# New Zealand Agricultural and Resource Economics Society (Inc.)

# Climate change and Australia's comparative advantage in broadacre agriculture

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## Paper presented at the 2010 NZARES Conference

**Tahuna Conference Centre – Nelson, New Zealand. August 26-27, 2010.**

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Australia has long been a major exporter of the products of broadacre agriculture, a production system well suited to the economic and climatic conditions of the country. According to the conventional wisdom, Australia holds a comparative advantage in these products, among which wheat and livestock products predominate. However, the future validity of this proposition is sensitive to the projected impacts of climate change. This paper develops a framework with which to quantify the future patterns of comparative advantage in broadacre agriculture given the projections of several global climate models. We find empirical support for the conventional wisdom, and note substantial resilience in Australia's comparative advantage to adverse yield change.

# 1. Introduction

Australia has traditionally been a significant international agricultural exporter of wheat (3rd largest exporter) and livestock products (2nd largest exporter of sheep and beef meat) (FAOSTAT 2009). This is a likely consequence of the prevailing broadacre production conditions in Australia, in which land is employed intensively relative to both labour and capital, which has led to extremely low production costs, especially in grains production (Mauldon 1991). The conventional wisdom has treated this observation as an indication of a comparative advantage in broadacre agriculture (Davidson 1981; Wonder and Fisher 1990). However, the land intensity of production makes broadacre agriculture vulnerable to impacts of climate change which may alter the global endowment patterns of arable land.

Projections of climate change in Australia suggest that crop and livestock industries are likely to be adversely impacted, diminishing the established position of Australia as an exporter of food, including wheat (Heyhoe *et al.* 2007; Garnaut 2008). This presents policy makers with a significant challenge – designing policies which facilitate economically viable adaptations to climate changes. The Australian government has outlined broadly-defined objectives for its climate change policy, highlighting the need to develop strategies to adapt to unavoidable climate change (Commonwealth Treasury 2008). However, adaptation strategy has a strong economic dimension (for example, Clarke 2008; Dobes 2008).

We seek to examine the implications of climate change for Australia's wheat and livestock trade in a hybridised Heckscher-Ohlin-Vanek (HOV) Ricardian framework. Treating climate change as an exogenous process of productivity-adjusted land endowment alteration, we simulate the patterns of comparative advantage for several predictions of climate change. In section 2, we describe the state of the HOV literature and explore options for adjusting the

basic model. Section 3 outlines the analytical framework, and section 4 reports the methods and procedures with which to undertake the empirics. Section 5 describes the data used to estimate the model, and section 6 reports the simulation results. Section 7 presents a discussion of the policy implications, prior to concluding comments in section 8.

# 2.     Relevant literature[1]

The use of Heckscher-Ohlin-Vanek (HOV) models is well established in the literature, the intuition being, that a country abundant in a particular factor, say labour, will have a capital-labour ratio embodied in consumption that will exceed the capital-labour ratio embodied in production (Leamer 1980). Empirical tests, such as Leamer (1984), analyses a HOV framework for 10 trade aggregates (goods) and 11 factors in 58 countries, for which endowments are found to be significant in predicting trade patterns. More recently, employing the HOV model, Peterson and Valluru (2000) suggest that factor endowments at the national level describe well the variation in net trade patterns for cereal grains, oilseeds and cotton. A similar result is achieved in Arnade (1994), who applies the theorem to the case of Latin American agriculture, concluding that differences in relative factor abundance between countries better explain the trading patterns than differences in technology. Examining data over the period 1966-86 for 59 countries, Tobey and Chomo (1994) find changing factor endowments to be significant in explaining the changing patterns of trade in agricultural commodities during that period.

Using 1983 data for 33 countries, Trefler (1993) achieves a significant improvement in the explanatory power in terms of the factor content of trade and differences in international factor prices. More recently, Hakura (2001) relaxes the assumption of identical technology among countries to examine trade within the European Union. Employing a similar methodology and data for the period between 1960 and 1995 for 10 Organisation for Economic Co-operation and Development (OECD) countries, Davis and Weinstein (2001) propose an improvement in the explanatory power of the HOV model when technical differences are incorporated. Abbott and Thompson (1987) develop a model of agricultural comparative advantage that ensures the existence of weak Rybczynski effects for any specific-factors, although it also eliminates any Rybczynski effects for the mobile factors (Feenstra 2004).

The HOV model has been widely employed as a tool for simulation, such as Hayes *et al.* (1995), who project the evolution of the economies of former Soviet Union countries as they transition to market economies. Similarly, Fang and Beghin (2000) examine the potential implications of trade liberalisation on the patterns of Chinese agricultural production. Finally, the relationship between environmental policy and trade patterns has also been simulated using the HOV model, for instance, Tobey (1990), Cole and Elliott (2003) and Mukhopadhyay (2006).

