Asia-Pacific food markets in 2005: the influence of livestock productivity convergence on trade in livestock products and grains

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ABSTRACT

The ongoing trend towards livestock product consumption in many Asian countries has been accompanied by growth in some countries' imports of feedgrains for their domestic livestock sectors. It has also has put pressure on available grain supplies for human consumption. With regard to China, this contributes to the ongoing debate over future levels of her grain imports. Yet published projections often pay too little attention to developments in livestock production. In other Asian countries, livestock self-sufficiency targets are becoming more difficult to achieve due to policy reforms, resource constraints and environmental issues, and imports of livestock products have been growing more rapidly than those of feedgrains. Our objective is to evaluate the impacts of productivity convergence and technological catch-up in livestock production on trade in livestock and grains products among countries in the Asia-Pacific region. Production per animal unit is used as a proxy for productivity. Tests are conducted of the hypothesis that productivity levels in the Asia-Pacific region are converging and there exists 'technological catch-up'. Projections of livestock productivity are made and incorporated in a modified GTAP model in which feedstuff substitution is permitted. The consequences for global trade in grains and livestock products, as well as the specific implications for China's production and trade balance in these sectors are explored.

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Introduction

The way in which dietary patterns are changing in Asia as economic growth and development proceeds is now well documented. Due to factors such as income growth, urbanisation and the modernisation of marketing infrastructures, consumption patterns are switching from an emphasis on traditional foods (such as some cereals and root crops) to non-traditional cereals (eg wheat-based foods) and value-added processed and high-protein foods such as those derived from animal products (Huang and Bouis 1996, Huang and David 1993, Rae 1997 and 1998). This typically involves a switch in the domestic utilisation of grains from human consumption to feeding of livestock. Much recent debate has centered on the impacts of such consumption changes on world food markets, especially those for grains.

The above factors have contributed to a rapid increase in world trade in coarse grains, as countries expanded domestic livestock production and found their demand for feeds exceeded their ability to supply from domestic sources. But in more recent times, the rate of growth of global trade in coarse grains has slowed considerably, while that of global trade in meats has continued to increase. Figure 1 shows that at the global level, trade in coarse grains has shown no positive trend since the early 1980s, whereas growth in meat imports continued steadily. A similar pattern has become evident in East Asia[1] over the past decade, with a slowing of the rate of growth in imports of coarse grains but not of meats.

The countries of Northeast Asia in particular are major importers of feedgrains, with Japan and Korea accounting for almost 30% of global trade in 1995. But these countries also face economic and environmental constraints to further expansion of their domestic livestock industries suggesting a future trade-off of feed imports for those of meats and dairy products. While China is not yet a major feedgrain or meat importer, the size and rate of growth of that economy cast some doubt on the ability of China to remain largely self-sufficient in both livestock products and feedgrains.

Many, and in some cases widely-differing, projections have been made of China's future grain situation (Table 1). While demand projections have shown less variation, those for domestic production have varied considerably and therefore so have the projections of China's trade balance in grains. For example, projections of China's grain imports for the year 2005 range between 14 and 108 million metric tonnes (Table 1). The most extreme projection has been that of Lester Brown (1995) which suggested a 10-fold increase in China's imports before the year 2020.

Less attention appears to have been given to the implications of Asian growth on the region's trade in livestock products, and its implications for the traditional meat exporting countries of Australasia and North America. In fact, Fan and Agraoili-Sombilla conclude: "The livestock sector deserves much more attention than currently afforded by any of the models. Most of the models do not have a livestock sector. … The rapid structural change in the livestock industry … will have a large impact on future food security in China. In particular, improvements in feed-meat ratio arising from these technical and structural changes will save huge amounts of feed grains" (p.27).

A more recent projections model that did include livestock sectors was that of Anderson *et al* (1997). Using the GTAP applied general equilibrium model (Hertel 1997), their base projection (which incorporated the policy reforms agreed in the Uruguay Round) indicated that China would become a significant net importer of grains by 2005, to the tune of about 33 million metric tonnes. But much more significant were the projected increases in China's net imports of meat products, non-grain crops and processed foods. Comparing 2005 with their base year of 1992, grains accounted for only 13% of the dollar value of the increase in China's food trade deficit whereas the proportion for livestock products was 40%. However it should be noted that this projection assumed that productivity growth rates for each farm industry were the same across countries – an assumption which the authors themselves question[2].

What if livestock producers in China are able to "catch-up" with productivity levels in North America? Wouldn't this change the balance of their net imports in favor of feedgrains, with the livestock being produced domestically rather than being imported? This paper aims to address this question directly. We begin by constructing productivity indices for livestock producers in the Asia/Pacific region. We then test the degree to which technological "catch-up" with North America has been occurring over the past two decades. Based on these historical changes, projections of technological change in livestock production over the next decade are made. The impact of these differential rates of productivity growth on regional trade in both livestock products and grains is then examined.

Developments in Animal Production Technology[3]

Modern science has developed, and continues to develop, a large number of technologies for enhancing the productivity of livestock production, processing and marketing activities. These cover broad fields such as animal genetics, nutrition, health and mechanisation.

The use of exotic breeds has enabled genetic improvement within herds and flocks to be speeded up, and enhanced even further with the aid of biotechnology. The latter involves the use of living organisms to produce improvements within animals, such as the various genetic engineering (DNA) techniques to manipulate genetic material and to transfer genes from one organism to another. In such ways, animal quality may be rapidly upgraded through improvements in genetic make-up and in the rate of reproduction. Biotechnology has also aided improvements in feed efficiency, milk production, and in the development of vaccines. Numerous compounds have been developed to promote faster growth and improved feed efficiency, such as the use of anabolic steroids in cattle as a growth promotant. Also becoming well known is the elevation of natural levels of somatotropins (naturally-occurring protein hormones) in cattle, pigs, poultry and sheep. Growth rates, feed efficiency and milk yields may all be increased.

Biotechnology has led to more cost-effective health care, such as the production of new or genetically-engineered vaccines. In the area of nutrition, various additives and supplements have been discovered to increase the rate of weight gain, to increase the digestibility of feedstuffs, or to reduce the amount of feed required per unit of output.

Artificial insemination (AI) is a well-known reproductive technology, but recent developments in embryo transfer raise the possibility that it might replace AI. A range of associated techniques has been developed. The transfer of embryos from donor to recipient animals allows the build-up of genetically-superior animals using lower-grade and inexpensive recipients, at a faster rate than natural mating or artificial insemination. Other techniques include the splitting of embryos to produce multiple copies, embryo cloning, *in vitro* fertilisation and sex determination.

Numerous mechanical technologies have been developed for application on farms, and within processing and marketing systems. Some examples include electronic monitoring of individual animal performance and the use of computers to control feed rations and the animals' environment, and to make better use of herd-improvement and management records. Robotic techniques are increasingly used in processing operations, and other techniques allow product shelf-life to be extended and product quality to be enhanced.

Such developments are likely to continue apace into the future. Simpson refers to a 1992 report (U.S. Congress, OTA), that lists 42 potentially available animal technologies as of 1992, of which 22 were expected to be available by 1995 and all but nine by the year 2000. Of course, the success with which these can be transferred from the country of origin (in many cases the USA) to recipient countries in Asia, will be influenced by many factors which are beyond the scope of this paper. Our contribution here is to focus on the consequences of these spillovers for patterns of international trade.

