

# Future developments in global livestock and grains markets: the impacts of livestock productivity convergence in Asia-Pacific<sup>†</sup>

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Increasing livestock product consumption in many Asian countries has been accompanied by growth in some countries' imports of feedgrains for their domestic livestock sectors. This contributes to debate over future levels of grain imports. Yet projections often pay little attention to developments in livestock production. The impacts of technological catch-up in livestock production on trade in livestock and grains products among countries in the Asia-Pacific region are assessed. Tests are conducted of the hypothesis that productivity levels in the Asia-Pacific region are converging. Projections of livestock productivity are made and incorporated in a modified GTAP model. The consequences for regional and global trade in livestock and grains products are explored.

## 1. Introduction

The way in which dietary patterns are changing in Asia as economic growth and development proceed 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 (e.g. wheat-based foods) and value-added processed and high-protein foods such as those derived from animal products (Delgado *et al.* 1999; Huang and Bouis 1996; Huang and David 1993; Rae 1997, 1998). This typically involves a switch in the domestic utilisation of grains from human

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consumption to feeding of livestock. Much recent debate has centred 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, particularly during the 1960s and 1970s. In response to demand changes, many countries have assisted and expanded domestic livestock production and found their demand for feeds exceeded their ability to supply from domestic sources. But since the early 1980s, the rate of growth of global trade in coarse grains has slowed considerably, while that of global trade in meats has continued to increase. A similar pattern has become evident in East 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 South Korea accounting for almost 30 per cent of global trade in 1995. But these (and other) countries face economic and environmental constraints to further expansion of their domestic livestock industries suggesting a continuation of the 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 raise the question of China's ability to remain largely self-sufficient in both livestock products and feedgrains. However, should livestock productivity in China increase sufficiently rapidly, that country need not follow the East Asian trend to increased imports of livestock products.

Many, and in some cases widely differing, projections have been made of China's future grain situation (Fan and Agcaoili-Sombilla 1997). 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 tonnes. The most extreme projection has been that of Lester Brown (1995) which suggested a tenfold 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 Agcaoili-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,

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

improvements in feed-meat ratio arising from these technical and structural changes will save huge amounts of feed grains.

(1997, p. 27)

In this article, therefore, we pay specific attention to ways in which future growth in incomes, resource endowments and productivity might impact on global trade in livestock products. In particular, we explore the extent to which convergence in livestock productivity might influence Asia-Pacific country trade balances in livestock products, and also in those for feedstuffs.

Two recent projections models that did include livestock sectors were those of Anderson *et al.* (1997) and Delgado *et al.* (1999). Using the GTAP applied general equilibrium model (Hertel 1997), the base projection of Anderson *et al.* (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 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 per cent of the dollar value of the increase in China's food trade deficit whereas the proportion for livestock products was 40 per cent. 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.<sup>2</sup>

Delgado *et al.* (1999) modelled livestock sectors in some detail, and incorporated trends in herd size and productivity, feed conversion trends, and substitution among feeds due to changes in relative feed prices. Their projections to 2020 show China as a net exporter (in volume terms) for beef, pork, poultry and dairy products. China's net imports of cereals were projected at 46 million tonnes in 2020, compared with net imports of 0.9 million tonnes in 1993.

What if livestock producers in China are able to 'catch up' with productivity levels in North America and elsewhere? Wouldn't this shift the balance of their net imports in favour of feedgrains, with the livestock being produced domestically rather than being imported? This article aims to address this question directly. We begin by constructing productivity indices for livestock producers in the Asia-Pacific region. We then test econometrically the degree to which technological 'catch-up' has been occurring over the past two decades. Based on these historical changes, projections of

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<sup>2</sup>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. Second, by fuelling higher income growth rates, it stimulates demand for livestock products.

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 within an applied general equilibrium model.

## 2. Developments in animal production technology<sup>3</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 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 variety of associated techniques have 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. Thus herd improvement can be achieved at faster rates than with natural mating or artificial insemination. Other techniques include the splitting of embryos to produce multiple copies of genetically identical animals, embryo cloning, *in vitro* fertilisation and sex determination.

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<sup>3</sup> This section relies heavily on Simpson *et al.* (1994, Chapter 6).

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. Advances in herd health management through adjusted weaning age, animal flow and housing design have cut expenses on medications while increasing growth rates and feed efficiency. 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, Cheng and Miyazaki (1994) refer to a 1992 report (US Congress 1992), 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 brought into commercial use in the country of origin (in many cases the United States) and transferred to recipient countries in Asia, will be influenced by many factors which are beyond the scope of this article. Our contribution is rather to focus on the consequences of these potential spillovers for patterns of international trade.

### **3. 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 data, and surrogates for productivity such as GDP per worker (e.g. 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 unit of labour.

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<sup>4</sup> 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. Schimmelpfennig and Thirtle (1998) focused on agricultural TFP and found evidence of  $\beta$ -convergence between countries of the European Union and the United States. 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 article, we focus on productivity convergence in the livestock sectors.

#### 4. Livestock productivity convergence and catch-up in the Asia-Pacific region

##### 4.1 The measurement of livestock productivity

A generalised livestock production function may be written as:

$$Q = f(X_1, X_2 \dots X_n), \quad (1)$$

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:

$$\text{TFP} = Q / [\alpha_1 X_1 + \alpha_2 X_2 + \dots + \alpha_n X_n] \quad (2)$$

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<sup>4</sup>This approach to convergence analysis has recently been criticised for inherent problems that may bias the results. Some more recent analyses have avoided cross-country regressions and relied instead on time series information for testing convergence hypotheses (Ben-David 1996).

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:

$$\text{PFP} = Q/X_1. \quad (3)$$

Clearly, TFP and PFP are not the same, and the partial approach suffers from some limitations (Capalbo and Denny 1986). PFP will capture not only changes in the productivity of the various inputs but also substitution effects due to changes in the intensity with which the other inputs:  $X_2 \dots X_n$  are employed. 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. However, it has the overwhelming advantage that it is feasible based on current data sources. Finally, there is an additional problem posed by the fact that we use livestock inventory as the measure of livestock capital.<sup>5</sup> 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 for the same reason — namely incomplete data on other inputs.

