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Allocating Environmental Water and Impact on Basin Unemployment: Role of A Diversified Economy

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ABSTRACT

Water diversion for environmental purposes threatens many agricultural communities. This paper focuses on the water-agriculture-environment nexus in the Murrumbidgee River Basin, Australia, and attempts to explain how reduced water allocation to agriculture aimed at protecting the environment in turn impacted the wider economy and the community. Predictably reduced water allocation saw declines in agriculture production and employment. Despite this, paradoxically, the basin unemployment rate declined and basin median household income increased. To understand and interpret this, we first analyze available labour, economic and hydrology data, and then develop a simple dynamic model to interpret the observed pattern of basin employment and unemployment. Data analysis revealed the likely causes behind the paradox as (a) out-migration of people from the basin, and (b) absorption of the labour force in the fast growing non-agricultural sectors of the diversified basin economy. The model simulations reinforced this interpretation. Further model simulations under alternative realities of out-migration and sectoral transformation indicated that basins embedded in faster growing national economies, and are more diversified to begin with, are likely to be more conducive to agriculture sector reform (e.g., reduced water allocation) and environmental regeneration. This is a sobering message for other regions experiencing environmental degradation due to extensive agricultural development.

1. Introduction

Rising human population has heavily affected the hydrological cycle in several places, adversely affecting the quantity and quality of fresh water resources. Climate change has exacerbated this trend by either reducing fresh water resources or making it highly variable (Jiménez Cisneros et al., 2014). These changes have contributed to a growing sense of water insecurity (Gleick and Palaniappan, 2010) and sustainable development (UN, 2016). Water also plays a key role in economic development, particularly in agriculture-dominated economies. Agriculture is a major sector of regional and even national economies, providing around 60% of the total jobs in developing countries (UN, 2016). Yet management of the two key inputs to agriculture, i.e., water and land, has become difficult over time due to increasing competition between multiple human uses, as well as with the environment. Increasing water use in agriculture has inevitably reduced the share available for natural ecosystems. This has led to eco-system degradation, and community concern about long-term sustainable development. The potential for conflict is self-evident as different users of water attempt to maximize their benefits at the expense of others.

This study focuses on the Murrumbidgee river basin in south-eastern Australia where the competition for water between agriculture and the environment has come to the fore in recent times, leading to radical transformation of agriculture development, water management and the basin economy. The expansion of irrigated area in the first 60–70 years of agricultural development within the Murrumbidgee ultimately led to concerns about the resulting environmental degradation, which in turn led to concerted action that culminated in a contraction of the area under irrigation in the last 10–20 years.

Kandasamy et al. (2014) has analyzed in detail the causes of this "pendulum swing" in both the irrigated area and in the size of the agriculture sector within the basin. Based on extensive data analysis and synthesis, Kandasamy et al. (2014) hypothesized that the pendulum swing arose from a change of emphasis in water management, from an exclusive focus on agricultural development and food production during the growth phase, to an increased focus on environmental health following the gradual realization of the adverse environmental impacts

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resulting from agricultural development. This change of emphasis, arising from a change of human values in the wider community regarding the choice between economic livelihood and environmental health, led to concerted efforts and externally imposed solutions to restore environmental health and ecosystem services. Van Emmerik et al. (2014) followed up on this study and developed a numerical model to understand the causes of the coupled human-water system dynamics behind the pendulum swing.

This pendulum swing phenomenon has since been reported elsewhere, e.g., Lake Toolbin in Western Australia (Elshafei et al., 2014, 2015), Tarim basin in western China (Liu et al., 2014) and Kissimmee River basin in Florida in the USA (Chen et al., 2016). Kandasamy et al. (2014) explained that the diversification of economy and reduced economic dependency on agriculture sector facilitated the changes in water management. However, none of these studies explored the impact on the wider economy, and the key role of the economy in facilitating the changes desired by the community to restore environmental health, i.e., the role of the wider economy in facilitating the pendulum swing. This is the main subject of this paper.

Labour dynamics and unemployment in open economies have been extensively studied to understand the impacts of policies on minimum wage, equilibrium wage, unions, employment, labour mobility etc. (Brecher, 1992; Holmlund and Kolm, 2000; Mabro, 1971; Stepanok, 2013; Ljungqvist and Sargent, 1996). Different from these earlier general economic studies, this paper looks at these issues in the context of basin scale coupled human-water system dynamics. In particular, it focuses on an apparent paradox between declining employment in the agriculture sector as a result of the reduced water reallocation and a coincident decline in the rate of overall unemployment rate within the basin. Even as the Murrumbidgee basin witnessed a reduction in water allocation to agriculture in 1995, the basin unemployment rate continued to decline for more than a decade. Median household income continued to increase as well. What are the causes of this apparent paradox? Could it be that more and more farmers were willing to sell their water rights when they saw expanding alternate employment opportunities in other sectors of the economy, both inside and outside the basin, which might have paved the way for government intervention to reallocate water from agriculture to the environment?

Environmental Kuznets Curve (EKC) is another way that has been used to explain phenomena similar to the pendulum swing (Bhattarai and Hammig, 2001; Dinda, 2004; Munasinghe, 1999; Selden and Song, 1995; Stern, 2004). These studies used endogenous growth theory to understand the coevolution of economic growth and environmental quality (Chen and Li, 2011; John and Pecchenino, 1994). EKC hypothesizes that in an early stage of economic growth, ecosystem degrades and the trend reverses when high economic growth is achieved (Dinda, 2004; Stern, 2004). Many of the studies with regional water and air quality indicators show a pattern of EKC (Barbier, 2004; Choi et al., 2015; Zhou et al., 2015, 2013). Panayotou (1993) argued that “at higher levels of development, structural change towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology, and higher environmental expenditures, result in leveling off and gradual decline of environmental degradation” (Panayotou, 1993). When a country's economy thrives and is less dependent on environment degrading economic activities, society prioritises a better quality of life and demands better ecosystem services.

The aim of this paper is to understand the unemployment paradox in context of a basin scale coupled human water system through data analysis and modelling. This study will analyze census and hydrological data to explore the hypothesis that the presence of a diversified basin economy and a strong growth in non-agriculture sectors of the economy, both inside and outside the basin, helped the community to navigate the water management crisis, possibly leading to the falling rate of unemployment, in spite of the shrinking agriculture sector. The next section briefly describes the study area, i.e., the Murrumbidgee river basin, and recent water policy development within the basin. It is then followed by extensive data analyses, used to understand and highlight the impact of agricultural water allocation on basin economy. This is followed by a dynamical system model, which is used to reinforce the outcomes of the data analysis and to undertake scenario analyses to further understand and interpret the observed dynamics. We conclude with key messages arising from the study so far, including opportunities for future extensions of this line of research.

2. Data and Methods

2.1. Study Area and History

The Murrumbidgee is located in the south-east of the Murray Darling Basin (MDB) in eastern Australia with a population of over 540,000. Although only representing approximately 8% of the Murray Darling Basin's (MDB) land mass (Fig. 1), the Murrumbidgee basin accounts for 22% of surface water diverted for irrigation and urban use within the MDB (Kandasamy et al., 2014). Agricultural production within the Murrumbidgee basin is valued at over $A1.9 billion annually (ABS, 2012). A history of agricultural development of Murrumbidgee basin over the past century is given in Kandasamy et al. (2014).