# 3.     Conceptual framework

Treating climate change as a process which impacts upon the productivity of endowed land resources, we employ an HOV model with Ricardian elements. In this setting, the patterns of productivity adjusted factor endowments determine the patterns of comparative advantage. We follow the static model insights provided in the *m*-factor, *n*-good general equilibrium framework of Chang (1979), the static empirical application of the HOV framework in Leamer (1984) and the productivity adjustment concepts presented in Trefler (1993) and Trefler (1995). The basic HOV model is based on several assumptions, that is, the homogeneity of technical knowledge and preferences among countries, constant returns to

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[1] See Sanderson and Ahmadi-Esfahani (2009).

scale production, and perfect competition in factor and output markets which face the same set of prices. Signifying $a_{mn}$ as the amount of the factor (resource) $X_m$ needed to produce a unit of the good (output) $Y_n$, and allowing factor supply to equal factor demand, we have:

$$X_m = \sum_{n=1}^{N} a_{mn} Y_n \quad \forall m = 1, \dots, M \ and \ n = 1, \dots, N \quad (1)$$

This system of equations may be solved for outputs as a function of the endowments, and it is convenient to represent this system in matrix form:

$$AY = X \quad\quad\quad\quad\quad\quad\quad\quad\quad\quad (2)$$

where $A$ is an $n \times m$ 'technology' matrix of $a_{mn}$ elements, $X$ is a vector of $m$ endowed factors and $Y$ a vector of $n$ outputs. We can invert $A$ to obtain a set of solutions for each of the outputs:

$$Y = A^{-1}X \quad\quad\quad\quad\quad\quad\quad\quad\quad (3)$$

The linearity of these equations and the concomitant unresponsiveness of total world output to international factor migration, we can denote total world output $Y^W$ as a function of total world endowments $X^W$:

$$Y^W = A^{-1}X^W \quad\quad\quad\quad\quad\quad (4)$$

As all countries face the same vector of relative world prices and consumer preferences are assumed identical between countries, we can say each country consumes a vector $C$ of $n$ outputs in the same proportions:

$$C = sY^W \quad\quad\quad\quad\quad\quad\quad\quad\quad (5)$$

where $s$ is some scalar corresponding to the relative size of the country in terms of share of world GNP. Trade balance requires that value of production equal the value of consumption:

$$p'Y = p'C = sp'Y^W \quad\quad\quad\quad\quad (6)$$

where $p$ is a vector of prices corresponding to the vector of output $Y$. The vector of net exports $T$, is given by the difference between production and consumption:

$$T = Y - C = A^{-1}(X - sX^W) \quad\quad\quad (7)$$

We can transform this into the *factors embodied in net exports*, vector AT:

$$AT = X - sX^W \quad\quad\quad\quad\quad\quad (8)$$

This equation describes the relationship between the factor intensity of trade and excess factor endowment supplies, that is, the factors embodied in net exports equal the excess factor supplies. The vector AT is composed of positive and negative elements, reflecting the import – export flows. These are the HOV equations, according to which a country is said to be abundant in a factor $m$ if its share of the world's supply of that factor exceeds its consumption share. Similarly, a country abundant in a factor $m$ will return a positive net export value for goods in which that factor is employed intensively.

# 4.  Methods and procedures

In order to characterise broadacre agriculture, we estimate the HOV-Ricardian model with an explicitly-defined wheat and livestock producing sectors. For simplicity, we assume there to be four factors of production, capital, labour, wheat land and pasture land, each of these land types is defined as being suitable for producing wheat and livestock, respectively. These factors are employed in four possible productive sectors – labour intensive manufacturing, capital intensive manufacturing, wheat and livestock. Although wheat and pasture land is

strictly employable in those land-based sectors, capital and labour may move freely among all four sectors. The non-wheat sectors have been selected because they reflect differing labour and capital input requirements as revealed in the matrix of technical coefficients $A$. The $A$ matrix is formed using data in the GTAP 7 database (Narayanan and Walmsley 2008). We have aggregated data for the four sectors from which information on factor demand and output was gathered. Each of these was formed into a matrix, factor demand $U$ and output $V$ (Raa, 2005). There are as many factors as goods, with each sector using a vector of factor inputs to produce a single good. This means that $V$ is a diagonal matrix, such that the matrix of technical coefficients $A$ is given by:

$$A = UV^{-1} \qquad\qquad\qquad\qquad (9)$$

Given the $A$ matrix, the vector of trade values $T$ was derived by application of Cramer's rule to equation (9), having pre-calculated the vector formed by $X - sX^W$.

A combination of 20 producing entities have been defined, among which 19 are significant producers of wheat and livestock products according to (FAOSTAT 2009), these are: Argentina, Australia, Brazil, Canada, China, Egypt, India, Indonesia, Iran, Kazakhstan, Mexico, New Zealand, Pakistan, Russian Federation, South Africa, Turkey, Ukraine, the United States, and the European Union. In addition to these, an aggregate of the rest of the world countries has been formed, as these are thought to be the bulk of net importers of wheat and livestock products. Data collected on national endowments of wheat and pastureland land, labour and capital will be used to estimate equation (9), which helps to provide the patterns of factor endowments in excess of those which are consumed domestically. These patterns assist in exposing a preliminary view of the patterns of comparative advantage in Australian broadacre agriculture.