Data on livestock numbers and output were taken from the FAO (1997) and updated from the FAO website.<sup>6</sup> 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,<sup>7</sup> while milk productivity was measured as milk production divided by the number of milking cows. Note that the FAO data for China are inclusive of Taiwan. Since data for the latter economy could not be separately obtained from FAO, we are forced to analyse these two economies as a combined entity.

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<sup>5</sup> This measure is questionable 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.

<sup>6</sup> <http://apps.fao.org/>

<sup>7</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.

Given the range of countries and regions in this study, it need not follow that complete convergence of productivity levels would be expected to eventually occur. Differences in resource endowments and input costs, especially of land, labour and feedstuffs, provide reasons why our partial productivity measure may well differ in different countries, even when the most appropriate technology has been transferred. This may especially apply to beef and dairy production, where extensive grass-fed systems are found in relatively land-abundant regions like Australasia and South America, in contrast to the intensive grain-fed systems found elsewhere. The same is less likely to apply in non-ruminant production, where intensive system technologies appear to have been more easily adopted in a range of both land-scarce and land-abundant countries. We acknowledge this factor in our convergence analysis by splitting our sample of regions into two, depending on the share of purchased feeds in total livestock costs relative to the share of land.<sup>8</sup> The first group, labelled 'intensive livestock', includes North America, the EU, Japan and Korea, while the second 'extensive livestock' regional grouping comprises Australia, New Zealand, China-Taiwan, Southeast Asia and South America.

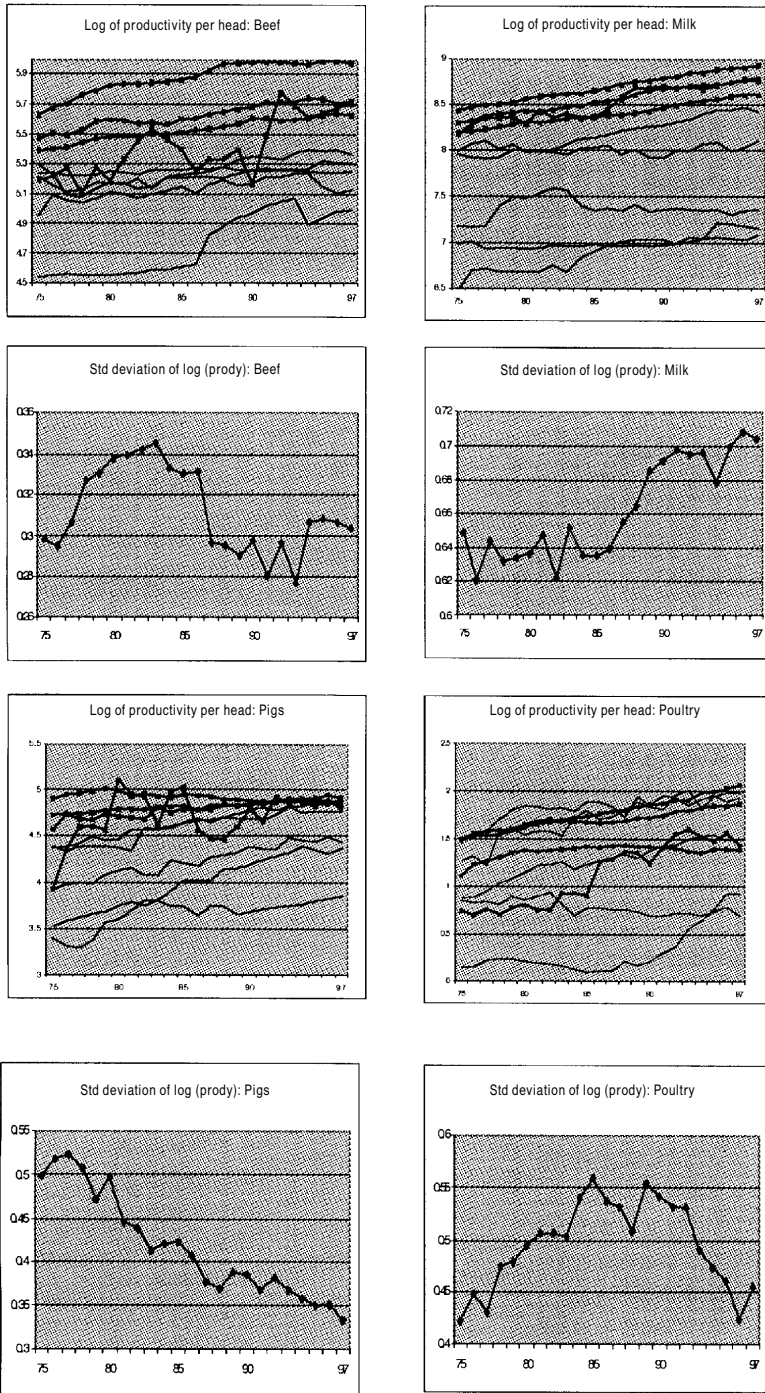
#### 4.2 Results for Asia-Pacific livestock production

Graphs of the natural logarithm of PFP, and its standard deviation, against time are given in figure 1, covering the period 1975–97. In the productivity graphs, the 'intensive' regions are denoted by bold lines and markers, while light lines without markers are used for the 'extensive' group members. There would appear to be convergence in pig productivity since the mid-1970s and in poultry productivity since the mid-1980s, indicated by the declining standard deviation of the sample productivities. Some decline in the dispersion of beef productivity levels is evident also from the mid-1980s, but levels of milk productivity across this sample of regions appear to have been diverging over the past twenty years. The convergence of beef productivity levels is apparent within both the intensive and extensive groups, with Korea (intensive group) and China-Taiwan (extensive group) exhibiting particularly rapid 'catch-up'. Pig productivity convergence within the intensive group became almost complete by 1997, although convergence within the extensive

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<sup>8</sup> The shares of feedstuffs and land in total costs were calculated from the GTAP database. For non-ruminants this ratio varied from 5.8 per cent to 17.3 per cent in the regional grouping comprising North America, EU, Japan and Korea; for the other regions the range of values was 0.5 per cent to 2.4 per cent. For beef, the range of values in the former group was 2.4 per cent to 7.9 per cent, and was 0.3 per cent to 1.5 per cent in the latter group. For milk production, the respective ranges were 2.5 per cent to 11.6 per cent, and 0.3 per cent to 1.8 per cent.





