Valuing Agricultural Land Using Commodity Price Variation and Soil Productive Capacity

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1.1 ABSTRACT

This study develops an alternative method to value agricultural land incorporating market drivers of agricultural land price variation in Australia. The study develops a site-specific hedonic land valuation method incorporating changes in soil carbon and nitrogen. Soil carbon is a highly valuable resource for agricultural production systems. It enhances the soil's ability to retain moisture and nutrients, making it a vital component in assessing the impact of management practices on soil and, therefore, agricultural land productivity and value. Soil carbon and nitrogen data from selected crop production areas in New South Wales (NSW), Australia, are used to create a soil productivity variable (SPV) which varies annually based on management practices and climatic conditions at each study site. The SPV is then integrated into a hedonic land valuation model that considers annual changes in global agricultural commodity prices, monetary policy, and inflation to create a periodic land value reflective of current market factors impacting land value. The land valuation model results presented in this study for sites across NSW is comparable with the NSW Auditor General land valuation data for the study sites across the modelling period.

1.2 PLAIN ENGLISH SUMMARY

This study presents a new way to determine the value of agricultural land in Australia. It considers factors that affect agricultural land prices and focuses on the impact of soil carbon and nitrogen. Soil carbon is important for agricultural productivity as it helps the soil retain moisture and nutrients. The study uses soil carbon and nitrogen data from specific areas in New South Wales, Australia, to create a measure called soil productivity variable (SPV), which changes annually based on management practices and climate. The SPV is then used in a model to calculate land value, taking into account changes in global agricultural

commodity prices, monetary policy, and inflation. The results of the land valuation model for sites across NSW align with the NSW Auditor General land valuation data for the study sites.

1.3 INTRODUCTION

The value of agricultural land is determined by its potential to produce agricultural products and is influenced by various factors, such as market trends, weather patterns, and borrowing expenses. Traditional land valuation techniques rely on sales data from comparable properties in the vicinity to estimate market value (Longhofer & Redfearn, 2022). However, this approach overlooks site-specific characteristics, including soil carbon loss, land degradation and other management factors impacting the productive capacity of agricultural land. An alternative land valuation method is required to account for these site-specific differences.

The market value of agricultural land is subject to various factors, including site-specific land characteristics, agricultural commodity prices, projections of future commodity prices, and capital costs. The revenue generated from land use is affected by commodity prices, and past prices shape expectations of future commodity prices impacting farmer land use management decisions and agricultural land market demand. While there is relatively inelastic global demand for grain commodities, global supply and prices are susceptible to climatic conditions and changes in key supplier government policies (Wright, 2012), which impacts agricultural land values(Larder et al., 2018). This study develops a land valuation methodology for dryland cropping land in NSW, Australia, incorporating agricultural commodity prices, the cost of financing capital investments, site land quality and factors influencing the market value of land.

1.4 LITERATURE REVIEW

Dryland crop production is a critical component of the agricultural industry in Australia (Sadras et al., 2003). NSW produced 22% of Australia's winter grains in 2022; however, it experiences significant climate variability, resulting in interannual crop yield variance (ABARES, 2023; Hughes et al., 2015). Australian soils have low soil carbon and nutrients, reducing water infiltration, nutrient retention and crop yields. Seasonal changes in rainfall patterns alter the quantities of nutrients in the soil, which affects crop growth and yields and, therefore, the quantity of carbon and nutrients stored in the soil and, thus, the returns and value of agricultural land (Ghaley et al., 2018; Williams, 1989).

Farmer income is primarily derived from the agricultural land assets controlled and used for agricultural production. The present value of agricultural land is influenced by its future potential income derived from the land (King & Sinden, 1988). Farmers typically have long-term land use plans, such as holding land for ongoing income generation, or as part of a bequest, or to meet a succession-planning objective; this contributes to the thin property markets in rural Australia (Fairbairn, 2014). In recent years, there has been a trend of farmers and multinational companies investing in Australian farmland to diversify their investment portfolios and mitigate climate-related supply risks increasing market demand and land values (Sippel et al., 2017). However, dryland soils in Australia are generally low in nutrients and carbon, and the soil quality can vary depending on land management activities which affects the market value of the land, as pointed out by King and Sinden (1988). Therefore, variations in soil quality resulting from crop management practices can significantly impact future returns from the land and its market value.

A common approach to valuing land is empirical analysis using realised yields and land market data (Tsoodle et al., 2006). Agricultural land with higher soil productivity is found to have a higher market value (Xu et al., 1993). An alternative is valuing individual site characteristics, used in hedonic methods or empirical regression analyses of market data to elicit land values (King & Sinden, 1988; Phipps, 1984). Yet market values may not reflect site-specific soil characteristics or the effect of climate shocks and management practices on the land's productive capacity. Chen et al. (1986) suggested that land value returns can be characterised as unrealised dividends from land assets; consistent with this, management actions that improve soil productivity can be considered periodic unrealised dividends that must be accrued to the asset's value. To date, there are limited methods of evaluating how soil quality variation affects the value of agricultural land. Developing a method of valuing land that can be calibrated to site characteristics is a research area requiring more consideration.

Dynamic simulation models simulate the long-term effects of changes in site-specific land value by integrating economic, physical, and regulatory factors over time. Australian farmers are exposed to several risks impacting land use, including commodity price variation, management decisions and land valuation. Wang et al. (2019) used simulation modelling to evaluate the impact of climate change on crops in southeastern Australia. Simulation modelling has been used to investigate methods for reducing economic risks to farmers by Bell and Moore (2012); however, it has not been widely used to estimate how alternative land uses impact soil productive capacity and land value.