# 5.   Data

We require information on the country level endowments of capital, labour, wheat land and pasture land, in addition to information about the relative size of each country's economy, given by gross national product. We derive an estimate of the capital endowment in 2006 by employing the method outlined in Leamer (1984) and Peterson and Valluru (2000). That is, assuming an asset life of 15 years, we sum data on gross capital formation available from the World Bank for the period 2006 – 1992, depreciated linearly at 6.67 percent per annum. Labour endowment and gross national product is extracted from the 2006 World Bank's *World Development Indicators 2009 Tables*. Each of these is reported in Table 1.

**Table 1** Capital and labour endowments, and gross national product, 2006

|  | Capital Endowment ($US Bil.) | Labour Endowment (mil. persons) | Gross National Product (% of World total) |
|---|---|---|---|
| **Argentina** | 375.29 | 18.06 | 0.004 |
| **Australia** | 851.25 | 10.77 | 0.015 |
| **Brazil** | 860.34 | 95.67 | 0.022 |
| **Canada** | 1200.30 | 18.00 | 0.026 |
| **China** | 4310.11 | 775.74 | 0.054 |
| **Egypt** | 150.49 | 24.72 | 0.002 |
| **India** | 1080.70 | 439.52 | 0.019 |
| **Indonesia** | 318.76 | 107.05 | 0.007 |
| **Iran** | 264.59 | 27.63 | 0.005 |
| **Kazakhstan** | 41.35 | 7.95 | 0.002 |
| **Mexico** | 938.90 | 44.62 | 0.019 |
| **New Zealand** | 97.04 | 2.24 | 0.002 |
| **Pakistan** | 101.90 | 52.96 | 0.003 |
| **Russian Federation** | 452.08 | 74.29 | 0.020 |
| **South Africa** | 185.73 | 17.24 | 0.005 |
| **Turkey** | 460.02 | 25.04 | 0.011 |
| **Ukraine** | 64.22 | 23.13 | 0.002 |
| **United States** | 14866.10 | 155.22 | 0.268 |
| **European Union** | 10507.68 | 153.19 | 0.219 |
| **Rest of World** | 19561.00 | 976.59 | 0.294 |

Source: World Bank (2009)

For each country/aggregate data on the endowments and producitvity of wheat and pasture land have been extracted from the land use database described in Ramankutty *et al.* (2008). The raw data were provided which contained total hectares of pasture land available in each country divided into 18 different land types, known as Agro-Ecological Zones (AEZ). Each of these AEZ land types has similar climate properties, and so, we may more easily and correctly compare country level endowments of land on a productivity basis. To this end, wheat yield data have been employed to scale the wheat land endowments to capture the productivity differences in the land. Pasture endowments have likewise been scaled, although the data on yield from pasture do not exist. This has been overcome in a similar manner to Lee *et al.* (2008) by appealing to the similarity in biological characteristics of pasture grasses, specifically the dominance of C4 grass types in tropical zones (such as maize), and C3 grasses (such as rye) in temperate zones. Acordingly, temperate zone pasture land has been scaled according to the relative productivity of C3 grasses (rye) for the given AEZ, and tropical pasture land has been scaled according to the productivity of C4 grasses (maize). For illustrative purposes, the calculated endowments of wheat land and pasture land for the modelled countries with associated adjusted endowments are presented in Table 2. This information constitutes the data for the model from which we examine the patterns of agricultural comparative advantage under climate change.

**Table 2** Wheat land and pasture land endowments

| | Wheat Land (mil. Ha) | | Pasture Land (mil. Ha) | |
|---|---|---|---|---|
| | Raw | Adjusted | Raw | Adjusted |
| Argentina | 6.21 | 7.29 | 124.25 | 94.69 |
| Australia | 7.97 | 7.07 | 298.31 | 298.31 |
| Brazil | 1.63 | 1.44 | 230.75 | 94.81 |
| Canada | 10.71 | 11.60 | 52.40 | 26.28 |
| China | 26.75 | 50.56 | 405.52 | 284.70 |
| Egypt | 1.04 | 3.21 | 2.88 | 3.02 |
| India | 26.20 | 34.58 | 157.18 | 36.75 |
| Indonesia | 0.00 | 0.00 | 57.16 | 23.13 |
| Iran | 5.61 | 5.13 | 73.83 | 66.99 |
| Kazakhstan | 9.58 | 4.69 | 199.73 | 60.96 |
| Mexico | 0.71 | 1.63 | 101.93 | 32.17 |
| New Zealand | 0.06 | 0.19 | 11.80 | 16.14 |
| Pakistan | 8.41 | 9.44 | 22.15 | 5.04 |
| Russian Federation | 19.67 | 17.91 | 189.01 | 103.77 |
| South Africa | 0.92 | 1.05 | 91.06 | 99.36 |
| Turkey | 9.22 | 9.49 | 29.44 | 18.53 |
| Ukraine | 5.89 | 7.06 | 39.00 | 16.44 |
| United States | 22.55 | 30.50 | 392.92 | 535.31 |
| European Union | 25.23 | 60.11 | 167.82 | 375.99 |
| Rest of World | 19.65 | 18.44 | 1513.84 | 394.30 |

Source: Ramankutty *et al.* (2008)

