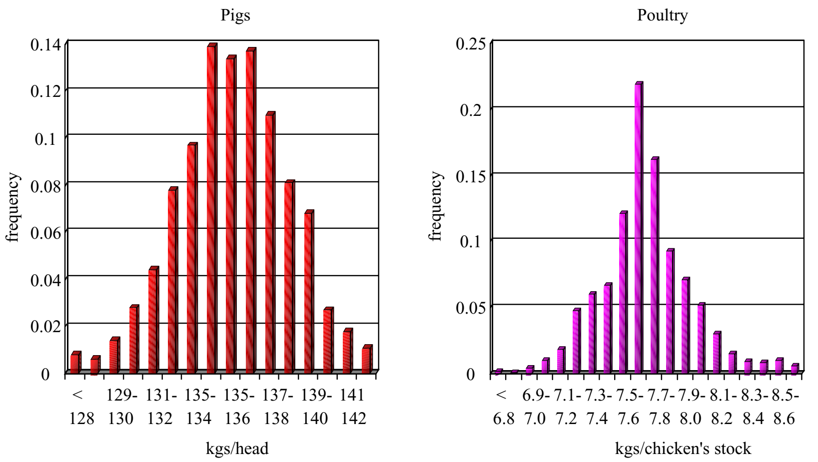
3.3. A distribution of productivity forecasts

For purposes of forecasting China's future livestock productivity and trade, it is useful to have some idea of the possible distribution of productivity outcomes, not just a point estimate. A distribution of the forecasts for each sector was approximated using the Efron bootstrapping method (Dorfman et al., 1990). Fig. 4 shows the histograms of the 2010 projected productivity values for China. Table 4 summarises the mean, standard

Table 3
Parameters and regression statistics for the frontier regions in non-ruminants productivity assuming an exponential functional form

	R^2	μ	*t*-statistic	γ	*t*-statistic	Period[a]
Pig production						
Japan	0.94	4.32	125.4	0.041	16.7	1961–1976
		5.11	258.6	−0.070	−9.8	1977–1997
US–Canada	0.93	4.48	159.9	0.017	3.7	1961–1970
		4.64	37.4	−0.002	−0.3	1971–1976
		4.52	159.9	0.011	10.27	1977–1997
EU-15	0.71	4.62	384.6	0.014	6.1	1961–1968
		4.58	442.9	0.010	16.85	1969–1985
		4.43	105.3	0.014	10.37	1986–1997
Poultry production						
Australia	0.79	0.87	14.0	0.046	8.48	1961–1979
		1.93	11.74	−0.004	−0.61	1980–1988
		1.89	10.99	0.001	0.18	1989–1997
US–Canada	0.99	1.18	114.9	0.022	16.91	1961–1973
		1.13	101.5	0.024	52.21	1974–1993
		1.10	5.71	0.026	4.80	1994–1997
New Zealand	0.93	0.20	3.31	0.056	5.39	1961–1970
		1.04	3.64	0.017	0.81	1971–1977
		1.09	15.56	0.025	9.99	1978–1997

[a] Periods with different estimated parameter values due to the existence of structural change in the series.



Mean	S.D.	Minimum	Maximum
136	2.9	124	146

(a)

Mean	S.D.	Minimum	Maximum
7.7	0.3	6.8	8.7

(b)

Fig. 4. China’s bootstrapped distribution of productivity forecasts.

deviation and implied growth rates for productivity in these two sectors for all regions in our sample. Productivity in poultry is expected to grow much faster than for pigs (9.5% versus 3.9% per year) over the forecast period in China. This is fuelled by a higher rate of growth in the poultry frontier as well as continued rapid catch-up in poultry productivity. In the case of pigs, catching up is slower as China reaches 80% of the productivity value at the frontier in 2010. This, coupled with slow growth of the frontier itself, translates into slower overall productivity growth. We now turn to a framework that will permit us to draw the implications of these productivity projections for world trade.

