Australian National University
Crawford School of Public Policy

Energy Transition Hub
an Australian-German innovation partnership

Centre for Climate Economics & Policy

Closures of coal-fired power stations in Australia: Local unemployment effects

CCEP Working Paper 1809
September 2018

Paul J Burke
Crawford School of Public Policy, The Australian National University

Rohan Best
Department of Economics, Macquarie University

Frank Jotzo
Crawford School of Public Policy, The Australian National University

Abstract
Around one-third of Australia's coal-fired power stations closed during 2012–2017, with most of the remainder expected to close over coming decades. Current investment in generation capacity is primarily in the form of alternative power, especially wind and solar. In this paper we conduct an event study to assess the local unemployment effects of Australia's coal-fired power station closures. This is an issue of considerable interest given the prominence of coal-fired power stations in local economies. Our analysis uses monthly regional labour force survey data from the Australian Bureau of Statistics. We find that there has on average been an increase in local unemployment of around 0.7 percentage points after the closures of coal-fired power stations, an effect that tends to persist beyond the months immediately after closure. The findings raise questions about appropriate policy responses for dealing with local structural adjustment issues facing coal-reliant communities.

Keywords:
coal; electricity; labour; structural change; unemployment

JEL Classification:
J65; E24; L94

Acknowledgements:
We are grateful for comments from presentation audiences, an Associate Editor, and two reviewers; discussions with stakeholders; funding from the Coal Transitions Project; and funding from the Department of Foreign Affairs and Trade through the Australian-German Energy Transition Hub. The corresponding author received funding from the Australian Research Council (DE160100750).

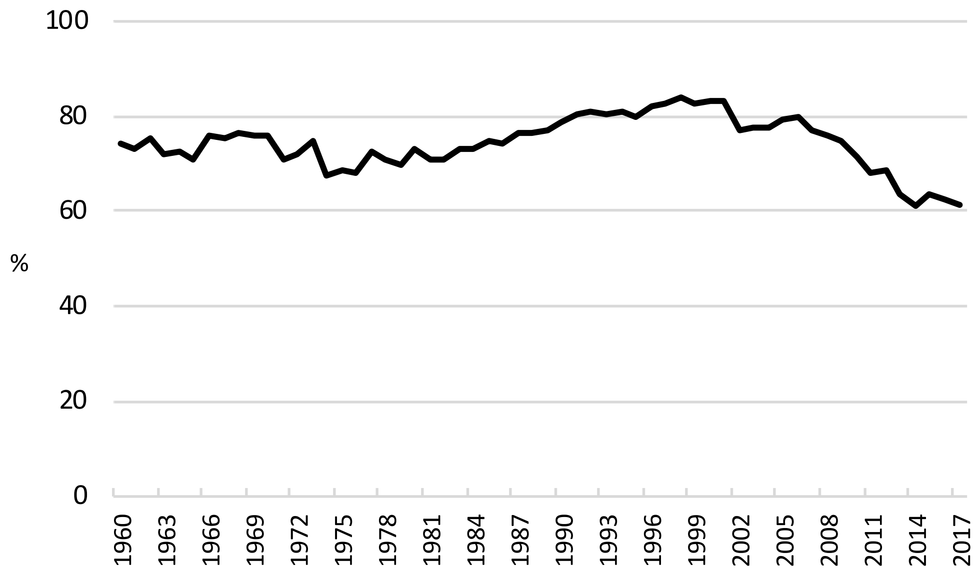
Suggested Citation:
Burke, PJ., Best, R. and Jotzo, F. (2018), Closures of coal-fired power stations in Australia: local unemployment effects, CCEP Working Paper 1809, September 2018, Crawford School of Public Policy, The Australian National University.

Address for Correspondence:
Paul J Burke
Fellow
Crawford School of Public Policy
The Australian National University
ANU College of Asia and the Pacific
J. G. Crawford Building
132 Lennox Crossing
Acton ACT 2601 Australia
Tel: +61 (0) 2 6125 6566
Email: paul.j.burke@anu.edu.au

1. Introduction

At the turn of this century, coal-fired power stations supplied more than four-fifths of Australia's electricity. Since then, coal's contribution to Australia's electricity mix has fallen steadily, reducing to 61% in 2017 (Figure 1). An ageing coal-fired power fleet, increased use of natural gas, policies to bring renewables onto the grid, the disadvantages associated with coal's emissions footprint, and relatively slow progress in reducing the cost of carbon capture and storage (Arranz 2016) have each contributed to coal's decline. Decommissioned stations have not been replaced with new coal-fired power stations, with no new coal-fired power station being opened since Bluewaters 2 power station in Western Australia (WA) in 2010. Technical progress is continuing to reduce the cost of new solar and wind energy installations (Blakers *et al.* 2017), making it increasingly unlikely that new coal-fired power stations will be built in response to private incentives alone. The Australian Energy Market Operator (2018)'s list of committed projects does not include any coal-fired power stations.

Figure 1. Coal's contribution to Australia's electricity mix, 1960–2017



Source: World Bank (2017). Data for 2016 and 2017 are from the Department of the Environment and Energy (2018), with the 2017 value being an official estimate.

As of 2010 Australia had 34 coal-fired power stations in operation or under refurbishment, listed in Table 1. These ranged in size from Eraring in New South Wales (NSW), with a capacity of 2,880 megawatts (MW), to the Queensland Alumina Limited (QAL) station in Gladstone, Queensland, with a capacity of only 25 MW. As of the end of 2017, twelve had closed, with a median age at closure of 43 years. The largest was the Hazelwood power station (1,760 MW) in the Latrobe Valley, Victoria, which ceased operations in March 2017. Many of Australia's remaining coal-fired power stations are nearing the end of their operating lives. The next major closure is due to be the Liddell power station in the Hunter Valley of NSW, which is slated to close in 2022 (Australian Energy Market Operator 2018). Its operating life will then have exceeded 50 years. A map of Australia's coal-fired power stations is provided in Figure 2.

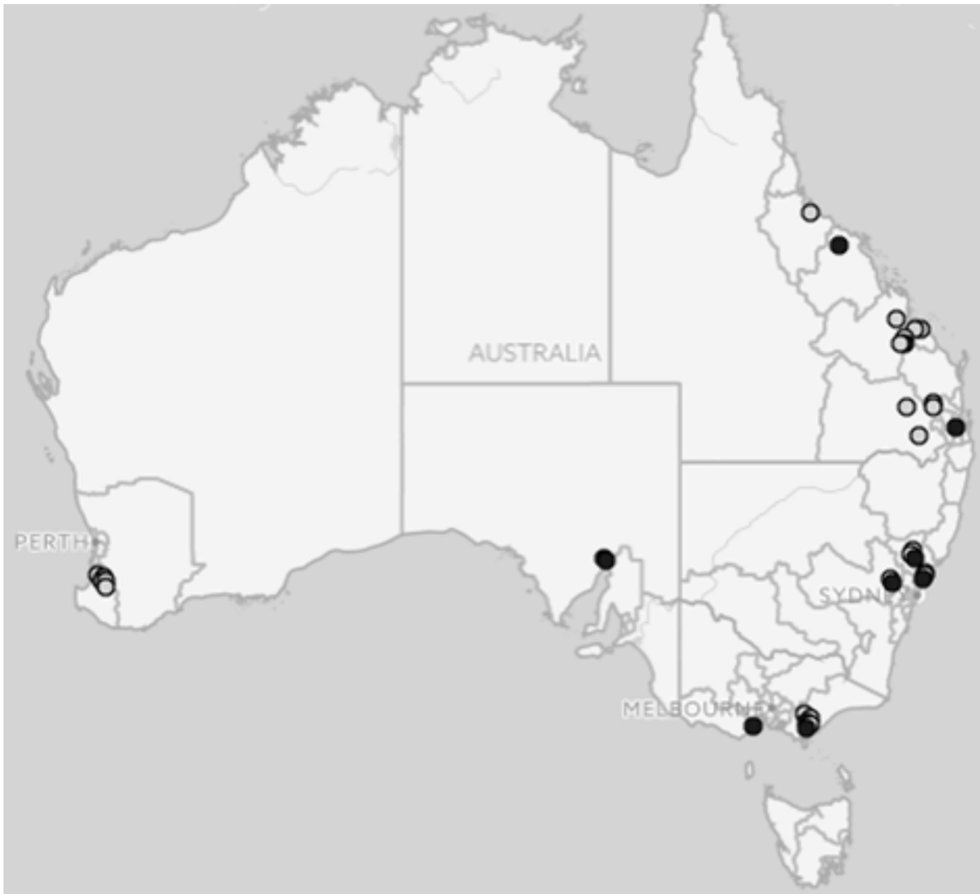
Table 1. List of Australia's coal-fired power stations

