Australian Government

Department of Agriculture and Water Resources

Climate Change and Dynamic Adjustment of Agricultural TFP : A Cross-regional Comparison of Broadacre Farms in Australia

EMG Workshop 2016

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Introduction

- Climate change is believed to impose a profound impact on agricultural productivity.
  - Climate condition (i.e. rainfall and temperature) determines the long-term relationship between inputs and outputs;
  - Seasonal shocks deviate agricultural productivity away from its long-run trend;
- For decades, there has been a large amount of literature focusing on the impact of climate change
  - International level: Rosenzweig and Parry (1994), Mendelsohn and Dinar (1999), and Calzadilla et al. (2010)
  - National level: Olesen and Bindi (2002) for EU, Quiggin and Horowitz (2003) for Australia, Deschenes and Greenstone (2007) and ERS (2013) for US

Introduction

- These studies can be categorised into three groups in terms of methodology
  - Agronomic models
  - Agro-economic models
  - Ricardian models
- Most existing studies provide measures of climatic effects in the long run while they overlook the dynamic response of agricultural productivity to climatic shocks.
  - Even in cases where farmers' adaptation was considered, the induced effects are hypothetically assumed;
- It is widely recognised that farmers' adaptation behaviour in response to climatic shocks can significantly offset the climate impact (Darwin et al. 1995).

Introduction

- This study investigates the dynamics in the impact of climate change on agricultural productivity in Australian broadacre agriculture, by using the data from 32 regions between 1978 and 2013.
  - We distinguish the climate effects in the short run from those in the long run;
  - We quantity the adjustment of regional total factor productivity (TFP) towards the long-term equilibrium;
- Methodologically, we apply a vector error correction model to analyse the panel data (Pesaran et al., 1999; Im et al., 2003; Blackburne and Frank, 2007), accounting for regional heterogeneity, to
  - Identify the channels through which adaptation to climate change takes place;
  - Explore the disparity of adaptation process between farms using different production systems;

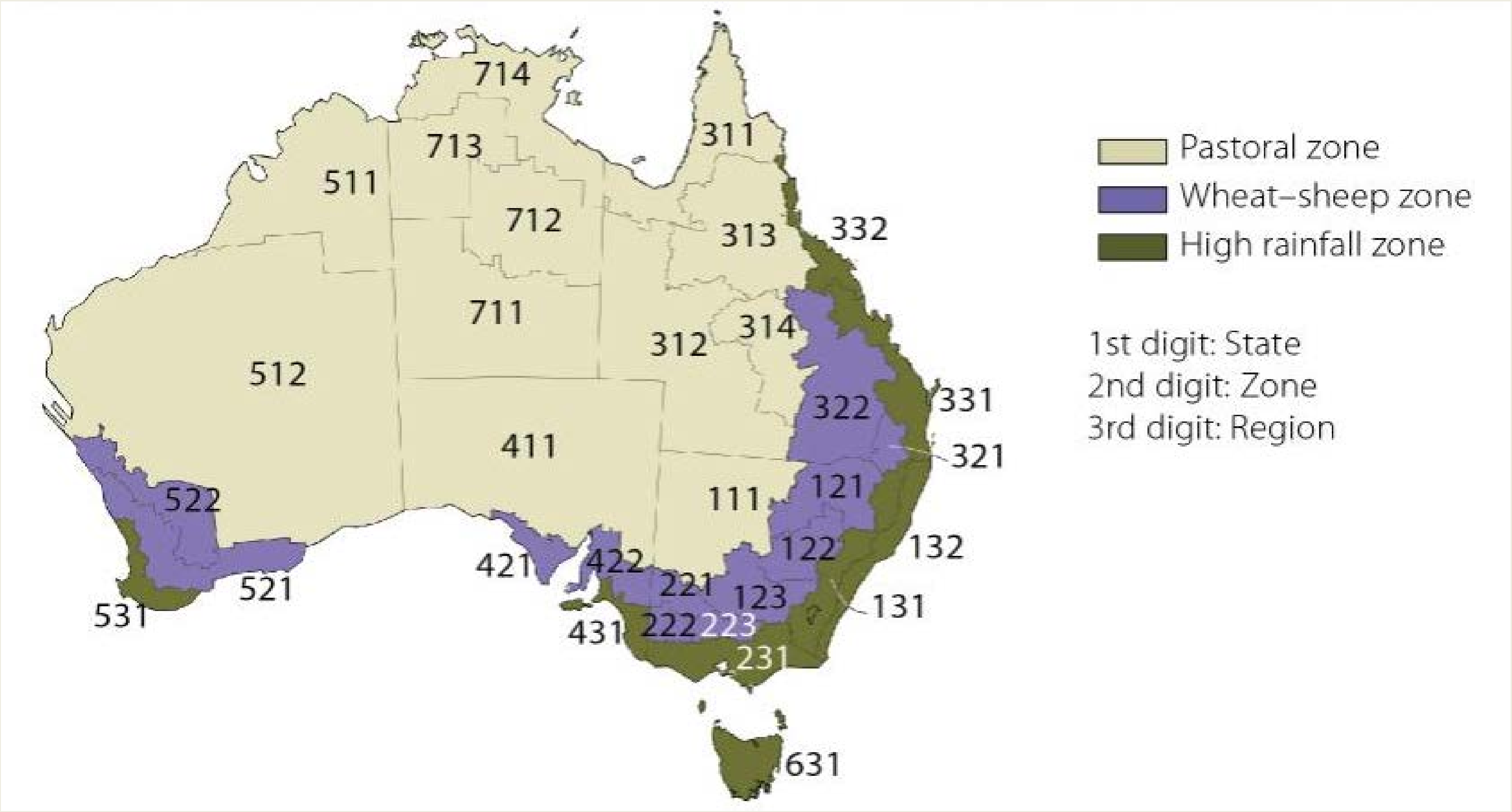
Introduction

- Our research contributes to the literature in three areas
  - To unravel the dynamic response of agricultural productivity to climatic shocks, and show the spatial pattern of these responses;
  - To investigate the channels through which region-level agricultural productivity adapts to climate change;
  - To provide a way to construct an agricultural production account at the regional level by using farm survey data;
- The findings of this study also provide an alternative explanation on cross-regional productivity disparity in a country, like Australia
  - the convergence analysis of agricultural productivity between regions: Ball et al. (1999), Acquaye et al. (2003), Ball et al. (2004) and Alston et al. (2015)