Agricultural commodity price movement is found to impact market land values. Eves (2000) used a regression model of land sales data from 1975-1996 and found that farm prices in marginal crop production areas of New South Wales are more correlated with commodity price changes than in less marginal crop production areas, suggesting that dryland crop production areas are more exposed to market volatility. Allan and Kerr (2013) examined the drivers of rural land value variance in New Zealand between 1980–2009 and found that economic conditions and agricultural commodity prices influenced land price variation. However, temporary shocks, such as climate, drought, and flood events, did not impact land prices in New Zealand. Other factors impacting land value are the size of the land parcel, size, prevailing climatic conditions and commodity cross-price elasticities, which have a small impact on agricultural land value in Australia (Oczkowski & Bandara, 2013). Evaluating the impact of economic conditions and agricultural commodity price variation on land value in Australia is an area requiring further attention.

Existing methods of valuing agricultural land rely on empirical data, whereas the market value of land is influenced by its site-specific productive capacity, prevailing climatic conditions, and agricultural commodity prices. Therefore, further research is required to incorporate the wealth of site-specific soil data generated with recent technological advances and integrate factors influencing market values into land valuation to generate site-specific land valuation techniques and support informed land management decision-making. Simulations can be used to explore how new management techniques or land use changes may impact land use returns and the market value of land, providing a site-specific evaluation technique.

Crop modelling software is a valuable tool that simulates and predicts crop growth, development, and yield under different environmental and management conditions. To generate crop yields, crop modelling software simulates crop production using soil characteristics, including soil nitrogen and carbon, combined with study site climatic conditions and land management processes. The Agricultural Production Systems Simulator (APSIM; (McCown et al., 1996) has been used globally for various economic land use analyses to investigate different aspects of land and crop management and their impact on yield and farmer income. For example, Cann et al. (2020) investigated the economic impact of continuous wheat production in southeastern Australia compared to crop rotation or a crop-fallowing system with various fertiliser inputs using APSIM. An analysis of methods to reduce the yield gap in southeastern Australia was explored by van Rees et al. (2014) using APSIM. Crop software enables the investigation and evaluation of alternative management practices on soil nutrients and carbon content, which improve soil productivity and the future productive capacity of the land and, therefore, land value.

This study will add to the literature by developing a land valuation model that incorporates commodity price variation, changes in soil conditions, and other factors that impact agricultural dryland crop production market land values in Australia. The model will be tested using APSIM simulations for selected study sites across NSW and compared to land valuer data.

1.5 METHOD

The value of agricultural land is influenced by its future productive capacity, agricultural commodity prices, and prior period crop yields. Crop yields are limited by soil nutrient content and texture, and prevailing climatic conditions. Farmers use management practices to manage soil organic material to improve soil cation exchange capacity (CEC), crop yields, and income (Agegnehu et al., 2016). Using the relationship identified by Agegnehu et al. (2016), this study develops and evaluates the effectiveness of a soil productivity variable (SPV). The SPV is incorporated into a hedonic pricing model to enable site-specific land valuation.

1.5.1 Study sites

This study investigates dryland crop production in the Junee, Walgett, and Dubbo regions of NSW, Australia over the period 1996-2020. These areas are typical of low-rainfall dryland crop production regions in southeastern Australia (O'Leary et al., 2018). The farm sizes in these regions range from 378 to 2,000 hectares (DPI, 2018). The study sites are based on NSW Land Valuers Office sites within each region used for crop production or mixed land use. Therefore, in this study, the plots of land and are used for modelling are assumed to be agricultural land previously managed using a crop rotation system.

According to BOM (2023) data, the study sites experience an average annual rainfall of 611–615 mm, which is evenly distributed throughout the year. Due to unsuitable conditions for productive plant growth in summer, crop fields are usually left fallow during this period, with crop production occurring between April and November (Hunt & Kirkegaard, 2011). As illustrated in *Table 1,* the study sites have low soil organic content, limiting soil water, nutrients, and organic matter infiltration and retention, which are essential for maximising crop growth and yield. The data in *Table 1* is used to calibrate APSIM software and undertake crop simulations at each of the study sites to generate changes in soil carbon and nitrogen which are used to develop the SPV and incorporated into the land value equation.

Table 1: Study Sites' annual rainfall and soil characteristics

Study site	**Annual rainfall (mm)**	**Average soil carbon content (%)**	**Cation exchange capacity (CEC)**	**Climate factor**
Dubbo	615	3.88	16	4.2
Junee	611	0.56	10.5	4.2
Walgett	611	0.43	7.6	4.2

Sources: (BOM, 2023; Johnston et al., 2003; McKenzie et al., 2012)

The most prevalent winter crops observed in the study areas include wheat, barley, and canola, and a leguminous break crop. Following Mendelsohn and Dinar (2003) a fixed production function was used in APSIM to ensure consistent management procedures and production inputs throughout the modelling period and across study sites. Planting times, fertiliser application type, quantity and frequency are presented in *Table 2.*

Table 2. Study site crop management characteristics

	Walgett	***Dubbo***	***Junee***
Canola			
Planting time	May	May	May
Fertiliser application time	February, May (seeding)	March, at sowing	At sowing
Fertiliser type	Urea, MAP	Nitrogen, DAP	DAP
Fertiliser application quantity	80kg/ha, 50 kg/ha	150 kg/ha, 60 kg/ha	150 kg/ha
Wheat			
Planting time	May	May	May
Fertiliser application time	May	May, at sowing	May, at sowing
Fertiliser type	Urea	Urea, MAP	Urea, MAP
Fertiliser application quantity	174 kg/ha	100kg/ha, 110kg/ha	100kg/ha, 110kg/ha
Field Pea			
Planting time	June	June	June
Fertiliser application time	nil	at sowing	at sowing
Fertiliser type	nil	MAP	MAP
Fertiliser application quantity	nil	100kg/ha	100kg/ha
Barley			
Planting time	Early May to mid June	Early May to early June	Mid May to late June
Fertiliser application time	At sowing	At sowing	At sowing
Fertiliser type	Urea, MAP	Urea, MAP	Urea, MAP
Fertiliser application quantity	70 kg/ha, 100 kg/ha	70 kg/ha, 100 kg/ha	70 kg/ha, 100 kg/ha

Sources: (GRDC, 2011, 2018a, 2018b; Matthews et al., 2023; McDonald & O'Leary, 2016; Meppem, 2020; Serafin et al., 2005)

Crop rotation land management involves planting different crops in sequence to optimise soil health, reduce pests and diseases, and improve yields. Identical crop rotations were used at all APSIM simulation sites, as detailed in *Table 3*. Soil nitrogen and carbon content for each rotation at every site was recorded and exported from APSIM for integration into the production function used in economic modelling. The data was used to evaluate how different crop rotations impact soil health and in the construction of the SPV to vary land values.