Remaining open (22)			**Closed by end of 2017 (12)**			
Station	State	Capacity (MW)	Station	State	Capacity (MW)	Month of closure
Eraring	NSW	2,880	Hazelwood	VIC	1,760	March 2017
Bayswater	NSW	2,640	Wallerawang C	NSW	1,000	November 2014
Loy Yang A	VIC	2,210	Munmorah	NSW	600	July 2012
Liddell	NSW	2,000	Northern	SA	546	May 2016
Gladstone	QLD	1,680	Swanbank B	QLD	500	May 2012
Yallourn W	VIC	1,480	Muja	WA	240	September 2017
Stanwell	QLD	1,460	Playford	SA	240	May 2016
Tarong	QLD	1,400	Morwell	VIC	189	August 2014
Mt Piper	NSW	1,400	Collinsville	QLD	180	December 2012
Vales Point B	NSW	1,320	Anglesea	VIC	160	August 2015
Loy Yang B	VIC	1,026	Redbank	NSW	144	August 2014
Milmerran	QLD	851	Callide A Unit 4	QLD	30	March 2015
Callide C	QLD	810				
Kogan Creek	QLD	750				
Callide B	QLD	700				
Tarong North	QLD	443				
Collie	WA	340				
Bluewaters 2	WA	208				
Bluewaters 1	WA	208				
Worsley (Alumina)	WA	135				
Yabulu	QLD	38				
Gladstone QAL	QLD	25				

Note: Restricted to coal-fired power stations that were open or under refurbishment as at the end of 2010. Sorted in descending order of capacity. Plant capacity varies over time; we report capacity numbers from the Australian Senate (2017) for all power stations except Muja (Watt Electrical News 2017) and Callide A Unit 4 (Holmes à Court 2017). Callide A was put in storage in 2001, but from 2008 its Unit 4 was retrofitted and during 2012–2015 it was used for a carbon capture and storage demonstration project (Callide Oxfuel Project 2017). The list does not include Kwinana Cogeneration Plant in WA, which was switched to primarily being fuelled by natural gas (ENGIE 2017). NSW = New South Wales. QLD = Queensland. SA = South Australia. VIC = Victoria. WA = Western Australia.

Transitioning to lower-carbon energy sources is necessary in order to have a chance of restricting global warming to 2°C or below (Figueres *et al.* 2017; Spencer *et al.* 2018), and cutting carbon dioxide emissions in the electricity sector is typically at the heart of any overall decarbonisation strategy (Williams *et al.* 2012). In the Australian context, this principally implies switching from coal to renewables (Denis *et al.* 2014). A transition to renewables offers economic opportunities, as Australia is richly endowed in emission-free energy sources such as solar and wind, as well as minerals needed for renewable energy and battery technologies, such as bauxite, copper, and lithium. The transition is likely to pose challenges, however, for local economies that have traditionally depended on emissions-intensive industries. Regions where coal mining and coal use in power generation are concentrated are particularly exposed, especially the Latrobe Valley in Victoria, the Hunter Valley in NSW, and the Mackay and Fitzroy regions of Queensland.

Figure 2. Map of Australia's coal-fired power stations



Note: Shows the 34 coal-fired power stations listed in Table 1. Dark = closed. Light = not closed. The boundaries of SA4 regions (2011 definition) are also shown.

In this paper we use monthly panel data at the regional (statistical area level 4, or SA4) level from the Australian Bureau of Statistics (ABS 2018a) to examine the local labour market implications of closures of Australia's coal-fired power stations. Focusing on the period 2010–2017, we test if higher local unemployment has been observable subsequent to the closures. We control for time-varying and time-invariant factors that might affect unemployment rates, including region fixed effects, state-specific month dummies, closures of plants in other key industries (vehicle manufacturing, nickel, aluminum, and steel), and the coal export price (for major coal-exporting regions). We find that regions with one or more recently-closed coal-fired power stations have on average seen an increase in their unemployment rate of around 0.7 percentage points, other factors held constant. This is predominantly due to increased unemployment among males. Our method could in future be used to study the effects of other region-specific events, such as closures or openings of major facilities in other industries.

Our results are not only of interest within the Australian context, but also to overseas jurisdictions. One example is Alberta, Canada, which has set up an advisory panel to "examine the potential effect of the retirements of coal-fired generation plants and associated mining operations on communities and workers" (Alberta Government 2017). There is a growing literature calling for the transition to a low-carbon economy to be "just" (Evans 2007; Rosemberg 2010; Investor Group on Climate Change 2017). The Paris Agreement affirms "the imperatives of a just transition of the workforce and the creation of decent work and quality jobs" (United Nations Framework Convention on Climate Change, 2015).

Looking at the international experience, it is evident that coal-mining regions have undergone structural declines that have led to social disadvantage in some key coal-mining countries, including the United Kingdom (Johnstone and Hielscher 2017) and United States (Carley *et al.* 2018). Spencer *et al.* (2018, p. 13) conclude that coal-sector transitions have often been "poorly anticipated and poorly managed". In Germany, unions were able to negotiate significant adjustment packages (Abraham 2017), although financial compensation does not necessarily solve the issue of regional structural adjustment. It is hoped that our results will provide a basis for a better understanding of the regional adjustment issues associated with the decline of coal-fired electricity generation in Australia.

The general class of problems that our paper focuses on is the regional effects of closures of large-scale employers. Our paper also adds to the literature on factors affecting unemployment in Australia. Among prior contributions, Dixon *et al.* (2001) reported that state-level disparities in unemployment rates in Australia tend to be largest when the national unemployment rate is low. Heaton and Oslington (2002) concluded that inter-industry shocks have been the primary cause of changes in Australia's unemployment rate. As a result, macro-level factors are of most importance for understanding overall changes in unemployment. Borland (2015) documented a strong negative correlation between national economic growth and changes in the national unemployment rate. Using census data at the SA4 level, Georgeson and Harrison (2015) found that manufacturing job losses have exacerbated local unemployment. Our paper is the first to examine the effects of closing coal-fired power stations on local unemployment.

Our results complement prior estimates of multiplier effects from localised jobs losses. For four states of the US, Black *et al.* (2005) estimated that 0.35 jobs were lost in local construction and services for every job loss in coal mining (using data from the 1980s). Moretti (2010) estimated that skilled jobs in the tradable sector in US cities generate an additional 2.5 jobs in the supply of local goods and services. Using five-yearly census data at the local government area level, Fleming and Measham (2014) estimated that around seven local jobs are created in other sectors for each new mining job in Australia. Fleming and Measham (2015) and Measham and Fleming (2014) explored local job multipliers and socio-economic effects of Australia's coal seam gas boom. Fleming *et al.* (2015) found positive local income and job multiplier effects for Australia's mining sector more broadly.

Closures of coal-fired power stations are of particular interest because these stations are in some cases among the largest regional employers, with local economies tending to be centred on the activities of the station. All of Australia's coal-fired power stations are located in regional areas. Adaptive capacities tend to be more limited in these areas than in capital cities (Productivity Commission 2017).