Background

- Broadacre agriculture is an important primary industry in Australia
    - The broadacre industry accounts for 1.9 per cent of GDP and 2.3 per cent of employment in 2015-16;
    - The industry covers all non-irrigated crop and livestock farms, accounting for around 70 percent of agricultural production;
    - Broadacre farms widely distribute throughout the country, and adopt different production systems in different locations;
- Given the nature of broadacre agriculture, climate conditions heavily influence the productivity of the industry;
    - For simplicity, two aspects are address: water and temperature.

Figure 1 the distribution of broadacre production in Australia



Background

- Rainfall (or soil moisture)
  - Australia is a relatively dry continent and for broadacre agriculture, rainfall is the main source of soil moisture
    - Rainfall determines the growth of crops (i.e. wheat and barley etc.);
    - Rainfall also affects pastoral grassland and livestock production
- Air temperature
  - Temperature affects the growth of plant in different development stages, together with other climate factors such as water, CO_2;
  - Temperature assists crop growth and livestock raising through a non-linear way, with extremely high temperature doing harm to farm production;

Background

- Over time, broadacre farms have demonstrated a remarkable adaptive capacity to cope with climate change.
  - A strong productivity growth of 2 % a year over the long run;
- In practice, farmers can adapt to climate change through many alternative channels, e.g.
  - Change the production technology by optimising the use of capital and labor;
  - Adjust the output mixture to diversify the risk from climate change;
- Many adaptation activities require a significant amount of time and incur additional costs.

Empirical Model

- Region-level agricultural TFP is a function of various productivity determinants
  - climate condition including water availability and air temperature
  - regional specific characteristics and other control variables

$$lnTFP_{rt} = f_{rt}(W_{rt}, T_{rt}, Z_{rt}, F_r, F_t) + \varepsilon_{rt} \quad (1)$$

- $lnTFP_{rt}$ is the logarithm of agricultural TFP at region $r = (1, \dots, R)$ and time $t = (1, \dots, T)$;
- W_{rt} and T_{rt} are a set of climate variables which capture the effects of climate change;
- Z_{rt} represent the control variables which consist of various macroeconomic and microeconomic factors;
- F_t and F_r are region and time specific effects;

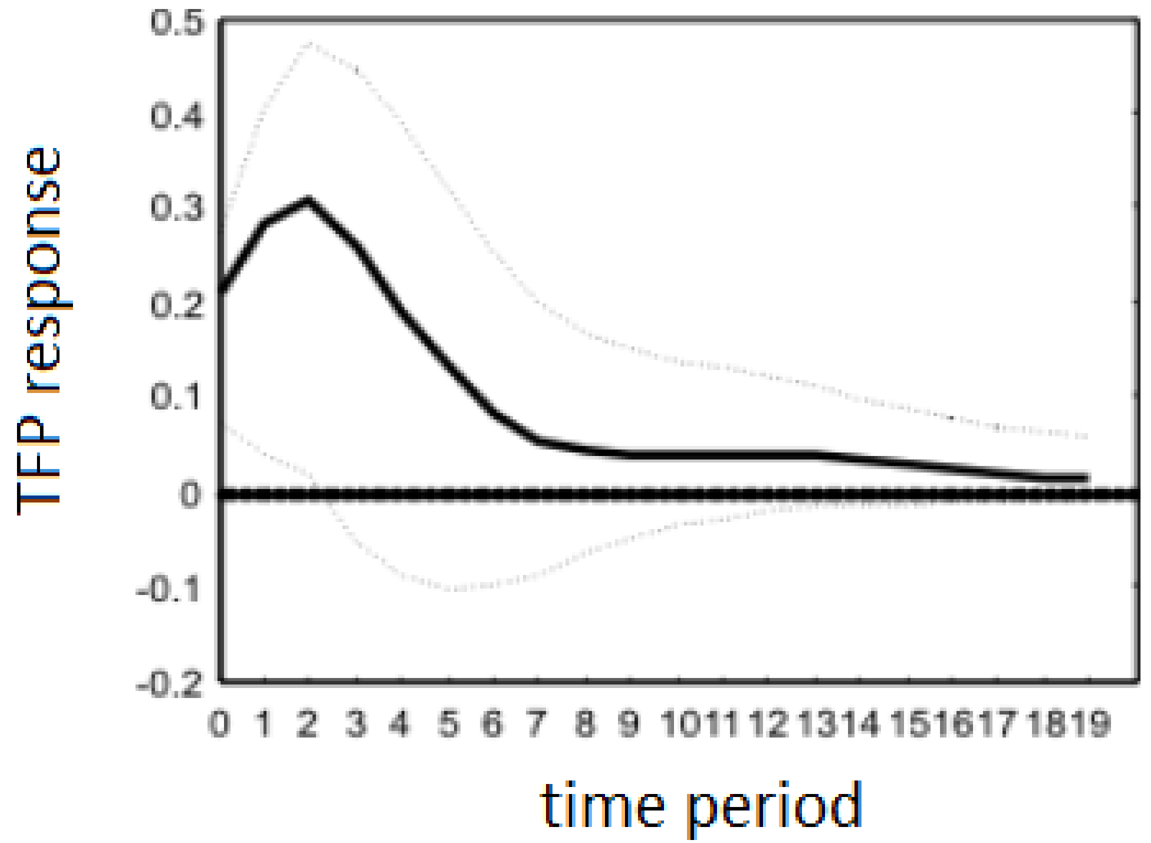
Empirical Model

- If two conditions hold
  - Regional agricultural TFP and its determinants are integrated of order one I(1);
  - The error term is integrated of order zero I(0) for all regions;

$$\Delta lnTFP_{rt} = \emptyset_i[lnTFP_{rt-1} - \theta'{}_i f_{rt-1}(W_{rt}, T_{rt}, Z_{rt}, F_r, F_t)] + \lambda_{rt}\Delta f_{rt}(W_{rt}, T_{rt}, Z_{rt}, F_r, F_t) + \varepsilon_{rt} \quad (2)$$