**Figure 1** Livestock productivity measures and their cross-region dispersion

regional group is less obvious. For poultry, major contributors to the more recent convergence appear to be productivity gains achieved in Korea (in the intensive group) and China-Taiwan (extensive group). Milk productivity levels do not appear to exhibit convergence within either regional group.

Average rates of growth in livestock productivity were computed<sup>9</sup> for the two periods 1975–86 and 1986–97. For poultry, productivity growth rates over the former period were higher than those in North America in New Zealand, South America, Australia and Korea. Over the following period, only in China-Taiwan did productivity growth exceed that in North America. Over both periods, all regions shown exceeded the North American pig productivity growth rate, with the exception of Japan where pig productivity growth was negative. Japan and Korea had faster productivity growth in beef than did North America during 1975–86, as did Korea, China-Taiwan and Australia over the following period. Only in Australia did milk productivity growth rates exceed those of North America over both time periods, although productivity growth in Southeast Asia and China-Taiwan exceeded that in North America during the former time period.

Focusing on China-Taiwan, pig productivity has been catching up to that in North America for at least the past two decades, and was within about 60 per cent of North American levels by the 1990s. China-Taiwan's beef productivity began to increase relative to that in North America since about 1985, reaching 50 per cent of North American levels by the mid-1990s, although there could have been a downward adjustment in the FAO production data for recent years.<sup>10</sup> China-Taiwan's poultry productivity increased (rather rapidly) relative to North America only since around 1990, and milk productivity in China-Taiwan continued to trend downward relative to North America throughout the period under study.

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<sup>9</sup> Throughout this article, average productivity 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.

<sup>10</sup> Considerable uncertainty surrounds China's official livestock production data (Fuller *et al.* 1998). Apparently local Chinese officials have faced incentives to further their careers through over-reporting of production figures. Fuller *et al.* believe that this 'human error' in Chinese livestock statistics may be extremely large. Some researchers have produced revised production data (see, for example, Fuller, Hayes and Smith 1998 and Colby *et al.* 1998). While these revised data could have been used in this study, no revisions appear to have been made to a sufficiently long time series on livestock numbers in China, which possibly have also been misreported. Our retention of the FAO data for China may still be satisfactory if a similar reporting error applies to livestock numbers as to production, since the data are used to measure production per animal. However, caution should prudently be applied to our results and projections for China.

**Table 1** Convergence coefficients by group, 1985–97

	Sub-groups					
	Whole group		Intensive		Extensive	
	$\phi$	<i>t</i> -statistic	$\phi$	<i>t</i> -statistic	$\phi$	<i>t</i> -statistic
Beef	0.974	-4.4	0.984	-0.7	0.928	-2.3
Milk	1.007	5.8	0.991	-0.5	1.006	1.7
Pigs	0.967	-5.3	0.711	-3.8	0.980	-1.4
Poultry	0.979	-3.3	0.963	-1.3	0.987	-1.3

Note: *t*-statistics test the null hypothesis that  $\phi = 1$

By 1995–97, considerable differences in livestock productivity remained among the regions in this sample. Both China-Taiwan and Southeast Asian productivity levels (and those of South America in the case of pigs) were well below those in the developed countries, and in some cases the gaps were considerable. The developed countries had reached rather similar levels of pigmeat production per head of inventory, but substantial variation existed for the other types of production. Poultry productivity in Japan, Korea and South America remained below that in North America and Australasia. Differences in beef and milk productivity reflect the production systems predominant in each country. Levels of milk productivity in Japan, Korea and North America were rather similar and were above the levels achieved in the grassfed systems of milk production in Australia and New Zealand whose levels in turn were well above those achieved in China-Taiwan, Southeast Asia and South America. A somewhat similar pattern can be seen in beef productivity with highest levels observed in Japan, North America and Korea.

Table 1 gives the results of the first of two formal time-series tests for convergence of productivity levels, both using data for the 1985–97 period. Ben-David’s (1993) model of convergence/divergence behaviour for each group of countries was used:

$$y_{i,t+1} - \bar{y}_{t+1} = \phi(y_{i,t} - \bar{y}_t) \tag{4}$$

where  $y_{i,t}$  = country *i*’s log of productivity in year *t*, and  $\bar{y}_t$  = the unweighted average of the log of the productivities for the group in year *t*.

Letting  $z_{i,t} = y_{i,t} - \bar{y}_t$ , equation 4 may be written as:

$$\Delta z_{i,t+1} = -\kappa z_{i,t} \tag{5}$$

where:

$$\Delta z_{i,t+1} = z_{i,t+1} - z_{i,t}$$

The coefficient  $\kappa$ , which equals  $1 - \phi$ , is the rate of convergence of country

$i$ 's productivity to the group's average productivity level. The larger is  $\kappa$ , the faster will be the convergence of productivity levels. Productivity convergence within the group is indicated by  $\kappa > 1$  ( $\varphi < 1$ );  $\kappa < 1$  ( $\varphi > 1$ ) indicates divergence. The countries and regions within each group were pooled together for the estimation of equation 5 and therefore a convergence coefficient was calculated for each group.<sup>11</sup>

Looking first at results for the 'whole group' of regions and countries (first set of columns in table 1), productivities for beef, pigs and poultry all exhibited convergence over the 1985–97 period, and the convergence parameters  $\varphi$  are all significantly different from unity. Only the milk productivities show a (significant) divergence over this time period. Seven of the eight convergence coefficients estimated for the regional sub-groups also indicate convergence, although only for two are the (absolute)  $t$ -statistics greater than 2.0. For beef, only within the extensive group is the convergence coefficient significant, suggesting this as the dominant reason for convergence of beef productivities. For milk, there is some evidence of convergence within the intensive regional group, although this is not statistically significant. Milk productivities were diverging within the extensive group. For poultry, the convergence coefficients are very similar for both extensive and intensive groups, and therefore similar to that for the whole group. Convergence of pig productivities also occurred within each group, although convergence was faster within the intensive group.