Table 3. Crop rotations simulated in APSIM for 1996–2020 for each study site.

Crop rotations	**Abbreviation**
Wheat, wheat, canola	WWC
*Wheat, wheat, field pe*a	WWFP
Wheat, barley, canola	WBC
*Wheat, canola, field pe*a*, wheat*	WCFPW
*Wheat, barley, field pe*a	WBFP

1.5.2 Soil Productivity Index

The crop production function used in the economic model has fixed capital (k), variable production inputs ($\boldsymbol{x}$), crop yield, y_t, (1), in each production period is constrained by the soil productivity (η_t)which is a state variable measured at the start of the crop production period (*t*). The approach is consistent with Benhin (2008) and Mendelsohn and Dinar (2003), who use an improved production function to evaluate the impact of climate on agricultural production. Each production period is one year and incorporates the summer fallow period. Crop yield increases with soil productivity, which is constrained to be non-negative:

$$y_t \equiv f(\boldsymbol{x}_t, k, \eta_t) \tag{1}$$

Crop yields vary; consequently, the volume of nutrients extracted from the soil varies. Calculating a crop production's soil carbon and nitrogen usage through APSIM simulations facilitates the evaluation of the impact of management processes on soil and crop productivity and, therefore, land value. APSIM soil carbon (kg/ha) balances after harvest each year will be used to measure the impact of climatic conditions, management practices and soil carbon variation on soil nutrient holding capacity. Olof and Thomas (1997) developed a mathematical relationship for estimating the quantity of new soil carbon inputs (NC) (kg/ha) retained in the soil annually. The model by Olof and Thomas (1997) predicts the effects of climate and fresh organic material (FOM) input variation on soil carbon pools. It was found that the fraction of carbon (C) remaining after one year can be expressed as follows:

$$\frac{dC_{t+1}}{dC_t} = e^{-k} \tag{2}$$

where k is the first-order kinetics or rate of decomposition of NC into carbon dioxide and humus. The decomposition rate, k, depends on the soil carbon type. NC decomposes at a different rate (k_1) than humus (k_2). The NC decomposition rate is influenced by soil temperature and moisture. The NC retention rate depends on the soil profile's clay volume (% expressed as a decimal; h) and a dimensionless climate factor (r). Andrén et al. (2007)(p. 380, Table 2) used climatic data records to construct climate factors for various African sites, including Pointe Noire in the Republic of Congo which has a similar mean temperature and rainfall to the study sites, with an *(r)* factor of 4.2. Therefore, climate factor 4.2 will be used for the study sites. The NC decomposition rate is estimated as follows:

$$k_1 = -\frac{1}{r} ln \frac{e^{-k}-h}{1-h} \tag{3}$$

The average soil carbon decomposition rate (k) is:

$$k = -\,ln[\,(1-h)e^{-k_1 r} + h] \tag{4}$$

Combining equation 4 into the annual change in soil carbon decomposition equation (3) and incorporating NC decomposition, the yearly change in soil carbon using Olof and Thomas (1997) becomes:

$$\frac{dC_{t+1}}{dC_t} = e^{-k_1 r} + h(1 - e^{k_1 r}) \tag{5}$$

Carbon is one quality required for soils to retain nutrients valuable for crop production. The ability of soils to retain nutrients is measured by the soil's cation exchange capacity (CEC). Soil CEC combines soil clay, carbon and nutrient particles and is an indicator of the overall fertility of the soil (McKenzie, 2004). The soil will hold an equal quantity of nutrients to the volume of clay and carbon in the soil. Therefore, soil clay and carbon are critical to maximising soil productivity, crop growth, and yields (Unkovich et al., 2020). Droge and Goss (2013) use soil CEC from standardised European Union soils in their laboratory analysis to fit a model that estimates the nutrient holding capacity of the soil (τ_t) using soil carbon (C) and clay (h), content. Droge and Goss (2013) use a fixed conversion rate of 3.4 for CEC nutrients in the NC together with the ratio of carbon in the organic material in the soil $\left(cc_t = \frac{NC_{c_t}}{C}\right)$ and the fresh organic material added to the soil to calculate soil nutrient holding capacity[1]:

$$\tau_t = h(CEC - 3.4 \cdot cc_t) + (cc_t \cdot FOM) \tag{6}$$

The soil nutrient holding capacity fluctuates depending on the quantity of soil carbon, crop production intensity, soil temperature, moisture and nutrient content (Keating et al., 2003). In this study the soil nutrient holding capacity for the study sites will use the average topsoil CEC taken from the Australian Soil Resource Information System database (McKenzie, 2004), together with the aggregated soil carbon ($BIOM_{c_t}$) and NC measurements taken from APSIM modelling after harvest has occurred in each production period. Therefore, the level of soil carbon and nutrients will vary in each production period depending on climate conditions and crop production management decisions, impacting the future land productive capacity and market value.

The soil nutrient holding capacity (equation 6) determines soil productivity influencing market value at a site. Soil nitrogen represents the broader body of soil nutrients necessary for crop growth. In this model, the soil nitrogen balance (kg/ha) at the end of each production period will be taken from APSIM modelling results at the end of each annual production period and converted into a ratio of nitrogen in the topsoil, consistent with the

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[1] Droge and Goss (2013) use a parameter for a single natural or fresh organic material that has not yet decomposed into soil carbon, such as peat, to calculate individual nutrient retention in the soil. For simplicity in this study, it is assumed that all fresh organic material is identical crop reisdue and adsorbs nutrients in the same manner.

approach taken for soil carbon content in equation 6. The net change can be positive or negative, influencing future land productivity; soil nitrogen fluctuates, decreasing with denitrification, immobilisation, and leaching while increasing with mineralisation and the addition of nitrogenous fertilisers.