Aggregate Productivity Convergence and Catch-up: Some Previous Studies

There is an expanding literature on the comparison of aggregate productivity levels across countries, much of which has been summarised by Fagerberg (1994) and de la Fuente (1997). The key question is: Are the less-productive countries catching-up with (converging on) the leaders? If so, how quickly and by what means? Such convergence implies the tendency for poorer countries to grow more rapidly than the rich countries. Most studies have used aggregate, national level, and surrogates for productivity such as GDP per worker (eg Baumol 1986). Some recent work has employed more complete measures, such as total factor productivity (TFP), and have also been applied at the sectoral level, including for agriculture. Knowledge of technological change at the sectoral level can provide a more complete understanding of changes in comparative advantage and its role in economic growth, and use of TFP measures provides the prospect of unravelling the confounding of productivity change and factor accumulation inherent in the use of partial productivity measures, such as output per labour unit.

Cross-section studies have commonly involved estimation of the relationship between national productivity growth rates and initial levels of productivity and perhaps other variables such as trade "openness" (Coe and Helpman 1995, Engelbrecht 1997, Edwards 1998), and the movement through time of cross-section variance of productivity. The former type of analysis is often referred to as β-convergence since it commonly involves the regression of growth rates on initial productivity (perhaps relative to the lead country), and the latter as σ-convergence. Dowrick and Nguyen (1989) used post-war estimates of both labour productivity and TFP in OECD countries and concluded that TFP catch-up stood out as a dominant and stable trend. Helliwell (1992) developed time-series models of TFP growth in a number of OECD countries, and found that the initially poorer countries exhibited faster technical progress. Bernard and Jones (1996a, 1996b) examined changes in both labour productivity and TFP in 14 OECD countries over the period 1970-87 using both cross-section and time-series analyses. They found evidence of convergence at the aggregate level and in some sectors, including agriculture, but not manufacturing. Schimmelpfennig and Thirtle (1998) focussed on agricultural TFP and found evidence of β-convergence between countries of the EU and the USA. The latter along with those EU countries with more advanced research systems formed a high-growth club within which convergence occurred, while remaining EU countries' productivities converged within a slower-growth grouping. It was concluded that private sector technology transfer may be the dominant force in explaining TFP convergence. In this paper, we focus on productivity convergence in the livestock sectors.

Livestock Productivity Convergence and Catch-up in the Asia/Pacific Region

The measurement of livestock productivity

A generalised livestock production function may be written as:

$$Q = f\,(X_1, X_2 \ldots X_n), \tag{1}$$

where: Q = output,
X_1 = livestock capital input, and
$X_2 \ldots X_n$ are inputs of non-livestock capital, land, labour, feedstuffs and other purchased inputs.

Total factor productivity (TFP) may be measured as:

$$TFP = Q/[\alpha_1 X_1 + \alpha_2 X_2 + \ldots + \alpha_n X_n] \tag{2}$$

where $\alpha_1, \alpha_2, \ldots, \alpha_n$ are appropriate weights. The difficulty in estimating TFP derives from the absence of data on many of the inputs to livestock production. For this reason, we focus our attention on a partial factor productivity measure (PFP) which assesses changes in the amount of output per unit of livestock capital input:

$$PFP = Q/X_1. \tag{3}$$

Clearly TFP and PFP are not the same, and PFP will capture not only changes in the productivity of the various inputs but output effects of changes in the levels of the inputs $X_2 \ldots X_n$. Thus not only will growth in PFP be a biased measure of total factor productivity growth, but we cannot be sure of the direction of the bias in the absence of information about other input levels and hence the degree of input substitution. Finally, there is an additional problem posed by the fact that we use of livestock inventory as the measure of livestock capital[4]. Nevertheless, we believe that our measure of PFP represents a considerable improvement on the Anderson *et al.* assumption that productivity growth is constant across regions. We also note the similarity of this PFP measure to the frequently used, output per worker measure of economy-wide productivity.

Data on livestock numbers and output were taken from the FAO (1997). Productivity values for pork and poultry were given by the volume of meat production divided by the animal inventory, beef productivity was measured by output per total slaughterings[5], while milk productivity was measured as milk production divided by the number of milking cows.

Results for Asia/Pacific livestock production

Graphs of the natural logarithm of PFP, and its standard deviation, against time are given in Figure 2, covering the period 1965-1995. At first sight, there would appear to be convergence in beef productivity levels since the early 1980s, and in pig productivity since the mid-1970s. Poultry productivity levels appear to show two periods of convergence – first over the decade between 1965 and 1975, and then again during the 1990s. Milk productivity levels appear to have been converging between 1970 and 1985, but could have diverged since then. The convergence in beef productivity across countries would appear to be primarily due to the increase in China's productivity relative to the other countries. The convergence of pig productivity levels is due to several countries (including China) catching up on North American productivity levels, and a decline in Japanese productivity to North American levels. For poultry, the convergence that appears to have occurred over the decade up to 1975 reflects productivity gains in Australia, New Zealand and Japan relative to North America. Since 1975, productivity in the first two countries has stabilised near North American levels, while that in the Japanese poultry sector has declined somewhat. During the 1990s, another period of convergence of poultry productivity appears to be due to gains achieved in Korea and China.

Table 2 gives average rates of growth in livestock productivity[6] for the two decades 1975-85 and 1985-95. For poultry, productivity growth rates over the former decade were higher than those in North America only in Australia and New Zealand. Over the following decade, productivity growth in New Zealand but also China and Korea exceeded that in North America. Over both decades, all countries shown exceeded the North American pig productivity growth rate, with the exception of Japan where pig productivity growth was negative. All countries except Australia, China and Southeast Asia had faster productivity growth in beef than did North America during 1975-85, and over the following decade Japan, New Zealand and Southeast Asia had slower growth in beef productivity than did North America. Milk productivity growth rates in Japan, Korea and New Zealand were below those of North America during 1975-85, and over the following decade only Australia and Korea achieved a higher average rate of growth than North America.

Figure 3 focuses on China. It displays the levels of livestock productivity in that country relative to those in North America. Pig productivity has been catching up to that in North America for at least the past two decades, and was within about 70% of North American levels by 1995. China's beef productivity began to increase relative to that in North America since about 1985 to reach around 60% of North American levels by 1995. China's poultry productivity increased (rather rapidly) relative to North America only since around 1990, and milk productivity in China continued to fall relative to North America throughout the period under study.

By 1995, considerable differences in livestock productivity remained among the countries and regions (Table 3). Both China and Southeast Asian productivity levels were well below those in the developed countries, and in some cases the gaps were considerable. The developed countries had reached similar levels of pigmeat production per head of inventory, but substantial variation existed for the other types of production. Poultry productivity in Japan and Korea remained below that in North America and Australia. Differences in beef and milk productivity reflect the production systems predominant in each country – levels of milk productivity in Japan, Korea and North America are rather similar and are above the levels achieved in the grassfed systems of milk production in Australia and New Zealand. A somewhat similar pattern can be seen in beef productivity, although the Korean performance is below those of Japan and North America due at least in part to the more recent move to intensive grain feeding in Korea.