- $\emptyset_i$ is the error-correcting speed of adjustment term
- θ'_i and λ_{rt} are the long-term and the short-term effects of various productivity determinants

Empirical Model



Empirical Model

- The estimated coefficients are used to quantify farmers' adaptation behaviour
  - θ'_i and λ_{rt} represent long-term and short-term climate effects;
  - $\emptyset_i$ captures the speed of famers' adjustment to the long-term equilibrium;
- The model is estimated by using the maximum likelihood method.
  - Both MG and PMG approaches can be applied;
  - The choice between the estimators from the two approaches is based on a Hausman test (Pesaran et al. 1999);
- The model is modified to examine potential channels for adaptation, by incorporating additional variables into the baseline regression.

Data Source

- The data used in this paper come mainly from four sources
  - Australian Agricultural and Grazing Industry Survey (AAGIS): regional TFP measures;
  - The Queensland University and the government of Queensland: soil moisture and air temperature;
  - The Census of Population and Housing from Australian Bureau of Statistics (ABS): general economic and social conditions;
- The data for major variables are collected and compiled
  - at the farm level, or
  - at the shire/SLA levels

and aggregated to the region level.

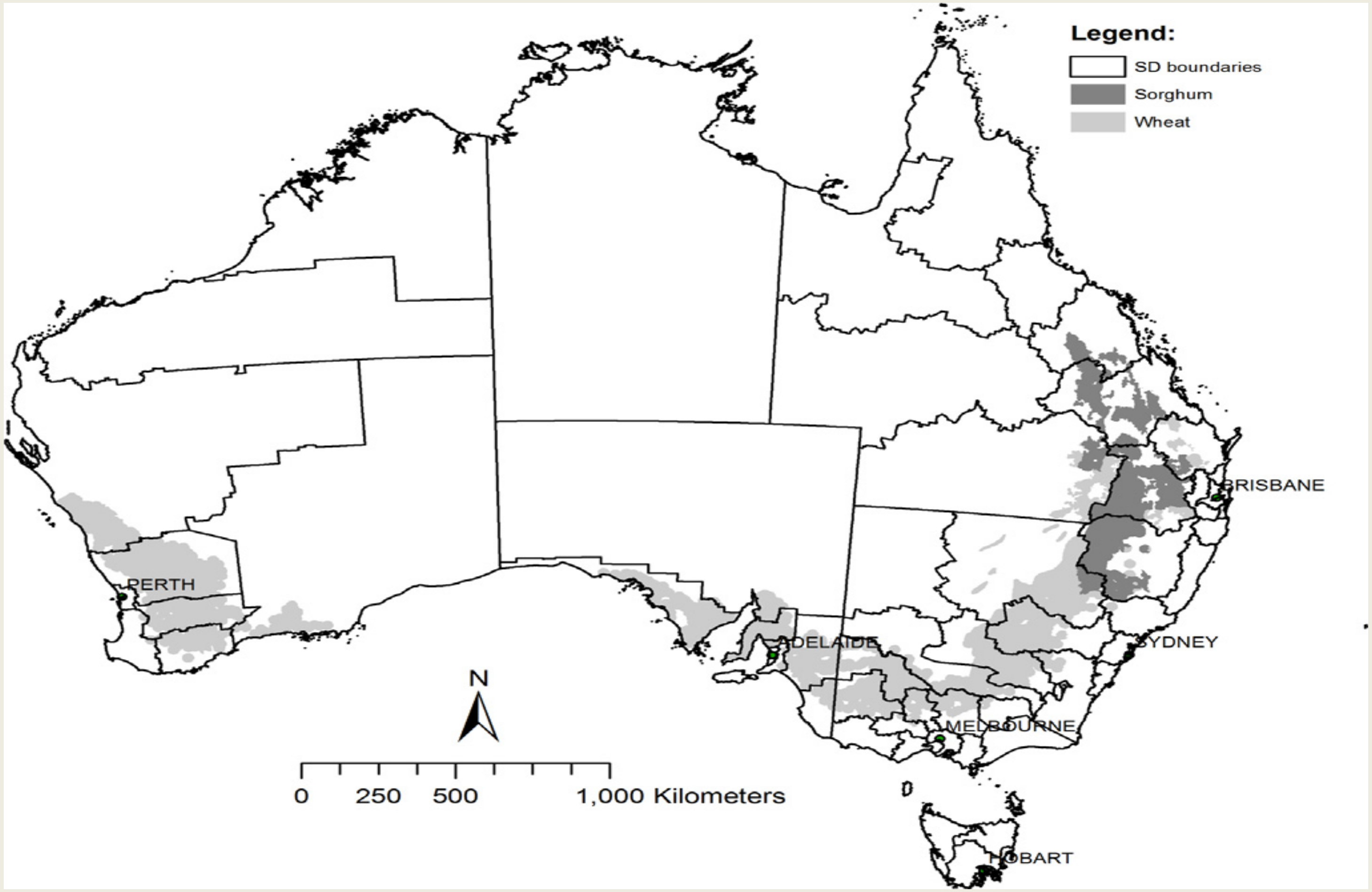
Data Source

- Region-level TFP Measure
  - TFP index is defined as the ratio of gross output over total inputs;
  - Outputs and inputs are aggregated using the Törnqvist-Theil index formulas;
  - The multilateral index formula suggested by Caves et al (1982) is employed to resolve the transitivity issue;
- The farm-level data obtained from AAGIS survey are used to construct the production account for broadacre agriculture.
  - 4 broad output categories (covering 13 types of commodities): crop, livestock, wool and "other farm income";
  - 5 input categories (encompassing a total of 26 types of inputs): land, labour, capital, materials and services;