The increasing volumes of water diverted to irrigated agriculture contributed to a severe deterioration of the basin's wetlands and river ecology (Fig. 4(f) in Kandasamy et al., 2014). In 1985, the state governments of New South Wales, Victoria, South Australia and the Commonwealth (i.e., Federal) gathered to address the environmental issues within the MDB, which led to a new Murray-Darling Basin Act (1993) (Turral et al., 2009). The incremental and piecemeal solutions implemented by the Murray Darling Basin Commission (MDBC) were unable to arrest the continued degradation of the environment and thus led to a rise in societal concern for the environment. In 1995 the MDBC introduced a temporary cap on further expansion of water extraction for agriculture, which was then made permanent in 1997. Other reforms included separation of water and land titles; adoption of water trading; and institutional and organisational reforms to facilitate these changes. The government also funded a “buy-back” of water licenses from farmers (through the Living Murray initiatives, etc.) and later in 2007 extended it through a $10 billion national water reform package. Funding for system and on-farm investments in water conservation accompanied the reductions in water allocation to the agricultural sector.

2.2. Data Analysis

We obtained a range of relevant census and economic data in order to understand how the change in water allocation affected the basin economy. Firstly, we obtained data on unemployment and median household income (MHI) within the basin to document the unexpected decline in the rate of unemployment and a rise in median household income within the basin after water reallocation. This data was obtained from the Australian Bureau of Statistics (ABS, 2014a). To explore their likely causes, we examined data on the employment both on the labour demand side and on the supply side. On the labour demand side, we obtained data on agricultural and non-agricultural sector employment, household expenditure in Australia (ABS, 2016a), output of various economic sectors and capital investment (ABS, 2014b, AEC Group, 2015, 2013, 2011). The analysis includes the total factor of productivity index data (TFP) (ABS, 2015a) to understand the impact of changing technology. On the labour supply side, data relevant for growth of basin labour supply, including population data, was obtained from Census data of Australian Bureau of Statistics (ABS, 2014a).

2.3. Modelling

In this paper we develop a simple dynamical system model of employment in a diversified economy to reinforce the understanding

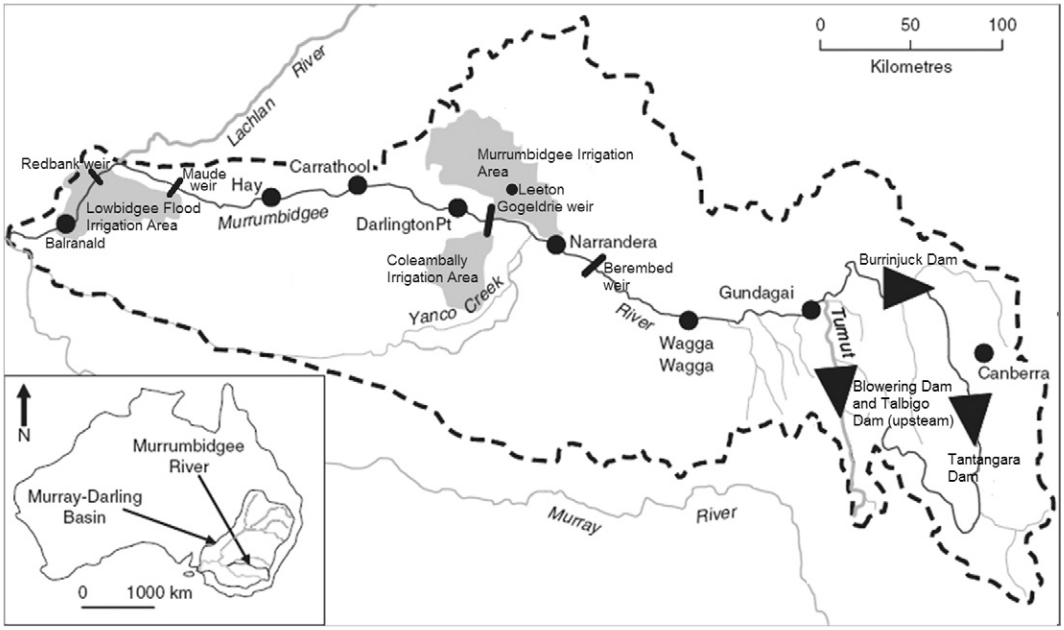

Fig. 1. Murrumbidgee Catchment within the Murray Darling Basin (adapted from: Kandasamy et al., 2014). The Murrumbidgee Irrigation Area incorporates the Yanco Irrigation Area, Mirrool Irrigation Area, Wah Wah Irrigation District, Beneremba Irrigation District, and Tabbita Irrigation District.

obtained from the data analysis and to further explore our working hypothesis. The model simulates the dynamics of interactions between labour demand and labour supply within the basin and computes the unemployment rate within the basin as the balance between the two. An additional feature of the model is that it can simulate migration into and out of the basin as this can influence labour supply. Dynamic system models can serve as powerful tools to investigate the interactions between state variables and to explain observed dynamics as the outcomes of two-way feedback between sub-systems, including possible features such as regime shifts, tipping points and time lags (Blair and Buytaert, 2016). In this paper we use a simple dynamical system model which has the ability to simulate complex multi-disciplinary systems and to explain the above mentioned emergent dynamics (Sivapalan and Blöschl, 2015).

2.3.1. Model Framework

The model, conceptualized in Fig. 2, consists of the following sub-models: (a) labour in the Murrumbidgee; (b) basin unemployment and (c) human population and migration to/from the Murrumbidgee. A simple two sector labour market model was used in this study

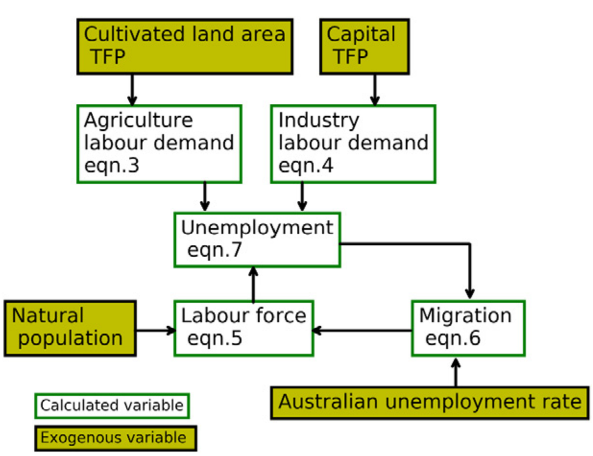

Fig. 2. Conceptual framework populated with variables, used to study emergent dynamics within the Murrumbidgee basin.

(Harris and Todaro, 1970). The governing equations (Eq. (3)–(7)) underpinning the various sub-models are described in the next section.

Each of the three sub-models is coupled through various feedback loops. The feedback loops mimic the co-evolution of the key state variables over time. For simplicity, as a first step, the model treats irrigated land area that partly drives the employment in the agriculture sector as an exogenous variable. The employment in the industry sector (composed of manufacturing and service sector) depends on industrial production that in turn depends on capital input. Higher labour demand in the agriculture and industry sectors reduces the basin unemployment rate, which when it is less than Australia's overall unemployment rate attracts new labour from outside. When a reduction in water allocation to agriculture affects cultivation, the demand for labour in the sector may decrease and the unemployed people may seek employment in the growing industry sector. If industrial growth is inadequate to accommodate the labour force from the agriculture sector, basin unemployment rises and labour may also migrate out as a result of negative attractiveness (i.e., they are attracted to employment outside the basin).