Table 4 gives the results of the first of two formal tests for convergence of productivity levels - the so-called β-convergence. For each commodity and two time periods, average productivity growth rates over the relevant time period were regressed on the logarithms of the initial levels of productivity, PFP_i^{t0} (Bernard and Jones 1996a):

$$\Delta \ln PFP_i = \alpha + \beta \ln PFP_i^{t0} \tag{4}$$

A negative β value would indicate a convergence of productivity levels over the relevant time period - in other words, the average growth in productivity would tend to be faster the lower the initial level of productivity. Five of the eight β coefficients of Table 4 are negative, and three of them have t-statistics in excess of 2.0. Both β values from the pig regressions were negative and significant ($t>2$), while that for poultry is negative and significant for the 1985-95 decade only. Convergence in beef productivity over the 1985-95 period is indicated by the negative β coefficient ($t=1.8$). Neither of the β coefficients in the milk equations were significant, and that for the latter decade was positive. These results support the evidence apparent from Figure 2 - that pig productivity has exhibited convergence since 1975, that for beef and poultry has converged since around 1985, while productivity convergence is absent in the case of milk.

Also following Bernard and Jones (1996a), Table 4 gives estimates of the speed of convergence, λ. This may be interpreted as the rate at which the productivity level is converging to some aggregate level, which may itself be growing over time. These rates of convergence are 6.9% and 4.2% per year for pig productivity over the two decades, and 3.8% and 3.7% per year for beef and poultry respectively over the 1985-95 period. The speed of milk productivity convergence over the earlier 1975-85 period was less than 0.7% per year. (As noted above, since 1985, milk productivity appears to be diverging.)

Additional time series evidence to supplement the above results is obtained by regressing the logarithm of the ratio of individual country PFP over North American PFP: $ln(PFP_{it}/PFP_{NA,t})$ for each commodity against time (Bernard and Jones 1996b). This provides the average trend in the productivity deviations of the i^{th} country from North America, and was computed over the 1985-95 period. Results are given in Table 5. A positive trend coefficient would indicate convergence between productivity levels in the relevant country with those in North America. Positive trends with a t-value above 2.0 are found for China (poultry, pigs and beef), Australia (pigs and milk), Korea (poultry and beef) and Southeast Asia (pigs and beef). With the exception of milk production, the speed with which the technology gap is closing is greatest for China over this time period, and is shown graphically in Figure 3. Negative trends in productivity relative to North America were found for all four products in Japan, and for milk production in New Zealand and China.

Projections of livestock productivity

Using the regression results of Table 5, projections were made of $ln(PFP_{it}/PFP_{NA,t})$ for each region or country and for each livestock commodity, to the year 2005 (which is ten years beyond the base year for the subsequent simulation analysis). Productivity levels in North America were also projected to that year, and these sets of results then allowed projections of productivity levels for the remaining countries and regions to be estimated for 2005. The percentage increase in productivity for each commodity from 1995 to 2005 was then calculated for each country or region. To match the commodity aggregations of simulation model introduced below, an aggregate productivity change was derived for pig and poultry production, using base-period production levels as weights. These projected productivity changes are presented in Table 6.

As expected from the above analyses, projected increases in ruminant and non-ruminant livestock productivity are by far the greatest for China, followed by Korea. Chinese productivity levels are projected to converge substantially on North American levels. Non-ruminant livestock productivity in New Zealand, Southeast Asia and Australia is also projected to converge on North American levels. The most notable projected convergence in milk productivity occurs in Australia.

By far the most rapid productivity growth rates are for beef and non-ruminants in China. By contrast almost no growth in milk productivity has been projected. This is probably unrealistic but is a consequence of our projections model – prior to 1995 there had been virtually no growth in milk yields per cow. It may also be noted that these projected growth rates imply that productivity levels in China would reach North American levels by the year 2011 for poultry, 2008 for pigs and 2007 for beef. The projected negative growth in non-ruminant productivity in Japan reflects the decline in Japanese productivity relative to North American levels that has occurred since the late 1970s. While the projected milk productivity growth for New Zealand is very low, this may simply reflect a weakness of our partial measure of productivity. Relative to labour and capital, land and pasture are abundant factors in New Zealand dairying and productivity gains are likely to be sought with respect to the former factors.

What does this convergence imply for trade in livestock vs. grains products? Will it permit China to curb its imports? To answer these questions, we now turn to a global trade simulation model.

Methodology

We follow Anderson *et al.* in using the GTAP applied general equilibrium model (Hertel 1997) to project national and regional production, consumption and trade flows in Asia. This is a relatively standard, multi-region model built on a complete set of economic accounts and detailed inter-industry linkages for each of the economies represented. The GTAP production system 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 modeled, and bilateral international transport margins are incorporated and supplied by a global transport sector. The model is solved using GEMPACK (Harrison and Pearson 1996). For a previous application of this model involving technological change and research spillovers, the reader is referred to Frisvold (1997).

In light of our interest in feed-livestock interactions, we have modified the standard GTAP model to allow for substitution between the various feedstuffs in livestock and milk production. Also, we utilize the newly developed, version 4 GTAP data base, which is benchmarked to 1995 and which offers an important disaggregation of livestock production into ruminants and non-ruminants. We aggregate this data base up to the level of 10 regions and 14 commodities (see Appendix Tables 1 and 2). The regional focus is on the Pacific Rim. In order to match up with the analyses of productivity conducted in the first part of this paper, we combine Canada and the USA into a single North America region, while Southeast Asia is an aggregation of Indonesia, Malaysia, the Philippines and Thailand. The 50 commodities in the version 4 GTAP database have been aggregated up to 14, of which 6 commodities (rice, wheat, other grains, oil crops, other crops and processed food) compete for use in the feedstuffs composite. Livestock farming is represented by three aggregates: beef cattle (i.e. ruminant livestock), other livestock (i.e. non-ruminants)[7] and raw milk production.

These farming sectors provide inputs to the beef processing (ruminant meat), other meat (non-ruminant meat) and dairy products industries in each region. All remaining production sectors are aggregated into manufactures and services, or other natural resource based commodities.

Base-case projections

The productivity catch-up which we have projected here is only part of the story of what will be happening in the world economy in the coming years. Other sectors will also be experiencing technological change. Income growth will tend to boost the demand for livestock products, relative to grains, and in some regions, there will be a strong shift away from food products altogether. On the supply side, historical accumulation of skilled labor and capital in the Asia economies has promoted the shift of activity away from agriculture, in favor of manufacturing and services. However, the recent crisis in this region has slowed this process and a more current projections scenario is clearly required.

As has become standard with the GTAP model, following the work of Gehlhar *et al.*, projections are made through exogenous shocks to each region's endowments of physical capital, skilled and unskilled labour, population, and technology. Appendix Table 3 gives these shocks, and the sources upon which they were based.[8] Of greatest interest here are the shocks to technology. If the rate of non-agricultural technological progress is too high, relative to agriculture, then the projections will exaggerate the shift of resources out of agriculture. This was an important feature of the Anderson *et al.* projections scenario for China, with non-agricultural productivity growing at 3% per year. The latter was necessary in order to achieve the targeted GDP growth rate. However, to the extent that this growth rate is too high – it is clearly above the historical norm – they will have exaggerated the down-sizing of the farm sector.[9]

We assume an average rate of non-agricultural productivity growth[10] in the OECD economies of 0.75% per year. For non-OECD economies, we assume a somewhat higher rate of productivity growth, 1.25% per year. Together with projected growth rates in capital, skilled and unskilled labor, this yields overall GDP growth rates for these countries which are similar to those forecast by the World Bank (World Bank, 1998). For agriculture, we assume a common rate of productivity growth, world-wide, which is 0.6% per year above the rate of growth of productivity in the non-OECD countries. This is the differential estimated by Martin and Mitra (1996).

