

*Livestock Productivity Convergence in the Asia-Pacific Region: Impacts 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 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 is 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 Asia<sup>1</sup> 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 some alternative projections for China's grain imports for the year 2005 range between 14 and 108 million metric tonnes. 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 Agraonil-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" (p27).

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<sup>1</sup> China, Northeast Asia and Southeast Asia

A more recent projections model that did include livestock sectors was that of Anderson *et al* (1997). Using the GTAP (Hertel 1997) applied general equilibrium model, 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 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.

The focus of this paper will be livestock productivity catch-up among the countries of the Asia-Pacific region. Productivity indices are constructed, and the degree to which productivity in Asia/Pacific economies is catching up with that in North America will be examined. Consequently, projections of technological change in livestock production are made. The impacts of such productivity enhancement on regional trade in both livestock products and grains is then examined.

### **Developments in Animal Production Technology<sup>2</sup>**

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 lead 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.

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<sup>2</sup> This section relies heavily on Simpson et al (1994, Chapter 6)

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, and the rate and success with which they may be adopted, will be influenced by many factors that we refrain from discussing here.

### **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). Questions of interest include whether the lesser-productive countries are catching-up with (converging on) the leaders, and if so how quickly and by what means? Such convergence implies the tendency for poorer countries to grow more rapidly than the rich countries. Earlier applications used aggregate data at the national level, and surrogates for productivity such as GDP per worker (eg Baumol 1986). Some recent work has employed more complete measures of productivity such as total factor productivity (TFP), and have also been applied at the sectoral level, including 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  $\beta$ -convergence since it commonly involves the regression of growth rates on initial productivity (perhaps relative to the lead country), and the latter as  $\sigma$ -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.

## **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:

$$Q = f(X_1, X_2 \dots X_n) \text{ where}$$

Q = output,

$X_1$  = livestock capital input, and

$X_2 \dots X_n$  are inputs of non-livestock capital, land, labour, feedstuffs and other purchased inputs.

Total factor productivity (TFP) may be measured as:

$$TFP = Q / [\alpha_1 X_1 + \alpha_2 X_2 + \dots + \alpha_n X_n]$$

where  $\alpha_1, \alpha_2, \dots, \alpha_n$  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:

$$PFP = Q / X_1.$$

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  $X_2 \dots X_n$ . 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. There is an additional problem posed by the fact that we use of livestock inventory as the measure of livestock capital<sup>3</sup>.

Data on livestock numbers and output were taken from the FAO (1997). Productivity values for beef, pork and poultry were given by the volume of meat production divided by the animal inventory<sup>4</sup>, while milk productivity was measured as milk

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<sup>3</sup> This poses an additional problem of including in the measure of livestock capital those animals too young to be productive or those ready for sale for slaughtering and which might be considered as output in inventory. Lack of data prevents a more satisfactory measure being constructed

<sup>4</sup> 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.

production divided by the number of milking cows. Without looking for justification for this approach, we note its similarity to many recent reported analyses that employed output per worker as a surrogate for TFP at the economy-wide level.

### ***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 – over the decade between 1965 and 1975, and 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<sup>5</sup> 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 shows the levels of livestock productivity in China 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.

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<sup>5</sup> 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.

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  $\beta$ -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 (Bernard and Jones 1996a):

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

A negative  $\beta$  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  $\beta$  coefficients of Table 4 are negative, and three of them have t-statistics in excess of 2.0. Both  $\beta$  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  $\beta$  coefficient ( $t = 1.8$ ). Neither of the  $\beta$  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. 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.

Additional time series evidence to supplement the above results is obtained by regressing  $\ln(PFP_{it}/PFP_{NA,t})$  for each commodity against time (Bernard and Jones 1996b). This provides the average trend in the productivity deviations of the  $i^{\text{th}}$  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  $\ln(\text{PFP}_{it}/\text{PFP}_{NA,t})$  for each region or country and for each livestock commodity, to the year 2005 (which is ten years beyond the base year of our general equilibrium model). 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 the general equilibrium model, 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, and Chinese productivity is 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.