2.3.2. Model Equations

We use the Cobb-Douglas production function to estimate the labour demands in agriculture and industry sectors. Production theory suggests that industry output (both manufacturing and services) can increase due to technological advancement, labour and capital growth (Bah, 2009; Cobb and Douglas, 1928; Ngai and Pissarides, 2007). We simplify the Murrumbidgee basin economy to comprise just two sectors, i.e., agriculture and industry (i.e., manufacturing and services). The Cobb-Douglas production function is used to interpret how growth in inputs (such as irrigated area, labour and capital), technology and migration are linked to the relative growths in the two sectors and employment. The Cobb-Douglas production functions for industry output (Y_i) and agriculture output (Y_a) are given by:

$$\begin{aligned} Y_a &= A_a\, I_a{}^{\alpha} L_a{}^{1-\alpha} \\ Y_i &= A_i\, K_i^{\theta} L_i{}^{1-\theta} \end{aligned} \qquad (1)$$

where A_i, and A_a are total factors of productivity (TFP) in the industry and agriculture sectors, respectively, and incorporate the role of technology in the growth of production in each sector, K_i is capital input, L_i is labour input towards production in the industry sector and θ is the productivity share of capital in industrial output. Similarly, I_a is the irrigated land area input and L_a is the labour input to production in the agriculture sector and α is the productivity share of land in agricultural output.

We assume that labour wages are equal to the marginal productivity of labour ($\frac{\partial Y_i}{\partial L_i}, \frac{\partial Y_a}{\partial L_a}$) in the corresponding two sectors (Borjas, 2010). Then, the wages in the two sectors are given by:

$$w_a = A_a(1-\alpha)\left(\frac{I_a}{L_a}\right)^{\alpha} \tag{2a}$$

$$w_i = A_i(1-\theta)\left(\frac{K_i}{L_i}\right)^{\theta} \tag{2b}$$

One key observation that emerges from the above equations is that if capital or irrigated land input increases but the TFP and wage rates remain constant, then the producers would increase labour input. Thus, increasing capital pushes the labour demand curve right, as shown in a simplified depiction in Fig. 3. This illustrates how capital investment in the industry sector may put a downward pressure on basin unemployment rate. However, unlike this simplified illustration, in reality wages, technology and inputs may change over time, often in response to policy interventions. For example, water policy intervention in the Murrumbidgee caused a change in the land area under irrigation.

We use Eq. (2a), (2b) to account for how changes in wages, technology and inputs could affect the employment in the two sectors of the Murrumbidgee economy and how it is linked to basin out-migration and total unemployment rate. In this manner, the resulting model serves as a tool to interpret and understand how the impacts of water allocation may cascade across the basin economy and community.

Differentiating Eq. (2a) with respect to time, we obtain,

$$\dot{w}_a = \dot{A}_a(1-\alpha)\left(\frac{I_a}{L_a}\right)^{\alpha} + A_a\alpha(1-\alpha)\left(\frac{I_a}{L_a}\right)^{\alpha}\frac{\dot{I}_a}{I_a} - A_a\alpha(1-\alpha)\left(\frac{I_a}{L_a}\right)^{\alpha}\frac{\dot{L}_a}{L_a}$$

(Note: A dot over a variable indicates the time derivative of that variable, i.e., $\dot{f} = \frac{df}{dt}$). Dividing both sides of the above equation by w_a

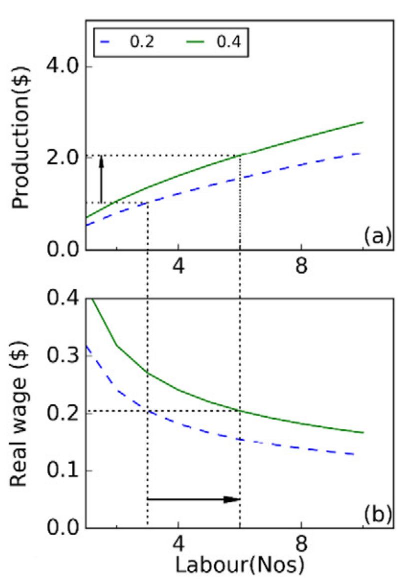

Fig. 3. (a) Illustration of changing labour demand with increased capital; (b) explains the increasing production with increasing capital and labours for given real wage. Solid line and dash line represent the capital of \$0.2 and \$0.4 (arbitrary value) respectively. θ, A_i is set to 0.4, 1.0 respectively. Increasing capital can stimulate labour demand in the industry sector.

and noting from Eq. (2a) that $w_a = A_a(1-\alpha)(\frac{I_a}{L_a})^{\alpha}$, we obtain

$$\frac{\dot{w}_a}{w_a} = \frac{\dot{A}_a}{A_a} + \alpha\frac{\dot{I}_a}{I_a} - \alpha\frac{\dot{L}_a}{L_a}$$

Rearranging the above terms, we note that labour demand in the agriculture sector (L_a) depends on the land area under irrigation, technology and wages and can be given by:

$$\frac{\dot{L}_a}{L_a} = \frac{\dot{I}_a}{I_a} + \frac{\gamma_a}{\alpha} - \frac{\gamma_w}{\alpha} \tag{3}$$

where $\frac{\dot{I}_a}{I_a}$ is the rate of change in irrigated area, γ_a is the growth rate of TFP and γ_w is the growth rate of labour wage. Similarly, labour demand in the industry sector (L_i) depends on growth of capital, technology and wages and is given by:

$$\frac{\dot{L}_i}{L_i} = \gamma_c + \frac{\gamma_i}{\theta} - \frac{\gamma_w}{\theta} \tag{4}$$

where γ_c is growth rate of capital in industry. In this model, for simplicity, capital growth rate is assumed to be constant. The wage growth rates of the two sectors are also assumed to be equal to the growth of unit labour costs for the entire economy (agriculture and industry) and the non-farm (industry) sector respectively. Since the unit costs of the two sectors have been observed to be the same (ABS, 2016a), this meant that that the wage growth rates for the two sectors can be assumed to be the same. For this reason, some care must be exercised when deploying this model to other study areas, where wages in the two sectors may grow at different rates.

Labour supply (L_s) depends on the on population (P) growth by natural means (births minus deaths), and in- and out-migration, and also on the participation rate (ϕ). Assuming a constant participation rate, the labour supply for production is given by:

$$\frac{\dot{L}_s}{L_s} = \zeta - \Omega + M \tag{5}$$

where ς is birthrate; Ω is death rate; and M is attractiveness of migration to the basin. More broadly, M can be influenced by many factors such as the economy, employment opportunity, social wellbeing, climate, environment, and political or security related issues. This study focuses on the internal migration of people within Australia only, driven by economic wellbeing. For simplicity, we assume M to be driven by the difference in unemployment rates between the basin and the rest of Australia. Positive M leads to the net in-migration.

$$M = \nu(U_A - U_b) \tag{6}$$

where U_A is unemployment rate of Australia (obtained from World Bank, 2014) and ν is an attractiveness parameter, which at present can only be obtained through calibration. Migrated Labour (Mg) was obtained by multiplying attractiveness (M) and Labour supply (Ls). The unemployment rate of basin (U_b, in %) was estimated as:

$$U_b = \max\left(0, \frac{L_s-(L_i+L_a)}{L_s}\right) \times 100 \tag{7}$$

It is assumed that whenever there is an employment demand, it is filled by available labour and the labour have enough skill and knowledge capacity to switch between the sectors. The effects of skill and knowledge transferability on labour mobility are left for future research.

2.3.3. Model Data - External Drivers

The two external drivers are irrigated land area within the Murrumbidgee and the Australian unemployment rate (see also Fig. 2). The latter is obtained from the World Bank (2014). Data on irrigated land

Table 1
Model parameters, initial values and variables used in the model.