Similarly, we also want to avoid biasing the overall rate of agricultural development in the world towards crops or towards livestock production. Solid evidence of one being significantly higher than the other is not available.[11] Therefore, we adopt the simple case whereby productivity in livestock is equal across countries and sectors, worldwide. Specifically, we impose the condition on our base case simulations that worldwide livestock productivity equals that for crops (1.85% per year). In this base simulation, all shocks are modelled so as to enhance the productivity of the value-adding composite. We call this the "no convergence" case. Within this environment of balanced productivity growth we then proceed to explore the implications of convergence in livestock productivity as shown in Table 6.

Analysis of livestock productivity convergence

Scenario 1: No change in feed efficiency

This simulation implements the differential shocks outlined in Table 6, with a global scaling factor designed to ensure that the weighted average growth rate in productivity for livestock equals that for crops. As in the base case, this experiment involves enhancing the productivity of value-added.

A comparison of the two columns of numbers in Table 7 shows the impact of technological convergence on global trade in all 14 commodities. The first column provides estimates under the no-convergence assumption, whereas the second column reports convergence estimates. Not surprisingly, the primary impact is on trade in livestock products. It is interesting that convergence actually boosts trade in beef cattle and beef, whereas trade in other livestock and other meats falls as a result of convergence. In order to understand this, we need to decompose the global change into changes in trade by individual regions.

Table 8 reports the changes in regional export and import volumes in 2005 due to convergence. In the cases of cattle and beef, the increases in exports are fueled primarily by the EU, with increases also from Australia, North America, New Zealand, China and South America. The big increase in imports due to convergence is to the rest-of-the-world, and to a lesser extent to Southeast Asia where negative beef productivity growth was projected. In the case of the non-ruminant trade, exports decline everywhere but China, in response to a substantial decline in China's imports. Hence global trade expands for beef products since the major productivity gains occur in traditional beef exporting regions. For the non-ruminant products, global trade declines due to the rapid productivity growth in China which allows that country to reduce import volumes. It can be noted that in the 1995 base data, China had a net trade surplus of $1.6 billion in non-ruminant products. This changed to a deficit of $6.9 billion in the 2005 non-convergence projections. However, under convergence China's non-ruminants trade in 2005 is essentially in trade balance.

Table 9 shows the impact of productivity convergence on the bilateral livestock product trade flows in 2005 (trade volumes at 1995 prices). These flows include cattle, other livestock, beef and other meats and dairy products. Each element measures the difference between the trade volumes under convergence and non-convergence. Figures in parentheses measure this change as a percentage of the trade flow in 2005 under no convergence. Application of the convergence scenario has the effect of increasing livestock productivity growth rates on average for China, Korea and Australia, and reducing them for other regions. Hence it is not surprising that convergence increased total livestock product exports from China and Australia, and decreased them from North America, New Zealand, Japan and Southeast Asia. But despite Korea's rapid productivity catch-up, her total livestock exports fell. In the base data, and under the non-convergence projection, Korea's major livestock exports were other livestock to

China and other meats to Japan. Korea's increased productivity relative to Japan's led to an increase in its exports to the latter destination. However, Korean productivity growth was below that in China, and resulted in a decline in Korea's exports to China and a decrease in Korea's total livestock product exports. Australia's productivity gains under convergence encouraged increased exports to Southeast Asia and the rest-of-the-world region. China's rapid productivity catch-up resulted in increased exports to all regions, but especially to Japan and the rest-of-the-world. We do not show an equivalent table of changes to bilateral trade volumes for grains, but note that convergence causes a 3% decline in North American exports of all grains to China, and a 0.4% drop in total North American grains exports.

At this point it is most interesting to narrow in on China, as a particular focus region. In our base case, China is the only East Asian region which retains a relatively high rate of growth (see Appendix Table 3) – although it is lower than the double-digit annual growth rates of the past decade. As a consequence, structural change in China is accentuated. We see this in Table 10, which reports projected changes in the composition of value-added in the Chinese economy. There are declines in all farm and food products owing to an increased role for manufactures. The share of grains in real GDP is projected to experience a particularly sharp decline. Only processed beef and milk experience a more modest decline. In the presence of convergence, the livestock declines are moderated considerably for beef cattle, non-ruminants and meats. Beef meats actually increase their importance in the economy slightly. This is due to the massive rate of improvement in efficiency projected in Table 6 (80% improvement between 1995 and 2005). The lack of progress in dairy efficiency actually leaves that sector further behind under convergence.

This shift in the relative composition of value-added in China is also reflected in the trade balance for that country. This is reported in Table 11 where each entry in the final three data columns shows the difference in the trade balance in 2005 relative to 1995, in millions of constant (1995) US dollars. Due to the macro-economic closure assumed, the total trade balance for China is assumed fixed. Thus an improvement in the trade balance for one commodity must be offset by a deterioration somewhere else. In the non-convergence case, China is projected to be a major net importer of grains and livestock products by 2005. All of the food and resource commodities excepting for beef, show a deterioration – i.e. the value of imports rises more than the value of exports for each of these products. When convergence is introduced, the deterioration is far more modest. This turn-around is especially striking for non-ruminants, where the change in trade balance shrinks from -$8.5 billion to -$1.6 billion for the combined farm and manufactured products. Interestingly, the change in the trade balance is much smaller for beef. Of her total projected increase in food net imports over the 1995-2005 period, grains account for 24% and livestock products 5%. Anderson *et al* (1997) projected shares of grains and livestock in their projected increase in net food imports of 13% and 40% respectively. Our results differ substantially from these, in part because our experiment recognises livestock productivity catch-up in China which contributes positively to her increased domestic livestock production and therefore also to her increased demands for feedgrains. Hence despite China's rapid catch-up towards

North American ruminant and non-ruminant productivity levels, the growth of demand in China coupled with her changing comparative advantage towards the relatively capital intensive manufacturing sector appear to ensure China's emergence as a major importer of grains but not necessarily of livestock products .

We can also examine the impact of convergence on China's grain deficit. In the no-convergence case, the change in the grains and oilseeds trade balance is about –$10 billion. Introducing convergence (second column in Table 10) actually reduces this deficit. This is somewhat surprising given the increase in livestock production and the assumption in this scenario of constant feed conversion ratios. However, the reason for this outcome is that grains output increases substantially under the convergence scenario relative to non-convergence. This is because a more efficient livestock sector requires less land, labor and capital for a given amount of output, thus freeing up some factors of production for other uses. Grains production absorbs some of these inputs.