4. Projections to 2010

4.1. Trade model

Following Rae and Hertel (2000), we incorporate our projections of productivity growth into a modified version of the GTAP applied general equilibrium model (Hertel, 1997) to project national and regional production, consumption and trade flows between 1995 and 2010. Our analysis has abstracted from changes in trade policy. China still has relatively high tariffs on meat imports, and these will be reduced upon China’s entry to the WTO. This could also have an important impact on China’s future role in international livestock products trade.

For purposes of this study, several modifications are introduced to the standard GTAP model. First, we follow Rae and Hertel (2000) introducing a unitary elasticity of substitution between feedstuffs in livestock production. Several minor modifications are introduced to the standard model to make it more suitable for its use in growth projection simulations with the most important being the assumption that regional investment is constrained to increase in proportion to regional capital stock as would be the case in steady-state equilibrium (Dimaranan, 1998).

The GTAP framework distinguishes sectors by their intensities in five primary production factors: land (agricultural sectors only), natural resources (extractive sectors only), capital, and skilled and unskilled labour. In trade, products are differentiated by country of origin, allowing bilateral trade to be modelled, and bilateral international transport margins are incorporated and supplied by a global transport sector. The model is solved using GEMPACK (Harrison and Pearson, 1996).

The 50 commodities in the version 4 GTAP database have been aggregated up to 14 commodity groups, of which 6 commodities (rice, wheat, other grains, oil crops, other crops and processed food) compete for

Table 4
Productivity forecasts (kg per head) and productivity growth decomposition (%) 1995–2010

	Productivity forecast in year 2010				Annual rates of growth (%)		
	Mean	Standard deviation	Maximum value	Minimum value	Productivity 1995	Total growth	Catch-up[a]
Pigs							
Logistic forecasts							
China	136	2.90	149	123	77	3.9	2.5
Korea	167	2.39	178	156	124	2.0	0.6
South East Asia	133	2.89	146	120	85	3.0	1.6
Australia	163	2.71	175	151	132	1.4	0.0
New Zealand	153	3.14	167	139	118	1.7	0.4
Latin America	67	1.83	75	58	45	2.6	1.3
Sub-Saharan Africa	50	1.54	56	43	33	2.8	1.4
ROW	123	2.99	137	110	88	2.2	0.9
Exponential forecasts							
Japan	117	1.47	123	110	129	−0.7	−2.0
US–Canada	156	2.93	169	143	131	1.1	−0.2
EU-15	168	2.36	178	157	137	1.4	0.0
Poultry							
Logistic forecasts							
China	7.7	0.28	9.0	6.4	2.0	9.5	7.1
Korea	9.1	0.37	10.7	7.5	4.4	5.0	2.7
EU-15	8.2	0.07	8.5	7.9	6.3	1.7	−0.5
Latin America	7.5	0.28	8.7	6.2	4.7	3.1	0.9
Exponential forecasts							
Japan	4.1	0.05	4.3	3.8	4.0	0.0	−2.2
South East Asia	1.8	0.06	2.0	1.5	2.1	−1.0	−3.2
Australia	6.9	0.30	8.3	5.5	7.1	−0.2	−2.4
New Zealand	10.3	0.42	12.2	8.4	7.0	2.6	0.3
US–Canada	11.0	0.28	12.2	9.7	7.4	2.7	0.4
Sub-Saharan Africa	1.4	0.01	1.4	1.3	1.3	0.4	−1.8
ROW	0.9	0.07	1.2	0.6	2.1	−5.2	−7.3

[a] Technical change for the period 1995–2010 was projected to grow at an annual rate of 0.9% for pig production and at an annual rate of 2.24% for poultry production.

use in the feedstuffs composite. Meat producing livestock farming is represented by two aggregates: beef cattle (i.e. ruminant livestock) and other livestock (i.e. non-ruminants). These farming sectors provide inputs to the beef processing (ruminant meat) and other meat (non-ruminant meat sectors). All remaining production sectors are aggregated into manufactures, services or other natural resource based commodities. The GTAP countries/regions are aggregated to match those reported in Table 1.