Additional time-series evidence to supplement the above results, and to generate region-specific productivity shocks for the projections, was obtained from:

$$y_{i,t} - y_i^* = \alpha_i + \beta_i t \quad (6)$$

where  $y_i^*$  = the log of the productivity of the 'lead' region in year  $t$ . The evidence of figure 1 and table 1 suggests that regions were converging towards a common productivity level for pigs and poultry, but not for beef and milk. Therefore single 'lead' regions were selected for the non-ruminant cases, but 'lead' regions were selected from both the extensive and intensive groups for the ruminant cases. Selection of 'lead' regions was based on that region with the highest level of productivity most often over the 1985–97 period. They were North America (poultry), the EU (pigs), Australia (beef and milk for the extensive group), North America (milk, intensive group) and Japan (beef, intensive group). Results<sup>12</sup> are given in table 2.

<sup>11</sup> The estimation procedure was the SHAZAM pooled cross-section time-series approach.

<sup>12</sup> The estimation procedure corrected for first-order autocorrelation.

**Table 2** Country tests for convergence, 1985–97

	Poultry		Pigs		Beef		Milk	
	Trend	<i>t</i> -statistic	Trend	<i>t</i> -statistic	Trend	<i>t</i> -statistic	Trend	<i>t</i> -statistic
Australia	-0.0197	-5.4	0.0063	2.3	<sup>a</sup>		<sup>a</sup>	
China-Taiwan	0.0455	4.5	0.0219	6.0	0.0154	1.5	-0.0299	-9.7
Japan	-0.0305	-17.2	-0.0202	-11.7	<sup>a</sup>		-0.0006	-0.3
Korea	0.0108	1.0	0.0047	0.4	0.0296	2.4	0.0073	1.0
New Zealand	-0.0054	-1.1	-0.0015	0.8	-0.0138	-3.7	-0.0221	-4.4
Stheast Asia	-0.0297	-13.6	0.0118	4.2	-0.0103	-4.8	-0.0059	-1.9
N America	<sup>a</sup>		-0.0045	-2.2	0.0025	1.2	<sup>a</sup>	
EU-15	-0.0086	-5.9	<sup>a</sup>		0.0013	0.6	-0.0009	-0.5
S America	-0.0012	-0.3	-0.0001	-0.0	-0.0093	-2.2	-0.0190	-9.9

Note: <sup>a</sup>denotes a ‘lead’ region or country.

Note that the left-hand side of equation 6 will be negative when region *i*’s productivity level is less than that of the lead region, and that convergence over time will result in such values becoming less negative. Thus a positive trend coefficient ( $\beta_i$ ) would indicate convergence between productivity levels in the relevant country with those in the ‘lead’ country. Positive trends with a *t*-value above 2.0 are found for China-Taiwan (poultry and pigs), Australia (pigs), Korea (beef) and Southeast Asia (pigs). Positive trends in relative productivity with *t*-values between 1.0 and 2.0 were estimated for Korea (poultry and milk), China-Taiwan (beef) and North America (beef). For non-ruminant meat production, the rate at which the technology gap is closing was greatest for China-Taiwan over this time period — relative to the ‘lead’ country, China-Taiwan’s annual productivity growth rates were 2.2 per cent (pigs) and 4.5 per cent (poultry). Negative trends in productivity relative to the ‘lead’ regions were found in several cases, including for all four products in South America and New Zealand (although not always significantly so), in the case of three commodities for Japan, and for milk production in all countries except Korea.

### 4.3 Projections of livestock productivity

Using the regression results of table 2, projections were made of  $(y_{i,t} - y_t^*)$  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 each of the lead countries were also projected to that year. This, in turn, facilitates projections of absolute productivity levels for the remaining countries and regions 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

**Table 3** Projected livestock productivity growth, 1995–2005 (percentage)

	Beef	Pig and Poultry <sup>a</sup>	Milk
Australia	13.8	8.9	27.4
China-Taiwan	42.2	49.4	0.2
Japan	8.3	−5.8	25.9
Korea	46.3	30.3	34.8
New Zealand	1.5	19.4	9.1
North America	10.3	21.3	24.8
Southeast Asia	4.0	10.3	16.1
EU-15	9.5	14.3	22.1
South America	1.9	19.3	6.1

Notes: <sup>a</sup> ‘Pig and poultry’ is a weighted average of pig and poultry productivity growth using base period production as weights.

Projections are based on results reported in table 2, coupled with trend forecasts for productivity in the lead countries to the year 2005.

of the 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 3. Livestock shocks in the rest-of-the-world region (ROW) were set equal to those of Southeast Asia.

As expected from the above analyses, projected increases in non-ruminant livestock productivity are the greatest for China-Taiwan, followed by Korea. Chinese productivity levels are projected to converge substantially on North American and EU levels. For beef productivity, the most rapid growth in table 3 is projected for Korea followed by China-Taiwan. The most notable projected growth in milk productivity occurs in Korea. The most rapid productivity growth rates overall in table 3 are for non-ruminants in China-Taiwan and for beef in Korea and China-Taiwan.<sup>13</sup> Almost no growth in milk productivity has been projected for China-Taiwan. This is probably unrealistic but is a consequence of our data and projections model — prior to 1997 there had been virtually no growth in milk yields per cow. The projected negative growth in non-ruminant productivity in Japan reflects the decline in Japanese productivity relative to North American or EU levels that has occurred since the late 1970s. While the projected milk and beef productivity growth rates for New Zealand and South America are very low, this may

<sup>13</sup> It may be of interest to indicate China’s projected productivity levels relative to the lead countries in 2005. For poultry, China’s productivity is projected to reach 44 per cent of North American levels by 2005 (it was 28 per cent of North American productivity in 1995). For pigs, China’s productivity could reach 71 per cent of EU levels by 2005 (it was 57 per cent in 1995). For beef, the relevant proportions are 80 per cent by 2005 compared with 64 per cent in 1995 (Australia was the lead country).

simply reflect a weakness of our measure of partial factor productivity. Relative to labour and capital, land and pasture are abundant factors in these regions and productivity gains are likely to be sought with respect to the former factors, with adverse consequences for output per head.