# 6.  Results

Given equation (9), we calculate the status quo excess factor endowments of pasture and wheat land, labour and capital (Table3). The revealed patterns broadly correspond to *a priori* suspicions that Australia is abundant in both pasture and wheat land and scarce in labour. As identified above, a country is said to be abundant in a factor if its share of the world's supply of that factor exceeds its consumption share, that is, if (*AT*) is positive. Further, a country which happens to be relatively abundant in a factor, say wheat land, is likely to return a positive net export value for goods in which that factor is employed intensively, that is wheat. However, this is subject to the country's specific patterns of abundance, and where there is a stronger abundance of some other factor, this may overwhelm exports in

**Table 3** Status quo excess factor supplies

|  | Pasture Land | Wheat Land | Labour | Capital |
|---|---|---|---|---|
| **Argentina** | 3.22 | 2.54 | 0.97 | 1.17 |
| **Australia** | 10.05 | 1.22 | -7.10 | 0.11 |
| **Brazil** | 1.44 | -2.02 | 5.75 | -3.67 |
| **Canada** | -1.59 | 1.80 | -12.70 | -2.53 |
| **China** | 5.58 | 14.82 | 126.09 | 11.29 |
| **Egypt** | -0.10 | 1.09 | 3.72 | 0.24 |
| **India** | -0.45 | 12.32 | 79.05 | 0.19 |
| **Indonesia** | 0.15 | -0.88 | 17.43 | -0.95 |
| **Iran** | 2.13 | 1.62 | 2.84 | 0.06 |
| **Kazakhstan** | 2.19 | 1.77 | 0.60 | -0.48 |
| **Mexico** | -0.69 | -1.61 | -3.00 | -1.47 |
| **New Zealand** | 0.40 | -0.18 | -0.93 | -0.26 |
| **Pakistan** | -0.07 | 3.66 | 9.31 | -0.42 |
| **Russian Federation** | 1.99 | 5.13 | 2.60 | -6.37 |
| **South Africa** | 3.31 | -0.18 | 0.25 | -1.03 |
| **Turkey** | -0.37 | 2.71 | -1.65 | -1.41 |
| **Ukraine** | 0.42 | 2.70 | 3.39 | -0.56 |
| **United States** | -6.14 | -18.90 | -137.02 | -3.15 |
| **European Union** | -7.35 | -0.62 | -106.28 | -17.41 |
| **Rest of World** | -14.13 | -26.98 | 16.67 | 26.64 |

Source: Ramankutty *et al.* (2008)

that good. Therefore, we need to disentangle the patterns of factor abundance from those of trade by employing the technology matrix to establish opportunity costs of factor employment. The status quo patterns of trade for wheat are presented in Table 4, and those for livestock are presented in Table 5. These patterns broadly correspond to the factor abundance patterns in Table 3, and confirm that Australia does in fact have a comparative advantage in both wheat and livestock.

To analyse the implications of climate change for comparative advantage in wheat and livestock, we employ the climate change agricultural yield impact simulations of Rosenzweig and Iglesias (2006). In this work three general circulation models (GCMs) are employed, the HadCM2-S550, HadCM2-S750 and HadCM3, each created at the Hadley Centre for Climate Prediction and Research. Within these, three levels of farmer adaptation have been considered: no adaptation, low cost adaptation and high cost adaptation. The impact of atmospheric

**Table 4** Status quo trade and simulated wheat trade impacts under climate change – measured in percentage of total exports or imports