4.2. Parameters

The parameters of the standard GTAP model have also been modified for this study. Because of the extremely rapid growth in China, coupled with its critical role in determining global meat demand, we have devoted special attention to the income elasticity of demand for meat in China. In the standard GTAP model, this value is set at 1.10 in 1995. This reflects the fact that a majority of the population in China is still quite poor, and livestock products are still a luxury for them. However, as Yu et al. (2004) have shown, this elasticity is expected to fall with continued income growth. Accordingly, we have used Yu's estimated AIDADS demand system to obtain an average value for this elasticity over the 1995–2010 projections period (0.89). We recalibrate the demand system for China to reproduce this value. This recalibration is particularly important since, as Yu et al. (2004) show, the Constant Difference of Elasticities demand system used in GTAP tends to prevent luxury goods from becoming necessities as income grows.

Following earlier long term projections with the GTAP (e.g., Rae and Hertel, 2000) we double the values of the standard trade elasticities. Gehlhar et al. (1994) and Liu et al. (2000) provide evidence that increasing these elasticities improves the fit of the model to long run structural changes in trade.

4.3. Macroeconomic projections

Following the work of Gehlhar et al. (1994), projections are made through exogenous shocks to each region's endowments of physical capital, skilled and unskilled labour, population and technology. Forecasts for population, investment (capital stock), and labour force are from a base case scenario developed from World Bank forecasts (Walmsley et al., 2000). This base case scenario reflects the changes expected to occur in the world economy through the year 2010. Projections were obtained for gross domestic product, gross domestic investment, population, skilled labour and unskilled labour. The stock of farmland in each region is simply held constant. Productivity growth for the non-livestock sectors is obtained endogenously using a region-specific technical change variable.

4.4. Characterising uncertainty in non-ruminant productivity forecasts

As there is considerable uncertainty associated with the productivity forecasts (recall Fig. 4 and Table 4), we seek to characterise the extent to which this uncertainty translates into uncertainty about China's non-ruminant trade balance. We begin with the bootstrapped non-ruminant productivity distributions, which we summarise with symmetric triangular distributions for purposes of sampling. This triangular distribution is centred on the mean of the bootstrapped distribution of productivity forecasts ($\bar{Z}$) and has support $\bar{Z} - W$ to $\bar{Z} + W$, where W is the extreme value from the bootstrapped distribution (see also Fig. 4). We introduce uncertainty in China's non-ruminant productivity growth[3] using the Gaussian quadrature approach to Systematic Sensitivity Analysis (SSA) proposed by DeVuyst and Preckel (1997). The procedure, as automated by Arndt (1996) and Arndt and Pearson (1998) draws a weighted sample from this estimated distribution of productivity growth rates, using the resulting model simulations to generate the means and standard deviations reported below. The Gaussian quadrature approach has the advantage of attaining a high degree of accuracy, while requiring limited number of solves of the model (De Vuyst and Preckel, 1997). In this case, the Gaussian quadratures are discrete distributions whose first three moments are identical with those of the continuous distributions. The SSA procedure implemented is based on Stroud's quadrature (Arndt, 1996).

Following Rae and Hertel (2000) we apply the productivity shocks to both value-added and to the feed composite, in order to maintain a constant ratio of feed use per animal. Therefore, under positive productivity growth, feed consumption per unit of output (the feed conversion ratio) will decrease. There is considerable evidence to support the assumption of more efficient feed conversion as discussed in Rae and Hertel (2000). The trend in China is towards development of specialised livestock production units and larger, more intensive management systems that will contribute to a declining demand for feedgrains per kilogram of meat production.

5. Implications for China's livestock trade

According to the mean projection (Table 5), China's trade balance in non-ruminant products will deteriorate by 2010 with China becoming a net importer in the non-ruminant sector (see also Fig. 1). Continued rapid investment and growth in the Chinese economy, under this base case scenario, leads to a deterioration in China's trade balance in agricultural products, and to an increase in its specialisation in manufactures and services.

In order to help understand what is behind these changes in China's non-ruminant trade balance in 2010, we also report the associated changes in exports, imports, domestic sales and output (annualised

[3] We have previously introduced uncertainty in non-ruminant productivity in the non-China regions. Since this makes little difference to China's livestock trade, and it significantly complicates the analysis, we have left this out of the present paper.