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

## 5. Methodology

### 5.1 The GTAP applied general equilibrium model

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 links 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 modelled. Bilateral international transport margins are incorporated and supplied by a global transport sector. The model is solved using GEMPACK (Harrison and Pearson 1996). For previous applications of this model involving technological change and research spillovers, the reader is referred to Frisvold (1997) and van Meijl and van Tongeren (1998).

In light of our interest in feed-livestock interactions, we have modified the standard GTAP model, introducing a constant elasticity of substitution among the various feedstuffs used in livestock and milk production. We also allow for substitution among intermediate inputs and value-added in all sectors.<sup>14</sup> Also, we utilise 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. The regional focus is on the Pacific Rim. In order to match up with the analyses of productivity

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<sup>14</sup> Specifically, we assume a unitary elasticity of substitution among feedstuffs. This composite input includes everything from coarse grains and soybean meal to foodgrains and by-products of various food-processing activities. As such, it is quite heterogeneous. A more detailed treatment of the cost-minimising feed mix decisions would be appropriate, but this is beyond the scope of the present article. The elasticity of substitution among intermediate inputs and value-added is assumed to be relatively small — equal to one-third of the substitution elasticity among the components of value-added.

conducted in the first part of this article, we combine Canada and the USA into a single North America region (NTH\_AMER), Southeast Asia (SE\_ASIA) is an aggregation of Indonesia, Malaysia, the Philippines and Thailand, and finally, China and Taiwan are aggregated to a single region (CH\_TWN). The 50 commodities in the version 4 GTAP database have been aggregated up to 14, of which six 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)<sup>15</sup> 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.

## 5.2 Modelling changes in livestock productivity

The GTAP model includes parameters to represent a variety of types of technical change: output-augmenting, value-added augmenting, and both primary factor and intermediate input augmenting technical change. What should we assume with respect to the nature of livestock productivity changes? It is likely that the improved livestock production techniques will increase output per animal inventory but they may also bring with them increased feed efficiency, and possibly improved efficiency with respect to other inputs. How we choose to represent improved livestock productivity could have important implications for feed demand, and hence for trade in grains and oilseeds.

Of critical importance in this regard is the feed conversion ratio, or feed consumption per unit output. Tweeten (1998) reports the US Office of Technology Assessment's projected gains in US feeding efficiency (the reciprocal of the feed conversion ratio). Annual growth rates in output per feed were 0.2 per cent (beef and pigs), 0.6 per cent (milk) and 2.0 per cent (poultry). If the United States is the source of much of the new livestock production technology that is transferred to other countries in the Asia-Pacific region and elsewhere, then such improvements will eventually be felt in those other regions.

Given the importance of China to future food projections, such feed conversion data for that country's livestock sectors are vital, yet information

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<sup>15</sup> 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.



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 per cent higher than in specialised units and 41 per cent higher than in the best large-scale systems. In beef production, the FCR in the backyard systems was 83 per cent 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 per cent and 5 per cent per year and is highest for poultry. Their 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 the United States and in Chinese livestock production, and most likely in other regions as well. Therefore in all simulations, we augment the productivity of the composite feed input in the livestock sectors. Less information exists regarding the efficiency of non-feed intermediate inputs in livestock production so the productivity of these inputs is held constant. In addition, we augment value-added in livestock production by assuming that our projections of output per animal inventory (livestock capital) also applies to the other primary factors. Identical rates of productivity improvement are applied to value-added and the feed composite in the livestock sectors.<sup>16</sup>

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<sup>16</sup> This implies that the amount of feed per animal remains constant. Also note for China that these shocks imply annual reductions in FCRs of 2.0 per cent and 4.2 per cent for beef and non-ruminants respectively. Simpson *et al.*'s (1994) projections imply rather similar reductions of 2.5 per cent (beef), 4.8 per cent (poultry) and 2.2 per cent (pigs).

## 6. 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 labour and capital in the Asia economies has promoted the shift of activity away from agriculture, in favour 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.* (1994), projections are made through exogenous shocks to each region's endowments of physical capital, skilled and unskilled labour, population, and technology. Appendix table A1 gives these shocks, and the sources upon which they were based.<sup>17</sup> 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 cent 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 — the authors will have exaggerated the down-sizing of the farm sector.<sup>18</sup>

We assume an average rate of non-agricultural productivity growth<sup>19</sup> in the OECD economies of 0.75 per cent per year. For non-OECD economies, we assume a somewhat higher rate of non-agricultural productivity growth,

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<sup>17</sup> 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 tariffification'.

<sup>18</sup> In this study we attain a high rate of GDP growth in China-Taiwan without extraordinary productivity growth in non-agriculture due to our use of a new Chinese data base (McDougall, Elbehri and Truong 1998), which exhibits a higher capital share, thereby lending more weight to the high rate of capital accumulation.

<sup>19</sup> Throughout this section when we refer to productivity growth we will be referring to productivity of value-added, excepting where explicit reference is made to feed efficiency.

1.25 per cent per year. Together with projected growth rates in capital, skilled and unskilled labour, this yields overall GDP growth rates for these countries which are similar to those forecast by the World Bank (World Bank, 1998). For agriculture as a whole, we assume a common rate of productivity growth, world-wide, of 2.0 per cent per year (Martin and Mitra 1996).<sup>20</sup>

Livestock sector productivity growth rates are based on the forecasts in table 3. However, in order to isolate the effect of productivity convergence on trade patterns, we conduct a 'counter-factual' simulation whereby livestock productivity grows at a common rate across all regions and sectors. We call this the 'no-convergence' scenario. Finally, crops productivity is assumed to grow at a common rate across all regions — namely 2 per cent per year — in both sets of simulations. (The convergence analysis is solely with respect to the livestock sector.)