Scenario 2: Effects of increased feed efficiency

Up to this point, we have assumed no change in feed efficiency. However, it is quite likely that the improved livestock production techniques will also bring with them increased feed efficiency, and possibly improved efficiency with respect to other inputs. If this is the case, then the implications for feed demand, and hence for trade in grains and oilseeds could be very different. A critical parameter in this regard is the feed conversion ratio, or feed consumption per unit output. Given the importance of China to future food projections such data for that country's livestock sectors is vital, yet information is sketchy. A recent survey conducted by Wailes et al (1998) gathered data on feed use across a range of enterprise and livestock types in seven provinces of China. These covered three types of livestock production systems – small-scale backyard production, specialised household production and large-scale commercial enterprises. The trend is towards development of specialised livestock production units and larger, more intensive management systems. Feed rations and conversion rates were found to vary over production systems. For pigs, the feed conversion ratio (FCR) in backyard systems was 26% higher than in specialised units and 41% higher than in the best large-scale systems. In beef production, the FCR in the backyard systems was 83% higher than in specialised production systems. Therefore the changing structure towards large scale and specialist production has the potential to lower average FCR's substantially. Wailes *et al* concluded that as the structure of livestock production systems change in China, and as the share of poultry in total meat production increases, the demand for feedgrains per kg of meat production is expected to decline.

Another set of livestock and feeds projections for China are those of Simpson et al (1994, Tables 7.6, 7.7 and 8.1), covering the period 1989-91 to 2000. Their projections of total meat or milk production, total feed use by type of animal and total animal inventories implied that growth in output per animal lies between 2% and 5% per year and is highest for poultry. The projections imply little increase in feed inputs per animal so feed per unit output (the FCR) shows negative growth in each case, indicating increases in feed efficiency especially for poultry. This is consistent with the

projections of Wang et al (1998) who assume improvements in feed efficiency for all animal types and technologies.
This evidence points to a view of increases in feeding efficiency in Chinese livestock production, due to shifts from backyard to specialist and commercial production systems as well as to technological change. Prospects for the latter improvements also gain support from US Office of Technology Assessment's projected gains in US feeding efficiency (Tweeten 1998). Annual growth rates in output per feed were 0.2% (beef and pigs) , 0.6% (milk) and 2.0% (poultry). If the US is the source of much of the new livestock production technology that is transferred to China, then such improvements will eventually be felt there.

In order to assess the sensitivity of our findings to improvements in feed efficiency, we conduct an additional experiment in which we also augment the productivity of the composite feed input in the livestock sectors. This is done world-wide, with the rate of productivity improvement equaling the rate applied to value-added in these sectors[12].

Introducing a comparable increase in feed efficiency in livestock activity has a strong effect on feed use in China. Instead of rising, projected feed use in beef actually falls between 1995 and 2005. The increase in feed use in non-ruminant production is now a modest 7%, whereas it was 77% under the convergence experiment without feed efficiency changes. This is also reflected in the trade balance, with the deterioration in the grains and oilseeds balance for China now being reduced to -$7.4 billion (Table 11).

Output of livestock and associated products in China expands more in this case than in the previous convergence experiment, and that of grains expands less so. As a consequence, introducing feed efficiency gains reduces the grains share of GDP but increases that of the livestock sector compared with 1995 (Table 10). Increased feed efficiency also provides a further boost to China's total livestock sector export volumes (an increase of 24% over the previous convergence experiment), especially to Japan and the rest-of-the-world. At the same time, China's livestock import volumes decline by 9%. On the grains side, increased feed efficiency reduces China's imports from North America by 13%. The latter region's total grains exports decline by 1.5%.

Conclusions and Directions for Further Research
Empirical projections of the impacts of economic growth, especially in rapidly-growing, populous economies such as China, have emphasized impacts on the global grains situation. These studies have often neglected trade in livestock products, which has been shown to be even more important in the work of Anderson *et al.* The fundamental question is whether China will produce most of its own livestock products and import the necessary feedstuffs, or whether she will continue the rapid increase in imports of livestock products directly. This paper examines this question in some detail.

Using a partial measure of livestock productivity, convergence in productivity levels among Asia-Pacific economies was shown to have occurred in recent times for pig, beef and poultry production, but generally not in milk production. At the country level, significant "catch-up" to North American levels was demonstrated for China (poultry, pigs and beef), Australia (pigs and milk), Korea (poultry and beef) and Southeast Asia (pigs). With the exception of milk production, the speed with which the technology gap had been closing was greatest for China.

Despite rapid productivity catch-up in China's livestock sectors, that country could become a major net importer of both grains and livestock products by 2005. In the absence of technological convergence in livestock, compared with 1995, the increase in net imports will be roughly comparable for livestock products and for grains. This differs significantly from the projections by Anderson *et al*, largely due to more modest assumptions about productivity growth in the non-agricultural sectors. When we introduce technological catch-up in livestock, the livestock deficit narrows sharply. When these efficiency improvements are also applied to feed use, the livestock deficit narrows even further and the grains deficit narrows as well. In all projections, the share of livestock products in China's increase in food imports was substantially less than projected by Anderson *et al* (1997).

Overall, we find that technological convergence in livestock production has an ambiguous effect on world trade in livestock and meats. For non-ruminants, we obtain the result that convergence dampens trade. This is perhaps as expected. However, for cattle and beef, the opposite is true. This illustrates the fact that the impact of technological catch-up in the livestock industries is more complex than may at first meet the eye, and depends upon whether convergence occurs in net exporting or importing regions.

Future research in this subject could usefully attempt more sophisticated estimation of livestock productivity and the factor bias of technical change. Whether or not feed efficiency increases was shown to have a major impact on livestock products and grains trade, and further econometric research into livestock productivity is urgently needed to better address this issue. The functional form we used to project livestock productivity did not permit a region's productivity relative to North America's to increase at a decreasing rate. This may have given rise to overly optimistic projections and therefore over-estimates of feed efficiency improvements as well. Finally, as our research was initially encouraged by an interest in the Asia-Pacific region, productivity projections were not made for other regions. This should be rectified, since these regions in the aggregate are major players in global livestock product markets.

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Table 1 Projections of China's production, consumption and trade in grains (million tonnes)

Year	Brown	Rosegrant et al	Huang et al	USDA	World Bank	OECF
2005						
production	329	418	455	382	445	382
consumption	437	434	480	414	459	435
imports	108	16	25	32	14	52
2010						
production	317	453	486	403	483	389
consumption	472	468	513	443	502	492
imports	155	15	27	39	22	104

Note: 1995 actuals:
Production = 355
Consumption = 375
Imports = 20
Source: Fan and Agcaoili-Sombilla 1997

Table 2 Livestock productivity average growth rates (% per year)

	Poultry		Pigs		Beef		Milk	
	75-85	*85-95*	*75-85*	*85-95*	*75-85*	*85-95*	*75-85*	*85-95*
Australia	3.66	0.96	2.62	2.34	0.45	1.75	2.17	3.29
China	-1.13	7.50	7.30	4.71	0.56	5.94	3.05	0.14
Japan	2.49	-0.23	-0.10	-0.79	2.29	0.99	1.97	2.29
Korea	1.92	5.07	8.30	2.56	3.25	2.80	1.62	2.70
New Zealand	4.65	2.44	3.05	1.42	1.20	0.80	-0.46	0.16
Nth America	*2.56*	*1.22*	*1.37*	*0.92*	*1.16*	*1.48*	*2.16*	*2.37*
SE Asia	-0.81	0.77	2.73	2.86	-0.19	-0.23	2.60	2.06

Source: FAO
Note: Average growth rates are measured as the trend coefficient from the regression of the log of productivity on a constant and a linear trend.