Table 5
Mean and standard deviations of the changes in China's trade balance when uncertainty is introduced in China's non-ruminant productivity projections (mUS$, 1995)

	Trade balance		Change 1995–2010	Standard deviation of the change
	1995	2010		
Base case				
Non-ruminants	1651	−1093	−2744	1144
Other agriculture	−2096	−50372	−48276	241
Manufactures	52611	229843	177233	1565
Services	239	45774	45535	853
Total	52404	224152	171748	
Slow growth[a]				
Non-ruminants	1651	12994	11344	2108
Other agriculture	−2096	−14701	−12605	69
Manufactures	52611	122896	70286	2426
Services	239	10767	10529	617
Total	52404	131956	79553	

[a] GDP growth in China: 5.55% per year and capital growth adjusting to maintain productivity growth in non-livestock at the same level of that in the rapid growth scenario.

rates) in Table 6. From the section labelled 'base case' we see that agricultural imports grow strongly over this period, while exports are flat (non-ruminants) or declining (other agriculture). Non-ruminant output growth is faster than for other agriculture, but slower than that in the non-agricultural sector.

Table 6
Annual growth rate for China's exports, imports, domestic sales and output (%)

	Exports	Imports	Domestic sales	Output
Base case				
Non-ruminants	0.4	10.6	6.8	6.6
Other agriculture	−5.9	14.0	4.8	4.5
Manufactures	7.9	6.1	9.0	8.9
Services	9.9	4.8	8.7	8.8
Total	8.0	6.6	8.5	8.5
Slow growth[a]				
Non-ruminants	11.6	1.8	5.9	6.2
Other agriculture	6.7	6.9	4.4	4.3
Manufactures	5.4	4.7	6.1	6.0
Services	6.1	4.5	5.8	5.8
Total	5.6	4.8	5.8	5.8

[a] GDP growth in China: 5.55% per year and capital growth adjusting to maintain productivity growth in non-livestock at the same level of that in the rapid growth scenario.

The standard deviations in Table 5 give us a good idea of the sensitivity of these findings to uncertainty in China's non-ruminant productivity forecasts. While the mean non-ruminant trade balance in 2010 is 1093 million US$ (mUS$), the standard deviation is 1144 mUS$. Therefore, we are not in a position to state definitely that China will be a net importer of non-ruminants in 2010. Indeed, applying Chebychev's inequality, the 95% confidence interval on the 2010 trade balance varies from 4055 US$ to 6241 mUS$.

6. The role of macroeconomic uncertainty in China

The rate of growth of productivity in the non-ruminant livestock sector is not the only source of uncertainty in our productivity forecasts. Growth in the other sectors of the Chinese economy, and indeed the Chinese overall rate of macroeconomic growth, is also uncertain. China has maintained an extremely rapid rate of economic growth over the past decade. Will this continue into the future? What impact would a slowdown have on livestock trade?

Angus Maddison (1998) has studied this question in some detail. Maddison highlights two periods in the post-war growth of the world economy. Firstly, 1952 to 1978, in which Japan and the advanced capitalist countries rapidly caught up to the US. Although China's real income during this period grew faster than ever before, its growth was less than the world average. In contrast, over the 1978–1995 period, world economic growth was much slower, with a sharp decrease in the total factor productivity performance of the US and the other advanced capitalist countries, while China and the East Asian economies were the most dynamic component of the world economy.

Comparing the baseline projections for the period 1995–2010 used here with the projections for 1995–2015 made by Maddison, we conclude that both projections show similar relative growth across most regions, with the baseline projections being somewhat more optimistic in terms of growth of the world economy in the coming decade. The most important difference between both sets of projections is in China's GDP forecast. The GDP forecast in the baseline projections assumes that China will exhibit a similar growth rate to that of the past two decades, continuing to rapidly catch-up to the frontier. Maddison agrees that China is likely to grow faster than most other Asian countries because: (a) its level of real income/productivity is quite low; (b) it has sustained a high growth trajectory for two decades and has proved capable of maintaining high rates of investment in physical and human capital; and (c) it was less exposed to the shocks which other dynamic Asian countries sustained in 1997. However, he argues that future growth is unlikely to be as fast as in 1978–1995 because China faces major problems in reforming state industry, fiscal and monetary policy; has eroded some of the once-for-all gains from previous liberalisation; and faces a slowdown in the Asian markets.