2. Australia's labour market and coal-fired power stations

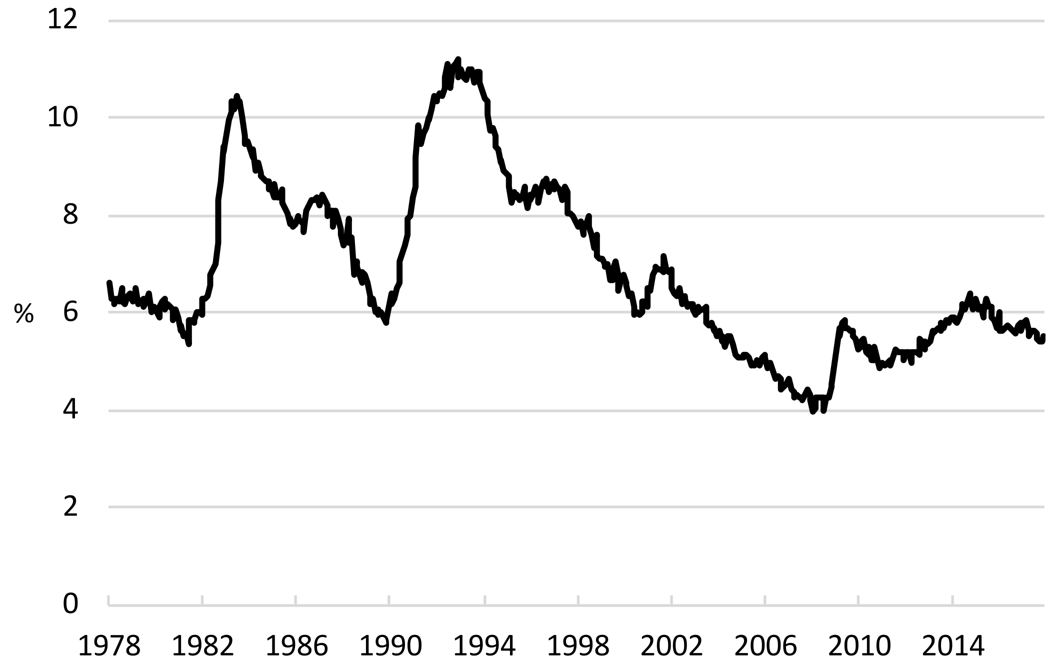
Around 64,300 people were employed in Australia's electricity supply industry sub-division as of November 2017 (based on their main job; ABS 2018b). This was down from more than 80,000 in the mid-1980s. Most are employed at the transmission, distribution, and retail levels rather than in electricity generation. Around 94% have full-time jobs. Almost three-quarters are male. From a macro perspective, the number of people working in electricity supply is relatively small, accounting for only 0.5% of the total number of employed people nationwide. The number of people working in electricity supply is less than the annual flow of involuntary retrenchments across the national economy (around 355,000 in the year to February 2013; Productivity Commission 2014) or the annual total flow from employment to unemployment (Chapman and Lounkaew 2013). Across Australia, another 51,500 people were employed in coal mining as of November 2017 (ABS 2018b). Many of these work in supplying coal for export.

Australia's seasonally-adjusted unemployment rate was 5.5% in December 2017. This is below the 1978–2017 average of 6.9%, but remains stubbornly above the pre-global financial crisis low of 4.0% (see Figure 3). Australia's unemployment rate is also higher than those of New Zealand (4.5% as of December 2017) and the United States (4.1%) (StatsNZ 2018; Bureau of Labor Statistics 2018). As of December 2017, Australia's labour force participation rate was 65.7% (seasonally-adjusted), above the 1978–2017 average of 63.2%.

National unemployment figures hide substantial variation among SA4 regions (Figure 4). The average unemployment rate during the year to December 2017 ranged from 2.2% in Sydney's Eastern Suburbs to 12.2% in the Queensland Outback (ABS 2018a). There are sizeable fluctuations in regional unemployment rates over time (Productivity Commission 2017).

Structural change is a persistent feature of Australia's economy. Services now account for around 88% of employment (based on individuals' main job; ABS 2018b), up from less than 55% in 1900 (Connolly and Lewis 2010). Manufacturing now employs 17% fewer people than in the mid-1980s (ABS 2018b). To date, job losses in sunset occupations have been more than offset by new jobs. As of late 2017, more than 12.4 million people were employed nationwide, more than ever before (ABS 2018b).

Figure 3. Australia's unemployment rate, February 1978–December 2017

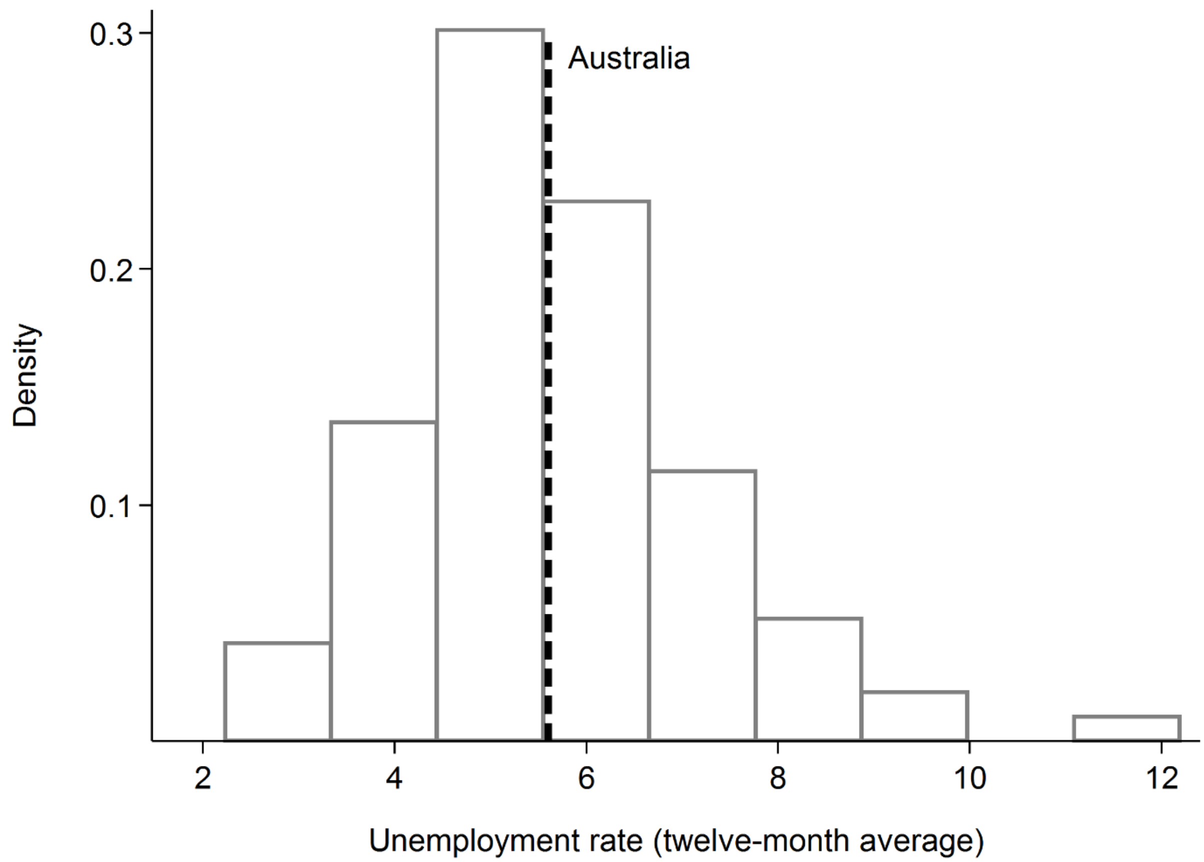


Note: Shows seasonally-adjusted monthly series. Source: ABS (2018c).

From a national perspective, a transition from coal-fired electricity generation does not necessarily involve fewer jobs in electricity generation, in the short run at least. This is because installation of solar and wind generation capacity is a relatively labour-intensive process (Diesendorf 2004; Fankhauser *et al.* 2008; Wei *et al.* 2010), with more people now working in installing and maintaining solar panels than in coal-fired power stations (Grudnoff and Denniss 2014). While relatively few people are employed by operating solar and wind farms, it is also important to note that new coal-fired generators would also not be large employers (on account of increasing automation).

The closure of a coal-fired power station can be a major event for a local community. Around 750 workers (including contractors) were employed at Hazelwood power station and its adjacent brown coal mine at the time of their closures in March 2017 (ENGIE 2016). Not all lost their jobs, as more than 235 workers were retained for site decommissioning (Alcorn 2017), and some workers were transferred to other power stations. Net job losses represented around 0.4% of the labour force of the Latrobe-Gippsland SA4 region, and in the order of 5% of the total number of unemployed people in the region (ABS 2018a).

Figure 4. Histogram of unemployment rate (twelve-month average) by SA4 region, December 2017



Source: ABS (2018a). Data are for 87 SA4 regions. The Australian unemployment rate is also shown.

In addition to direct job losses from the closure of a coal-fired power station, indirect job losses might also be expected. These are particularly likely for jobs located earlier in the supply chain, such as at local coal mines. For example, the Angus Place coal mine in NSW was closed after the decommissioning of the nearby Wallerawang C power station (Pearce 2014). There might also be job losses in industries supplying other locally-consumed goods and services (Black *et al.* 2005). The local construction industry may face reduced demand, for example, which would flow through to fewer construction jobs.

While workers in coal-fired power stations and local suppliers have skills that are transferable, new jobs are not always located near newly-closed coal-fired power stations. If there are limitations to geographical mobility, and if alternative employment is slow to eventuate, local unemployment might rise. Australia's best sites for solar power are not in the Latrobe Valley, for example, but in sunnier locations (Australian Government 2014). On the other hand, new power-sector investors in the Latrobe Valley have the advantage of ready access to electricity transmission lines.