Data Source

- Water availability measure
  - The index is measured by using three agro-climatic indicators called “wheat water-stress index”, “sorghum water index” and “pasture growth index”.
  - Wheat and sorghum water-stress indexes are derived from a water-balance model (Potgieter et al. 2005, 2006).
  - The pasture growth index is also calculated based on a water balance model (Carter et al 2000, Rickert et al 2000).
- We aggregate the indexes up to the regional level using land areas for cropping and grazing as weights.
  - The three indexes, in their original form, are annual time series defined at sub-regional (shire) level.
- Total rainfall has also been used as a robustness check

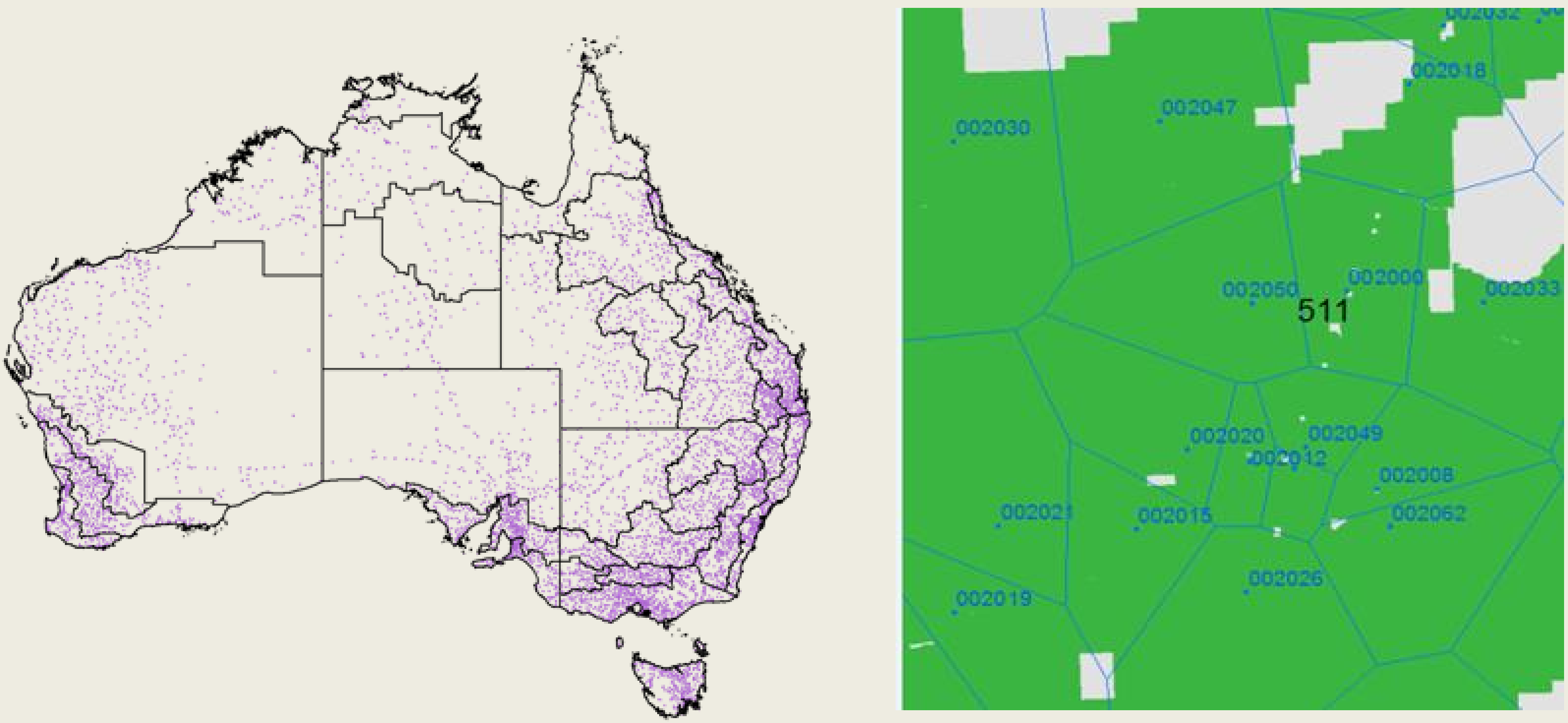
Figure 2 crop water-stress index



Data Source

- Two indicators are used to measure temperature / radiation:
  - degree-days accumulated over the growing seasons;
  - average daily temperature;
- A base of 8^{o}C and a ceiling of 32^{o} C are used as the temperature threshold (Schlenker et al., 2006 and Deschenes and Greenstone, 2007)
  - 1st April to 31st October for the winter season;
  - 1st November to 31st March for the summer season;
- The daily average temperature and rainfall are
  - obtained at the 8, 023 weather stations of the Australian Bureau of Mereology (BoM);
  - Matched with each farm in our survey;

Figure 3 weather information match



Empirical Results

- A descriptive statistics shows the relationship between region-level agricultural TFP and climate conditions.
  - There are monotonic relationship between water-stress index and regional TFP;
  - The relationship between degree-day measures and regional TFP is non-linear;
- Panel-data co-integration test has been conducted
  - I(1) stationary tests have been conducted for all variables used in the model
  - A co-integration relationship has been identified between region-level TFP and climate variables