In order to capture the effect of a slower overall rate of economic growth in China, we conduct an additional simulation where we assume that China's GDP will grow at 5.5% annually as projected by Maddison, as opposed to the projection of 7.8% per year. We then analyse the effect of this slower rate of growth on production, demand and trade of non-ruminant products. Of course, there are a number of alternative ways to implement this slow-down. Given our emphasis on productivity forecasts, we leave those unchanged and implement this slow-down entirely through a reduction in the rate of capital accumulation.[4]

The impact of a slow-down on China's economic growth is reported in the bottom panels of Table 5. The differences with the base case results are striking. With China's GDP growing at a rate of 5.5% instead of the 7.8% projected in the first scenario, China is transformed into a net exporter of non-ruminant products. More important, this outcome is robust to uncertainty in non-ruminant productivity inherit in our forecasts of that variable. Comparing the mean value of the trade balance change (11,344 mUS$) with the standard deviation of this random variable (2108 mUS$), and applying Chebychev's inequality, we conclude that even with low rates of non-ruminant productivity growth, China is expected to be a net exporter of non-ruminant products in 2010.

The bottom panel of Table 6 helps to explain the sensitivity of the non-ruminant livestock trade balance to changes in macroeconomic growth. An economy-wide slowdown affects livestock trade on both the supply and the demand sides. Lower income growth obviously reduces domestic demand, and hence domestic sales and imports. However, lower productivity growth in the non-agricultural sectors also means less competition for scarce factors of production. Non-agricultural production grows much less rapidly under this scenario. This means that more resources are available for livestock production, thereby enhancing supply and further eroding the need for imports.

7. Summary and conclusions

This paper represents an attempt to better understand the growth and diffusion of productivity in the livestock sector and its implications for livestock trade. Our analysis of past productivity performance in the Chinese pork and poultry sectors serves as a basis for forecasting future developments. Having started the modernisation process a decade earlier, pork output per head is already at two-thirds of North American levels. On the other hand, poul-

[4] We have also implemented the slow-down as a reduction in productivity growth in the economy outside of the non-ruminant sector. This made little difference in our findings.

try productivity in China is only about one-third of that in North America. However, the growth in poultry productivity is accelerating. We project poultry output per head to grow by 9% per year out to 2010.

In order to assess the likely consequences of future changes in livestock productivity on international trade in livestock and related products, we used a modified version of the GTAP model of global trade to make projections to the year 2010. Uncertainty in China's future productivity growth rates was also taken into account. In our base case we find that China will increase net imports of non-ruminant products. This appears to be confirmed by trade data that has just become available for the period up to 2001 (see Fig. 1). However, it should be noted that the sharp drop in China's trade specialisation index from 1999 to 2001 is largely driven by hides and skins imports. The trade specialisation index in non-ruminant meat products alone remained in the neighbourhood of 0.2 from 1997 to 2001.

The analysis of potential uncertainties, both in China's non-ruminant sector and the macro economy, shows that the nation's net trade position is very sensitive to these factors. If livestock productivity growth is at the high end of possible outcomes, and if there is a slow-down in the rest of the economy, China could become a substantial competitor in export markets by 2010—particularly if sanitary standards are improved and disease problems can be overcome. On the other hand, slower than expected diffusion and adoption of livestock technology, coupled with a rapidly growing macro-economy could transform China in a major market for future meat exports.

The projections in this paper have assumed no policy changes in China or elsewhere. Events such as China's recent accession to the WTO suggest further research that can build on that reported here. The literature at present offers conflicting conclusions about the impact of WTO accession, ranging from China becoming a major net exporter of pork and poultry, to predictions of substantial meat imports. Combining our productivity convergence analysis with improved analyses of trade liberalisation impacts should further illuminate the continuing debate on China's future role in the global livestock economy.