In addition to influencing the local unemployment rate, the closure of a large facility such as a coal-fired power station might have other local labour market implications. The participation rate might fall if those who lose their jobs opt for early retirement. It is possible, however, that spouses and other family members might be more likely to join the labour force after the retrenchment of a breadwinner, which would place upward pressure on the participation rate. The magnitudes of such effects are not well known.

Australia's coal-fired power stations are major sources of local air pollutants, including particulates, sulfur dioxide, nitrogen oxide, lead, and mercury. These are the cause of health problems such as asthma, stroke, and cancer (Environmental Justice Australia 2017). Closing coal-fired power stations will likely reduce these problems (see Yang and Chou (2018) for a case study from the United States). Some local industries – such as tourism and agriculture – may thus benefit, generating additional jobs. Our estimates will measure the overall effect of power station closures on the local unemployment rate in the years immediately after closure.

3. Method and data

3.1 Estimation method

The basic form of our estimation model is:

$$U_{r,m} = \alpha C_{r,m} + \boldsymbol{X}'_{r,m}\boldsymbol{\beta} + \varepsilon_{r,m} \qquad (1)$$

where U is the unemployment rate; C is a dummy equal to 0 prior to a coal-fired power station closure and 1 thereafter; $\boldsymbol{X}$ is a vector of controls; and ε an error. r is region, and m is month. Our C variable estimates the magnitude of any structural break in local unemployment rates after closures of coal-fired power stations.

The $\boldsymbol{X}$ vector includes variables to control for key structural and time-specific factors affecting the unemployment rate in each region. This includes sets of (a) region fixed effects and (b) state-specific month dummies. Region fixed effects are included to control for unobserved factors that may cause persistent differences in regional unemployment rates across Australia. These may be correlated with the likelihood of having a coal-fired power station closure. Similar results are obtained using random effects (see Stata estimation code, available online). The vector of state-specific month dummies includes a separate dummy for each month of the estimation period, for each state. This is a powerful control set, allowing us to net out effects of shocks to unemployment that are common across regions in any state in any month. The state-specific month dummies also serve to deseasonalise the data. The Northern Territory and the Australian Capital Territory are handled as "states".

We also control for closures of other key employers: vehicle manufacturers, and nickel, aluminium, and steel processors. In coal-exporting regions we control for the coal export price, using the two-month lag (given the expectation of some delay from price changes to employment outcomes). $\hat{\alpha}$ will provide an estimate of the average conditional effect of closing a coal-fired power station on the local unemployment rate. We cluster standard errors by region to account for potential serial correlation within regions.

In additional estimates we modify the C variable, including splitting it into separate dummies for sub-periods. We also use alternative dependent variables, including the male and female unemployment rates, the total numbers of unemployed and employed people, the labour force participation rate, and the size of the labour force. We do not examine effects on the industry composition of employment, as doing so would require use of five-yearly census data.

We avoid specific priors about the expected size of the effect of closures of coal-fired power stations *vis-à-vis* the effects of closures of other industrial plants, such as metal processing plants. As the Productivity Commission (2017, p. 2) summarised, "transitions in the real world … depend on the specific nature of the shock, the options available to people and the decisions they make". In general terms, it should be expected that unemployment effects of closures are of greater magnitude for closures of larger plants; for more closures that are more sudden; and perhaps also for closures in more remote regions with fewer substitution and adaptation possibilities for workers and the local community.

3.2 Data

Our analysis uses ABS (2018a) monthly estimates of labour force status by labour market region. These are available for 87 Statistical Area Level 4 (SA4) regions. The labour force data are based on where people live, not where they work, with the regions being defined so that a high proportion of people live and work in the same region. This is easier to achieve outside capital cities. In regional areas, each SA4 region typically has a population of 100,000–300,000 people. In metropolitan areas, the typical population is 300,000–500,000. As can be seen in Figure 2, some SA4 regions cover large land areas. The allocation of each coal-fired power station to an SA4 region is detailed in Appendix A. An 88th SA4 spatial unit ('Other territories') exists, but labour force data are not available for this region. The data use the 2011 regional definitions. We use the terms 'local' and 'region' interchangeably when referring to the SA4 level.

The ABS data come from a monthly survey of around 26,000 dwellings, stratified by region. This sample represents around 0.3% of the Australian civilian population aged 15 years and over (ABS 2018a). The surveys are subject to sampling error. This introduces some data volatility, particularly for regions with small populations. As a consequence, the ABS (2018a) recommends that analysis of regional labour force estimates should use twelve-month averages. We heed this advice when presenting summary statistics in Figures 4–8. Our main estimates do not use twelve-month averages, as there is no reason to think that sampling error for the dependent variable would be correlated with the closure of coal-fired power stations. We find a similar result using the twelve-month moving average, as will be documented.

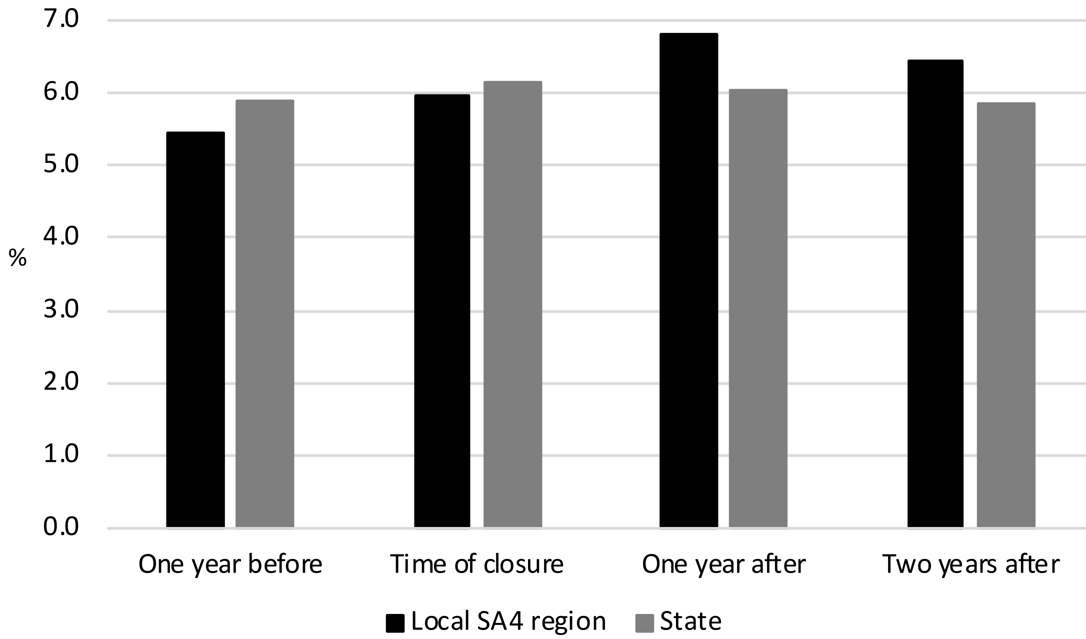
The definition of unemployment in Australia is in line with the international definition; the unemployed are those "of working age who were not in employment, (who) carried out activities to seek employment during a specified recent period, and (who) were currently available to take up employment given a job opportunity" (ABS 2018d). The unemployment rate is the number of unemployed people as a share of the labour force, where the labour force equals employed people plus unemployed people. Working one hour or more during the survey reference week qualifies as being employed.

The Department of Employment (2018) provides quarterly estimates of unemployment by statistical area level 2 (SA2), a more disaggregated geographical unit than the SA4 data we use. Data are available for 2,090 SA2 regions. We do not use the SA2-level data in our analysis, because many people work in an SA2 region other than the one where they live. SA2 data are also only available on a quarterly basis, and are only available from the final quarter of 2010. Because they were designed to roughly represent local labour markets, SA4 regions are better suited to our purposes (ABS 2018e). We will refer to the SA2-level data in section 5 when presenting case study descriptions. Smaller effects should be expected when analysing unemployment effects in larger areas (e.g. SA4-level) than in smaller areas (SA2-level). We do not examine spillover effects across regions.

Our estimates are for a sample that commences in January 2010 and extends to December 2017. Our dataset consists of 8,352 observations (87 regions * 96 months). We have a balanced panel. Only ten regions experienced a closure of a coal-fired power station during our study period. Definitions of our explanatory variables are in Appendix B. Our dataset and estimation codes will be available online.