Figure 4 the relationship between water-stress index and regional TFP

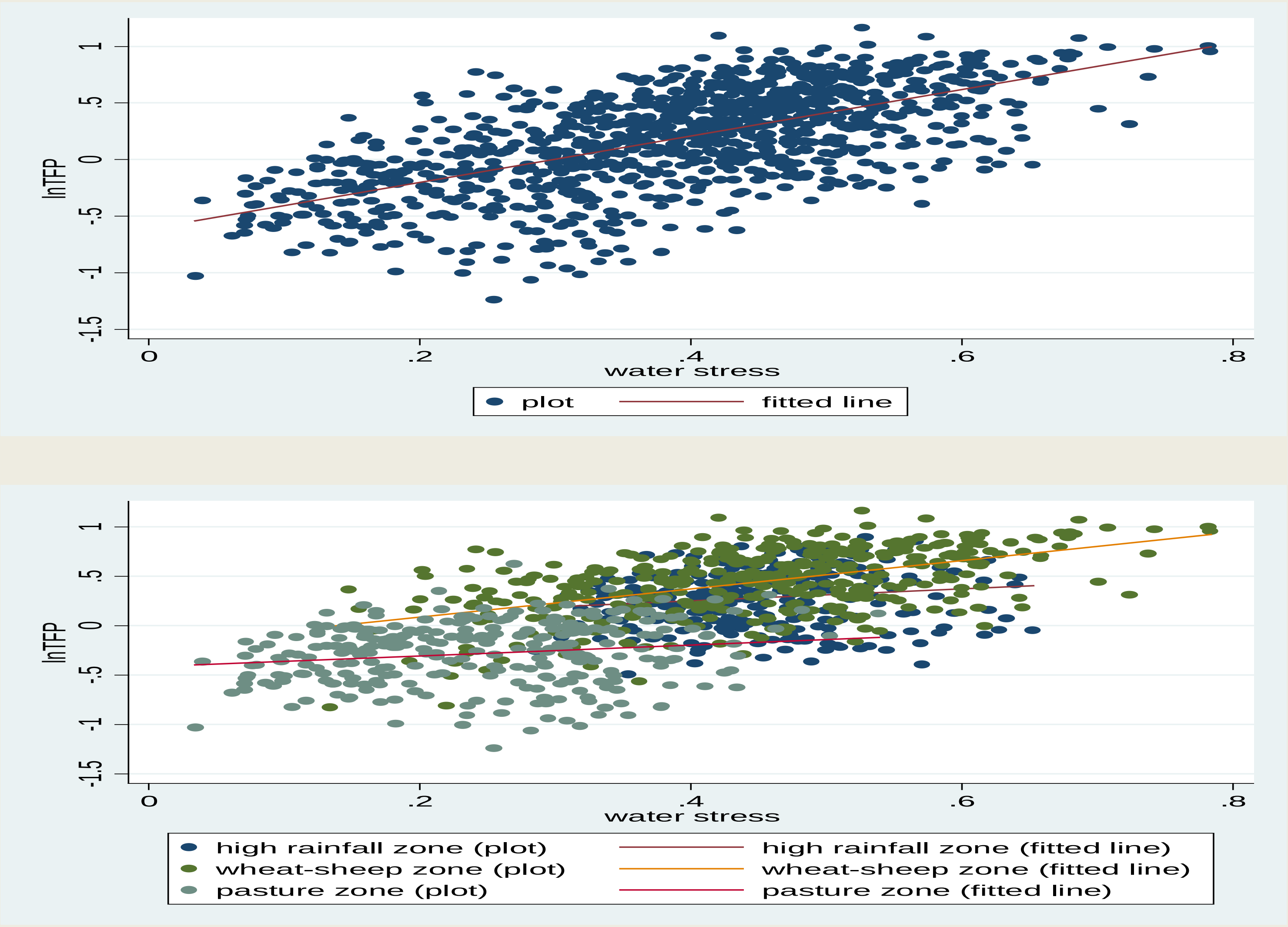
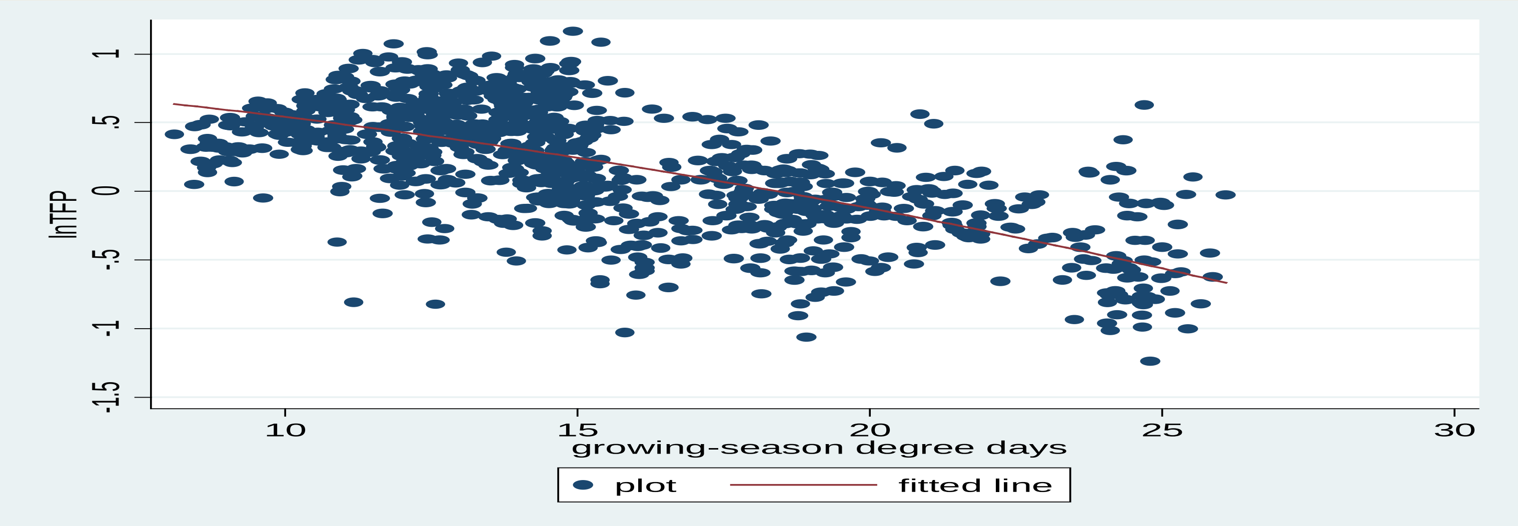