### **Methodology**

The national and regional impacts of projected livestock productivity convergence were simulated with the applied general equilibrium model known as GTAP ( Hertel 1997) and solved using GEMPACK (Harrison and Pearson 1996). 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, based on the year 1995. This application uses a modified version of the standard model to allow for substitution between the various feedstuffs in livestock and milk production. 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 modelled, and bilateral international transport margins are incorporated and supplied by a global transport sector. For a previous application of this model involving technological change and research spillovers, the reader is referred to Frisvold (1997).

We aggregate the GTAP version 4 prerelease data up to the level of 10 regions and 14 commodities (see Appendix Tables 1 and 2). The regional focus is on Asia. 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 into the 14 commodities. Six commodities (rice, wheat, other grains, oil crops, other crops and processed food) comprise the feedstuffs composite. Livestock farming is represented by three aggregates: beef cattle (ie ruminant livestock), other livestock (ie non-ruminants) and raw milk production. These farming sectors provide inputs to the beef (ruminant meat), other meat (non-ruminant meat) and dairy industries in each region. All remaining production sectors are aggregated into manufactures and services, or other natural resource based commodities.

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, the rapid accumulation of skilled labor and capital in some of the Asia economies is likely to promote a further shift of activity away from agriculture, in favor of manufacturing and services. In order to put the projected livestock changes in the context of a changing world economy, it will be necessary to imbed them in a more comprehensive projections scenario.

The projections from 1995 to 2005 were 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 on which they were based. The indicated shocks to total factor productivity ("ava") were applied to the non-livestock sectors in each region, as described. The specific livestock productivity shocks have already been discussed (Table 6). Note that (unlike Anderson *et al* 1997) we make no changes to domestic or trade policies.

### ***Experimental design***

As noted previously, our goal in this paper is to assess the impact of the pattern of productivity growth shown in Table 6, on trade in livestock and grains products. The first problem which we confront has to do with the appropriate exogenous variable to shock. The partial productivity measure reported above really only applies to the capital input in the livestock sectors. If we assume that these improved technologies do not affect the productivity of other inputs, then we can simply shock the rate of capital-augmenting technical change in the GTAP model [ $\text{afe}(\text{capital, livestock, region})$ ] and leave it at that. This is the first experiment which we conduct.

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. Simpson's (1994) projections for China are based on detailed farm enterprise and feed budgets. Over the period 1989-91 to 2000, one set of projections implied total growth in ruminant, pig meat and poultry meat production per head of inventory of 73%, 30% and 85% respectively. Feed inputs per head of inventory increased about 30% for cattle but showed almost no growth for non-ruminant livestock (Simpson 1994, Tables 8.10 – 8.12). Thus these projections imply rapid increases in feed productivity in China, and especially in non-ruminant

production. Wailes *et al* (1998) gathered household-level data in seven Chinese provinces, and concluded that the change from backyard to specialist and commercial production systems (with their lower feed conversion ratios) is leading to a decline in the derived demand for grains per unit of meat production. In order to assess the sensitivity of our findings to these alternative types of technical change, we conduct an additional experiment in which we augment the productivity of *all inputs* [shock to ao(livestock, region)].

Each of the above experiments is conducted in two steps. In the first the only shock is to livestock productivity, so as to isolate the impact of productivity catch-up without the confounding effects of growth in regional resource endowments and population. In the second step, shocks to resource endowments are added.

In order to make both experiments comparable in terms of overall impact, we scale the shocks for the latter experiment so that it generates the same cost savings as the first experiment.<sup>6</sup> Since we don't have explicit productivity estimates for the EU, South America and ROW, we apply the North American growth rates to the EU, Australian rates to South America and the Southeast Asian growth rates to ROW. Thus the results for these three missing regions should be viewed with some skepticism. Finally, both experiments were conducted with and without the shocks to the exogenous variables of Appendix Table 3, to isolate the impacts of livestock productivity catch-up.