		Unit	Definition	Reference
Coefficient	Value			
γ_i	1.1	%	Growth rate of TFP in industry	(ABS, 2015a)
γ_a	2.5	%	Growth rate of TFP in agriculture	(ABS, 2015a)
γ_w	3.4	%	Growth rate of wage	(ABS, 2015b
γ_c	7.0	%	Growth rate of capital	(World Bank, 2014)
α	0.61	–	Share of land productivity	(ABS, 2015a)
θ	0.41	–	Share of capital productivity	(ABS, 2010)
ς	1.4	%	Birth rate	(World Bank, 2014)
Ω	0.7	%	Mortality rate	(World Bank, 2014)
Parameter	Value			
ν	(0.012–0.034)[a], 0.023[b]	–	Coefficient of attractiveness	Calibrated
Variable	Value at initial (at 1971)			
L_a	10,262	No.	Labour demand in agriculture	(ABS, 2014a)
L_i	30,724	No.	Labour demand in industry	(ABS, 2014a)
L_s	41,838	No.	Labour available	(ABS, 2014a)
M	Model derived/output	–	Attractiveness of migration	NA
U_b	Model derived/output	%	Unemployment rate	NA

[a] 90% confidence interval of acceptable parameters based on Monte Carlo simulations of the model.
[b] Median of the confidence interval.

area, for most years (36 out of 42 years), is obtained from Australian Bureau of Statistics (ABS, 2016b, 2016c) and various other reports (Dunlop, 2001; Hope and Wright, 2003; Meyer, 2005). Missing data are estimated based on water diverted between Narrendra and Hay and average irrigation rate per hectare (Office of Water, 2016). Irrigated land area generally increased from 1971 to 1994, although rises and falls are evident from year to year. This is because the land area that could be irrigated each year is dependent upon the availability of water in storage dams (see Fig. 1), inflows to the dam from the upstream catchment and basin transfers, and rainfall over the catchment. Other significant factors that affected irrigated land area were the cap in agriculture water allocation introduced by the government in 1995 to support increased environmental water allocation, the severe drought that occurred over 2000–2009, and its breaking in 2010. The former two tended to reduce irrigated land area, while the latter caused an increase. In response to the cap and the drought, farmers sought to increase the land area under irrigation by improving the efficiency of water usage.

2.3.4. Model Coefficients, Parameters, Initial Values and Variables

The coefficients, parameters, initial values and variables used in the model are summarised in Table 1. All coefficients used in the model equations (Eq. (3)–(7)) are obtained (not calibrated or parameterized) from data or prescribed a priori and directly. The attractiveness parameter (ν) is calibrated. This is done by uniformly sampling 100,000 values of ν from a range [0 to 0.04] that produced realistic simulations, and selecting those parameter values for which the performance of the model is deemed 'acceptable' (Beven and Binley, 1992). A parameter value is deemed acceptable when (i) the Nash-Sutcliffe Efficiency (Houska et al., 2014) of simulated basin scale unemployment rate (U_b) relative to the observed data is >0.5 and when (ii) the R^2 value between the model simulation and observed data for simulated labour force (L_s) is >0.6 (Houska et al., 2014). Initial values are the values at the first time-step and are used to initiate model computations. Values of various variables are updated based on model calculations at subsequent time steps.

2.3.5. Model Simulation Period and Time-Step

Model simulations are run for acceptable parameters over the period 1971–2012, a period over which data on irrigated land area is available. The simulations are carried out with an annual time step. Labour supply, the predicted labour demand of the two sectors and unemployment rates are compared against observed data to gauge the fit of the model. The model simulations are then used to explore the effect of migration and economic diversification on unemployment rates.

3. Results of Data Analysis

In 1995, water allocation to agriculture was capped to protect riverine eco-systems and the impact on agriculture was profound (see Fig. 4c in Kandasamy et al., 2014). As the agriculture sector became constrained due to water allocation, farmers naturally became concerned about possible consequences such as increased unemployment, a drop in basin economy and feared for their economic livelihood (Bark et al., 2014; Dixon et al., 2011; MJA, 2010).

Fig. 5a shows the number of people employed in the agriculture sector and the basin unemployment rate. Increased diversion of water to ecosystems and the prolonged drought (2000 − 2010) reduced agriculture production and as expected the agriculture employment declined. Despite this, paradoxically, the basin unemployment rate (Fig. 5a) also declined and basin median household income (MHI) increased (Fig. 5b, diamond). Note that in the latter case the MHI within the Murrumbidgee is presented alongside gross domestic product per capita for Australia (GDPc) for comparative purposes. MHI includes contributions not included in the GDPc (e.g. superannuation, government pensions, workers' compensation, child support, etc.) and so is not completely comparable with GDPc. The inclusion of these items, whose increases are dependent on government policy and are somewhat biased towards the inflation rate, grew at a smaller rate than the GDPc at a time when Australia's GDP was rising rapidly due to the mining boom. On the

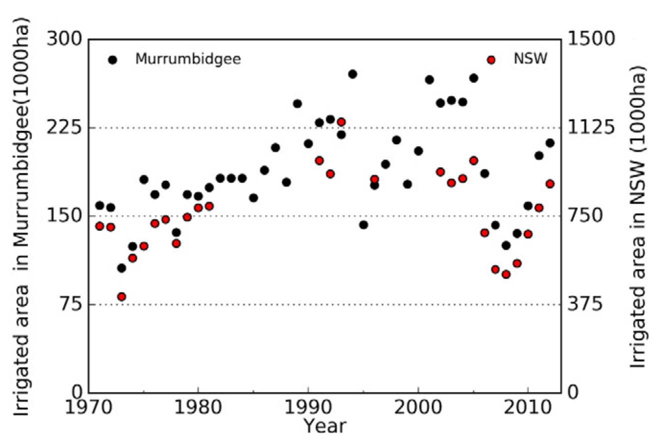

Fig. 4. Observed irrigated land area in Murrumbidgee (ABS, 2016b, 2016c); Dunlop, 2001; Hope and Wright, 2003; Meyer, 2005) and NSW state (ABS, 2016b, 2016c).The pattern of irrigated land area influenced employment in agriculture which subsequently translated across the basin economy.

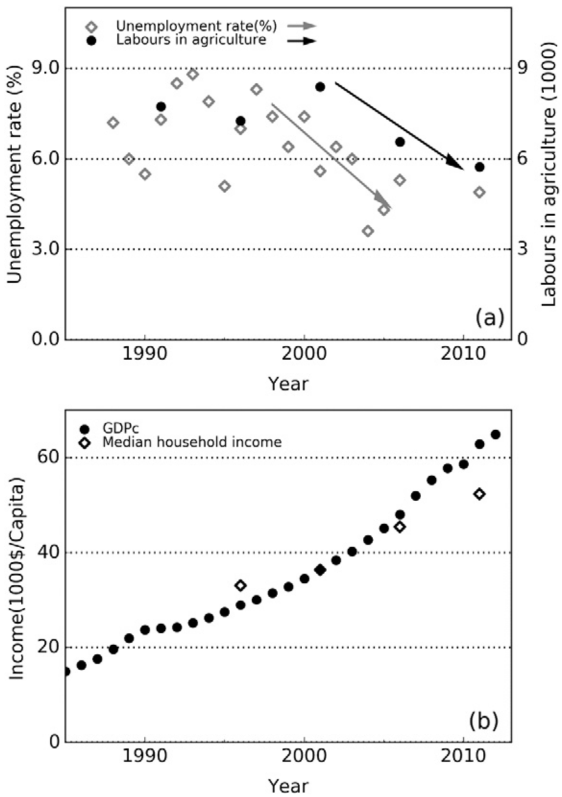

Fig. 5. (a) Labour employed in agriculture sector and basin unemployment rate of Murrumbidgee basin (ABS, 2014a). Arrows indicate the decline in employment in agriculture sector and unemployment rate; (b) Australian gross domestic product per capita (GDPc) and median household income (MHI) of Murrumbidgee basin, (GDPc from World Bank, 2014; MHI from ABS, 2014a). Paradoxically the unemployment rate declined and median household income kept rising despite a drop in agriculture labour demand after the water allocation to the agriculture sector was reduced in 1995.