Figure 5 presents initial evidence on the local unemployment effects of closing coal-fired power stations. A year prior to the closures, the regions with closed coal-fired power stations on average had a slightly smaller unemployment rate than their state. As at their time of closing, their unemployment rate was similar to their states' (6%, in twelve-month average terms). One year after a closure, the annual unemployment rate in these regions was on average 0.8 percentage points above their state's average. A positive differential (+0.6 percentage points) remained after two years. Our estimates will explore whether these effects remain once we condition on our controls, and will allow us to formally evaluate statistical significance.

Figure 5. Local versus state twelve-month average unemployment rates following closures of coal-fired power stations



Note: Shows the twelve-month average unemployment rate (ABS 2018a). The data are averages for the twelve closures of coal-fired power stations listed in Table 1. The 'one year after' calculations are for only eleven of the closures, as one year had yet to pass in the case of the Muja power station at the time of analysis. The 'two years after' calculations are for only ten closures (excluding Hazelwood and Muja). The underlying data are in Appendix A.

3.3 Estimation issues

There are several issues to consider. One is that some of the coal-fired power stations were mothballed prior to formal closure (e.g. Munmorah), were operated below capacity (e.g. Morwell), and/or were closed in stages (e.g. Swanbank B). Some reduced their workforces in the lead-up to closure, as maintenance activities were wound down. Anticipation of upcoming plant closures might also have dampened employment opportunities in other local industries. These issues mean that it is possible that our estimates underrepresent the effect of the closures on local unemployment. Rather than discrete, exactly-timed events, it is appropriate to interpret the closure timings that we have used as indicative. An alternative approach would be to use the timings of mothballing decisions, but some staff are retained to maintain (and potentially operate) mothballed plants. We consequently stick to using the date of formal closure. We will also test for any uptick in local unemployment in the year leading up to the closures.

While our use of state-specific month dummies removes effects of temporal shocks common to regions in each state, it is difficult to control for all region-specific events that merely coincided with – but were not caused by – closures of coal-fired power stations. Anomalous local shocks might be expected to be orthogonal to closures of coal-fired power stations. It is possible, however, that these shocks have been coincidentally correlated with the closures. As a result, our estimates should be considered to be suggestive rather than definitive.

It is also possible that the decision to close a power station may be influenced by local economic conditions. If so, our estimates would face a potential endogeneity challenge. For example, reduced local demand for electricity might induce a power station closure, or a station might be squeezed by tight local labour market conditions. We expect this issue to be relatively slight given that (a) the stations supplied electricity to the broader grid, and (b) firms have the potential to recruit from outside the local labour market. The primary reasons for the closures have related to factors such as plant age, maintenance costs, and corporate decisions to move away from coal. In some cases, local issues may be relevant. The closure of the Anglesea power station in Geelong in 2015, for example, followed the closure of the Point Henry aluminum smelter. After the smelter's closure, Alcoa was reportedly unable to find a buyer for the power station and so decided to close it (Arup and Willingham 2015).

Our estimates do not attempt to explain all variation in SA4-level unemployment. We also do not claim that all subsequent changes in local unemployment were due to the closures. Instead, we seek to estimate average conditional effects as accurately as we can. Data availability issues lead us to focus on labour market implications rather than effects on income or wellbeing. Our estimates will pick up effects that include any ameliorating influence of government interventions to stimulate regional employment.

Prior to running our estimates, we carried out Dickey and Fuller (1979) unit root tests on the unemployment rate for a sample of SA4 regions. We performed the tests on deseasonalised series (using the residuals from a regression on month-of-year dummies), chose test lag lengths using the Akaike information criterion (with a maximum lag length of four), and included a time trend in the test specifications. The test results pointed to an absence of unit roots in the series. We thus proceed to estimate our models in levels. The unit root tests are in our Stata code.

We also carried out a Hausman test to help to evaluate our choice of region fixed effects over region random effects. The test could not reject the null that the difference in coefficients between the two estimators is not systematic (see Stata code). This reflects the fact that random effects estimates are quite similar to fixed effects estimates. Given that we have a large estimation sample and so are not overly concerned with degrees of freedom issues, we continue to use fixed effects in our estimates. Doing so provides reassurance that we have controlled for time-invariant factors. As Wooldridge (2006, p. 497) points out, fixed effects "is almost always much more convincing than random effects for policy analysis using aggregated data".

4. Results

Table 2 presents our estimates of the effect of closing coal-fired power stations on the local unemployment rate. Column 1 shows an unconditional estimate. It suggests that regions with a recently-closed coal-fired power station on average have a higher unemployment rate, by around 0.9 percentage points. This effect differs from zero at the 1% significance level. The R^2 indicates that the variable explains only around 1% of the variation in the unemployment rate. A low R^2 makes sense, as there are many other factors – including macroeconomic shocks – that influence unemployment rates across Australia and over time. It should also be remembered that some of the variation in the SA4-level unemployment rate reflects statistical noise in the ABS data.

Column 2 of Table 2 includes our controls. The coefficient for the coal-fired power station dummy reduces to 0.7, significantly different from zero at the 5% level. We find a strong positive coefficient (+1.8) for the closure of a nickel refinery, significant at the 1% level. This represents the effect of the sudden closure of the Palmer Nickel and Cobalt Refinery near Townsville in March 2016, an event that saw more than 700 direct job losses (ABC News 2016).

We do not find significant positive effects for the vehicle, aluminium, or steel plant variables, even though there have been thousands of job losses in these industries. Positive point estimates are obtained for the vehicle and aluminium plant variables, but they are not precisely estimated. Note that the closures of vehicle manufacturing plants were in urban areas, with larger SA4 populations and generally better prospects for switching to other jobs. A negative coefficient is obtained for the steel variable. Additional specifications reveal an increase in the local unemployment rate in the first year after the single closure of a blast furnace in our sample, but that the unemployment rate subsequently fell (see Stata code). We find a negative coefficient for the coal export price, suggesting that local unemployment in coal-exporting regions is directly affected by commodity price cycles. The R^2 reaches 0.44 with our controls. The remaining estimates retain the full set of controls.

Column 3 of Table 2 uses a slightly different explanatory variable: the cumulative sum of closed coal-fired power stations in each region since 2010, noting that Latrobe-Gippsland and the South Australia Outback each had two closures. The coefficient reduces to 0.6. Column 4 of Table 2 uses a dummy that only equals 1 when a region's coal-fired power station closures since 2010 exceed 180 MW of cumulative capacity. A larger coefficient is obtained (+0.9), significant at 5%. This suggests that our findings are not driven by the smallest closures.

Column 5 of Table 2 splits our coal-fired power station closure dummy into three: one for the first six months after closure; one for the next six months; and one for thereafter. We obtain positive coefficients for each, with the largest (and most statistically significant) being for the second six-month period (+1.1). We are thus able to conclude that the effect persists beyond the first six months post-closure (see also Figure 5). The effect is unlikely to be permanent, but our study does not have an adequate time-series of post-closure data to explore long-run effects.

Table 2. Effects on the unemployment rate

Dependent variable: Unemployment rate$_{r,m}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dummy: Closed coal-fired power station$_{r,m}$	0.89***	0.74**						0.71*
	(0.33)	(0.34)						(0.38)
Closed coal-fired power stations (cumulative)$_{r,m}$			0.63**					
			(0.24)					
Dummy: Closed coal-fired power stations (180 MW or larger)$_{r,m}$				0.86**				
				(0.42)				
Dummy: Closed coal-fired power station within last 6 months$_{r,m}$					0.64*			
					(0.34)			
Dummy: Closed coal-fired power station 6–12 months ago$_{r,m}$					1.09**			
					(0.51)			
Dummy: Closed coal-fired power station ≥ 1 year ago$_{r,m}$					0.69			
					(0.49)			
Direct jobs lost in closed coal-fired power station (and adjacent coal mines if part of the same operation; '000; cumulative)$_{r,m}$						1.56		
						(1.21)		
Closed coal-fired power station capacity (cumulative; GW)$_{r,m}$							0.54	
							(0.50)	
Dummy: The year in advance of closure of a coal-fired power station$_{r,m}$								-0.09
								(0.39)
Dummy: Closed vehicle manufacturing plant$_{r,m}$		0.25	0.30	0.36	0.27	0.37	0.37	0.24
		(0.47)	(0.46)	(0.42)	(0.47)	(0.42)	(0.42)	(0.47)
Dummy: Closed nickel refinery$_{r,m}$		1.83***	1.82***	1.81***	1.84***	1.80***	1.80***	1.83***
		(0.36)	(0.36)	(0.36)	(0.36)	(0.37)	(0.37)	(0.36)
Dummy: Closed alumina refinery or aluminium smelter$_{r,m}$		0.16	0.21	0.52	0.16	0.42	0.42	0.19
		(0.50)	(0.49)	(0.52)	(0.50)	(0.51)	(0.50)	(0.53)
Dummy: Closed steel blast furnace$_{r,m}$		-0.80***	-0.83***	-0.84***	-0.79***	-0.94***	-0.93***	-0.81***
		(0.27)	(0.26)	(0.26)	(0.27)	(0.26)	(0.26)	(0.26)
Coal export price (US$ per metric ton)$_{r,m-2}$		-0.01*	-0.02*	-0.02**	-0.01*	-0.02**	-0.02**	-0.01*
		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
State-specific month dummies	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.01	0.44	0.44	0.44	0.44	0.44	0.44	0.44
# of observations: 8,352. # of regions: 87. # of months: 96. Time period: January 2010–December 2017								

Note: ***, **, and * indicate statistical significance at 1, 5, and 10%. Coefficients on fixed effects not reported. Standard errors are robust and clustered by region. R^2 values include the explanatory power of all dummies and fixed effects.