## Results

Table 7 reports the change in global trade volume under the “afe” experiment, in which only the productivity of capital stock is augmented. Shocking only livestock productivity raises trade in beef cattle by 1.2% and in non-ruminant live animals by 0.4%. Trade in processed livestock products is larger in absolute terms, but the farm-level productivity shock has a less direct impact here, so the percentage changes are smaller, ranging from 0.1 to 0.4%. Wheat and feed grains trade volumes also increase by almost 0.2%. Other products also experience small, but positive increases in trade. Once regional resource endowments and non-livestock productivity levels are also shocked, increases in trade volumes are much larger and dwarf those changes due to livestock productivity catch-up.

Table 8 reports the impact of the livestock-capital-augmenting productivity shock, along with all other exogenous shocks, on the projected commodity trade balances, by region. Each entry shows the difference in the trade balance in 2005 relative to 1995, in billions of constant (1995) US dollars. China is projected to be a major net importer of grains by 2005, but China's increases in net imports are projected to be even greater for livestock products (and also for other crops). Of her total projected increase in food net imports over the 1995-2005 period, grains account for 18% and livestock products 28%. 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 from these, perhaps because our experiment recognises livestock productivity catch-up

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<sup>6</sup> Specifically, we multiply the shocks in Table 6 by the share of capital in total costs of livestock production to obtain the “ao” shocks.

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 livestock products.

Table 9 focuses on the case of China's trade balance, and how it is affected by the two different types of technological progress in livestock production. We first shock only livestock productivity. When livestock capital productivity ("afe") is shocked, China's trade balance in grains deteriorates as the livestock sector expands and the domestic grain sector cannot expand sufficiently to supply the increased demand for feeds. When livestock technical change is modeled as factor-neutral ("ao"), China's grains sector actually contracts and the grains trade balance improves since feed efficiency in the livestock sector will have increased. When regional factor endowments and population are also shocked these livestock productivity impacts are masked, but China's projected increase in net imports of livestock products is smaller when livestock technical change is factor neutral since increased feed efficiency permits additional domestic production of beef and non-ruminant livestock.

### **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. This paper is an initial output of a project that aims to examine linkages between growth, grains markets, and the global markets for livestock products with an emphasis on the influence of technological catch-up in livestock technologies. 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. On a 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 is projected to become a major net importer of both grains and livestock products by 2005. Compared with 1995, the increase in net imports will be greater for livestock products than for grains. However, the share of livestock products in China's increase in food imports is less than projected by Anderson *et al.*, perhaps due in part to the productivity catch-up that we have modeled. The factor bias of livestock technical change does have some impact on the extent of China's increased livestock product imports. Productivity gains that also increase feed efficiency were shown to reduce somewhat China's need for livestock product imports but not for those of grains. Clearly, further econometric research which measures the productivity of other inputs in the livestock industry is urgently needed to address this question.

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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	OECD
<b>2005</b>						
production	329	418	455	382	445	382
consumption	437	434	480	414	459	435
imports	108	16	25	32	14	52
<b>2010</b>						
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)**

	<b>Poultry</b>	<b>Pigs</b>	<b>Beef</b>	<b>Milk</b>
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
<i>Nth America</i>	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**

<b>Livestock type</b>	<b>b</b>	<b>t statistic</b>	<b>l</b>	<b>R<sup>2</sup></b>
<i>Poultry</i>				
1975-85	0.0387	2.43	-0.0332	0.54
1985-95	-0.0312	2.05	0.0368	0.46
<i>Pigs</i>				
1975-85	-0.0512	3.44	0.0693	0.70
1985-95	-0.0348	2.56	0.0419	0.57
<i>Beef</i>				
1975-85	0.0099	0.70	-0.0095	0.09
1985-95	-0.0321	1.82	0.0380	0.40
<i>Milk</i>				
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,  $\lambda$ , calculated from  $\beta = -(1 - (1 - \lambda)^T) / T$

**Table 5 Country tests for convergence: 1985-95**

	<b>Poultry</b>		<b>Pigs</b>		<b>Beef</b>		<b>Milk</b>	
	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 (%)**

	<b>Beef</b>	<b>Pig &amp; poultry</b>	<b>Milk</b>
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** Change in global trade volume (percent): “afe” shock