Table 3 Livestock productivity: 1995 (kg per head)

	Poultry	Pigs	Beef	Milk
Australia	7.3	133.0	218.0	4783
China	3.3	88.7	199.9	1605
Japan	4.1	132.7	394.1	6334
Korea	4.8	134.4	257.7	6620
New Zealand	7.4	120.0	182.4	3166
Nth America	7.6	130.1	309.7	7299
SE Asia	3.0	87.1	171.3	1288

Source: FAO
Note: Beef productivity is output divide by livestock slaughtered

Table 4 Convergence regressions: livestock productivity

Livestock type	b	t statistic	l	R^2
Poultry				
1975-85	0.0387	2.43	-0.0332	0.54
1985-95	-0.0312	2.05	0.0368	0.46
Pigs				
1975-85	-0.0512	3.44	0.0693	0.70
1985-95	-0.0348	2.56	0.0419	0.57
Beef				
1975-85	0.0099	0.70	-0.0095	0.09
1985-95	-0.0321	1.82	0.0380	0.40
Milk				
1975-85	-0.0063	1.00	0.0065	0.17
1985-95	0.0029	1.05	-0.0029	0.18

Note: The speed of convergence, λ, calculated from $\beta = -(1-(1-\lambda)^T)/T$

Table 5 Country tests for convergence: 1985-95

	Poultry		Pigs		Beef		Milk	
	Trend	t-statistic	Trend	t-statistic	Trend	t-statistic	Trend	t-statistic
Australia	-0.0027	-0.35	0.0142	5.17	0.0027	1.48	0.0092	3.99
China	0.0628	4.44	0.0378	10.31	0.0446	8.30	-0.0223	-9.76
Japan	-0.0146	-3.64	-0.0171	-5.89	-0.0049	2.28	-0.0008	-0.41
Korea	0.0385	4.11	0.0164	0.90	0.0132	2.97	0.0033	0.73
New Zealand	0.0121	1.68	0.0050	1.4	-0.0068	1.83	-0.0221	-4.16
SE Asia	-0.0045	-0.42	0.0194	5.75	-0.0171	2.57	-0.0031	-0.60

Note: Trend statistics are measured as the trend coefficient from the regression of the log of a country's productivity relative to that of North America, on a constant and a linear trend.

Table 6 Projected livestock productivity growth: 1995-2005 (%)

	Beef	Pig & poultry	Milk
Australia	19.2	16.9	39.0
China	81.1	70.3	1.4
Japan	10.4	-5.0	25.7
Korea	32.3	41.1	31.0
New Zealand	8.3	23.3	1.6
North America	15.9	11.7	26.8
Southeast Asia	-2.3	19.4	22.9

Notes: "pig & poultry" is a weighted average of pig and poultry productivity growth using base period production as weights.
Livestock shocks in the EU were set equal to those of North America, in South America to those of Australia and in ROW to those of Southeast Asia.

Table 7 World exports by commodity: % change 1995-2005

	No convergence	Convergence
Rice	29	29
Wheat	54	53
Other grains	46	45
Oils	42	41
Beef cattle	29	56
Other livestock	54	29
Milk	29	30
Beef	23	28
Other meat	23	21
Dairy products	19	19
Other natres	43	43
Procfood	23	23
Other crops	34	33
Man_srvc	39	39

Table 8 Change in the volume of trade in 2005 due to convergence (1995 prices)

	Beef cattle & beef		Other livestock & other meat	
	Exports	Imports	Exports	Imports
Nth America	378	-36	-1826	11
Aus	691	-1	-374	-6
NZ	198	1	-39	-3
Japan	-3	54	-548	476
Korea	2	-60	-63	-221
China	180	-31	1197	-5606
SE Asia	-9	422	-1016	36
Sth America	137	0	-86	25
EU	4426	111	-1879	156
ROW	-988	4553	-867	-368

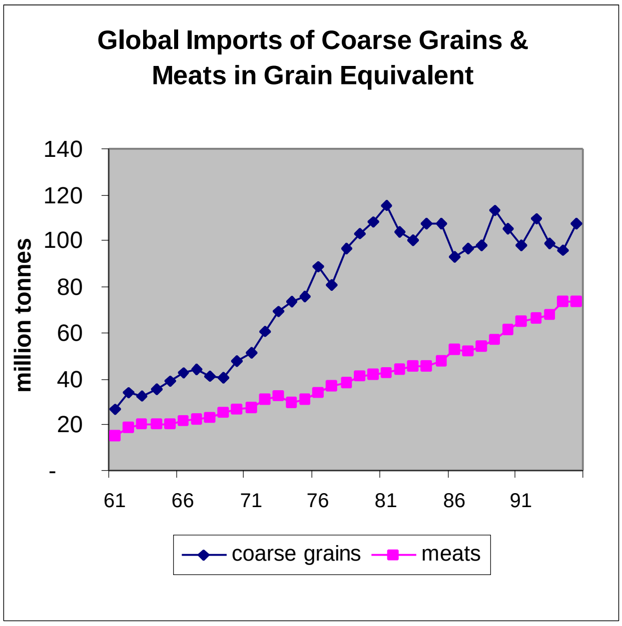
Table 10 Projected change (%) in composition of China's value-added: 1995-2005

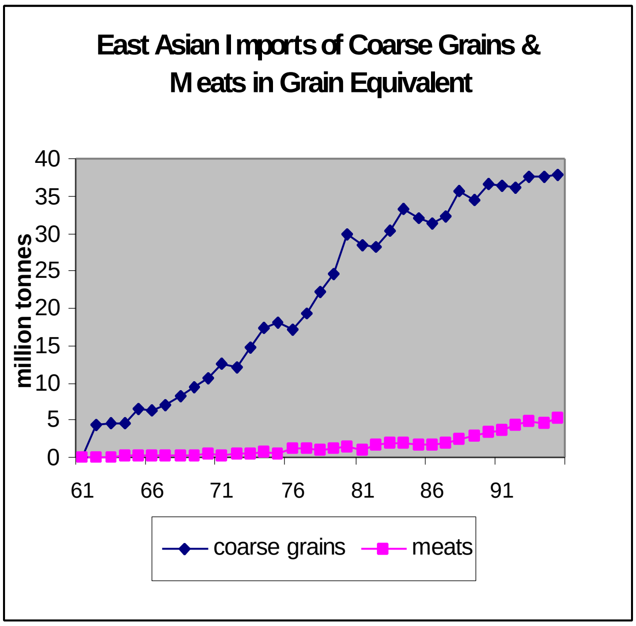
	No convergence	Convergence	Increased feed efficiency
Rice	-30	-28	-35
Wheat	-46	-43	-46
Other grains	-42	-39	-44
Oils	-30	-30	-31
Beef cattle	-24	-16	-14
Other livestock	-21	-12	-10
Milk	-9	-11	-11
Beef	-3	3	2
Other meat	-21	-11	-10
Dairy products	-24	-27	-27
Other natres	-18	-19	-20
Procfood	-29	-27	-31
Other crops	-30	-28	-30
Man_srvc	11	9	8
Capital goods	37	34	34

Table 11 China's trade balance under alternative convergence scenarios (US$millions)