| | | 2020 | | | 2050 | | | 2080 | | | 2110 | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Status Quo | Min | Average | Max | Min | Average | Max | Min | Average | Max | Min | Average | Max |
| **Argentina** | 4.95 | 5.08 | 5.16 | 5.28 | 5.15 | 5.26 | 5.38 | 5.10 | 5.38 | 5.69 | 5.17 | 5.34 | 5.54 |
| **Australia** | 2.37 | 2.16 | 2.42 | 2.80 | 2.18 | 2.37 | 2.57 | 1.90 | 2.11 | 2.33 | 2.06 | 2.18 | 2.28 |
| **Brazil** | -3.94 | -4.20 | -4.07 | -3.99 | -4.35 | -4.09 | -3.96 | -4.53 | -4.20 | -3.95 | -3.99 | -3.98 | -3.97 |
| **Canada** | 3.50 | 3.47 | 3.51 | 3.55 | 3.28 | 3.51 | 3.77 | 3.18 | 3.47 | 3.63 | 3.43 | 3.62 | 3.82 |
| **China** | 28.85 | 29.29 | 30.78 | 31.98 | 30.11 | 30.65 | 31.29 | 31.05 | 31.82 | 32.49 | 31.50 | 32.12 | 32.90 |
| **Egypt** | 2.12 | 2.07 | 2.12 | 2.18 | 2.04 | 2.09 | 2.12 | 1.85 | 1.98 | 2.05 | 2.02 | 2.04 | 2.05 |
| **India** | 23.97 | 22.35 | 22.59 | 22.88 | 21.62 | 21.99 | 22.64 | 20.57 | 21.13 | 21.66 | 19.93 | 20.63 | 21.35 |
| **Indonesia** | -1.71 | -1.73 | -1.72 | -1.71 | -1.74 | -1.73 | -1.73 | -1.74 | -1.73 | -1.71 | -1.73 | -1.73 | -1.72 |
| **Iran** | 3.15 | 3.08 | 3.16 | 3.24 | 3.02 | 3.10 | 3.16 | 2.72 | 2.93 | 3.05 | 3.00 | 3.02 | 3.05 |
| **Kazakhstan** | 3.45 | 3.01 | 3.24 | 3.38 | 2.84 | 3.23 | 3.47 | 2.92 | 3.24 | 3.40 | 3.43 | 3.48 | 3.52 |
| **Mexico** | -3.13 | -3.22 | -3.19 | -3.14 | -3.26 | -3.23 | -3.20 | -3.49 | -3.30 | -3.18 | -3.29 | -3.27 | -3.25 |
| **New Zealand** | -0.36 | -0.35 | -0.35 | -0.35 | -0.35 | -0.35 | -0.34 | -0.35 | -0.34 | -0.33 | -0.34 | -0.34 | -0.34 |
| **Pakistan** | 7.12 | 6.64 | 6.80 | 6.90 | 6.34 | 6.55 | 6.69 | 5.86 | 6.28 | 6.49 | 6.27 | 6.33 | 6.41 |
| **Russian Federation** | 9.99 | 8.25 | 9.16 | 9.71 | 7.64 | 9.11 | 10.00 | 7.92 | 9.13 | 9.77 | 9.90 | 10.06 | 10.22 |
| **South Africa** | -0.35 | -0.39 | -0.39 | -0.38 | -0.41 | -0.40 | -0.38 | -0.46 | -0.42 | -0.39 | -0.43 | -0.40 | -0.37 |
| **Turkey** | 5.27 | 4.35 | 4.96 | 5.27 | 4.11 | 5.02 | 5.45 | 4.56 | 5.09 | 5.35 | 5.22 | 5.27 | 5.31 |
| **Ukraine** | 5.26 | 4.59 | 4.94 | 5.16 | 4.35 | 4.93 | 5.29 | 4.47 | 4.94 | 5.19 | 5.23 | 5.30 | 5.37 |
| **United States** | -36.79 | -37.82 | -37.35 | -36.96 | -37.44 | -36.96 | -36.26 | -37.29 | -36.28 | -34.52 | -37.46 | -37.07 | -36.69 |
| **European Union** | -1.21 | 0.55 | 1.16 | 1.70 | 0.78 | 2.19 | 4.29 | 1.05 | 2.49 | 5.50 | -0.14 | 0.58 | 1.33 |
| **Rest of World** | -52.51 | -53.23 | -52.93 | -52.53 | -53.66 | -53.24 | -52.93 | -54.93 | -53.74 | -53.04 | -53.53 | -53.18 | -52.84 |

**Table 5** Status quo trade and simulated livestock trade impacts under climate change – measured in percentage of total exports or imports

| | | 2020 | | | 2050 | | | 2080 | | | 2110 | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Status Quo | Min | Average | Max | Min | Average | Max | Min | Average | Max | Min | Average | Max |
| **Argentina** | 10.43 | 10.65 | 10.76 | 10.86 | 10.30 | 10.89 | 11.30 | 10.34 | 10.95 | 11.94 | 10.53 | 10.75 | 10.98 |
| **Australia** | 32.55 | 32.06 | 33.27 | 35.39 | 32.07 | 33.12 | 34.83 | 31.41 | 31.96 | 32.66 | 31.24 | 31.62 | 31.97 |
| **Brazil** | 4.66 | 4.86 | 5.11 | 5.35 | 5.33 | 5.54 | 5.83 | 4.69 | 5.50 | 6.32 | 5.31 | 5.45 | 5.62 |
| **Canada** | -5.14 | -5.16 | -5.06 | -4.91 | -5.15 | -4.97 | -4.83 | -5.03 | -4.84 | -4.63 | -4.97 | -4.95 | -4.93 |
| **China** | 18.05 | 17.31 | 18.31 | 19.41 | 17.25 | 18.13 | 18.62 | 19.20 | 19.41 | 19.56 | 18.92 | 19.29 | 19.70 |
| **Egypt** | -0.33 | -0.36 | -0.34 | -0.33 | -0.36 | -0.35 | -0.33 | -0.38 | -0.36 | -0.34 | -0.38 | -0.37 | -0.37 |
| **India** | -1.45 | -1.67 | -1.62 | -1.53 | -1.84 | -1.67 | -1.45 | -1.95 | -1.76 | -1.61 | -2.06 | -1.96 | -1.86 |
| **Indonesia** | 0.48 | 0.38 | 0.47 | 0.58 | 0.31 | 0.46 | 0.65 | 0.26 | 0.42 | 0.66 | 0.25 | 0.27 | 0.30 |
| **Iran** | 6.91 | 6.52 | 6.58 | 6.67 | 6.22 | 6.41 | 6.66 | 6.02 | 6.22 | 6.47 | 5.81 | 5.92 | 6.02 |
| **Kazakhstan** | 7.09 | 6.19 | 6.76 | 7.08 | 6.02 | 6.79 | 7.24 | 6.36 | 6.89 | 7.18 | 7.31 | 7.34 | 7.37 |
| **Mexico** | -2.25 | -2.57 | -2.42 | -2.30 | -2.77 | -2.47 | -2.17 | -2.82 | -2.45 | -2.22 | -2.91 | -2.81 | -2.72 |
| **New Zealand** | 1.30 | 1.32 | 1.34 | 1.37 | 1.30 | 1.35 | 1.42 | 1.23 | 1.36 | 1.45 | 1.43 | 1.47 | 1.50 |
| **Pakistan** | -0.21 | -0.23 | -0.23 | -0.22 | -0.26 | -0.25 | -0.24 | -0.29 | -0.26 | -0.23 | -0.28 | -0.27 | -0.27 |
| **Russian Federation** | 6.44 | 5.06 | 5.90 | 6.38 | 4.77 | 5.97 | 6.75 | 5.19 | 6.16 | 6.70 | 6.87 | 6.89 | 6.90 |
| **South Africa** | 10.73 | 10.18 | 10.24 | 10.32 | 9.82 | 10.07 | 10.34 | 9.68 | 9.83 | 9.93 | 9.37 | 9.59 | 9.81 |
| **Turkey** | -1.19 | -1.37 | -1.28 | -1.22 | -1.39 | -1.26 | -1.17 | -1.29 | -1.19 | -1.08 | -1.23 | -1.20 | -1.17 |
| **Ukraine** | 1.35 | 1.12 | 1.26 | 1.34 | 1.07 | 1.27 | 1.39 | 1.15 | 1.30 | 1.37 | 1.41 | 1.41 | 1.42 |
| **United States** | -19.86 | -24.75 | -21.50 | -19.55 | -27.72 | -22.54 | -18.53 | -26.41 | -23.63 | -18.59 | -19.63 | -18.61 | -17.57 |
| **European Union** | -23.80 | -22.16 | -21.70 | -20.90 | -21.99 | -20.63 | -18.53 | -21.53 | -19.11 | -16.65 | -21.78 | -21.63 | -21.45 |
| **Rest of World** | -45.76 | -47.16 | -45.85 | -43.68 | -47.92 | -45.86 | -43.34 | -48.35 | -46.41 | -44.59 | -48.90 | -48.19 | -47.47 |