	Shock to livestock productivity only	Shocks to all projected variables
rice	0.10	47
wheat	0.18	76
other grain	0.16	62
oils	0.07	58
beef cattle	1.20	56
other livestock	0.43	99
beef	0.41	31
other meat	0.28	36
dairy products	0.11	23
other natres	0.04	50
procfood	0.06	32
other crops	0.07	48
man_srvc	0.04	44

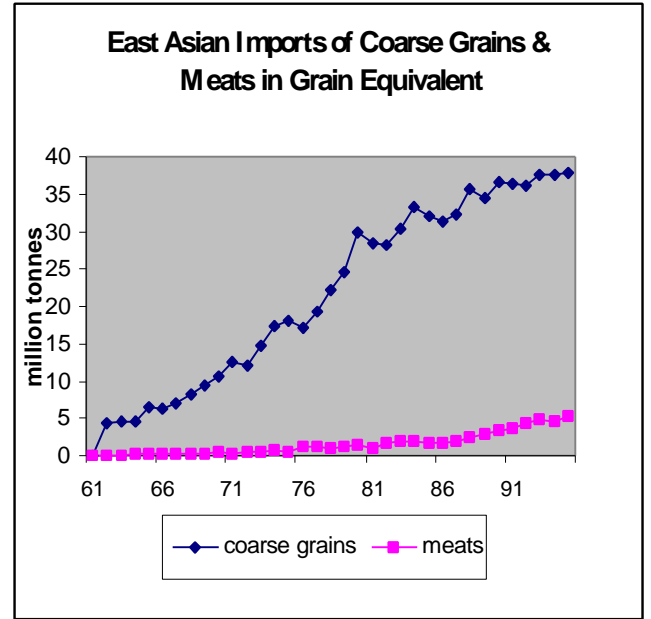
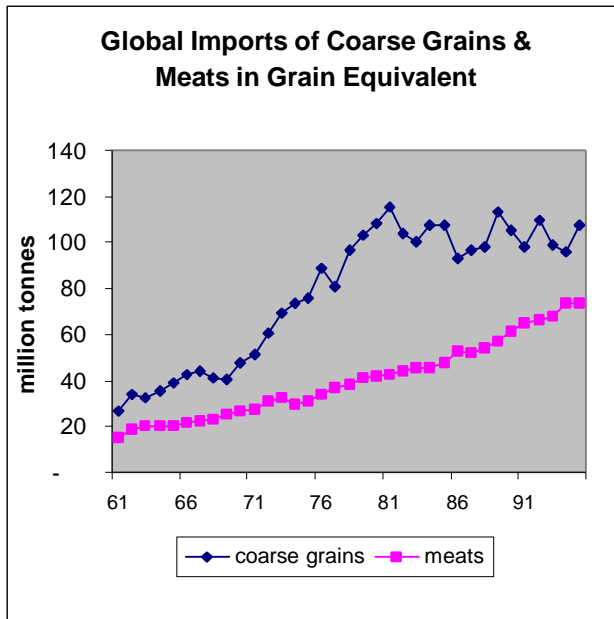
**Table 8** Change in trade balance, by commodity and region, 1995-2005  
(\$US billion): “afe” shock