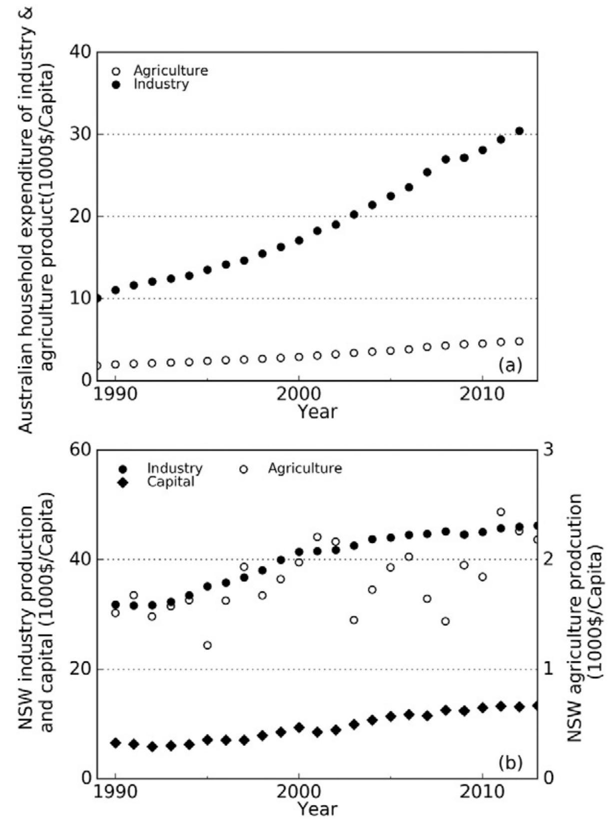

Fig. 6. (a) Average household expenditure per capita for Australia (ABS, 2016a); (b) output of industry sector and agriculture sector and cumulative capital in New South Wales (ex-Sydney), (ABS, 2014b, AEC Group, 2015, 2013, 2011). Industry and agricultural production data for New South Wales (NSW), the state where the basin is located, and excluding Sydney metropolitan area (ABS, 2014a) is used since the production data for the basin's industry sector was not available. Note the relative size of industry production and agriculture production.

basin scale, therefore, the reduction in water allocation to agriculture in the Murrumbidgee did not translate to the expected rise in unemployment rate and associated economic stress. How did the basin economy and society adapt to the reallocation of water to the environment? To answer the question and understand the paradox, we explore economic statistics of agricultural and non-agricultural (or industry sector comprising manufacturing and services sectors) sectors and the growth of the basin population, migration and labour supply.

3.1. Economic Output, Production and Employment

Fig. 5b shows that the Australian economy grew from 1970 to 2011. In the meantime, the demand for industry products increased as reflected in the growth in household expenditure on industrial (manufacturing and services) sector goods and services shown in Fig. 6a. Correspondingly, Fig. 6b shows that a high demand for industry products stimulated production in the industry sector. The increasing amount of capital input appears to have further fueled the output of the industry sector (Fig. 6b). We can expect that these observations apply equally to the Murrumbidgee where the industry sector grew faster than the agriculture sector over the years since at least 1990. One can speculate that growing employment in the industry sector buffered the adverse impact of the 1995 policy intervention in the basin. We explore the viability of this proposition further by investigating the role of technology.

3.2. Role of Technology

Economic output depends on the level of technology used in production. Technology makes production faster, simpler and more efficient using, for example, advanced machinery to meet the demand of goods and services. However, if technology grows faster than the growth of production, it can lead to reduced demand for labour (see also Section 3 for further discussion). This means that there is a direct connection between technology adoption and employment/unemployment, which goes to the heart of the subject matter of this paper.

Fig. 7a shows the TFP of the agriculture (A_a) and industry sectors (A_i) of Australia as a whole (ABS, 2015a). TFP is a measure of the increase in productivity with technological development in each sector. TFP is difficult to measure directly and was estimated by the Australian Bureau of Statistics based on labour and capital mix, and output (ABS, 2015c). TFP is referenced as 100 in 1990 and in subsequent years is calculated by multiplying the ratio of the TFP in certain year to the TFP in 1990. We use Australian TFP rates by assuming that improvements in practices spread typically through government agencies and industry bodies are adopted across Australia without evident spatial differentiation.

Fig. 7b shows the ratio of output index to TFP index in the agriculture and industry sectors. The output index is based on NSW (ex-Sydney data) output growth relative to the output of 1990. In the industry sector, output to TFP index ratio has been >1, i.e., output growth has been higher than the technology growth. This means that growth in capital and/or labour contributed to output growth. This may help explain the growth in employment or low unemployment rate. On the other hand, output/technology index ratio in agriculture has been predominantly below 1. This can help explain increased unemployment in the agriculture sector.

These observations also apply to the Murrumbidgee since its industrial and agricultural growth rates are expected to be the same as NSW (excluding Sydney, the major capital city). There is a high correlation

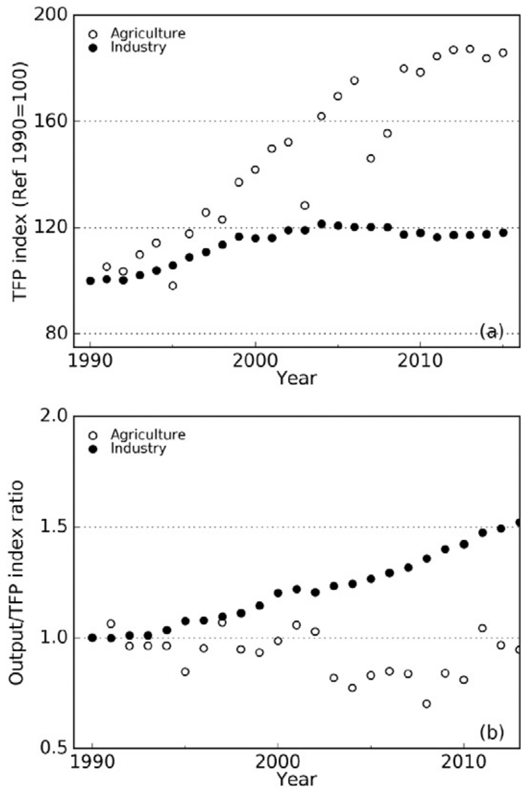

Fig. 7. (a) TFP of agriculture and industry sector in Australia (ABS, 2015a); (b) Ratio of output to TFP (Total Factor of Productivity) index for agriculture and service sector. Output (or TFP) index value for a particular year is obtained by taking the ratio of output (TFP) in a particular year to the output (or TFP) in 1990 (ABS, 2015a, ABS, 2014b, AEC Group, 2015, 2013, 2011). Industry sector output grew faster than technology, putting upward pressure on labour employment, unlike the agriculture sector.