Column 6 of Table 2 uses the direct number of jobs lost in closed coal-fired power stations (including adjacent coal mines if part of the same operation) in each region since 2010. The coefficient suggests that on average there was an uptick in the local unemployment rate, but this effect is not precisely estimated. Column 7 uses each region's cumulative closed coal station capacity since 2010, in GW. A positive coefficient is obtained, but is again not significant. Column 8 tests for an increase in unemployment in the year prior to a closure. We do not find a significant coefficient.

Table 3 uses alternative dependent variables. We revert to our initial explanatory variable. Column 1 uses the twelve-month moving average unemployment rate instead of the same-month unemployment rate. A coefficient of +0.55 is obtained. This smaller coefficient is as expected, as it takes time for any effect on the twelve-month moving average to play out. Columns 2 and 3 indicate that in point-estimate terms, the effect is largest for males. This makes sense given the high representation of males in power station workforces. The estimate for the female unemployment rate is positive (+0.5), but not precise. Columns 4–6 use the number of unemployed people (rather than the unemployment rate) as the dependent variable. The estimates suggest that closing a coal-fired power station on average leads to around 470 males becoming unemployed, an effect that is significantly different from zero at the 10% level. Columns 7–9 estimate effects for the number of employed people, the participation rate, and the labour force. The estimates do not reveal statistically significant effects.

It is notable that our results are more precise using unemployment rate data than using unemployment/employment count data. This may be due to the accuracy of the ABS (2018a) data; it is likely easier to measure unemployment rates than it is to estimate the total stocks of people in employment and unemployment on a monthly basis. Note that the ABS (2018a) surveys slightly less than 300 households per SA4 region per month (on average).

Table 4 presents specifications in which we exclude the ten regions with closed coal-fired power stations from the sample, one by one. The effect of closing a coal-fired power station on local unemployment is positive in each, with statistical significance in nine of the ten columns. In point estimate terms, the smallest effect is when Ipswich is excluded (+0.55). There was a loss of public service and manufacturing jobs in Ipswich that followed the closure of Swanbank B. This does not provide a reason for excluding Ipswich from all estimates, as there may have been positive shocks to employment in other regions after coal-fired power station closures.

Table 3. Effects on other labour market indicators

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Unemployment rate$_{r,m}$			Unemployed total ('000)$_{r,m}$			Employed total ('000 people)$_{r,m}$	Participation rate$_{r,m}$	Labour force$_{r,m}$
	Twelve-month moving average	Male	Female	People	Males	Females			
Dummy: Closed coal-fired power station$_{r,m}$	0.55*	0.88***	0.53	0.69	0.47*	0.22	-3.43	0.80	-2.74
	(0.31)	(0.33)	(0.45)	(0.57)	(0.27)	(0.34)	(3.29)	(1.03)	(3.59)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-specific month dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.69	0.37	0.33	0.85	0.78	0.78	0.99	0.78	0.99

# of observations: 8,352. # of regions: 87. # of months: 96. Time period: January 2010–December 2017

Note: ***, **, and * indicate statistical significance at 1, 5, and 10%. Controls are those included in Table 2. Coefficients on controls and fixed effects not reported. Standard errors are robust and clustered by region. R^2 values include the explanatory power of all dummies and fixed effects.

Table 4. Excluding individual regions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Excluding: Bunbury	Central Coast	Fitzroy	Geelong	Hunter Valley exc Newcastle	Ipswich	Latrobe-Gippsland	Mackay	NSW Central West	SA Outback
Dummy: Closed coal-fired power station$_{r,m}$	0.71**	0.84**	0.78**	0.93***	0.73**	0.55*	0.61	0.70*	0.94***	0.72*
	(0.35)	(0.38)	(0.38)	(0.33)	(0.35)	(0.33)	(0.37)	(0.37)	(0.31)	(0.38)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-specific month dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
# of observations: 8,256. # of regions in each estimation: 86. # of months: 96. Time period: January 2010–December 2017										

Note: ***, **, and * indicate statistical significance at 1, 5, and 10%. Controls are those included in Table 2. Coefficients on controls and fixed effects not reported. Standard errors are robust and clustered by region. R^2 values include the explanatory power of all dummies and fixed effects.

We carried out several additional estimations. First, we included separate state-specific month dummies for regions outside greater capital cities. We obtained a slightly larger estimate for our coal-fired power station closure dummy (+0. 9). Second, we attempted to estimate the average conditional effect of direct job losses in coal-fired power stations on the number of locally unemployed people (cf. the unemployment rate). Our estimates had wide confidence intervals, and were sensitive to the exclusion of individual regions. They are thus not reported. Our main estimates using dummy variables are more stable. Finally, we obtained similar estimates in specifications that exclude the three SA4 regions with the highest unemployment rates during 2017. These robustness checks are available in our Stata code, available online.

5. Case studies

We now present brief case studies of coal-fired power stations closures during our study period.

5.1 Latrobe Valley, Victoria

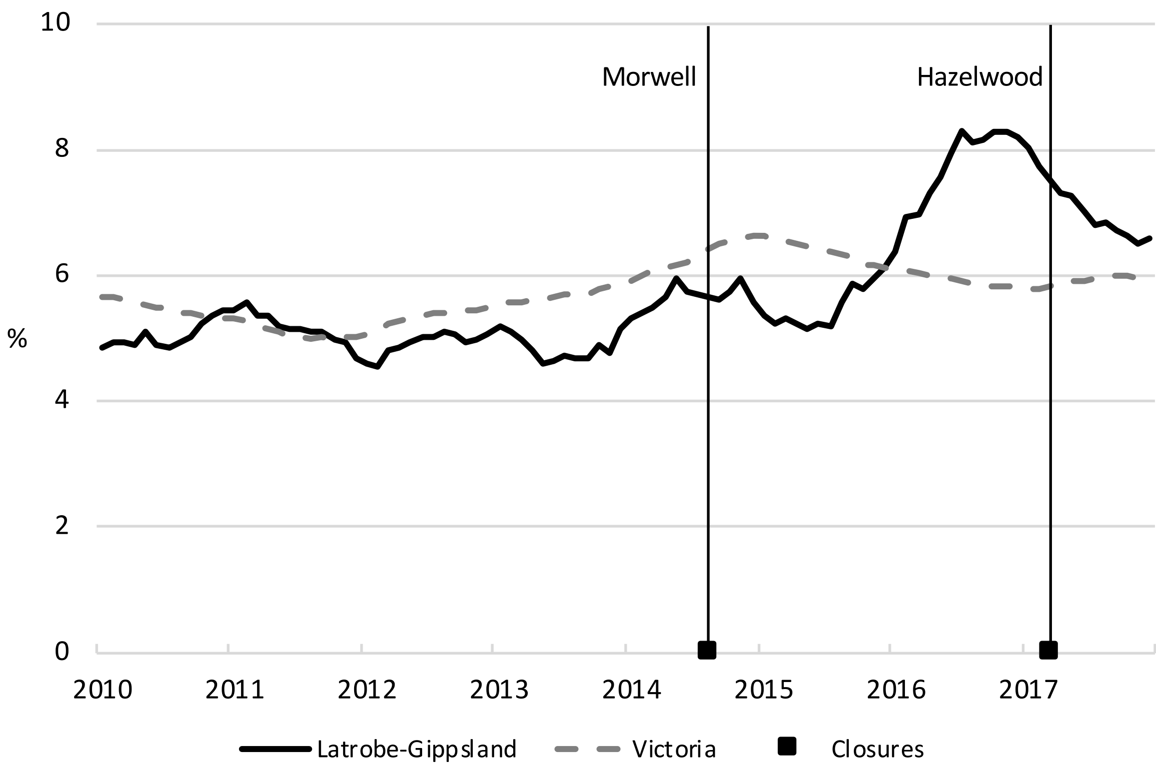
The Latrobe Valley has one of the world's largest endowments of brown coal, and has been Victoria's key region for electricity generation (State Government of Victoria 2012). The region experienced many job losses in the 1980s and 1990s as a result of corporatisation and privatisation of the State Electricity Commission (SECV; Weller 2012). Recent years have also seen relative stagnation; the Latrobe-Gippsland labour force was larger in 2011 than it is today (ABS 2018a).