	ROW	Nth Amer	Aus	NZL	Japan	Korea	China	SE Asia	Sth Amer	EU
rice	-0.4	0.3	0	0	0	-0	-0	-0	-0	0.1
wheat	-7.2	8.7	0.8	0	-0.4	-0.2	-6.2	-1	-0.9	4.1
other grain	-3.7	7.4	0.1	0	-1	-0.8	-4.3	-0.7	-0.9	2.3
<b>Total grains</b>	<b>-11.3</b>	<b>16.4</b>	<b>0.9</b>	<b>0</b>	<b>-1.4</b>	<b>-1</b>	<b>-10.5</b>	<b>-1.7</b>	<b>-1.8</b>	<b>6.5</b>
oils	-4.6	7	0.1	0	-1.1	-0.4	-1.6	-0.7	1.3	-1.4
other crops	-25.4	7.2	2.4	0.4	1	-3.6	-21.8	-5.3	18.5	18.8
<b>Total crops</b>	<b>-41.3</b>	<b>30.6</b>	<b>3.4</b>	<b>0.4</b>	<b>-1.5</b>	<b>-5</b>	<b>-33.9</b>	<b>-7.7</b>	<b>18</b>	<b>23.9</b>
beef cattle	-3.4	1	0.9	0.2	0	0	-0.1	-0.7	-0.6	2.7
other livestock	-5	7.3	0.8	0.5	2.1	-1.2	-11.9	-1.7	-0.4	7.3
beef	-2.3	0.8	0.7	1.5	-1.1	-0.6	0.4	-0.4	-0.6	1.3
other meat	-4.2	5.6	0.2	0.2	-1.6	-0.4	-4.2	-0.2	-0.4	4.8
dairy products	1	0.2	-0.2	-0.2	-0.2	-0.1	-0.4	-0.8	-1.2	1.7
<b>Total livestock</b>	<b>-13.9</b>	<b>14.9</b>	<b>2.4</b>	<b>2.2</b>	<b>-0.8</b>	<b>-2.3</b>	<b>-16.2</b>	<b>-3.8</b>	<b>-3.2</b>	<b>17.8</b>
procfood	-0.6	2.1	-0.1	0	-0.7	-2.6	-7	-4.4	1	8.3
<b>Total food</b>	<b>-55.8</b>	<b>47.6</b>	<b>5.7</b>	<b>2.6</b>	<b>-3</b>	<b>-9.9</b>	<b>-57.1</b>	<b>-15.9</b>	<b>15.8</b>	<b>50</b>
other natres	149.8	-47.2	3.6	0.6	-45.4	-20.3	-24.1	-3.3	4.4	-35.6
man_srvc	-100.2	5.2	-11	-1.9	55.6	27.2	31.3	11.7	-10.7	30.3

**Table 9 Does technology bias matter? Some results for China's trade balance**

	Shock to livestock productivity only		Shocks to all variables	
	Trade balance (US\$mill)		Trade balance (US\$bill)	
	“afe”	“ao”	“afe”	“ao”
rice	-0.0	0.0	-0	-0
wheat	-16.0	19.2	-6.2	-6.2
other grain	-10.2	9.5	-4.3	-4.3
<b>Total grains</b>	<b>-26.2</b>	<b>28.7</b>	<b>-10.5</b>	<b>-10.5</b>
oils	-5.3	0.6	-1.6	-1.6
other crops	-49.4	19.2	-21.8	-22.1
<b>Total crops</b>	<b>-80.9</b>	<b>48.5</b>	<b>-33.9</b>	<b>-34.2</b>
beef cattle	5.7	12.5	-0.1	-0.1
other livestock	92.8	242.5	-11.9	-9.7
Milk	0.0	0.0	0	0
Beef	-1.1	-1.7	0.4	0.4
other meat	60.1	142.1	-4.2	-3.6
dairy products	-2.3	-2.0	-0.4	-0.4
<b>Total livestock</b>	<b>155.2</b>	<b>393.4</b>	<b>-16.2</b>	<b>-13.4</b>
Procfood	-22.0	40.3	-7.0	-6.9
<b>Total food</b>	<b>52.3</b>	<b>482.2</b>	<b>-57.1</b>	<b>-54.5</b>
other natres	-103.3	-96.0	-24.1	-24.5
man_srvc	-325.0	-301.7	31.3	30.0