concentration of $CO_2$ has been alternately modelled. For these levels, each of the combinations of adaptation and $CO_2$ effects is generated for time periods 2020, 2050, 2080 and 2110, resulting in 22 alternative scenarios. Wheat yields are explicitly modelled, although pasture yields are not. Recognising that the pasture species are predominantly C3 or C4 species, we use yield change in coarse grains as a proxy for pasture productivity.

Simulation results of these future yield changes for the agricultural trading model are presented in Table 4 and Table 5, respectively. The minimum, average and maximum predicted trade position is reported, given the comparative analysis of the outcomes of the scenarios. These are measured in percentage contribution to total exports (positive values) or imports (negative values). Strikingly, the modelling results suggest a pattern of broad resilience to climate change, in both wheat and livestock activities. An exception to this is the European Union, which experiences an emergence of comparative advantage in wheat. Likewise, Argentina, China and Canada experience a strengthening in their advantage in wheat production. In livestock, Argentina, Brazil and New Zealand appear to improve their position under the predicted changes. For Australia, adverse yield impacts of climate change act to diminish only slightly the comparative advantage in wheat and livestock. Examination of the predictions of the Hadley CM3, CM2-S550 and CM2-S750 models for Australia and the world (Table 6) helps to explain Australia's maintained comparative advantage. That is, aggregated world productivity changes are generally negative, similar to Australia, although in the majority of cases the magnitude of change is less than that of Australia.

**Table 6** Predicted Australian and world[a] productivity changes[b] in wheat and livestock

| | Wheat | | | | Livestock | | | |
|---|---|---|---|---|---|---|---|---|
| | **2020** | **2050** | **2080** | **2110** | **2020** | **2050** | **2080** | **2110** |
| **No CO₂ Effects** | | | | | | | | |
| **CM3** | 0.0 (-6.7) | -10.0 (-12.8) | -26.0 (-18.8) | - | 0.0 (-10.6) | -10.0 (-18.3) | -26.0 (-23.3) | - |
| **CM2-S550** | -5.0 (-4.0) | -5.0 (-4.5) | -6.0 (-5.4) | -8.0 (-5.8) | -4.0 (-3.2) | -3.0 (-4.1) | -3.0 (-7.7) | -5.0 (-3.1) |
| **CM2-S750** | -7.0 (-3.5) | -10.0 (-6.6) | -14.0 (-8.6) | -18.0 (-13.1) | -5.0 (-3.3) | -6.0 (-3.9) | -8.0 (-5.6) | -11.0 (-8.7) |
| **CO₂ Effects** | | | | | | | | |
| **CM3** | 6.0 (-0.7) | 2.0 (-0.8) | -9.0 (-1.8) | - | 4.0 (-6.6) | -6.0 (-14.3) | -20.0 (-17.3) | - |
| **CM2-S550** | -1.0 (0.2) | 1.0 (1.9) | 2.0 (3.2) | 2.0 (4.2) | -3.0 (-1.7) | -2.0 (-2.6) | -1.0 (-5.3) | -2.0 (-0.1) |
| **CM2-S750** | -3.0 (0.5) | -2.0 (1.4) | -2.0 (3.4) | -3.0 (1.9) | -3.0 (-2.3) | -4.0 (-1.9) | -4.0 (-1.6) | -6.0 (-3.7) |