Acknowledgements

The authors are grateful to Simeon Ehui for his encouragement of this research. Valuable comments on this paper were received from Yijun Han and Spiro Stefanou as well as an anonymous reviewer and participants at the AAEA annual meetings, Chicago, August 2001. Partial support for this research was provided by the International Livestock Research Institute (ILRI) as well as USDA National Research Initiative for Markets and Trade (2001-35400-10214).

References

Abramovitz, M., 1986. Catching up, forging ahead and falling behind. J. Econ. Hist. 46, 386–406.

Arndt, C., 1996. An introduction to systematic sensitivity analysis via Gaussian quadrature. GTAP technical paper no. 2, West Lafayette, IN.

Arndt, C., Pearson, K.R., 1998. How to carry out systematic sensitivity analysis via Gaussian quadrature and GEMPACK. GTAP technical paper no. 3, West Lafayette, IN.

Brown, L.R., 1995. Who Will Feed China? Wake-up Call for a Small Planet. Worldwatch Institute, Washington, DC.

Cai, H., Brown, C., Wan G., Longworth, J., 1998. Income strata and meat demand in urban China. Aust. Agribusiness Rev., 6.

Capalbo, S.M., Vo, T.T., 1988. A review of the evidence on agricultural productivity and aggregate technology. In: Capalbo, S.M., Antle, J.M. (Eds.), Agricultural Productivity. Measurement and Explanation. Resources for the Future. Washington, DC, pp. 96–137.

Coyle, W., Gehlhar, M., Hertel, T.W., Wang, Z., Yu, W., 1998. Understanding the determinants of structural change in world food markets. Am. J. Agric. Econ. 80, 1051–1061.

De Brauw, A., Huang, J., Rozelle, S., 2000. Responsiveness, flexibility, and market liberalization in China's agriculture. Am. J. Agric. Econ. 85, 1133–1139.

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S., Courbois, C., 1999. Livestock to 2020: the next food revolution: food, agriculture and the environment. Discussion paper no. 28. Co-sponsored by IFPRI, FAO and ILRI. International Food Policy Research Institute, Washington, DC.

DeVuyst, E.A., Preckel, P.V., 1997. Sensitivity analysis revisited: a quadrature-based approach. J. Policy Model 19, 175–185.

Diewert, W.E., 1981. The comparative statics of industry long-run equilibirum. Can. J. Econ. 14, 78–92.

Dimaranan, B., 1998. Comparative Static Projections Using the GTAP Model. Center for Global Trade Analysis, West Lafayette, IN.

Dorfman, J.H., Kling, C.L., Sexton, R.J., 1990. Confidence intervals for elasticities and flexibilities: re-evaluating the ratios of normal case. Am. J. Agric. Econ. 72, 1006–1017.

Fan, S., Agcaoili-Sombilla, M., 1997. Why projection on china's future food supply and demand differ? Aust. J. Agric. Econ. 41, 169–190.

Food and Agriculture Organization of the United Nations (FAO). FAOSTAT database. http://www.apps.fao.org/. This was accessed on 5 May 2000 for productivity data and 3 January 2003 for trade data.

Färe, R., Grosskopf, S., Norris, M., Zhang, Z., 1994. Productivity growth, technical progress and efficiency change in industrialized countries. Am. Econ. Rev. 84, 66–83.

Fuller, F., Beghin, J., De Cara, S., Fabiosa, J., Fang, C., Matthey, H., 2001. China's accession to the WTO: what is at stake for agricultural markets. CARD, Working paper no. 01-WP 276.

Fuller, F., Hayes, D., Smith, D., 2000. Reconciling Chinese meat production and consumption data. Econ. Dev. Cult. Change 49, 23–43.

Gehlhar, M., 2002. Bilateral time series trade data. In: Dimaranan, B., McDougall, R. (Eds.), Global Trade Assistance and Production: The GTAP 5 Data Base. Center for Global Trade Analysis, Purdue University (Chapter 7).

Gehlhar, M., Hertel, T.W., Martin, W., 1994. Economic growth and the changing structure of trade in the Pacific Rim. Am. J. Agric. Econ. 76, 1101–1110.

Griliches, Z., 1957. Hybrid corn: an exploration in the economics of technological change. Econometrica 25, 501–522.