Figure 4 the relationship between degree-day measure and regional TFP



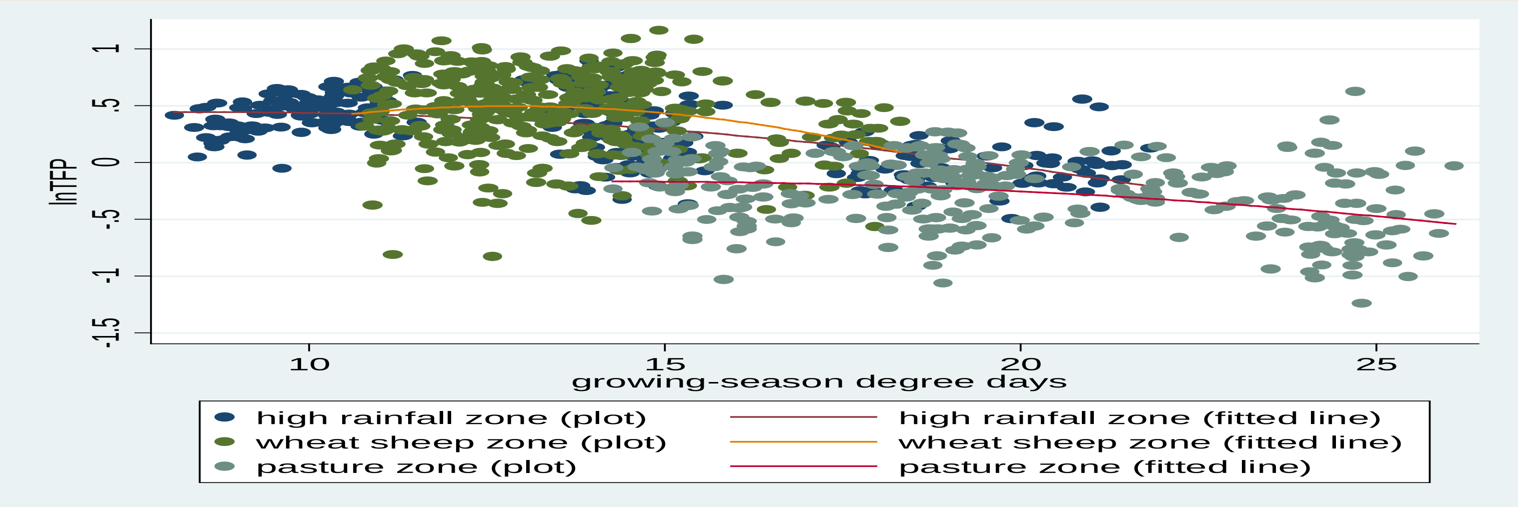


Table 1 Co-integration test results

		Gt Test		Pt Test	
		Statistics	P-value	Statistics	P-value
All Regions	include climate variables (Model I)	-2.38	0.00	-11.74	0.00
	Include all variables (Model II)	-3.23	0.00	-14.23	0.01
High-rainfall Zone	include climate variables (Model I)	-2.88	0.00	-7.66	0.00
	Include all variables (Model II)	-3.39	0.00	-9.33	0.00
Wheat-sheep Zone	include climate variables (Model I)	-2.76	0.00	-7.73	0.00
	Include all variables (Model II)	-3.20	0.01	-9.73	0.02
Pasture Zone	include climate variables (Model I)	-2.97	0.00	-7.81	0.00
	Include all variables (Model II)	-3.18	0.02	-9.51	0.00

Empirical Results

- There is a significant long-term relationship between climate condition and region-level agricultural productivity.
    - Water availability positively contributes to regional TFP growth in the long run;
    - Degree-days will positively contribute to regional TFP initially but its marginal contribution tends to decline when the degree-day measure reach a threshold;
- In the short run, water availability also generate the short-term volatility in agricultural productivity
- Region-level agricultural TFP will gradually returns to the long-term equilibrium value
    - the estimated error correction coefficient is negative and significant at 1 per cent level.

Table 2 climate change and its impact on region-level agricultural productivity

	Baseline Model (Model I)		Full Model (Model II)	
	EC	SR	EC	SR
Dependent variable: regional-level agricultural TFP (log)				
Water-stress index (log)	2.279***	0.244**	1.853***	0.204**
	(0.268)	(0.108)	(0.176)	(0.105)
Growing season degree-days	1.886**	7.74	1.644**	8.255
	(0.817)	(6.422)	(0.827)	(5.078)
Growing season degree-days (log) square	-0.153**	-0.542	-0.127*	-0.579
	(0.064)	(0.444)	(0.065)	(0.354)
SEFA index (log)	-	-	1.148***	1.560***
	-	-	(0.280)	(0.265)
Proportion of operators with primary school or less education level	-	-	0.965***	-0.078
	-	-	(0.122)	(0.186)
Average Farm Size - land areas (log)	-	-	0.222***	0.058
	-	-	(0.047)	(0.045)
Error Correction Coefficient	-	**-0.340*****	-	**-0.395*****
	-	(0.032)	-	(0.031)
Constant	-	-2.180***	-	-1.043***
	-	(0.213)	-	(0.048)