**Figure 1 Imports of coarse grains and meats**



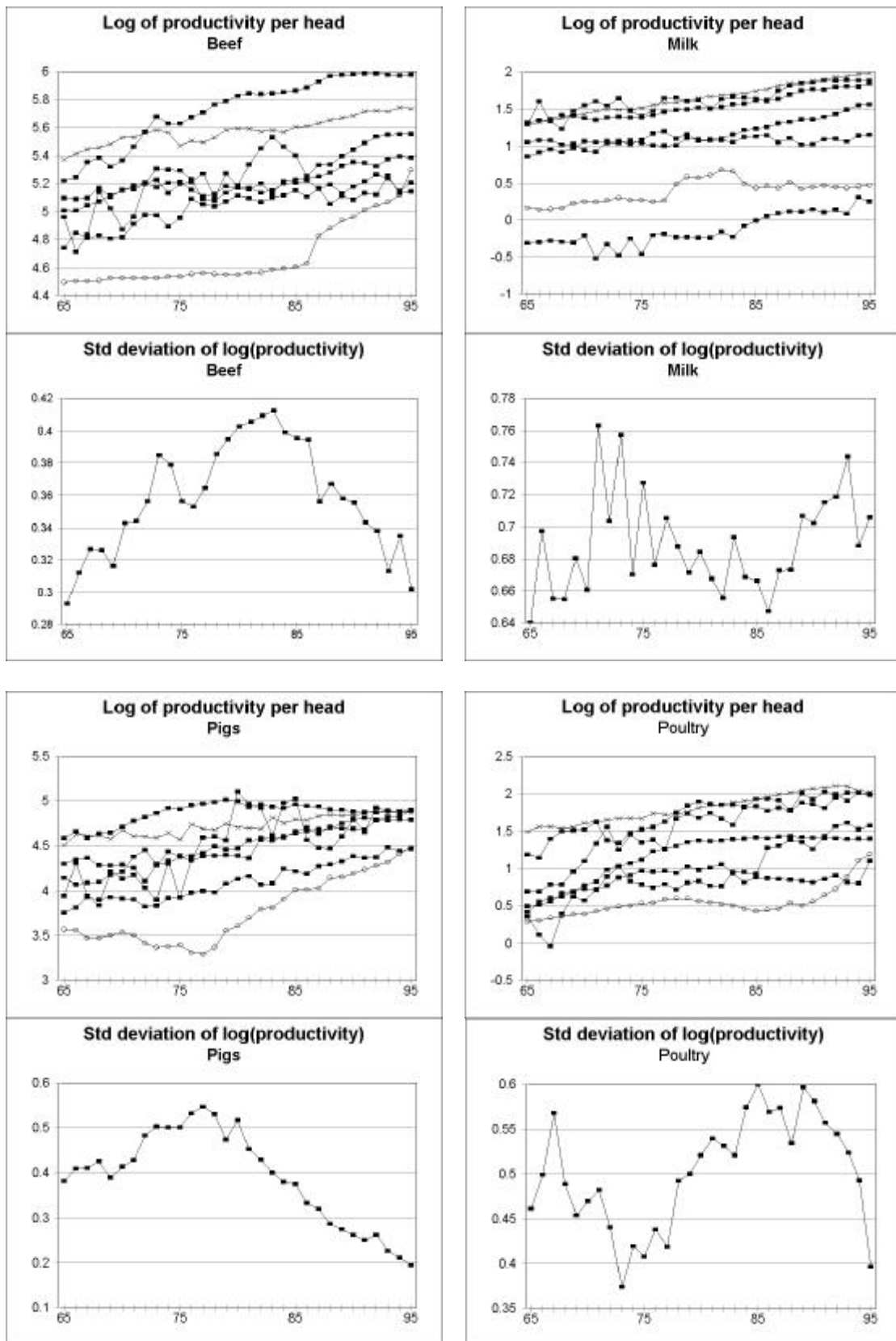
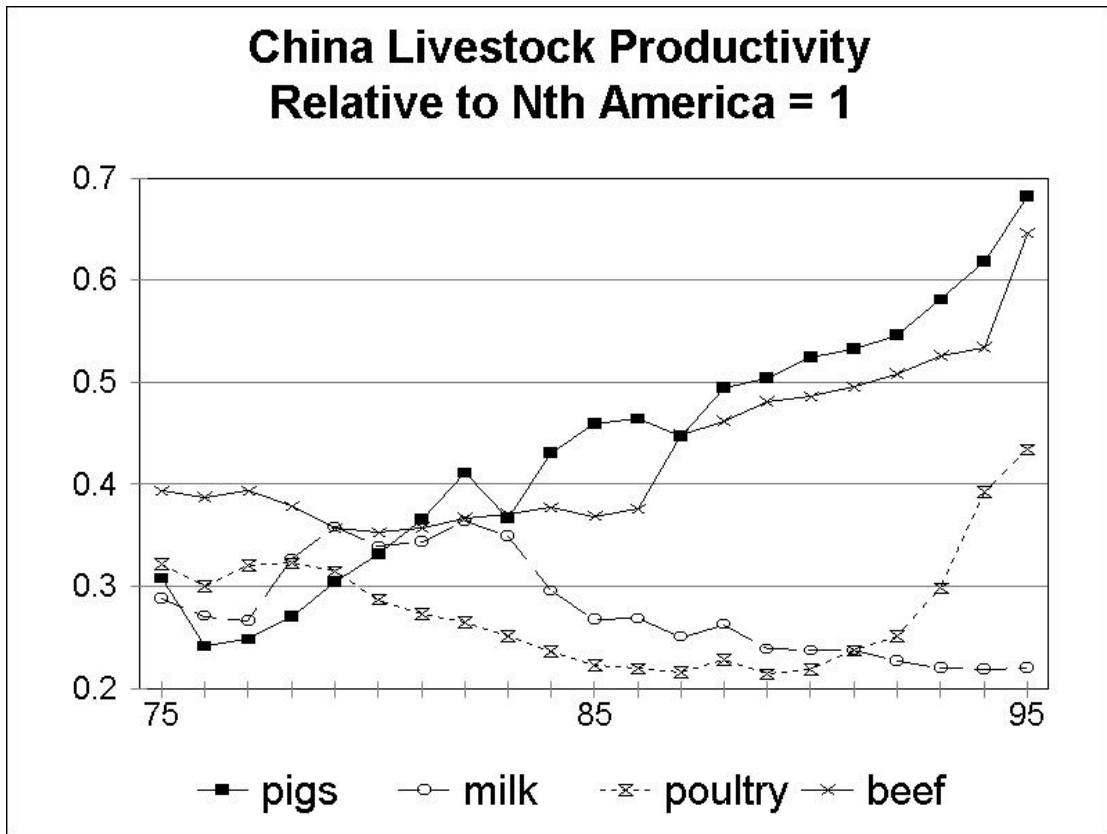