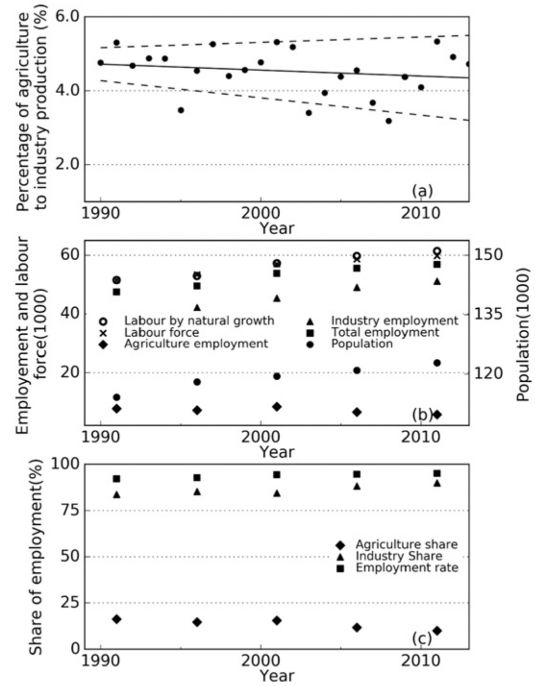

Fig. 8. (a) Percentage of agriculture to industry production in New South Wales (ex-Sydney), (ABS, 2014b, AEC Group, 2015, 2013, 2011). The solid line indicates trend of data. Dash lines indicate the 95% Confidence Interval; (b) changes in the employment in the agriculture sector and in the industry sector, the total labour force and population in the Murrumbidgee from 1991 to 2011 (ABS, 2014a); (c) share of agriculture and industry labour force and employment rate The rise in employment in industry sector is evident. The figure shows robust sectoral transformation (i.e. growing industry sector) has occurred in the past.

($R^2 > 0.99$) between employment in industry in the Murrumbidgee and within NSW (ex-Sydney). (ABS, 2014a, ABS, 2014b, AEC Group, 2015, 2013, 2011). Sectoral transformation, which is the change in the relative size of production in the various sectors of the economy, influenced by technological advances, therefore appears to play an important role in helping to interpret the unemployment paradox.

3.3. Sectoral Transformation

Fig. 8a shows the percentage of agriculture to industry production over the last 25 years, indicating how the NSW economy has transformed itself. In 1996, following the introduction of the cap to agricultural water allocation, the employment in agriculture was 15% of the total employment and that in the industry sector was 85%. Over the next 15 years, the agriculture sector became constrained by reduced allocation of water and the prolonged drought (2000–2010). Meanwhile, the industry sector continued to expand (see Fig. 6). This meant that the relative size of the agriculture sector in the basin shrank over time and, in relative terms, the industry sector expanded. Did this pull downwards the total unemployment rate in spite of technological advancements in the two sectors?

Fig. 8b shows the changes in the labour employed in the agriculture sector, in the industry sector, and the total labour force in the Murrumbidgee (ABS, 2014b). Fig. 8c shows the share of agriculture and industry employment and employment rate in the basin. Employment and the labour share in agriculture continued to decline due to reduced water allocation away from agriculture implemented in 1995 and the drought that followed. However, total employment continued to increase partly because the employment growth in the industry sector was sufficiently strong to absorb what was lost in the agriculture sector. Industry sector was 85% and continued to grow. The increase was also facilitated by a drop in employable people due to out-migration as a result of stronger demand for labour outside the basin, e.g., in industry sector.

3.4. Basin Out-Migration

Unemployment rate depends on the labour demand and available labour force. The latter, i.e., the labour supply, is a function of natural population growth, the participation rate, and basin migration. The natural labour force is then given by natural population growth after factoring the participation rate (the portion of natural population, excluding net-migration that participates in various production activities of the economy).

Fig. 8b shows the population and labour force within the Murrumbidgee basin. The population, natural labour force and labour force that includes the migration effect rose at different growth rates. It shows that until 1995, the labour force was slightly larger than the natural labour force. This reversed after 1995, when the latter was higher. This means that after 1995, when agriculture water allocation was capped, the labour force seeking employment grew at a slower pace due to out-migration. Consequently, the unemployment rate declined. If, hypothetically, out-migration had not occurred, e.g., perhaps due to the high cost associated with migration or poor economic conditions outside the basin, then the basin unemployment rate would have increased.

In summary, the data analysis at the basin scale reveals that sectoral transformation with a growing industry sector and population out-migration appears to have reduced the adverse economic impacts, in terms of unemployment rate, of cuts to agricultural water allocation within the Murrumbidgee. This has been corroborated by the study carried out by Cheesman and Wheeler (2012), which reported on a 2009 survey involving interviews with farmers who had sold their water entitlements (licenses) to the Government (Fig. 9). It showed that around 40% of the farmers gained employment in the industry sector,

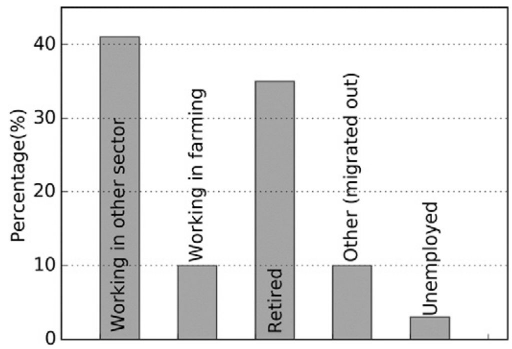

Fig. 9. Percentage of farmers who were reemployed in the industry sector, continued to work in farms, retired, migrated-out or became unemployed after selling their water entitlement (license) to the government (reproduced from Cheesman and Wheeler, 2012). The survey results support the hypothesis that unemployed agricultural workers mostly gained employment in the industry sector or migrated out. This may have dampened the economic impacts of water re-allocation to the environment.

supporting the claims of sectorial transformation. Another 35% retired and it was estimated that upto 10% of the farmers could have out-migrated.

4. Modelling Results

Model simulations further explored the dynamics underlying the employment paradox within the Murrumbidgee basin. Fig. 10a shows a comparison with the model results with the recorded unemployment

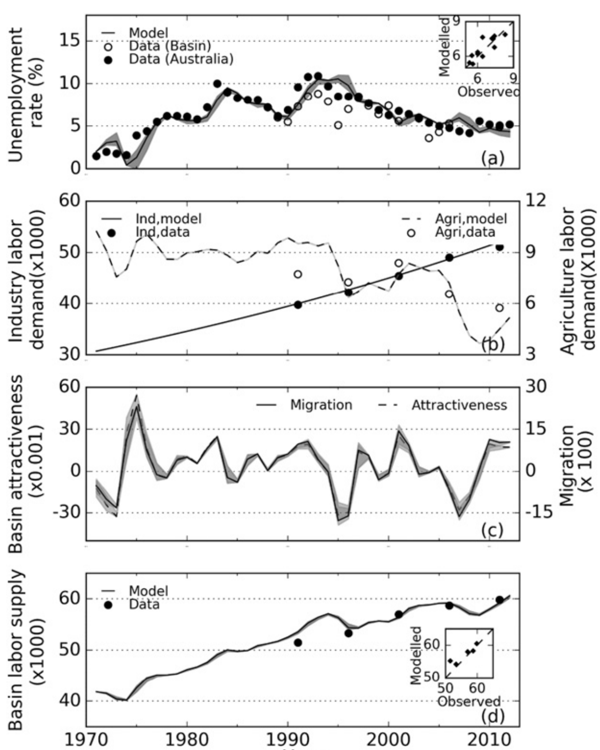

Fig. 10. (a) simulated and observed unemployment rate in the Murrumbidgee and observed Australia unemployment, (b) simulated and observed labour demand in agriculture (Agri) and industry (Ind) sector, (c) simulated attractiveness of the basin for migration and the rate of migration and (d) simulated and observed labour force in the basin. Shaded area indicates the 90% confidence interval, the line corresponds to simulations using median value in the uncertainty range for ν. Scatter plot in (a), (d) shows observed vs simulated unemployment rate and labour supply respectively. The model captures and explains observed unemployment paradox of falling unemployment during the post-1995 decline in agriculture reasonably well.

rate in Australia and in the Murrumbidgee. Coefficient of determination (R^2) between observed and simulated data for labour supply, labour demand in industry, labour demand in agriculture and unemployment rate are 0.86, 0.99, 0.73 and 0.78 respectively (using the median value of ν, i.e. 0.023). Also shown are the 90% confidence intervals, accounting for the uncertainty in the estimation of attractiveness parameter, ν. The model simulations help to interpret what happened in the Murrumbidgee from 1971 to 2011 more precisely.