Soil nitrogen comprises organic and inorganic materials that are converted into plant-accessible nitrogen through mineralisation. The soil organic nitrogen mineralisation rate, developed by Stanford and Smith (1972), estimates the change in the soil that can be mineralised and has been widely applied to various topics, e.g. Mulvaney et al. (2009), Mary et al. (1996), and Binkley and Hart (1989). Stanford and Smith (1972) estimated soil mineralisation potential using a fixed soil mineralisation rate (z_t) based on the change in soil nitrogen balance (ϕ_t) between periods:

$$\phi_{t+1} = \phi_t(1 - e^{z_t}) \tag{7}$$

The soil mineralisation rate (z_t) was set at 0.110 using the soil organic matter mineralisation rates calculated by De Neve and Hofman (2000)(p. 546, Table 1). Combining the soil nitrogen content (equation 7) with the soil carbon calculations in equations (2–6), the soil productivity variable (SPV) for a period (η_t), can be calculated as:

$$\eta_t = G(\tau_t, \phi_t) = 1 - e^{-\tau_t \phi_t} \tag{8}$$

The SPV reflects changes in soil carbon and soil nutrient holding capacity, enabling farmers to assess the impact of management actions and climate shocks on land value. By increasing soil productivity, farmers can increase future potential yields and land use returns. The rate of return on financial assets is typically quantified by determining the change in value from the current to the previous periods. By applying this concept to soil productivity, farmers can quantify the impact of their land management practices on land value. A soil productivity index (SPI) is developed using the net change in the SPV from one period to the subsequent period where:

$$\delta_{\eta,t+1} = \left(\frac{\eta_{t+1} - \eta_t}{\eta_t}\right) \tag{9}$$

The SPI ($\delta_{\eta,t+1}$) can be used with nominal interest rates to evaluate the crop production intensity, management practices, and prevailing climatic conditions on future returns from land use, and land value. However, the land value adjusted using the SPI does not capture market price variations, which include changing tastes and preferences, farmer expansion with favourable international commodity prices, or climatic conditions and other exogenous factors.

1.5.3 Land valuation model

To capture changes in market demand resulting from variable climatic conditions, the Australian Bureau of Agricultural and Resource Economics and Sciences' (ABARES) winter dryland crop production area for the whole of Australia ('000s ha) and the total volume of key grains produced across Australia in kilo tons (kt) are used to create a winter crop productivity index (WCPI) (10). As discussed previously, grain production in Australia is winter-dominant, therefore summer crop production is not considered in this analysis. Let $\boldsymbol{q}$, be a vector of winter grains produced in *kt* across Australia restricted to key grains exported, where there are *i= [1,...., N]* crops. Let $\boldsymbol{a}$, be the area of agricultural land in ('000s) of ha in period *t* used for winter grain production across Australia.

$$WCPI_t = \sum_i^N \left(\frac{\boldsymbol{q}_{i,t}}{a_{i,t}}\right) \tag{10}$$

The WCPI is an instrument where favourable conditions increase returns per hectare, and the WCPI, with less favourable conditions such as drought, reduces the WCPI. Another factor influencing farmer profitability and market demand for agricultural land is the global crop commodity prices realised in the past two years. Changes in global crop commodity prices impact farmer income derived from exports. Australian farmers are exposed to global agricultural commodity price variations (FAO, 2023). Let $\boldsymbol{\beta}$ be a vector containing global nominal prices in a given year in AUD for Australia's agricultural export commodities of interest, in this case, barley, canola, and wheat. The ratio of a price change for a crop (*i*) in *t-1* compared to *t-2* is combined with the crop output in t-1 and the national output for key grains in the produced previous period to obtain a commodity price output variable ($z_{t,i}$) (eqn 11).

$$z_{i,t} = \left(\frac{\boldsymbol{\beta}_{i,t-1} - \boldsymbol{\beta}_{i,t-2}}{\boldsymbol{\beta}_{i,t-2}}\right) \times \left(\frac{q_{i,t-1}}{\sum_{i}^{N} q_{i,t-1}}\right) \tag{11}$$

The sum of individual crop price output quantity variables ($z_{t,i}$) is used to estimate how global commodity fluctuations impact agricultural land value in period *t* ($h_{i,t}$) (eqn 12). Changes in prior period WCPI, global commodity prices, and prior period Australian crop output, all impact farmer income in the current period and therefore market demand for agricultural land. Let λ_t be the annual change in land value arising from the prior period's global agricultural commodity price variation and changes in WCPI.

$$h_t = \sum_{i}^{N} z_{i,t} \tag{12}$$

$$\lambda_t = \left(\frac{WCPI_t - WCPI_{t-1}}{WCPI_{t-1}}\right) * h_{t-1} \tag{13}$$

Land value is impacted by financial market activity in conjunction with other market forces, and demand for agricultural land increases when capital costs are reduced. To account for the impact of financial market fluctuations, let s_t be a cost of capital variable in period *t*. The cost of capital variable uses the variance between the annual Reserve Bank of Australia (RBA) cash rate (c_t) for period *t* and the average cash rate for the entire modelling period ($\bar{c}$).

$$s_t = \bar{c} - c_t \tag{14}$$

The impact of changes in monetary policy uses the average RBA cash rate and the cost of capital variable to develop a cash rate impact in equation 15 (v_t). The periodic change in inflation (r_t) (equation 16), uses the Australian Bureau of Statistics (ABS) average annual inflation rate for the period (i_t).