	Initial trade balance 1995	Projected change in trade balance under:		
		No convergence	Convergence	Increased feed efficiency
Rice	2	-6	-5	-4
Wheat	-1924	-4943	-4825	-3654
Other grains	-989	-3675	-3507	-2715
Total grains	***-2911***	***-8624***	***-8337***	***-6373***
Oils	377	-1236	-1097	-1016
Other crops	-583	-18141	-16497	-14844
Total crops	***-3117***	***-28001***	***-25931***	***-22233***
Beef cattle	31	-41	57	92
Beef	-6	51	212	179
Total ruminants	***25***	***10***	***269***	***271***
Other livestock	684	-6045	-1118	-716
Other meat	935	-2473	-484	-207
Total non-ruminants	***1619***	***-8518***	***-1602***	***-923***
Dairy products	-24	-153	-224	-207
Total livestock & products	***1620***	***-8661***	***-1557***	***-859***
Procfood	1115	-8015	-7464	-5980
Total food	**-382**	**-44677**	**-34952**	**-29072**
Other natres	-2384	-46651	-48851	-49988
Man_srvc	49983	91327	83803	79060
Total	**47219**	**0**	**0**	**0**

Figure 1 Imports of coarse grains and meats





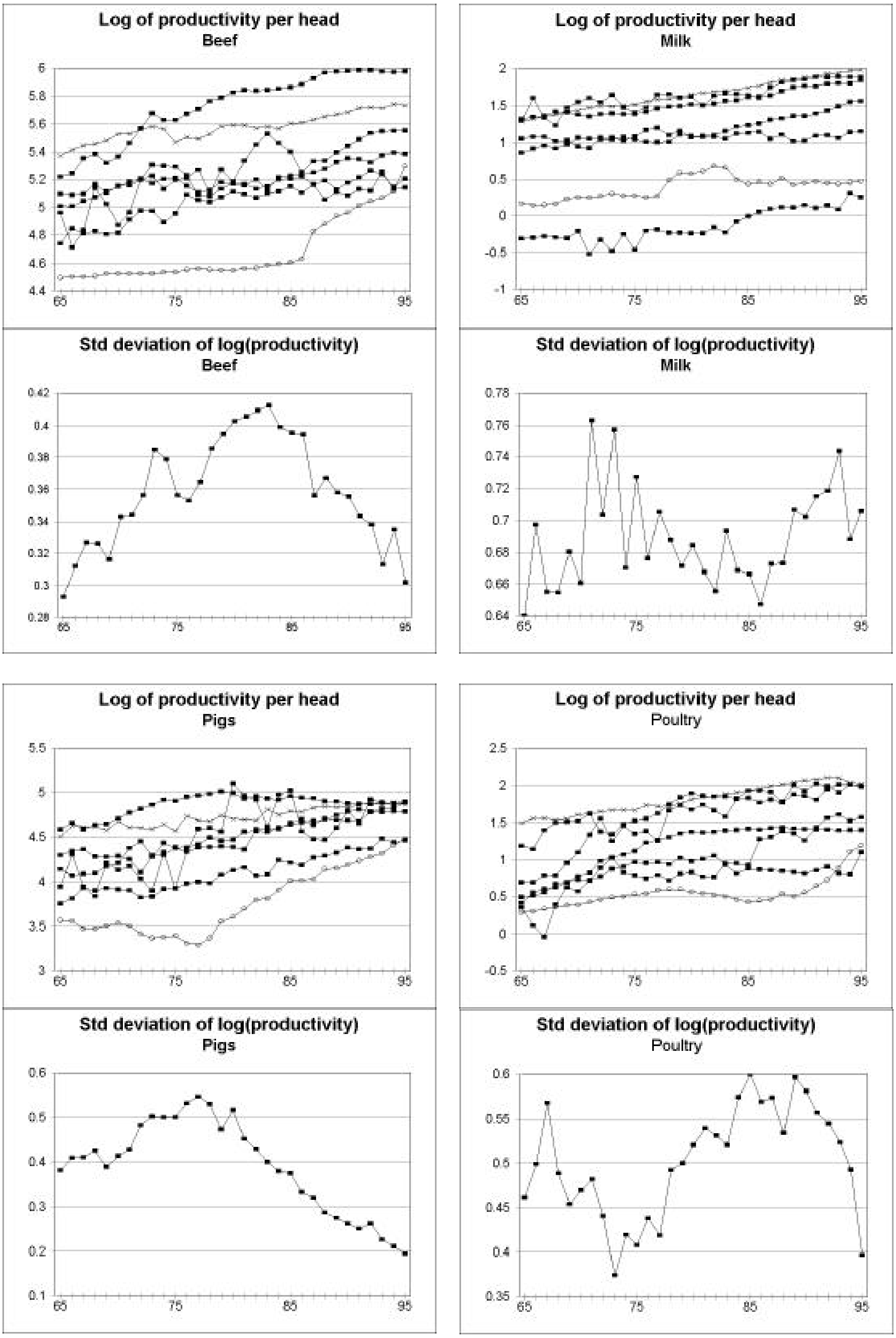


Figure 2 Livestock productivity measures and their cross-region dispersion

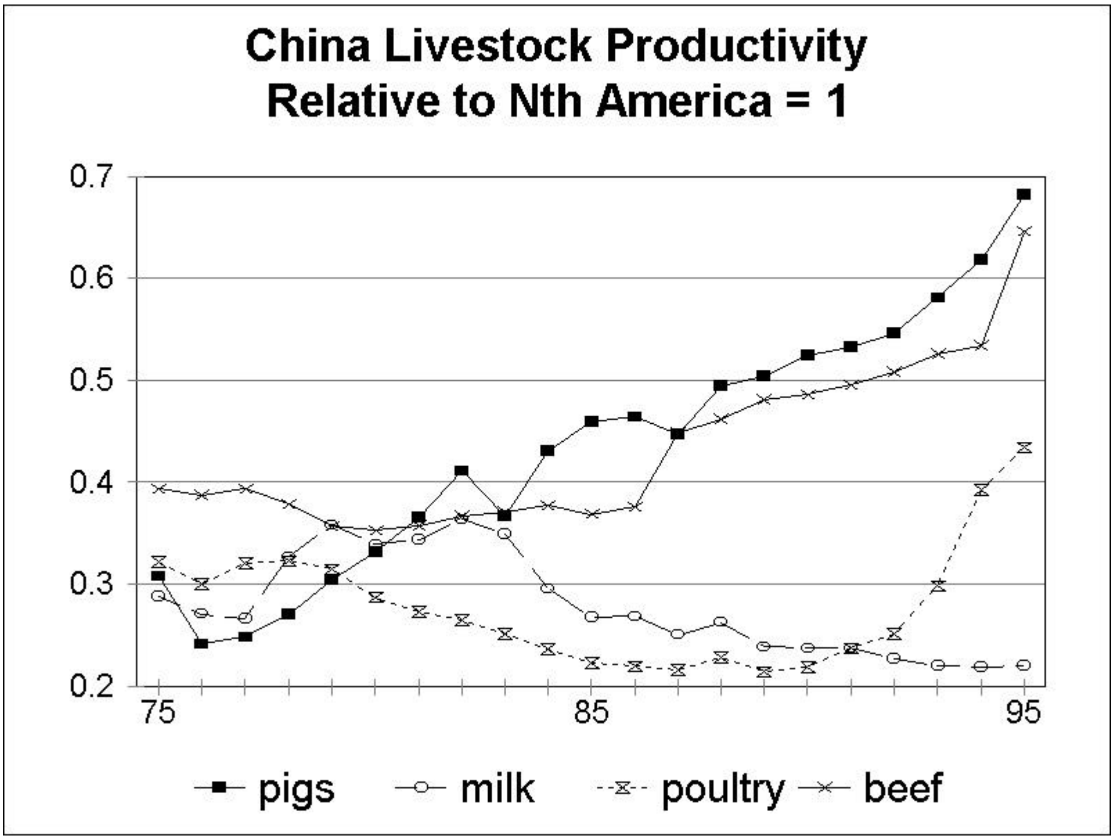


Figure 3 Convergence of livestock productivity: China and North America

Appendix Table 1 Regional aggregation

Regional Aggregation	*GTAP Aggregation*
NZ	New Zealand
Aus	Australia
Japan	Japan
Korea	Korea
China	China
SE Asia	Indonesia Thailand Malaysia Philippines
Nth America	United States Canada
Sth America	Mexico Central America and the Caribbean Venezuela Colombia Rest of the Andean Pact Argentina Brazil Chile Uruguay Rest of South America
EU	United Kingdom Germany Denmark Sweden Finland Rest of European Union
ROW	Singapore Vietnam Hong Kong Taiwan India Sri Lanka Rest of South Asia (Bangladesh, Bhutan, Maldives, Nepal, Pakistan) EFTA (Iceland, Norway, Switzerland) Central European Associates (Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia) Former Soviet Union Turkey Rest of Middle East Morocco Rest of North Africa South African Customs Union Rest of Southern Africa Rest of Sub-Saharan Africa Rest of World

Appendix Table 2: Commodity aggregation

Abbreviation	GTAP Commodity
Rice	Paddy rice
Wheat	Wheat
Other grains	Cereal grains nec
Oils	Oil seeds
Beef cattle	Bovine cattle, sheep and goat, horses
Other livestock	Animal products nec
Milk	Raw milk
Beef	Bovine cattle, sheep and goat, horse meat prods
Other meat	Meat products nec
Dairy products	Dairy products
Other natres	Wool, silk-worm cocoons
	Forestry
	Fishing
	Coal
	Oil
	Gas
	Minerals nec
	Vegetable oils and fats
Procfood	Processed rice
	Sugar
	Food products nec
Other crops	Vegetables, fruit, nuts
	Sugar cane, sugar beet
	Plant-based fibers
	Crops nec
Man_srvc	Beverages and tobacco products
	Textiles
	Wearing apparel
	Leather products
	Wood products
	Paper products, publishing
	Petroleum, coal products
	Chemical, rubber, plastic products
	Mineral products nec
	Ferrous metals
	Metals nec
	Metal products
	Motor vehicles and parts
	Transport equipment nec
	Electronic equipment
	Machinery and equipment nec
	Manufactures nec
	Electricity
	Gas manufacture, distribution
	Water
	Construction
	Trade, transport
	Financial, business, recreational services
	Public admin and defence, education, health
	Dwellings

Appendix Table 3 Assumptions made in the projections: cumulative [and annual] percentage changes in AVA and factor endowments for the period 1995 to 2005 – These shocks apply in each of the three scenarios

Region	*"ava" All crops*	*"ava" All non-farm*	*Physical capital*	*Unskilled labour*	*Skilled labour*	*Population*
AUS	21.9	7.8	40	5	66	8
	[2.0]	[0.75]	[3.4]	[0.48]	[5.2]	[0.77]
NZ	21.9	7.8	34	12	63	10
	[2.0]	[0.75]	[3.0]	[1.1]	[5.0]	[1.0]
JAPAN	21.9	7.8	44	-2	32	2
	[2.0]	[0.75]	[3.7]	[-0.2]	[2.8]	[0.2]
KOREA	21.9	13.2	59	9	71	8
	[2.0]	[1.25]	[4.7]	[0.9]	[5.5]	[0.8]
CHINA	21.9	13.2	153	12	41	9