[a] World figures are reported in brackets
[b] Changes are reported as percentage deviation from status quo

# 7.    Policy implications and discussion

It is possible to conceptualise the policy maker's problem as one in which the state of a country's comparative advantage in any good is characterised by a system of resilience. That is, when a country possesses a strong comparative advantage position, its distance to some "comparative advantage threshold" is greater than another country with a weaker position. A threshold from an Australian policy perspective may be constructed by comparing Australia to an aggregation of all the other countries (world). Then for combinations of changes to the endowments of agricultural lands the resulting general equilibrium comparative advantage outcome may be described graphically. Consideration of such impacts in the framework is especially important, given the likely Rybczynski effects, which in a general equilibrium framework will result in changes in comparative advantage which are more dramatic than the excess factor supply change alone. This establishes a picture of comparative advantage (and disadvantage) and the associated change required in the endowments to switch between them. These have been constructed for wheat (Figure 1) and livestock (Figure 2). Analysis of Australia's comparative advantage

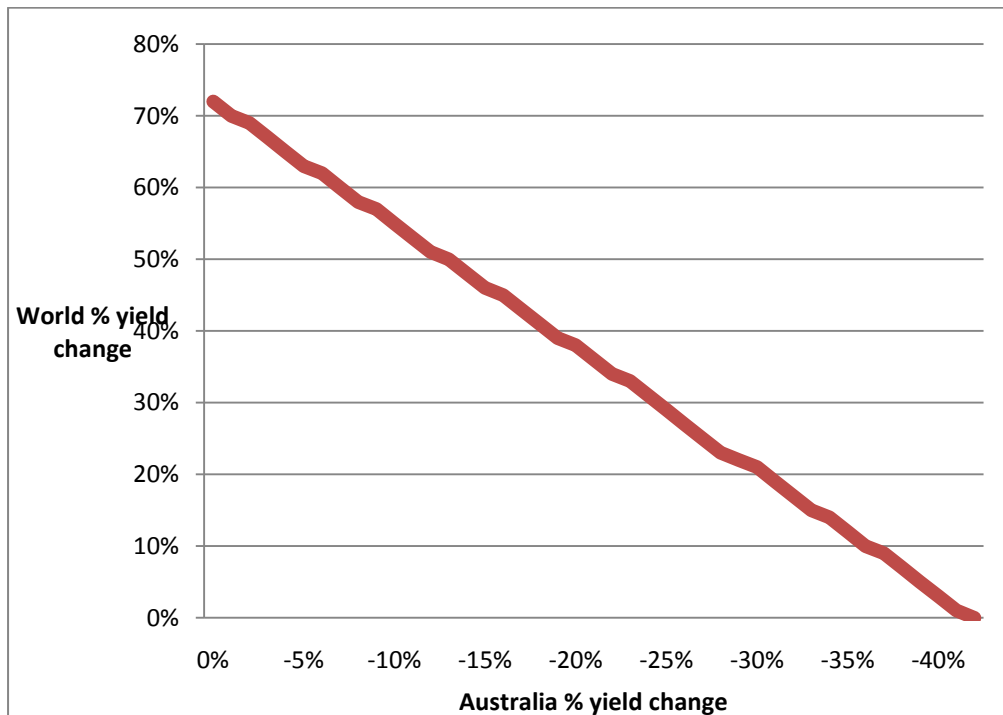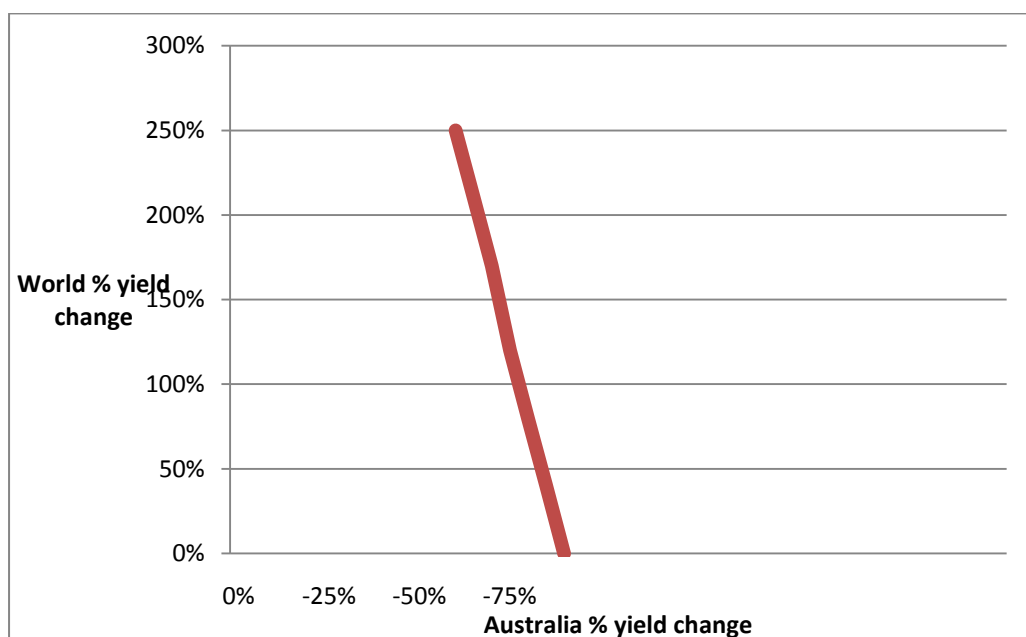**Figure 1** Comparative advantage threshold – wheat