$$v_t = 1 - \left\{ \left(\frac{\bar{c}}{s_t} \right) + exp^{\bar{c}} \right\} \tag{15}$$

$$r_t = \frac{i_t - i_{t-1}}{i_{t-1}} \tag{16}$$

The nominal value of a 1-hectare plot of land in 1996 was taken from the New South Wales *Valuer General's Long Term Land Values* (2023) for Junee, Dubbo, and Walgett, which are the crop production areas in NSW being investigated. Using equations 8–16, the change in land value is incorporated into an economic model to calculate the price of land ($p_{L,t}$) at the end of a given period (*t*) based on the work of Tack et al. (2015). Hence, the value of a 1 ha plot of cropped land at the beginning of the following period is:

$$p_{L,t+1} = p_{L,t} \left(\left(\frac{1 \times v_t}{v_t} \right) + \lambda_t + r_t + \eta_t + i_t + s_t \right) \tag{17}$$

The study assumes that the land is held for the entire modelling period and does not consider alternative crop rotations, land uses, management methods, government policy changes, and production input quantities. Land value is impacted by various factors, including the cash rate, global commodity prices and site-specific soil characteristics. An increase in soil productivity improves soil quality, which is valuable in a competitive market for farmland. However, soil productivity can also decline depending on the production management practices or climate shocks experienced during the production period. Similarly, management practices that maintain or improve the quality of the land increases crop yields in subsequent production periods, thereby increasing the value of the land.

1.6 RESULTS

For 1996–2020, the alternative crop rotations presented in *Table 3* at each study site were simulated in APSIM. Annual soil carbon, nitrogen, changes were generated in APSIM and used to develop the SPV. The average changes across for these variables across rotations at each site are presented in *Table 4*. Initial soil carbon influences CEC content, soil nitrogen, carbon, and therefore soil productivity variation across study sites. Walgett and Junee simulations generated the largest losses in soil productivity, however had lower initial soil carbon, while Dubbo had the highest initial soil carbon content and generated the smallest productivity losses, confirming the link between soil carbon, nutrient holding capacity, and CEC identified by Droge and Goss (2013).

Table 4. Simulated average changes in soil carbon, nitrogen and productivity at Junee, Dubbo and Walgett 1996–2020

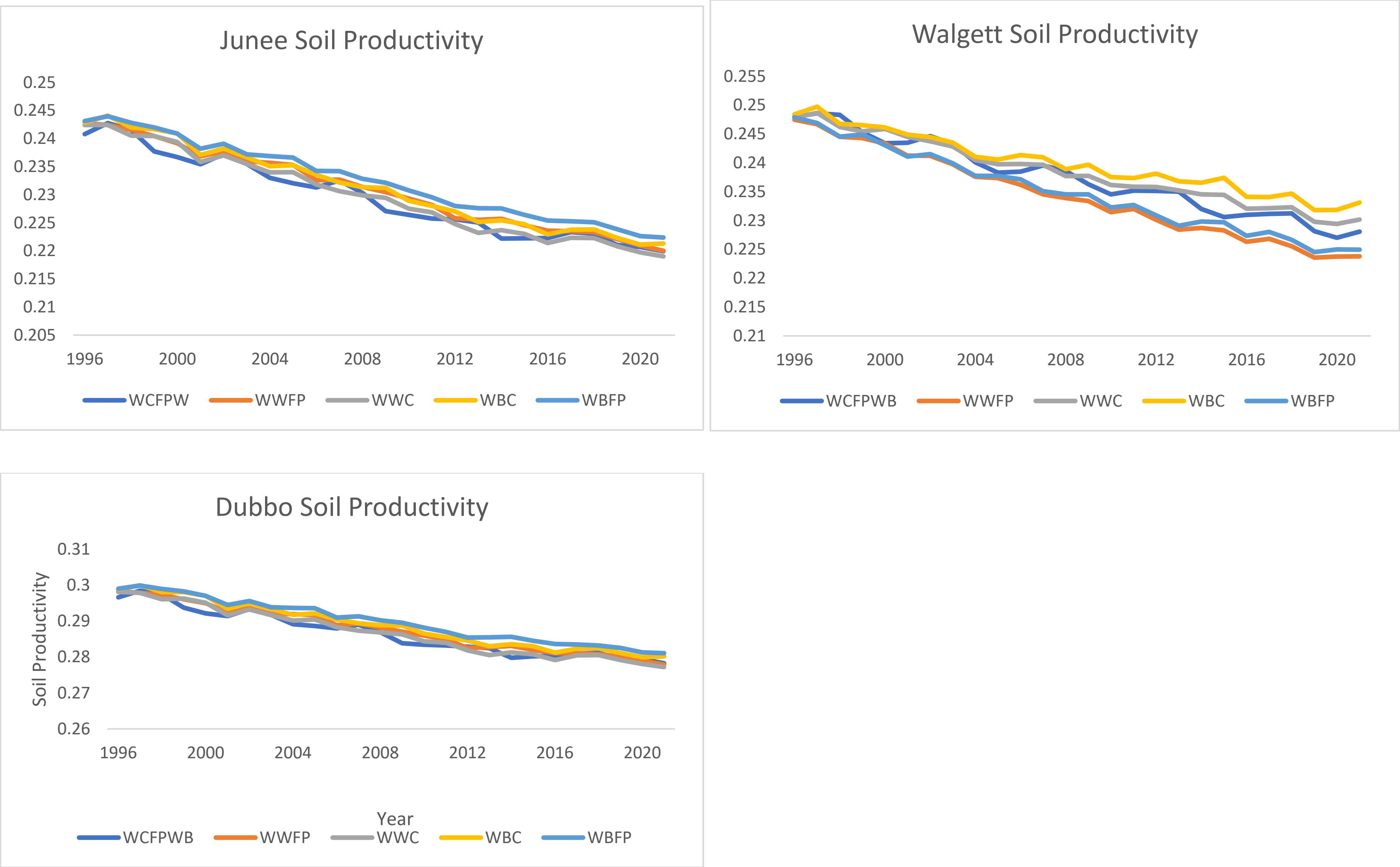
Study site	Soil clay content (%)	Soil CEC	Average change in soil nitrogen (%)	Average change in soil carbon (%)	Average change in soil productivity (%)
Dubbo	3.88	16.0	-7.99	-9.66	-6.47
Junee	0.56	10.5	-12.52	-12.85	-9.09
Walgett	0.43	7.6	-11.31	-11.37	-8.02