### 7. Analysis of livestock productivity convergence

Table 4 reports the percentage change in global trade volume, by commodity, over the 1995–2005 period, for both the no-convergence and convergence in livestock productivity cases. A comparison of the two columns in table 4 shows the impact of livestock technological convergence on global trade. Not surprisingly, the primary impact is on trade in livestock products. It is interesting that convergence actually boosts trade in beef cattle, other meats and dairy products, whereas trade in other livestock falls as a result of convergence. In order to understand this, we need to decompose the global export change into changes in trade by individual regions.

Table 5 reports the impact of productivity convergence in livestock on gross exports, by region, in terms both of percentage changes as well as absolute volume changes (in parentheses). The first set of figures represent percentage changes in export volume in the year 2005, relative to the total volume of exports in that year under the no-convergence assumption. The

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<sup>20</sup>When we apply the productivity growth projections in table 3 to the livestock sectors in GTAP, we obtain an average annual growth rate in livestock productivity of about 1.6 per cent — somewhat lower than that observed for agriculture as a whole. While definitive evidence comparing livestock with crop productivity is not available, Bach and Frandsen (1998) conclude from their review of existing studies that livestock TFP rates in the past few decades have tended to be slightly higher than those for crops. Given the uncertainty about how best to implement the estimated rates of technical change in the GTAP model, we seek to remove this discrepancy between crop and livestock productivity as a source of divergence in trade. To do so, we re-scale all the livestock forecasts by a common factor so that the global rates of productivity growth in livestock and crops are the same, i.e. equal to 2 per cent/year.

**Table 4** World exports by commodity: per cent change, 1995–2005

	No convergence	Convergence
Rice	27	28
Wheat	42	41
Other grains	35	35
Oils	40	40
Beef cattle	28	34
Other livestock	52	36
Beef	24	24
Other meat	19	22
Dairy products	19	21
Other natres	38	39
Procfood	21	21
Other crops	29	28
Man _srvc	40	40

entries in parentheses translate the percentage changes into an absolute volume — measured in millions of \$US at 1995 prices. For example, as a result of convergence, Chinese<sup>21</sup> exports of non-ruminant meat products are estimated to be 156 per cent higher in 2005 than they would be in the absence of convergence. This amounts to an estimated \$1802 million higher volume of meat exports.

From the entries in table 5, it is clear that the strongest *relative* impacts on gross exports occur for Chinese beef cattle and non-ruminant livestock and meats, and Chinese and Korean beef, where the highest rates of productivity growth and most rapid convergence are expected. With the exception of China's exports of non-ruminant livestock and meats, however, the absolute volume changes are rather small. Most regions apart from China experience declines in export volumes of non-ruminant livestock and non-ruminant meat, and substantial absolute declines appear in the cases of North America, the EU and Southeast Asia. The projected impact of convergence on North America and the EU is relatively modest in the cases of beef and dairy products, although the absolute increases in export volumes are more substantial. For example, North American beef exports are 3 per cent higher while those from the EU increase by 6 per cent under convergence. However, these two regions are major traders and so these relatively small percentage changes translate into fairly large volume changes. South America, whose beef productivity was projected to diverge from that of the lead region (table 2) experiences a 28 per cent reduction in exports under the convergence scenario. Australia's superior milk

<sup>21</sup> All references to China refer to the aggregated China-Taiwan region.

**Table 5** Percentage change in export volume due to convergence = change/2005 volume under non-convergence  
(absolute changes in parentheses in \$US million at 1995 prices)

	NTH-AMER	AUS	NZ	JAPAN	KOREA	CH-TWN	SE-ASIA	STH-AMER	EU	ROW	Total
Beef cattle	19 (326)	38 (238)	-8 (-9)	0 (0)	0 (0)	700 (28)	-33 (-1)	-48 (-392)	12 (574)	-29 (-288)	(464)
Other livestock	-16 (-1155)	-38 (-302)	-5 (-35)	-74 (-471)	-31 (-58)	641 (962)	-34 (-125)	11 (50)	-4 (-369)	-37 (-922)	(-2425)
Beef	3 (199)	0 (7)	2 (48)	-10 (-4)	67 (2)	163 (104)	-15 (-2)	-28 (-751)	6 (691)	-12 (-107)	(187)
Other meat	-3 (-191)	-17 (-25)	-6 (-8)	-29 (-26)	12 (18)	156 (1802)	-22 (-534)	4 (58)	-1 (-279)	-13 (-289)	(526)
Dairy products	7 (94)	19 (247)	-14 (-308)	13 (1)	29 (2)	-29 (-5)	-3 (-3)	-15 (-86)	3 (735)	-6 (-103)	(574)

productivity performance relative to New Zealand means that convergence boosts Australian exports by 19 per cent, but produces a decline of 14 per cent in New Zealand's dairy exports.

These changes can, in turn, be related back to the global export changes reported in table 4. From the total exports column in table 5, we see that the estimated pattern of productivity convergence leads to more trade in cattle and beef, non-ruminant meat and dairy products, and less trade in non-ruminant livestock. In the cases of cattle and beef, the increases in exports are fuelled primarily by the EU, with increases also from Australia, North America and China. In the case of the non-ruminant trade, exports decline almost everywhere except China, in response to a substantial decline in China's imports (not shown in table 5). Hence global trade expands for beef products since significant productivity gains occur in traditional major beef exporting regions. For the non-ruminant products, global trade changes reflect the rapid productivity growth in China-Taiwan which allows that region to reduce import volumes. It can be noted that in the 1995 base data, China-Taiwan had a net trade surplus of \$3.0 billion in non-ruminant products. This changed to a deficit of \$5.3 billion in the 2005 non-convergence projections. However, under convergence the China-Taiwan composite region's non-ruminants trade in 2005 was in surplus by \$1.0 billion.