**Figure 2** Comparative advantage threshold - livestock



in wheat against an aggregated rest-of-world reveals substantial resilience to adverse yield change - below the threshold Australia maintains a comparative advantage, and above which it is lost. A *ceteris paribus* decline in the comparative advantage enjoyed by a country, will result in a concomitant decline in the absolute advantage for that good. This implies that the returns to factors − land, labour and capital, employed in that sector will decline. In this framework, the distance from the threshold indicates the strength of the position, and hence the strength of returns (absolute advantage) to the factors used intensively in wheat production. This implies that as climate change induced yield change diminishes the distance to the threshold, the returns to activities in the wheat sector likewise diminish. Examination of Figure 2, reveals a more substantial resilience than wheat − an expected outcome, given the prediction that Australia has the strongest comparative advantage in livestock of any of the countries modelled.

Building on the magnitude of Australian and ROW yield change, the policy maker may choose to invest in adaptation activities, which will have, *ceteris paribus*, the effect of further enhancing resilience of the comparative advantage position. The need for, and choice of investment, must surely reflect expectations about the trajectory of change, and whether or not that change causes the threshold to be crossed, and by how much. As indicated in Table 6, this trajectory of change is insufficient to breach the threshold, and substantially greater adverse change in Australia would be required to do so. According to Mullen (2007), there exist strong returns to public investment in broadacre agricultural research and development activities in Australia. It is, therefore, possible to establish a *prima facia* case for investment in yield-preserving adaptation activities.

The above analysis implies that the United States and EU possess a status quo comparative disadvantage in wheat and livestock sectors. This may be thought of as operating to the left of the comparative advantage threshold, a state in which negative economic returns exist, and may only be maintained beyond the short run by the application of government subsidies. A move towards liberalised trading markets would see the collapse of grains and grazing livestock production in these countries. This position is broadly reversed for the EU in wheat under climate change, and slightly worsened on all accounts for the US. For the latter, climate change means that the cost of maintaining the systems of support for grains and

livestock production will entail progressively higher costs, as disadvantage is exacerbated. This process is driven by declining domestic yields in the US and improved yields in other competitor countries. The EU, on the other hand, may come to enjoy a comparative advantage in wheat and a lessened disadvantage in livestock, which implies a decline in the cost of support to those sectors. The increase in yield is sufficient to overcome the effect of improved yields in those competing countries.

The result which suggests that Australia continues to possess a status quo comparative advantage in wheat help to establish that, in the absence of climate shocks, there exists some scope to maintain that advantage in the presence of positive shocks to the cost of production. These shocks may take the form of government intervention through imposed environmental standards or the mandated inclusion of agriculture in an Australian emissions trading scheme (ETS). The apparent robustness of the advantage that Australia enjoys in wheat production, including that under climate change, implies that the inclusion of agriculture (at least the wheat sector) in the proposed ETS is unlikely to substantially diminish that advantage. In 2005, sheep and beef cattle production accounted for some 80.1 percent of total agricultural emissions, and grains 2.5 percent. Examination of the costs imposed by an ETS, such as those in Garnaut (2008), indicates that grazing livestock such as sheep and beef cattle will experience a cost impost of 5.5 and 6.2 percent, respectively, at a prevailing carbon permit price of \$40 per tonne. Similar data are not reported for grains, although given the lower emissions structure of production, presumably the cost impost on grains is less than that for sheep and beef cattle. It is reasonable to view changes in the cost of production as akin to changes in yield, which given the comparative advantage thresholds suggested above allows us to evaluate the impact of such costs on those broadacre activities we have examined. In both the wheat and livestock sectors the adverse changes cause the distance to the threshold to be diminished, although in neither case this is significant. This implies that any positive price on carbon emissions will have a substantially lesser effect on grains than on sheep and beef, and diminishes the strength of any argument against the exclusion of broadacre agriculture from the ETS.

# 8. Concluding comments

In this simple representation of an agricultural trading world under climate change, we have demonstrated that Australia does continue to enjoy a comparative advantage in wheat and livestock, the predominant activities in Australian broadacre agriculture. Further, in spite of declines in the resilience of that comparative advantage, for the GCMs considered above, the proposition remains true for the simulated years up to 2110. Further empirical work may help to trace the patterns of change within the agricultural sector itself. This may be achieved by incorporating other agricultural industries, for which data are pending.

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