Latrobe-Gippsland saw two coal-fired power station closures during our study period: Morwell power station (Energy Brix) in August 2014 and Hazelwood power station in March 2017. Hazelwood directly employed 750 workers (including contractors) at the time of its closure. Other notable events include the Hazelwood mine fire (February–March 2014) and the closure of the Carter Holt Harvey saw mill (mid-2017). Figure 6 shows that there was an uptick in the region's twelve-month average unemployment rate from 2015, and that it exceeded the state average by more than 2 percentage points in the second half of 2016. Interestingly, the Latrobe-Gippsland unemployment rate has been falling since the closure of the Hazelwood power station, although it remained above the state average as of the end of 2017.

Using SA2-level data, the average unemployment rate for the town of Morwell over the year to December 2017 was 17%, compared to 11% in 2013 (Department of Employment 2018). This saw Morwell have the 8th-highest unemployment rate among SA2 regions in Victoria in 2017, compared to the 24th-highest unemployment rate in 2013. This is a fairly clear case of increased local unemployment after coal-fired power station closures.

There are a number of possible explanations for why the Latrobe-Gippsland unemployment rate did not rise further in the months after the Hazelwood closure. One is that some workers were retained for site decommissioning, as mentioned. Some others received transfers to nearby coal-fired power stations under a worker transfer scheme formed under cooperation between the state government, unions, and the companies involved, and which received a financial subsidy from the state government (ACTU 2017). Concern about the fate of Hazelwood workers also saw the state and federal governments commit a substantial sum of money (more than $300 million) for infrastructure and other local initiatives (Wiseman *et al.* 2017). A Latrobe Valley Authority, funded by the state government, was established to manage the community's transition away from coal. Former employees also reportedly received an average separation payment of $330,000 (including leave payouts; Alcorn 2017), a large injection to the local economy. Nevertheless, some local impacts have been observable. For example, local retailers have suffered a loss of business, with some deciding to close their outlets (Field *et al.* 2018).

Figure 6. Twelve-month moving average unemployment rate, Latrobe-Gippsland, January 2010–December 2017



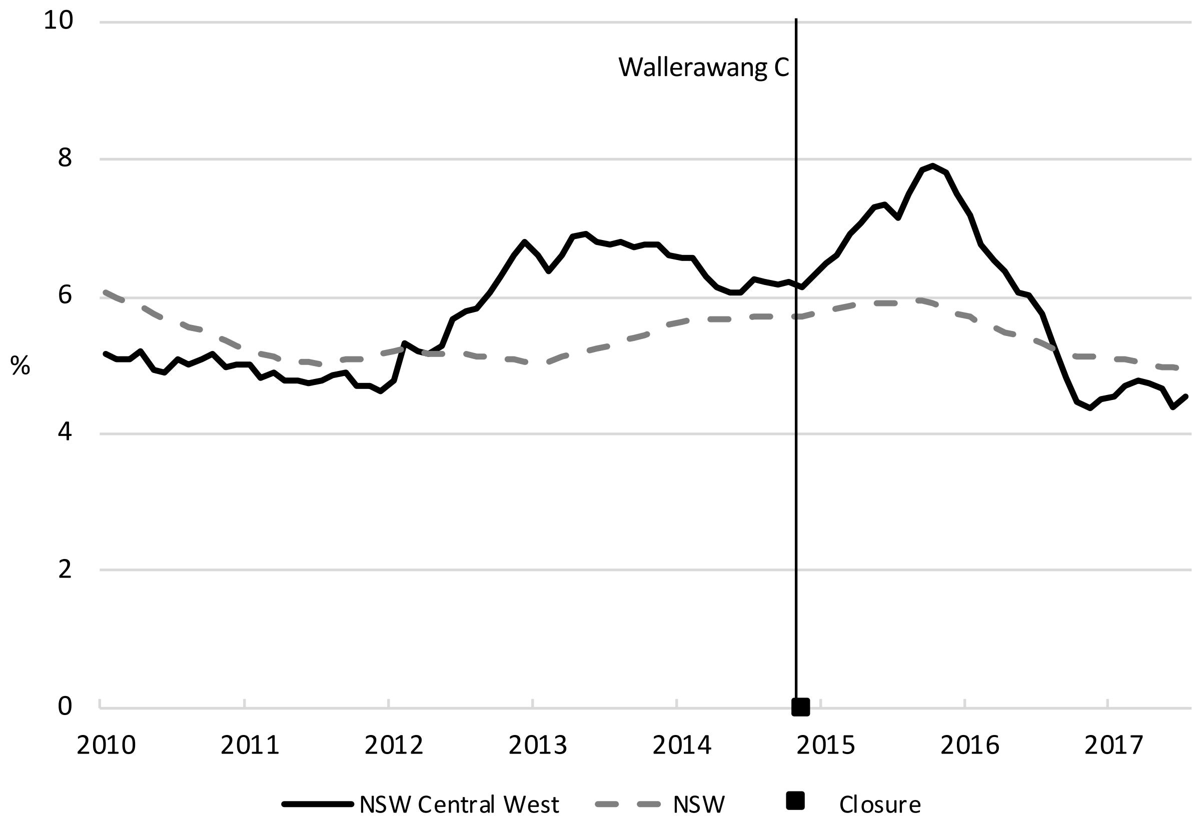
Source: (ABS 2018a).

5.2 Wallerawang C, NSW

The second-largest coal-fired power station closure during our study period was Wallerawang C, located north-west of Lithgow in NSW. One of its two 500 MW units was mothballed in January 2013, and the other in April 2014. Full closure occurred in November 2014. Around 300 people had been working for the plant (ABC News 2014). The closure precipitated the closure of the nearby Angus Place coal mine, which employed around 268 people. Not all lost their job; around 100 were transferred to another mine (Pearce 2014).

Figure 7 indicates a substantial increase in the twelve-month moving average unemployment rate in the local SA4 region (Central West NSW) following the closure of Wallerawang C. This only lasted around one year; the twelve-month moving average unemployment rate fell back below the state average by late 2016. The SA2 pattern (Lithgow Region) is similar, with the twelve-month moving average unemployment rate increasing from around 7% before the closure to more than 8% a year later, and then falling below 5% by late 2016 (Department of Employment 2018). These data show just how quickly local unemployment rates can rise and fall.

Figure 7. Twelve-month moving average unemployment rate, NSW Central West, January 2010–December 2017