Table 6 combines changes in imports with the export changes in table 5 and places these changes on a value basis so that they are comparable across countries and commodities. The resulting changes in regional trade balances are grouped into four broad categories: grains and oilseeds, beef (cattle and beef products), non-ruminants (other livestock and non-ruminant meat products), and dairy products. For each grouping we have three columns. The first column is the 1995 trade balance for each region, reported in millions of US dollars.<sup>22</sup> This is followed by the projected trade balance in 2005 under the convergence scenario. The third column under each commodity group reports the change in trade balance due to convergence. The latter is the difference between the change in trade balance under the convergence case and the change under no-convergence (equal productivity growth in all regions) in livestock sectors.

In the case of beef products, convergence leads to an improvement in the trade balances for North America, Australia, New Zealand, Korea, China and the EU. Increased exports are the main contributor to this result in all of these regions except Korea, where productivity growth encourages a reduction in imports. Despite the very high percentage increase in gross

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<sup>22</sup> In all of our simulations, we assume that the macroeconomic trade balance is fixed. Thus any increase in net exports of one product, must be offset by an increase in net imports of some other product.

**Table 6** Initial trade balance (1995), projected trade balance under convergence (2005) and change in trade balance due to convergence (US\$ millions)

Region	Grains and Oils			Beef			Non-ruminants			Dairy products		
	1995	2005	Change due to convergence	1995	2005	Change due to convergence	1995	2005	Change due to convergence	1995	2005	Change due to convergence
NTH-AMER	24317	33258	11	2242	4564	726	5051	8602	-1288	186	422	86
AUS	1341	1455	-9	3086	3734	279	461	465	-299	899	1240	212
NZ	-49	-59	-2	1812	2003	59	537	653	-42	1751	1699	-254
JAPAN	-6360	-6833	-52	-4347	-5039	-79	-6383	-7690	-1402	-845	-892	7
KOREA	-2371	-2761	19	-761	-957	101	-1441	-1883	43	-139	-156	9
CH-TWN	-4206	-9730	577	-259	-716	382	3015	1045	6295	-301	-699	-94
SE-ASIA	-2445	-3148	1	-520	-875	-143	1641	1209	-711	-1260	-1543	-2
STH-AMER	-1702	-2840	-237	1798	378	-1215	301	470	112	-1711	-2425	-325
EU	-4373	-3043	-113	-1573	575	1035	715	4170	-545	3029	4950	534
ROW	-7068	-9928	-189	-3004	-5430	-1160	-5268	-8638	-2070	-3962	-5173	-215

Korean beef exports owing to convergence, the impact on the global beef market is far more modest, and tends to be dominated by other regions. In the case of non-ruminant products, convergence has a dramatic impact on China's trade balance, which improves by \$6.3 billion as a result of both increases in exports and decreases in imports of these products. Decreased imports under convergence also increase the trade balance for Korea and increased exports produce the same change for South America, but all other regions experience a decline in their trade balance in order to make room for the substantial improvement in productivity in China's massive non-ruminant sector, under the convergence scenario. As anticipated from table 5, the impacts of convergence on dairy trade balances are mainly very modest. The EU and Australia both experience substantial increases in their trade balances. These countries were the nominated 'leaders' in the convergence analysis reported in table 2, and those results showed that no other regions were exhibiting significant convergence. In fact, most were diverging from EU or Australian productivity levels. Relatively speaking, China, New Zealand and South America were diverging most rapidly from the lead regions and these three all suffer deteriorations in the dairy trade balances.

Table 6 also reports the impact of convergence on grains and oilseeds trade balances. In most regions, this impact is relatively modest. However, in the case of the China-Taiwan region, convergence actually reduces the projected trade deficit in 2005. In the no-convergence case, the grains and oilseeds trade balance is about  $-\$10.3$  billion. Introducing convergence actually reduces this deficit to  $-\$9.7$  billion in 2005. This is somewhat surprising given the substantial increase in livestock production in this region under the convergence scenario. However, one reason for this outcome is that grains output is higher under the convergence scenario relative to no-convergence. This is because a more efficient livestock sector requires less land, labor and capital for a given amount of output, thereby freeing up some factors of production for other uses. Grains production absorbs some of these inputs, thereby enabling an expansion in output, relative to the no-convergence case.<sup>23</sup> Another reason for the reduced grains deficit has to do with the assumed increase in feed efficiency in livestock production and its effect on feed use in China. The increase in feed use in both non-

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<sup>23</sup> As pointed out by an astute reviewer, we likely overstate the expansion in grains output for the following reason. In the absence of commodity-specific primary factor allocations, the GTAP database assumes a common factor intensity across sub-sectors within agriculture. It is surely the case that this overstates the land intensity of livestock production, while understating the same for crops. When technical change in livestock production conserves inputs, it therefore will overstate the amount of land released for use in other types of agriculture. This additional land will also go further in promoting crop production than it would with differentiated factor intensities.



ruminant and ruminant production between 1995 and 2005 is now a modest 12 per cent, whereas it was around 25 per cent under the no-convergence experiment.

Of China-Taiwan's total projected increase in food net imports over the 1995–2005 period under convergence, grains account for 16 per cent and livestock products 11 per cent. Anderson *et al.* (1997) projected shares of grains and livestock in increased net food imports of 13 per cent and 40 per cent, respectively. Our results differ substantially from these, in large 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.