Figure 2 Livestock productivity measures and their cross-region dispersion



**Figure 3** Convergence of livestock productivity: China and North America

**Appendix Table 1 Regional aggregation**

<b>Regional Aggregation</b>	<b>GTAP Aggregation</b>
NZL	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**

<b>Abbreviation</b>	<b>GTAP Commodity</b>
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**

<i>Region</i>	<i>“ava” All crops</i>	<i>“ava” All non- farm</i>	<i>Physical capital</i>	<i>Unskilled labour</i>	<i>Skilled labour</i>	<i>Population</i>
<b>AUS</b>	17	4	40	5	66	8
	[1.6]	[0.4]	[3.4]	[0.48]	[5.2]	[0.77]
<b>NZL</b>	17	4	34	12	63	10
	[1.6]	[0.4]	[3.0]	[1.1]	[5.0]	[1.0]
<b>JAPAN</b>	15	10	40	-5	32	1
	[1.4]	[1.0]	[3.4]	[-0.5]	[2.8]	[0.03]
<b>KOREA</b>	15	10	63	9	71	8
	[1.4]	[1.0]	[5.0]	[0.9]	[5.5]	[0.8]
<b>CHINA</b>	10	28	148	9	41	7
	[1.0]	[2.5]	[9.5]	[0.85]	[3.5]	[0.72]
<b>SE ASIA</b>	22	10	79	20	68	14
	[2.0]	[1.0]	[6.0]	[1.8]	[5.3]	[1.33]
<b>NTH AMER</b>	17	4	34	10	38	8
	[1.6]	[0.4]	[3.0]	[1.0]	[3.3]	[0.73]
<b>STH AMER</b>	22	8	48	18	49	13
	[2.0]	[0.75]	[4.0]	[1.7]	[4.1]	[1.2]
<b>EU</b>	22	13	36	-2	29	1
	[2.0]	[1.25]	[3.1]	[-0.17]	[2.6]	[0.01]
<b>ROW</b>	22	22	76	27	32	13
	[2.0]	[2.0]	[5.8]	[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}