Empirical Results

- Farmers adapt to climate change through particular channels
    - The capital-labor ratio is more likely to play a role in the long run;
    - The output mixture is more likely to play a role in the short run;
- Impacts of the afore-mentioned two channels differ between farms using different production systems
    - Adjustment speed in the high rainfall zone is much quicker than in wheat-sheep zone and pasture zone;
    - Impact of water stress on agricultural production in the long run still exists, even if full adaptation behaviours have been taken into account;
    - Agricultural TFP is more vulnerable to climatic shocks in the pasture zone than in the high-rainfall zone and in the wheat-sheep zone;

Table 3 dynamic impact of climate change on agricultural TFP by Zone

	All Zones		High-rainfall Zone		Wheat-sheep Zone		Pasture Zone	
	EC	SR	EC	SR	EC	SR	EC	SR
Dependent variable: regional-level agricultural TFP (log)								
Water-stress index (log)	1.678***	-0.111	1.534**	-0.48	1.425***	-0.144	2.836***	-0.543
	(0.327)	(0.144)	(0.605)	(0.299)	(0.237)	(0.107)	(0.429)	(0.406)
Growing season degree-days	1.598	1.875	1.527	1.179	3.667	-0.514	2.558**	-0.98
	(1.717)	(8.286)	(4.141)	(21.36)	(6.404)	(14.438)	(1.182)	(1.230)
Growing season degree-days (log) square	-0.121	-0.101	-0.138	-0.024	-0.275	0.061	-0.215**	0.089
	(0.121)	(0.569)	(0.297)	(1.439)	(0.454)	(1.003)	(0.096)	(0.094)
SEFA index (log)	1.165**	0.947**	1.505	2.544***	2.028**	-0.112	-0.47	1.031*
	(0.518)	(0.401)	(1.048)	(0.809)	(0.824)	(0.488)	(0.493)	(0.480)
Proportion of operators with primary school or less education level	-1.706***	-0.306**	-0.650***	-0.08	-2.862***	0.464	-0.515***	-0.196
	(0.516)	(0.147)	(0.227)	(0.143)	(0.808)	(0.306)	(0.143)	(0.265)
Average Farm Size - land areas (log)	0.135*	0.02	0.014	0.012	0.350***	-0.079	0.165*	0.000
	(0.081)	(0.043)	(0.108)	(0.065)	(0.101)	(0.055)	(0.095)	(0.059)
Capital-labour ratio (log)	**-0.294*** **	-0.001	-0.162	0.043	-0.365***	-0.083	-0.192**	0.025
	(0.107)	(0.042)	(0.170)	(0.071)	(0.096)	(0.059)	(0.096)	(0.070)
Crop-livestock mixture	0.055	**0.043** **	0.07	-0.026	0.095	0.101***	-0.01	0.031
	(0.035)	**(0.020)**	(0.052)	(0.029)	(0.069)	(0.037)	(0.013)	(0.021)
Error Correction Coefficient	-	**-0.728*** **	-	**-0.834*** **	-	**-0.712*** **	-	**-0.420*** **
	-	(0.048)	-	(0.054)	-	(0.094)	-	(0.059)
Constant	-	-3.676***	-	6.583	-	-110.428	-	-2.965***
	-	(4.306)	-	(12.863)	-	(71.385)	-	(0.407)