### 8. Sensitivity analysis

One of the frequent criticisms of applied general equilibrium trade models is the large number of parameters which must be specified. Typically these are drawn from surveys of the literature and they are likely to be rather uncertain. Therefore, it is important to conduct sensitivity analysis which respect these parameters. We use the Gaussian Quadrature approach as proposed by DeVuyst and Preckel (1997), and implemented by Arndt (1996) and Arndt and Pearson (1996) (we chose the Liu quadrature). We found that the results in tables 4–6 were quite robust to changes in the assumptions about elasticities of substitution in production.<sup>24</sup> We also considered the sensitivity of our finding with respect to variation in the trade elasticities.<sup>25</sup>

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<sup>24</sup>We explored the sensitivity of results to changes in certain livestock-feedstuffs parameters, namely the elasticities of substitution among the various feedstuffs, and the elasticity of substitution between the feedstuffs composite and the other intermediate inputs. For the livestock sectors in all regions, triangular distributions were chosen with minimum and maximum values of one-half and twice the base values, respectively. The finding was that our results were extremely robust to these variations, so they will not be further reported here.

<sup>25</sup>We conducted a systematic sensitivity analysis with respect to the elasticities of substitution between imports and domestic goods, and among imports from different sources. The distribution of these elasticities was assumed to be triangular, with mean equal to the base values used in our simulation, minimum equal to half the mean and maximum equal to twice the mean. We assumed that if these elasticities are too large, then they are all too large, and similarly if they are too small. That is, they are assumed to vary together over this distribution.

The change in most commodity trade balances is robust to this wide variation in trade elasticities. However, in the case of livestock products there are some exceptions. The deterioration in Korea's trade balance in beef and other meat products, as well as the changes in trade balances for other livestock in Australia, dairy products in New Zealand, and other meats in Southeast Asia, are all quite uncertain. Fortunately, these are all relatively small changes. The big changes, and thus our major findings, seem to be very robust to this parameter variation.

## 9. Conclusion

Empirical projections of the impacts of economic growth, especially in rapidly-growing, populous economies such as China, have emphasised impacts on the global grains situation. These studies have often neglected trade in livestock products, which has been shown to be potentially even more important, in value terms, by the work of Anderson *et al.* (1997). The fundamental question is whether China and the other East Asian economies will produce most of their own livestock products and import the necessary feedstuffs, or whether they will continue the rapid increase in imports of livestock products directly. This article examined 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, poultry and beef production, but generally not in milk production. At the country level, significant 'catch-up' to productivity levels of the 'lead' regions was demonstrated for China-Taiwan (poultry and pigs), Australia (pigs), Korea (beef) and Southeast Asia (pigs). For non-ruminant production, the rate at which the technology gap had been closing was greatest for China-Taiwan.

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.

This convergence is shown to have important implications for China-Taiwan's net trade in livestock products. In the absence of convergence, our projections to 2005 show China-Taiwan becoming a major net importer of livestock products — in the order of \$7 billion. However, when we take account of recent trends in China-Taiwan's livestock productivity via the convergence projections, then this region is projected to be roughly in trade

balance with respect to livestock products in 2005 — with a lingering trade surplus in non-ruminants and trade deficits in beef and dairy. While our non-convergence scenario produced results for increased grains and livestock trade roughly comparable with those of Anderson *et al.* (1997), those from the convergence scenario differ substantially.

On the other hand, with more exports from China, and fewer imports, as compared to the no-convergence case, livestock productivity convergence sharply reduces the 2005 trade balances for this commodity group for most other regions (either lower net exports or higher net imports). This is an important warning to those who are banking on a large Chinese market for their livestock exports in the future. Demand is growing fast — but supply is also increasing rapidly, and some investors may be surprised to find themselves competing with Chinese exports in the future, instead of supplying her large domestic market.

Future research in this area could usefully attempt more sophisticated estimation of livestock productivity and the factor bias of technical change. The question of whether or not feed efficiency increases apace with the gains in output per head will 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 the lead regions 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. While our research did not attempt to address directly issues of policy reform, this could also be examined against a backdrop of productivity convergence. The agreed reforms of the Uruguay Round, of various regional agreements and last but not least China's possible entry to the WTO, could well alter the production and consumption responses to the convergence of productivities in livestock production. Finally, as our research was initially encouraged by an interest in the Asia-Pacific region, detailed productivity projections were not made for other regions apart from the European Union. This should be rectified, since these other regions in the aggregate are important players in global livestock product markets.

### Appendix

**Table A1** Assumptions made in the projections: cumulative [and annual] percentage changes in AVA and factor endowments for the period 1995 to 2005<sup>c</sup>

Region	'ava' All Crops <sup>a</sup>	'ava' All Non-farm <sup>b</sup>	Physical Capital	Unskilled Labour	Skilled Labour	Population
AUS	21.9 [2.00]	7.8 [0.75]	40 [3.4]	5 [0.48]	66 [5.2]	8 [0.77]
NZ	21.9 [2.00]	7.8 [0.75]	34 [3.0]	12 [1.1]	63 [5.0]	10 [1.0]
JAPAN	21.9 [2.00]	7.8 [0.75]	44 [3.7]	-2 [-0.2]	32 [2.8]	2 [0.2]
KOREA	21.9 [2.00]	7.8 [0.75]	59 [4.7]	9 [0.9]	71 [5.5]	8 [0.8]
CHTWN	21.9 [2.00]	13.2 [1.25]	156 [9.9]	12 [1.1]	48 [4.0]	9 [0.9]
SE ASIA	21.9 [2.00]	13.2 [1.25]	22 [2.0]	22 [2.0]	68 [5.3]	14 [1.33]
NTH AMER	21.9 [2.00]	7.8 [0.75]	30 [2.7]	10 [1.0]	38 [3.3]	9 [0.9]
STH AMER	21.9 [2.00]	13.2 [1.25]	20 [1.8]	24 [2.2]	49 [4.1]	16 [1.5]
EU	21.9 [2.00]	7.8 [0.75]	36 [3.1]	1 [0.1]	29 [2.6]	2 [0.2]
ROW	21.9 [2.00]	13.2 [1.25]	36 [3.1]	27 [2.4]	32 [2.8]	13 [1.2]

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

Notes: <sup>a</sup> All crops = (rice, wheat, other grain, oils, other crops)

<sup>b</sup> All non-farm = (beef, other meat, dairy products, other natures, procfood, man\_srvc)

<sup>c</sup> These shocks apply in each of the three scenarios.

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