Harrison, W.J., Pearson, K.R., 1996. Computing solutions for large general equilibrium models using GEMPACK. Comput. Econ. 9, 83–127.

Hayes, D., Fuller, F., 1999. Optimal Chinese agricultural trade patterns under the laws of comparative advantage. CARD, Working paper no. 99-WP 233.

Hertel, T.W. (Ed.), 1997. Global Trade Analysis: Modeling and Applications. Cambridge University Press, Cambridge and New York.

Huang, J., Chen, C., 1999. Effect of trade liberalization of agriculture in China: commodity aspects. CGPRT Center, Working paper no. 43. Bogor, Indonesia.

Huang, J., Chen, C., Rozelle, S., Tuan, F., 2000. Trade liberalization and China's food economy in the 21st century: implications to China's national food security. In: Paper presented at the Meetings of the American Association for the Advancement of Science, Washington, DC, February 2000.

Huang, J., Rozelle, S., 2002. Trade reform. WTO and China's food economy in the 21st century. CCAP, Working paper no. 02-E5.

Jarvis, L.S., 1981. Predicting the diffusion of improved pastures in Uruguay. Am. J. Agric. Econ. 63, 495–502.

Lin, J.Y., 1992. Rural reforms and agricultural growth in China. Am. Econ. Rev. 82, 34–51.

Liu, J., Arndt, C., Hertel, T.W., 2000. Estimating trade elasticities for GTAP. An entropy approach. In: Paper presented at the Third Annual Conference in Global Trade Analysis. Monash University, Australia, 27–30 June.

Maddison, A., 1998. Chinese economic performance in the long run. Organization for Economic Cooperation and Development (OECD), Paris, 194 pp.

Nin, A., Hertel, T.W., Rae, A.N., Ehui, S., 2002. Productivity growth, 'catching-up' and trade in livestock products. ILRI, Socio-economics and policy research working paper no. 37. Nairobi, Kenya.

Nin, A., Arndt, T.C., Hertel, T.W., Preckel, P.V., 2003. Bridging the Gap between Partial and Total Factor Productivity Measures using Directional Distance Functions. Am. J. Agric. Econ. 85 (4) 928–942.

OECD, 2002. OECD Agricultural Outlook 2002–2007. OECD, Paris.

Oude Lansink, A., Silva, E., Stefanou, S., 2000. Decomposing productivity growth allowing efficiency gains and price-induced technical progress. Eur. Rev. Agric. Econ. 27, 497–518.

Rae, A.N., 1998. The effects of expenditure growth and urbanization on food consumption in East Asia: a note on animal products. Agric. Econ. 18, 291–299.

Rae, A.N., Hertel, T.W., 2000. Future developments in global livestock and grains markets: the impacts of livestock productivity convergence in Asia-Pacific. Aust. J. Agric. Resour. Econ. 44, 393–422.

Rosegrant, M.W., Paisner, M.S., Meijer, S., Witcover, J., 2001. Global Food Projections to 2020. Emerging Trends and Alternative Futures. IFPRI, Washington, DC.

Rutherford, A.S., 1999. Meat and milk self-sufficiency in Asia: forecast, trends and implications. Agric. Econ. 21, 21–39.

Tuan, F.C., Peng, T., 2001. Structural changes in China's livestock and feed production: trade implications. In: Paper presented in the Winter IATRC Meeting, 18–19 January 2001, Auckland.

US Department of Agriculture, Economic Research Studies, 1998. China's Livestock Sector Growing Rapidly. Agricultural Outlook.

US Department of Agriculture, Foreign Agricultural Service, 1998. FASonline. Retrieved from http://www.fas.usda.gov//dlp2/circular/1998/98-10LP/chinarv4.htm, 23 October.

Walmsley, T.L., Dimaranan, B., McDougall, R.A., 2000. A base case scenario for the dynamic GTAP model. Center for Global Trade Analysis, West Lafayette, IN.

Yu, W., Hertel, T.W., Preckel, P.V., Eales, J.S., 2004. Projecting World Food Demand Using Alternative Demand Systems. Econ. Modell., in press.