The modeled basin unemployment rate mostly follows the observed unemployment within the basin, except for a surprisingly sharp drop in observed unemployment at one data point around 1995. The modeled unemployment reached a peak in 1993 and remained at about that level till 1995 when agricultural water allocation was reduced. After 1995, the economic wellbeing and potential outlook for agriculture appeared to be bleak (Kirby et al., 2014, Bark et al., 2014; Dixon et al., 2011; MDBA, 2011; MJA, 2010; Witter and Dixon, 2011). During this time, labour demand in the industry sector (Fig. 10b) continued to increase with capital growth and technology development. Growth of labour demand in industry was able to absorb some of the labour force that had earlier abandoned agriculture. The modeled labour demand dynamics is not subject to calibration but it is influenced indirectly by the attractiveness parameter. It shows good performance based on the comparison of model predictions with the observed data.

Before 1995, the economic attractiveness of the basin was generally positive apart from two short periods (Fig. 10c). This was driven by agricultural potential and the expansion of industry sectors. While cumulative net-migration and basin population rose, so did the unemployment rate (Fig. 10a). In effect, the basin labour force resulting from natural population growth and net-migration exceeded the labour demand. This observation parallels the Todaro paradox (Todaro, 1969) whereby job creation in a region leads to increased unemployment due to factors such as net-migration. This rise in unemployment can partly also be explained by technological advancement and improvement in agricultural practices, which increase productivity and reduce the demand for labour. Nonetheless, humans motivated to migrate by the signal of basin attractiveness (perhaps in the form of herd-like behavior) are always more likely to do so in a manner that might overshoot the potential that exists within the basin (Bikhchandani et al., 1992; Todaro, 1969).

Attractiveness was mostly negative over the 1995–2009 period. The attractiveness of the basin became negative in 2003 due to resource constraints and the decline in agriculture output within the basin. The resource constraint was due to a change in water management policy and the impact of the Millennium drought that occurred in the region. The industry sector grew throughout the study period. When the agriculture sector became constrained, and as agriculture labour became unemployed, on a collective basin level, there would be a net labour movement to the industry sector. Others would move out of basin. The latter would occur if the growth of the industry sector was not enough to accommodate all the labour that left agriculture. This in effect reduced the attractiveness, which even became negative thus restoring or minimizing the unemployment rate gradient. Meanwhile the Australian economy outside the basin continued to grow (Fig. 5b). These factors led to an out-migration of workers. Out-migration countered the natural population growth, thus giving rise to a slower growth in modeled labour supply (Fig. 10d). This matches well with observed labour supply data.

Australia's GDP has been on the rise since 1970 and rose sharply largely from 2002 in response to Australia's mining boom. Unemployment in Australia was falling (generally since 1993). Model simulations suggest that basin attractiveness was already negative (Fig. 10c), and to enhance their economic wellbeing, some people moved to the industry sector (i.e. manufacturing or services) (Fig. 10b). Others migrated to regions outside the basin where prospects were better (Fig. 10c). Unemployment declined and basin labour supply increased slowly (Fig. 10d), due to negative attractiveness of the basin, resulting in out-migration. In Australia, the mining boom attracted many workers from areas such as the Murrumbidgee. Moreover in the Murrumbidgee, youth unemployment was reasonably low, with most leaving to find work elsewhere (Wilkinson and Montoya, 2012).

The model simulations thus reinforce the interpretation of the data analysis that out-migration and sectoral transformation helped the basin to cope with the water stress that resulted from a change in water allocation policy and the subsequent drought. We now assess the sensitivity of the unemployment trajectory to migration and sectoral transformation in a comparative setting by simulating alternate scenarios to learn from what could have happened otherwise.

4.1. Impact of Migration

In our model, labour migration depends on the difference between unemployment rates between the basin and in Australia and the coefficient of attractiveness (ν). Australian unemployment is therefore one of the drivers of migration. As alluded to previously, the mining boom contributed to a significant drop in Australia's unemployment. The contribution of the mining boom that began in 2002 is estimated to have contributed to 6% of the Australia's GDP and is estimated to have lowered the unemployment rate by 1.25% (Downes et al., 2014). In order to understand the effect of the mining boom and the movement of labour across Australia, we explored a scenario had no mining boom occurred. In this case we adjusted Australia's unemployment rate by removing from the data the sharp growth in employment in the mining sector (ABS, 2014c) during the period of the mining boom.

Fig. 11a shows that in the case of 'no mining boom' the modeled unemployment increased significantly within the basin. The increase is around 1.5%, close to the employment effect of the boom reported elsewhere (Downes et al., 2014). The basin labour force (supply) also increased (Fig. 11d) as out-migration decreased when compared to the base case shown in Fig. 11c. This shows the impact that out-migration has on labour supply within basin and the knock-on impact on the unemployment rate.

If the out-migration had not occurred during the period that followed the 1995 water policy, the unemployment would have increased due to increase in labour supply resulting from growth in natural population. The modelling shows that out-migration reduces the economic stress in the basin by reducing the labour supply. The above scenario shows that the out-migration from the basin in the early 2000s was facilitated by the strong Australian economy that resulted from the mining boom. The policy to reallocate water away from agriculture was implemented at a time before the mining boom was foreseen or anticipated. Yet its later occurrence was fortuitous to the basin economy and softened the impact of cuts to agriculture water allocation. This shows how a booming economy outside the basin, through migration, can reduce the impact of agricultural downturn within the basin. It also suggests that basins in countries with weak economies could face adverse economic conditions if they introduce policies to allocate water more sustainably by taking it away from agriculture.

4.2. Impact of Basin Economic Dependency on Agriculture

Migration affects unemployment rate by influencing the labour supply. We now explore the demand side drivers of unemployment. This depends on the proportions of agricultural and industrial sectors in the basin and how fast these sectors grow. In order to understand the impact of the relative dependency of the basin economy on agriculture, we construct two alternative scenarios from 1996 onwards (after water allocated to agriculture was reduced). We change the initial ratio of people employed in agriculture to industry from 15% (here called the base rate) to 5% and to 25%, while maintaining the total number of employed to be same in the year 1996.

In the case of higher (than the base case) initial agriculture to industry labour share, the unemployment rate is higher on average (Fig. 12a). It is also more volatile, as it is more susceptible to volatility in the irrigated land area under cultivation (Fig. 4). Note that in the period 2000–2010

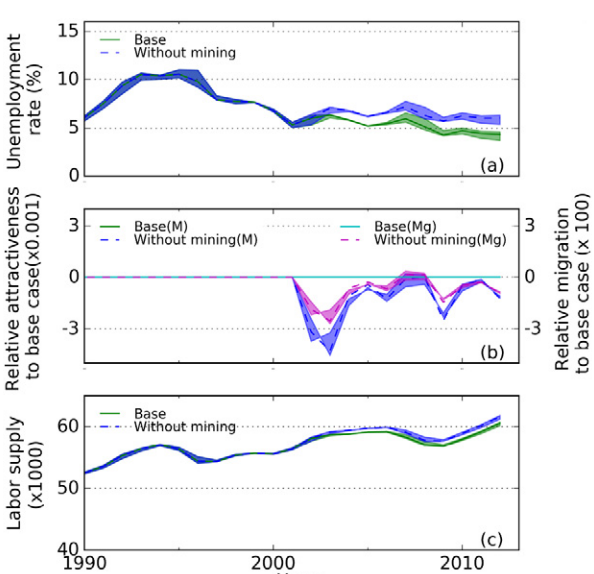

Fig. 11. (a) Simulated unemployment rate; (b) attractiveness of migration (M) and migration (Mg) related to base in Murrumbidgee; (c) labour force when there is no mining boom (blue) and base (green). Shaded area indicates the 90% confidence interval, the line corresponds to the simulation using the median value of the uncertainty range for ν. It demonstrates that out-migration reduced the effect of policy changes to redistribute water in 1995 on basin unemployment.