Source: Malone and Searle (2022); McKenzie (2004); Mullen et al. (2006); Young et al. (2014)

The impact of crop production on soil productivity varies depending on climatic conditions and site characteristics. The SPV variable increased the SPI by up to 0.48% in 2004 in Walgett, which received the average annual rainfall with a rotation of, wheat, canola, field peas and wheat. The same rotation at Walgett decreased the SPI by 1.34% in 2019, with below average rainfall. This suggests that the volume of precipitation a site receives is linked to SPV and therefore impacts the future productive capacity of the land. Climatic and site soil characteristics have a larger impact on SPV variation than the crop rotation sequence, as the data in *Table 4* illustrates, suggesting that land use is a significant driver of land productivity and market value.

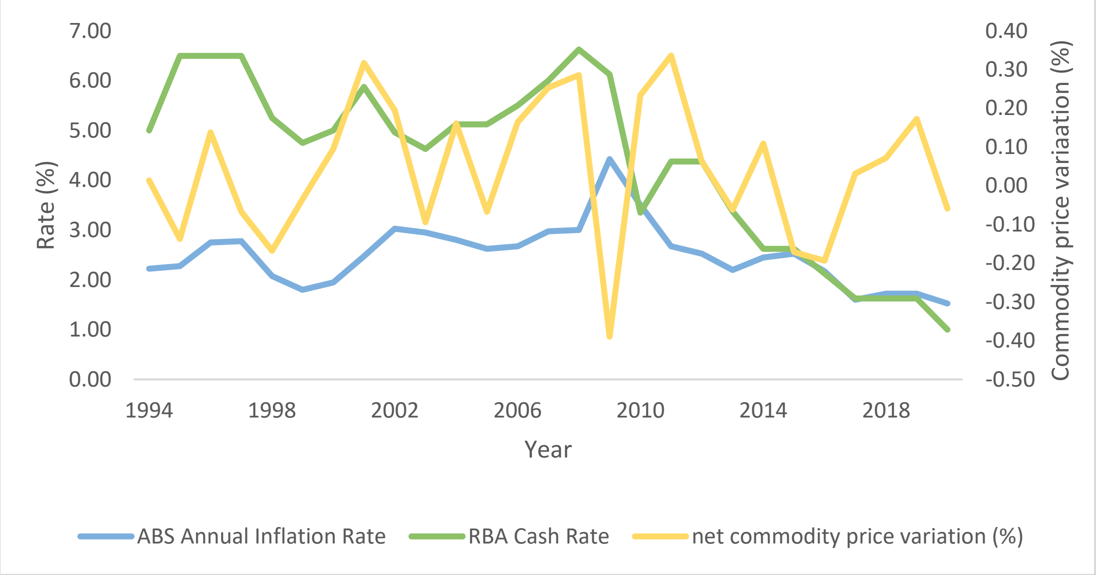
Across the study sites different crop rotations increase the SPV, as illustrated in *Figure 1*. At Walgett the WBC rotation has the lowest variation in SPI, whilst at Dubbo and Junee the WCFPW rotation generates the lowest variation in SPI. The largest variance in SPI at Walgett is generated with WWFP rotations, whilst at Dubbo and Junee both sites generate the largest variance in SPI with WWC. At Walgett the largest average increase in SPI (0.13%) was in 2017, which experienced average annual rainfall, whilst at Dubbo (0.33%) and Junee (0.50%) the largest increase in SPI occurred in 2002. The largest decrease in SPI (-1.09%) occurred in Walgett in 2019, at Dubbo in 2006 with a loss of 0.79% and at Junee in 2001 with a loss of 1.13% negatively impacting land value.

Figure 1. Change in soil productivity 1996–2020 for Junee, Walgett and Dubbo with alternative crop rotation simulations.



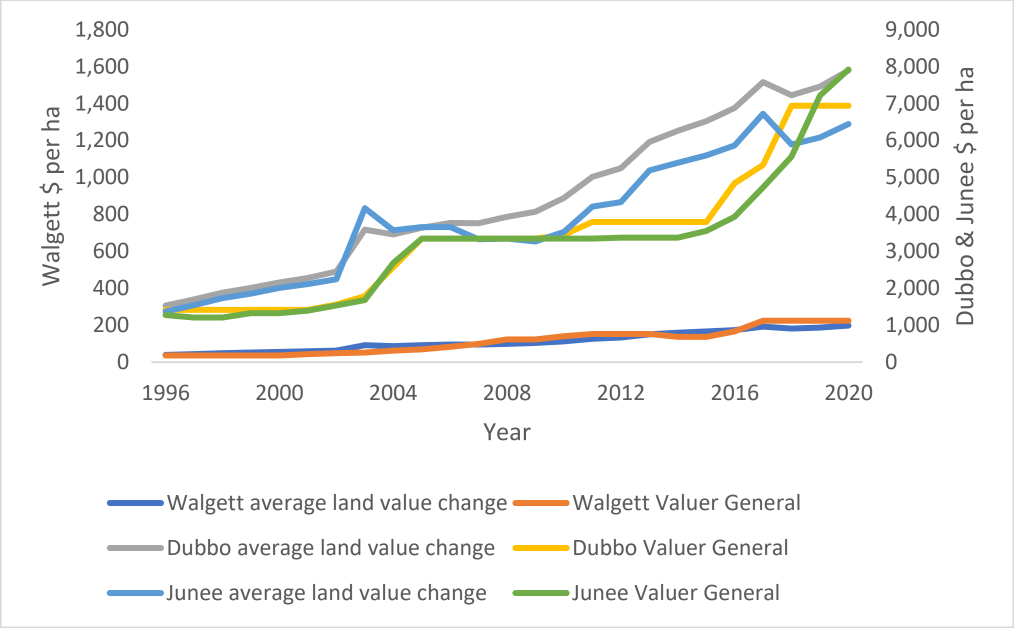
Another driver of agricultural land market activity is global grain commodity prices. Increases in grain commodity prices are consistent with increased land use revenue illustrated in *Figure 2* (Carberry et al., 2011), with the commodity price index developed in this study generating results consistent with the NSWVG values (see *Figure 3*). Wheat and barley experienced minor price variations between 1996 and 2020, except for 2007–2008, when poor yields were experienced in Australia, Europe, and Canada (Piesse & Thirtle, 2009; WorldBank, 2020). However, canola prices exhibited stronger variation driven by European Union legislation and the use of canola in biofuels (Yahya et al., 2022). A poor canola harvest in Australia, Canada, and Europe in 2007 led to a spike in canola prices, while wheat and barley were comparatively less affected (Piesse & Thirtle, 2009). Global canola price variation has the largest impact on land values, increasing returns from dryland canola production and, therefore, the land values for the study sites.