Figure 1 the distribution of broadacre production in Australia

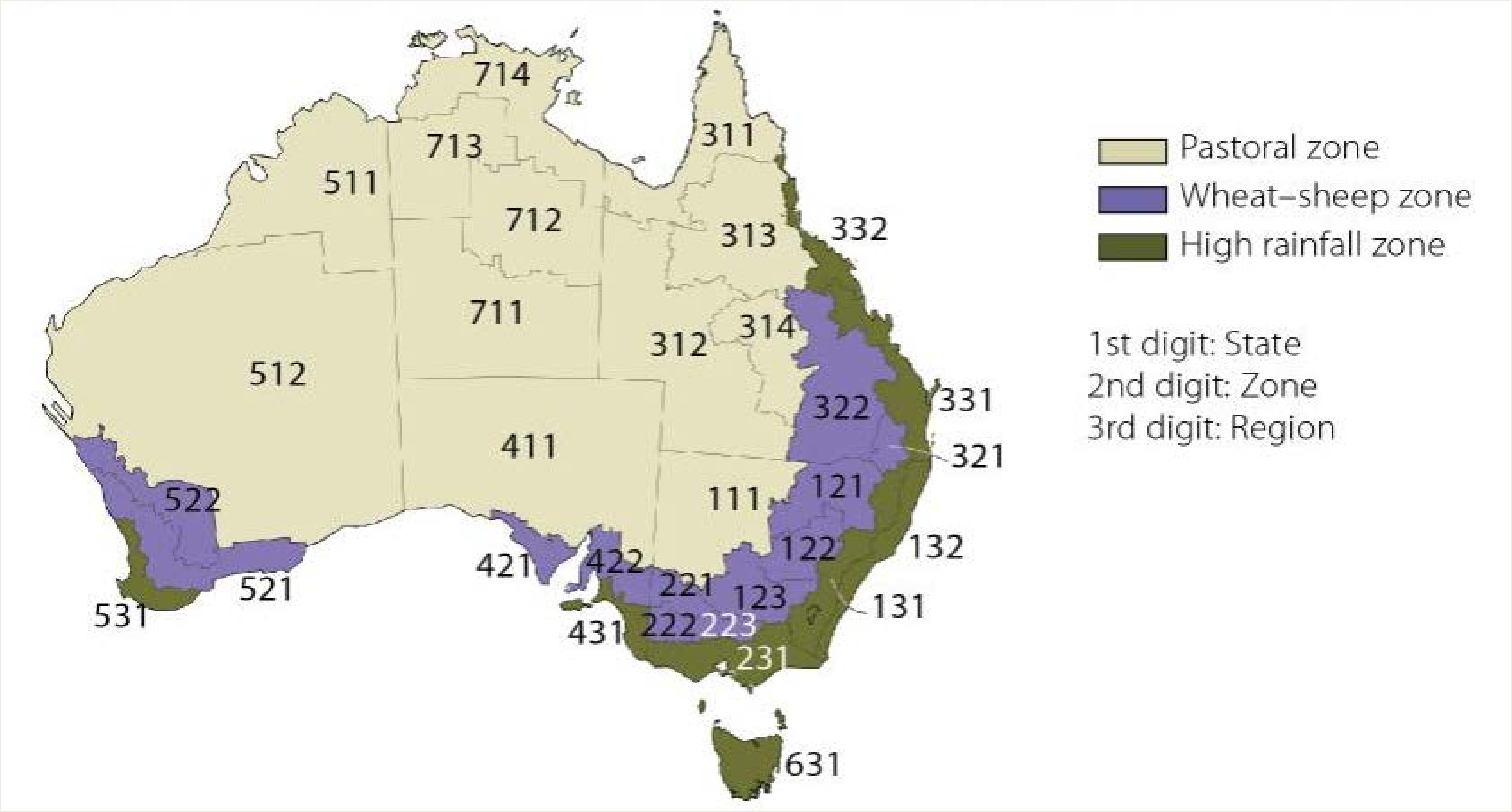
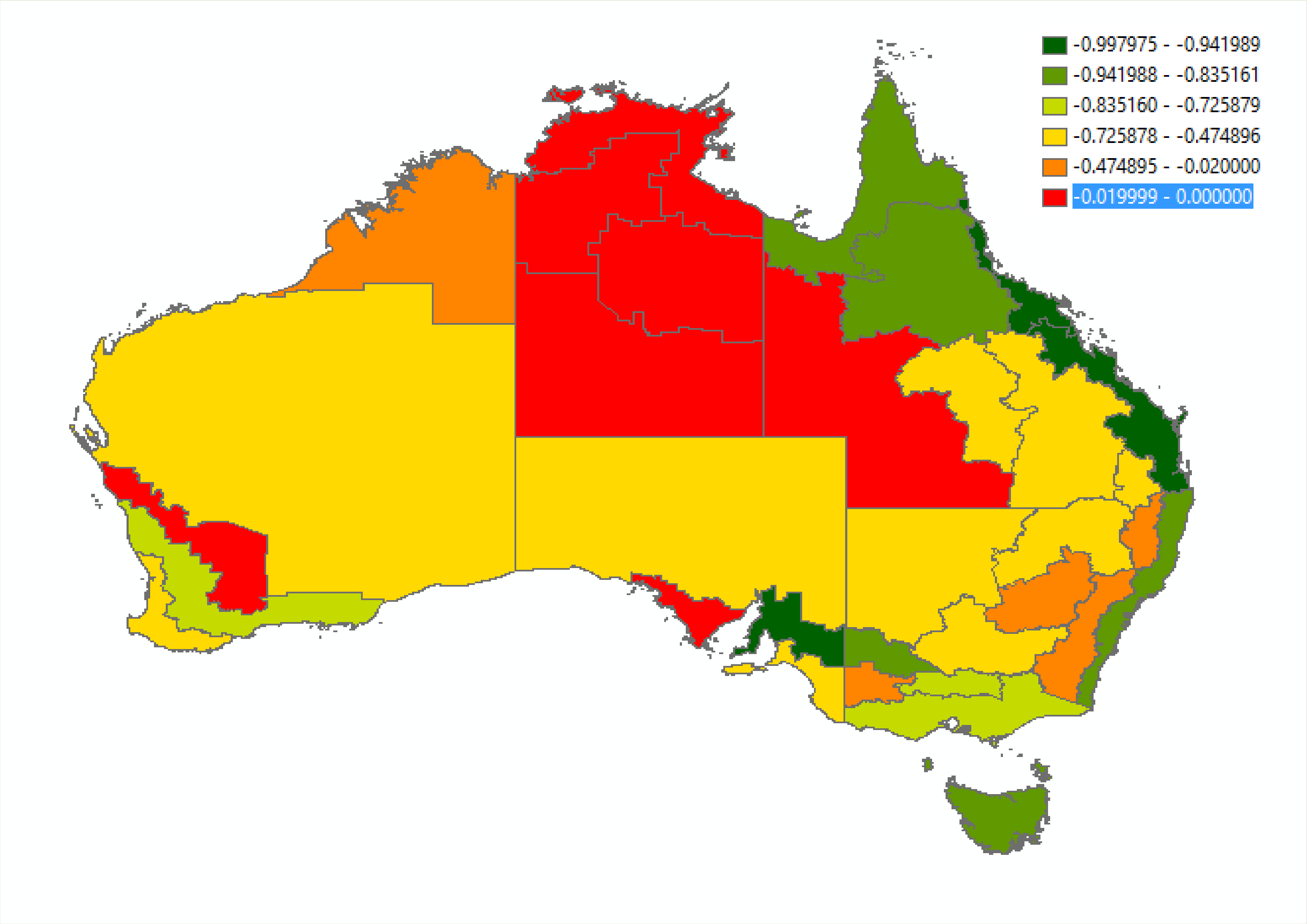


Figure 5 speed of adjustment across regions: 1978-2013



Robustness checks

- Region-level TFP is re-measured by using an alternative index formulas
  - The Fisher index adjusted by the EKS formula is used instead;
- Climate variables are re-defined by directly using
  - the total rainfall over the growing season
  - the daily average temperature over the growing season
- Stability of the PECM model has been double-checked.

Conclusions

- We investigate the dynamic impact of climate change on agricultural TFP in Australia through
  - Using a vector error correction model to the panel data;
  - Allowing for regional heterogeneity and other control variables;
- Climate change generates a complex impact on agricultural productivity across regions
  - In the long run, water availability and temperature
  - In the short run, water availability matters more
- Farmers are able to adopt to climate change through
  - Optimising the capital-labor ratio;
  - Adjusting the output mix

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Questions and Comments