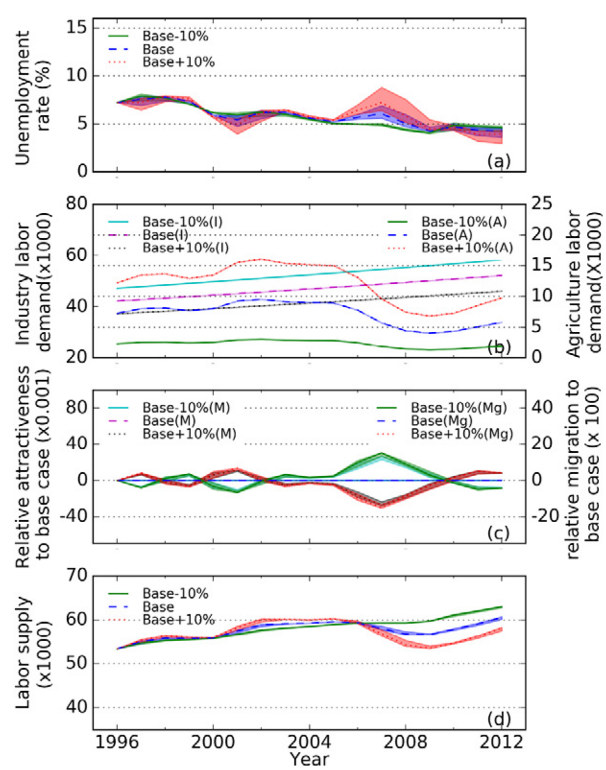

Fig. 12. (a) Simulated unemployment rate, (b) labour demand in agriculture (A) and industry sector (I), (c) attractiveness (M) of migration and migration (Mg) in Murrumbidgee, (d) labour force when 5% (Base-10%), 15% (Base), 25% (Base + 10%) of labour engaged in agriculture production in 1996. Shaded area indicates the 90% confidence interval, line correspond to simulation using median value of the uncertainty range for ν. The figure shows that a more diversified economy is better able to cope with economic stress created by policy change of 1995.

when the unemployment rate was high the basin witnessed heavy out-migration (Fig. 12c). When compared with the base case scenario, more labour became unemployed as fewer could be re-employed in the now smaller industry sector (Fig. 12b). The increased unemployment in the basin leads to higher negative attractiveness. This leads to out-migration, resulting in lower labour supply over time when compared to the base case (Fig. 12c, d). Note that since migration is a function of the gradient of unemployment within and outside basin, sectoral composition influences labour supply within the basin as well.

In the case of smaller agriculture sector compared to the base case, the basin will witness lower economic stress, in terms of unemployment. Here unemployment is lower on average over the period of the simulation (Fig. 12a) and industry labour demand is strong (Fig. 12b). Employment in agriculture sector follows the cycles of irrigated land area dynamics. These cycles however dampen when they propagate to the unemployment rate (Fig. 12a). This is because unemployment is influenced by past out-migration and hence by past demand-supply dynamics. This is evident from Fig. 12c (migration) and Fig. 12d (labour supply). When more of the basin's workforce is employed in agriculture, the amplitude of unemployment fluctuations (Fig. 12a) and migration (Fig. 12c) is high. This shows that sectoral transformation in a diversified economy increases the capacity of society to cope with changes in water allocation.

The preceding comparative analyses highlighted the advantages of economic diversification, and in particular how it can soften the impact of water policy interventions in case of reduced water allocation to agriculture. This demonstrates that a diversified economy can facilitate introduction of unpopular measures such as reduced allocation of water to agriculture in 1995. If the policy had been introduced earlier to divert water from agriculture and if the drought had occurred earlier, the basin could have witnessed higher unemployment and lower production on average within the basin. This is because agriculture at earlier times constituted a larger share of the entire Murrumbidgee economy.

This suggests that basins that do not have diversified economies may face unfavorable economic conditions when introducing unpopular water conservation measures. Such conditions may even discourage introduction of sustainable water management practices such as giving water back to the environment. This brings to attention agriculture dominated places such as the Aral Sea, which dried out due to the absence of sustainable water policy intervention in spite of visible human (health) costs of desiccation (White, 2013). Perhaps a similar picture can be painted for Urmia Lake in Iran (AghaKouchak et al., 2015) which is drying out at a very rapid pace and yet there are no apparent interventions in place.

5. Discussion and Conclusions

This paper focused on the reduction of water allocation to agriculture in the Murrumbidgee river basin located in south-eastern Australia, its impact on the basin economy and community and how they adapted to the resulting economic stress. Data analysis showed, as expected, that the agriculture production decreased and the agriculture employment declined. Yet, paradoxically, the overall basin unemployment decreased and basin median household income increased at the same time. Data analysis revealed that this emerged as a result of out-migration from the basin and the growth of other economic sectors within the basin.

Dynamical system modelling was used to interpret the observed unemployment pattern, and to understand the complex interactions between human-water system within the Murrumbidgee basin. The model simulations reinforced the interpretation from data analysis that out-migration and sectoral transformation helped the basin to cope with water stress resulting from a change in water allocation policy after 1995 and the severe drought that occurred coincidentally in the period 2000–2010.

This is followed by a comparative analysis of basin employment based on two main drivers that softened the impact of cuts to agriculture water allocation, i.e., out-migration and sectoral transformation or diversification of the economy. This study went beyond merely replicating the unemployment dynamics of MRB and went on to highlight the advantages of diversification and the role of a strong overall economy. It showed that open, diversified economies could facilitate, and in the end, ease the introduction of otherwise unpopular measures such as reduced allocation of water to agriculture. Importantly, it suggested that basins that do not have 'well' diversified economies might face unfavorable economic conditions when introducing policies to allocate water more sustainably between humans and the environment. Results centering around out-migration catalyzed by Australia's mining boom showed how unemployment in the basin would have increased by over 1% if not for the boom and how out-migration can help to reduce the economic stress in the basin. Further it showed how a booming economy outside the basin, through migration, can reduce the impact of agriculture downturn in the basin. It suggests that basins within countries with weak economies could face adverse economic conditions if polices are introduced to allocate water to agriculture more sustainably. The utility of such a model is clear. It allows for an extensive evaluation of alternative adaptation strategies or policy implementations such as increasing investment of capital, controlling wage rate, and economic performance outside the basin. Furthermore, it facilitates critical thinking and opens the way for innovation and flexibility in developing adaptation strategies. Nonetheless, models of the kind presented here are limited if the ultimate goal is to understand socio-hydrological realities across a gradient of hydrological and socio-economic conditions. This requires a modelling framework to understand the dynamics between sectoral transformation, migration and policy implementation in diverse hydro-climatic, sociological, and economic settings. In such a case, the model needs to endogenise how humans value consumptive use of water versus their environment, how water is allocated within a basin, how the portfolio of economic activities may diversify and the feedbacks between them in response to exogenous variables such as climate and global economy. We leave such an extension of the presented model to account for these extensive features to future work.

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