Figure 2. Monetary policy and commodity price contribution to Australian agricultural land value changes 1996-2020



Dominating commodity price fluctuations and climatic conditions is the cost of capital, which significantly affects the return generated from land use. Many agricultural landholders use their land as collateral to finance their farming businesses and additional land acquisition. The cost of capital was impacted by strong export demand increasing the cash and inflation rates leading up to the Global Financial Crisis (GFC), which resulted in an increase in the cash rate as illustrated in *Figure 2* and had a minor positive effect on land valuation across the study sites. Following the GFC, inflation and cash rates remained somewhat volatile; however, they had an overall downward trend for the remainder of the period. There is no clear trend or linkage between commodity price variation combined with the WCPI and the inflation or cash rate. However, the overall effect results in price variation at study sites that is broadly consistent with the *NSW Auditor General's Annual Land Valuation (VGO, 2023)* presented in *Figure 3.*

Figure 3. Junee, Walgett and Dubbo study site land value variation (1996–2020)



Sources: (ABARES, 2020; ABS, 2023; DAFF, 2024; RBA, 2021; VGO, 1993, 2023; WorldBank, 2020)

The results of simulation and modelling for the study sites across NSW as presented in *Figure 3* and Appendix A show that the average variation between the NSWVG and the simulated land value is comparable across study sites in 1996, with simulations generating land values between 7.1 – 8.2% higher across study sites. In 2020, there is a larger difference in land values, with Walgett simulations returning a land value 4% lower than the NSWVG. However, Dubbo simulations were 14.5% higher and Dubbo 16.5% higher than the NSWVG. Across all years and simulations, the variation in land value is driven by changes in the cash and inflation rates, increasing land values by 8.3% in 1996 and 6.1% in 2020. The largest variance for all study sites was experienced across the millennial drought period, with the RBA cash rate decline in 2001 – 2003 increasing land value in simulations that was not reflected in the NSWVG price. Commodity prices and the WCPI have a smaller impact, reducing land value by 0.5% in 1996 and increasing land values by 0.4% in 2020. Other rotations in Dubbo saw losses in both 1996 and 2020 of between 0.071 and 0.262%. Simulations generate land value changes that are comparable over the long run; however, they may generate short-term price differences when compared with the NSWVG valuation.

The annual changes in land value for a rural production landholding of average size were based on the NSW Valuer General's land valuation database.[2] The findings show that the method developed in this paper is consistent with the market value (VGO, 2023). However, there were discrepancies in the modelled land values for some study sites in 2003 and 2015 (as shown in *Figure 3*). The modelled values were 30–70% above the NSW VGO valuations in 2015. Nonetheless, the modelled values converged with the NSW VGO values for all study sites in 2018 before diverging in 2020, with the modelled values being above the NSW VGO values for Junee and Walgett and below for Dubbo (*Figure 3*). Overall, the modelled land values are generally consistent with the nominal land values from the NSW VGO for the study

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[2] Dubbo's average farm size is 233 ha with the study using the Newell Hwy, Eumungerie site, Junee's average farm size is 338 ha using the Eurongilly Rd, Eurongilly site, and Walgett has an average farm size of 1,751 ha and uses the Gingie Rd, Walgett site taken from the NSW VGO (2023) database.

sites. However some impacts not fully captured and have a lagged effect on NSW VGO valuations. The modelling approach developed in this study can be used as an agricultural hedonic valuation approach as an alternative to empirical evaluation techniques.

1.7 DISCUSSION

Agricultural land is the most significant asset a farmer controls. Therefore, evaluating the impact of soil productive capacity changes on land value can support strategic land use planning. The volume of soil carbon in conjunction with CEC and clay influences the volume of soil nutrients stored within the soil, consistent with Dalal and Chan (2001), who identified a link between the loss of soil carbon and reduced quantities of accessible soil nutrients for crop production. The decline in soil carbon reduces the soil's CEC, reducing soil fertility. The net change in SPV from one production period to the next provides a mechanism for farmers to evaluate the effect of their management decisions on land quality.

The SPV links previous biophysical research identifying the importance of maintaining soil carbon to retain soil nutrients and maximise crop yields (Aguilera et al., 2013; Turmel et al., 2015). The SPV is concordant with results in biophysical studies that measure the impact of soil nitrogen or carbon losses on soil productivity (Dai et al., 1993; Lassaletta, 2014). When applied to land value using the SPI it provides a realistic estimation of the impact of land management practices on soil productivity and the value of the land, consistent with Gretton and Salma (1996). Biophysical studies investigating the impact of changed soil structure (e.g. Oldfield et al. (2019)), and the loss of soil carbon or nutrients (e.g. Hunt et al. (2019)) do not consider the economic impact of changes to the future productive capacity of the soil. The SPI is a flexible valuation method for calculating the impact of soil productivity variation, representing a new site-specific approach to valuing agricultural land.