	[2.0]	[1.25]	[9.7]	[1.1]	[3.5]	[0.9]
SE ASIA	21.9	13.2	22	22	68	14
	[2.0]	[1.25]	[2.0]	[2.0]	[5.3]	[1.33]
NTH AMER	21.9	7.8	30	10	38	9
	[2.0]	[0.75]	[2.7]	[1.0]	[3.3]	[0.9]
STH AMER	21.9	13.2	20	24	49	16
	[2.0]	[1.25]	[1.8]	[2.2]	[4.1]	[1.5]
EU	21.9	7.8	36	1	29	2
	[2.0]	[0.75]	[3.1]	[0.1]	[2.6]	[0.2]
ROW	21.9	13.2	36	27	32	13
	[2.0]	[1.25]	[3.1]	[2.4]	[2.8]	[1.2]

Source: Authors' modifications of Anderson et al. (1996), Arndt et al. (1997), Frandsen et al. (1998), Coe and Helpman (1995), Coe et al (1997), drawing on World Bank projections.

All crops = {rice, wheat, other grain, oils, other crops}

All non-farm = {beef, other meat, dairy products, other natres, procfood, man_srvc}

[1] China,Northeast Asia and Southeast Asia.

[2] The authors also assumed a continuation of very high productivity growth in the non-farm sectors. This has two important consequences for their projections. First of all, it serves to pull additional resources out of agriculture, into the rapidly growing manufacturing sector. Secondly, by fueling higher income growth rates, it stimulates demand for livestock products.

[3] This section relies heavily on Simpson et al (1994, Chapter 6)

[4] This measure is flawed since it includes in livestock capital those animals too young to be productive, as well as those ready for sale for slaughtering. The latter would more appropriately be considered an output.

[5] Most notably in China, but also in Korea and Southeast Asia, there has been an increase over time in the proportion of the cattle inventory slaughtered. One explanation for this is a greater emphasis on meat production from cattle, as draft power is replaced through mechanisation. Such trends can influence productivity values estimated from production per head of inventory, and instead output divided by the number of animals slaughtered was used.

[6] Throughout this paper, average growth rates are constructed as the trend coefficient from a regression of the log of the productivity level on a constant and a linear trend.

[7] While we refer to these aggregates as ruminant and non-ruminant livestock, it should be remembered that the former also includes sheep, goats and horses, while the latter comprises eggs, honey, hides and skins in addition to pigs, poultry and live animals not otherwise covered.

[8] Note that unlike Anderson *et al.* (1997) we make no changes to domestic or trade policies to reflect implementation of the Uruguay Round reforms. Unfortunately these are currently unavailable for the GTAP version 4 data base. (The previous authors used a special data set developed by the World Bank for evaluation of the Uruguay Round. They are keyed to the more aggregated, GTAP version 3 data base which uses a 1992 base year.) From a practical point of view we believe that for much of agriculture, the actual 1995 protection rates are not that far off the post-Uruguay Round rates, due to the problem of "dirty-tariffication".

[9] In this study we attain a high rate of GDP growth in China without extraordinary productivity growth in non-agriculture due to our use of a new Chinese data base (McDougall and Elbehri, 1998), which exhibits a higher capital share, thereby lending more weight to the high rate of capital accumulation.

[10] Throughout this paper when we refer to productivity growth we will be referring to productivity of value-added, excepting where explicit reference is made to feed efficiency.

[11] After their review of the literature, Bach and Frandsen set livestock TFP rates slightly higher than those for crops.

[12] This implies that the amount of feed per animal remains constant. Also note for China that these shocks imply annual reductions in FCR's of 5.8% and 5.2% for beef and non-ruminants respectively. Simpson et al's (1994) projections imply lower reductions of 2.5% (beef), 4.8% (poultry) and 2.2% (pigs).