The SPV explains why higher soil nitrogen through increased fertiliser application is insufficient to increase soil productivity. The exponential relationship between soil and soil carbon becomes most evident when soil productivity losses or gains increase. Empirical analysis uses historical land values capturing the land quality and market conditions when the land was sold and may not reflect current market or site conditions (Ervin & Mill, 1985; Pope & Goodwin, 1984). The SPI provides good explanatory insight into changes in the soil's productive capacity and is an alternative to traditional *ex-post* empirical land price data analysis.

Previous land value economic analysis has been dominated by empirical analysis using a range of instrumental variables. Previously, hedonic modelling approaches have focused on the impact of a single variable on land values, including government policy, soil erosion rates, and soil carbon content (Berazneva et al., 2019; Burt, 1981; Pope & Goodwin, 1984) however, they have not fully explained the impact of land management practices on future land use and market value. Using the SPI to vary land value at Walgett, Junee and Dubbo generated variations in land value consistent with the NSW Government's land valuation (VGO, 2023). Consistent with the stock market theory of Chen et al. (1986), changes in soil productivity represent unrealised returns to land assets that must be allocated to the asset. Incorporating biophysical changes in the productive capacity of land into an economic land value analysis represents a new approach using the wealth of soil data available to farmers and enabling an evaluation of alternative management processes.

Agricultural land values are affected by commodity prices, *ceteris paribus* and with the expectation of higher future agricultural commodity prices, farmers are willing to increase the price paid for agricultural land (Penson Jr, 2008). A dynamic economic model by LaFrance (1992) found that increased commodity prices increased cultivation rates and accelerated land degradation; however, the study did not consider the impact of commodity prices on land value. Interest rates are used by Stinn and Duffy (2012) to determine their contribution as part of an empirical analysis of agricultural land valuations in Iowa, USA. Typically, land value analysis has used fixed discount rates (e.g., Borchers et al. (2014)) while focusing on other factors impacting land value. This paper has sought to address a knowledge gap regarding the use of stochastic discount rates and commodity prices within agricultural land value modelling in Australia.

An empirical analysis of US agricultural land values by Gardner (2002) found that government agricultural price subsidies positively impacted US commodity prices and land values. Using agricultural commodity price fluctuations to vary agricultural market land values has had less attention. Employing previous land areas planted and cereal crop yields as a proxy for farmer land use income variation is consistent with Jouf and Lawson (2022), who use regression analysis and find a relationship between farmer revenue and agricultural land values in the United States. The results in this study suggest that there is an inverse relationship between agricultural commodity prices and the costs of borrowing in Australia. The land valuation method presented in this paper incorporates some of the key factors influencing changes in agricultural land value in Australia that have not been previously considered, contributing to the research literature.

1.8 CONCLUSION

Estimating the effect of management processes on the future productive capacity of the soil provides a method to determine land asset value. Agricultural land markets are traditionally thin, with land value influenced by site-specific characteristics. Using historical sales data in empirical analysis for properties in the region incorporates market factors and site-specific characteristics that may not accurately reflect the carrying value of the evaluated land asset. The change in the soil productivity applied to land provides a site-specific method to evaluate the effect of management practices on land value. The results demonstrate that the SPV is concordant with results in biophysical studies measuring the impact of soil nitrogen or carbon losses on soil productivity (Dai et al., 1993; Lassaletta, 2014).

The land valuation method developed in this study is a new approach to estimate the variation in the market price of agricultural land. It captures the impact of management processes on asset value, providing an alternative to empirical regression analysis. Combining the SPI with the areas under dryland grain production and the volume of grains produced in the previous season, captures the impact of climatic variation on farmer and investor investment preferences. The hedonic pricing model developed in this paper, incorporating commodity prices, cash, and inflation rate variations, captures key factors impacting agricultural land values in Australia. This paper fills an important research gap, providing an alternative to previous economic approaches that are reliant on historical data. A crucial future area of research is to determine if the SPI can be applied to field data and to apply the land valuation model to a wider range of crops and soil types across Australia and internationally.

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Appendix A

Table 5. Land valuations at Dubbo, Junee and Walgett 1996-2020 using soil productivity, cash and inflation rate, commodity price and WCPI[3]

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Commodity price & WCPI (%)	-0.53%	1.52%	1.88%	0.15%	1.14%	-0.33%	-1.28%	39.06%	-10.74%	-2.61%	-3.52%	-8.57%	-4.06%	-5.81%	-0.85%	6.57%	-1.76%	6.37%	-0.84%	-0.53%	-0.33%	4.13%	-7.64%	0.30%	0.38%
Inflation & cash rate (%)	8.32%	10.78%	11.03%	7.61%	7.61%	6.59%	7.05%	47.04%	-3.17%	5.32%	4.24%	-0.30%	5.05%	4.07%	9.34%	13.39%	5.32%	13.75%	5.06%	4.49%	5.64%	10.29%	-4.69%	3.65%	6.08%
Walgett Average soil productivity	0.2424	0.2431	0.2417	0.2405	0.2394	0.2367	0.2379	0.2362	0.2349	0.2347	0.2327	0.2325	0.2312	0.2301	0.2286	0.2277	0.2263	0.2253	0.2249	0.2242	0.2231	0.2237	0.2235	0.2221	0.2210
Dubbo Average Soil Productivity	0.2479	0.2481	0.2461	0.2453	0.2444	0.2431	0.2431	0.2419	0.2394	0.2387	0.2386	0.2380	0.2367	0.2363	0.2344	0.2346	0.2340	0.2329	0.2323	0.2321	0.2302	0.2304	0.2301	0.2276	0.2274
Junee Average Soil Productivity	0.0657	0.0657	0.0655	0.0652	0.0649	0.0644	0.0646	0.0642	0.0640	0.0640	0.0635	0.0635	0.0633	0.0629	0.0627	0.0625	0.0621	0.0620	0.0619	0.0617	0.0616	0.0616	0.0615	0.0613	0.0612

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[3] The change in land value is calculated at the end of theriod, therefore the opening land value for the period for 1996 is the land value for the site in 1995 which is adjusted for the impact of crop production land use, commodity prices and monetary policy. Full results are available from the author on request.