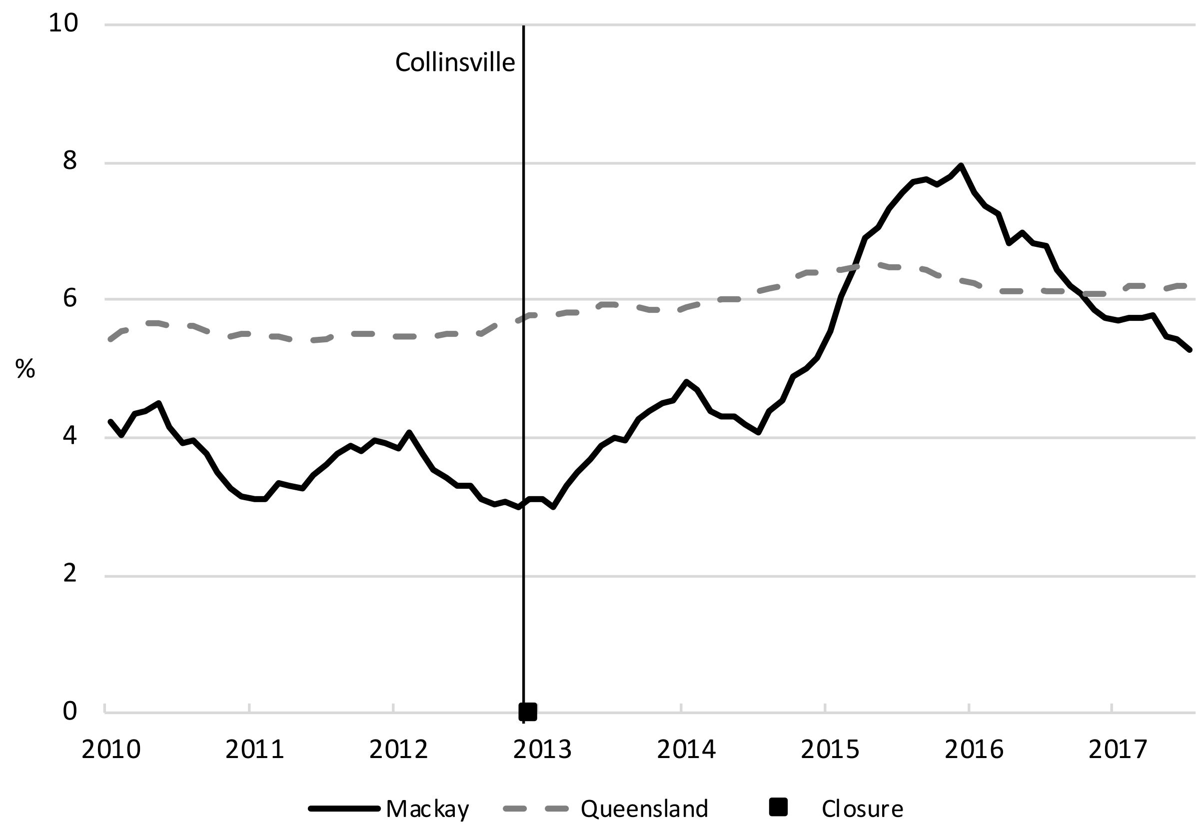
Source: (ABS 2018a).

5.3 Collinsville, Queensland

The closure of the 180 MW Collinsville power station in the Mackay region of Queensland in December 2012 led to the direct loss of 140 jobs (Andersen 2017). This, together with a lower coal export price, contributed to the financial difficulties faced by the nearby Collinsville mine. The mine closed in 2013, with around 300 people losing their job (McCarthy 2014). It has since re-opened. As can be seen in Figure 8, there has been an increase in the SA4 annual-average unemployment rate, from around 3% at the time of closure of the power station to a peak of 8%

in late 2015. By late 2016, Mackay had returned to a twelve-month moving average unemployment rate below the state average. At the SA2 level, there was a noticeable increase in unemployment in Collinsville, from a twelve-month moving average of less than 5% in late 2012 to one that exceeded 10% by late 2015. Collinsville's unemployment rate had reduced to around 6% by the end of 2017, helped by a recovery in the coal export price (Ker 2016).

Figure 8. Twelve-month moving average unemployment rate, Mackay, January 2010–December 2017



Source: (ABS 2018a).

6. Discussion

We have presented an event study of the effect of closing coal-fired power stations on local unemployment in Australia, a key topic of interest in the ongoing discussion about Australia's energy transition. We find that regions with one or more closed coal-fired power stations have tended to experience an increase in their unemployment rates of around 0.7 percentage points on average, *ceteris paribus*. The estimate is somewhat sensitive to specification choice. We find that the increase in unemployment persists beyond the initial six months, and also that some key regions have gone on to achieve reductions in their unemployment rate within a year or two. While our method is not able to study long-run effects (due to the relatively recent nature of the closures), Blanchard and Katz (1992) found that shocks to state-level unemployment rates in the US typically do not persist beyond five to ten years.

To a local region, an additional 0.7 percentage points of unemployment is material. In the context of the variations across time and space in Australia, however, it is fair to say that this effect is relatively modest. Among the six worst-performing SA4 regions in Australia in terms of the twelve-month average unemployment rate (as of December 2017), none are regions that have been affected by the closures of coal-fired power stations that we have studied here. This includes the Queensland Outback (12.2%), Wide Bay (9.3%), and Melbourne – West (9.1%; ABS 2018a). At the SA2 level, areas such as Palm Island (50% average unemployment rate in 2017), Kowanyama – Pormpuraaw (48%), and Yarrabah (47%) – indigenous communities in Queensland – have much higher unemployment rates than regions with closed coal-fired power stations (Department of Employment 2018). From an equity point of view, one might argue that more attention be paid to these regions rather than regions with power station closures.

It is also important to note that other episodes of structural change have had or will have larger overall implications for employment than the coal-fired power station closures that we have studied here. The reduction in manufacturing jobs in Australia since the mid-1980s exceeds 188,000, for example (ABS 2018a). In 2014, the Productivity Commission (2014) estimated that up to 40,000 people will lose their jobs due to the closure of Australia's vehicle manufacturers. Millions of jobs are at risk from automation over coming years (AlphaBeta 2017).

While jobs are being lost in some coal-fired power stations, new jobs are being created elsewhere in both the electricity sector and across the economy. An example of energy transition at the local level is the 150 MW Aurora solar energy project announced for Port Augusta, previously home to two coal-fired power stations. Construction, commencing in 2018, involves around 650 jobs (ABC News 2017). There are a number of other renewables projects also planned for the area (Morton 2018). Collinsville in Queensland is slated to be the home of several solar farms, including one at the site of the former coal-fired power station (Vorrath 2017).

There are several general principles for facilitating successful labour-market adjustments after closures of large employers in regional areas. These are not unique to energy-sector closures. A first is that it is important for a safety net to remain available. Second, it is important for workers to have access to high-quality retraining opportunities. These can often be organised within the private sector; retraining coal workers for jobs in the solar industry is often relatively inexpensive, for example (Louie and Pearce 2016). There is also a role for governments in ensuring that skill-upgrading opportunities are broadly available. Third, labour market adjustments would benefit from reduced barriers to mobility. A phase-out of stamp duty on homes is commonly recommended as a key way of improving geographical mobility in Australia (Henry *et al.* 2009; Productivity Commission 2017).

Worker transfer schemes, as used for workers at the former Hazelwood power station, offer a potential approach to ameliorate unemployment concerns associated with the energy transition. Where suitable, new energy-sector projects might be able to directly negotiate worker transfer arrangements with coal-fired power stations, without government subsidies.

While our results identify a legitimate concern over local economic and social outcomes after closures of large-scale energy-sector facilities, whether and to what extent this justifies special policy interventions is of considerable interest. Freebairn (2003) argued that issues of equity are best addressed by economy-wide policies focused on individuals and households rather than *ad hoc* region- and industry-specific initiatives by governments. The Productivity Commission (2017) cautioned against regional spending initiatives given concern about a lack of effectiveness, instead emphasising the need for a suitable overall policy environment for economic transition and growth. Nevertheless, recent experience in Australia shows that governments sometimes devote substantial resources to individual regions (Wiseman *et al.* 2017). It is important for any such funding to focus on boosting the productivity and economic prospects of targeted individuals and communities.

There are many potential avenues for further research. One is to use individual-level data to track labour market and other outcomes of retrenched workers over time. Such an approach would not capture the broader regional effects we examine here. Another is to estimate effects of Australia's coal-fired power station closures on local air quality. In several years' time it would be possible to revisit the issue studied in the current paper to determine how many years were required for local unemployment effects to dissipate. It may also be feasible to explore the use of alternative estimation approaches such as the synthetic control method. There is also considerable scope for research on transition strategies for coal-dependent communities (Spencer *et al.*, 2018).

References

ABC News (2014). Wallerawang jobs lost as unit shuts down, *ABC News*, 9 May, http://www.abc.net.au/news/2014-05-09/wang-jobs/5441360.

ABC News (2016). Queensland Nickel: Jobs of 550 workers terminated, administrators say; union says entitlements in doubt, *ABC News*, 11 March, http://www.abc.net.au/news/2016-03-10/administrators-queensland-nickel-terminate-most-of-550-jobs/7237240.

ABC News (2017). Fledgling solar thermal power industry '100 times' smaller than wind and photovoltaic, *ABC News*, 15 August, http://www.abc.net.au/news/2017-08-15/solar-thermal-a-new-industry-with-challenges/8805930.

Abraham, J. (2017). Just transitions for the miners: Labor environmentalism in the Ruhr and Appalachian coalfields, *New Political Science* 39(2), 218–240.

ACTU (2017). Government, unions and power station operators reach agreement on historic Latrobe Valley worker transfer scheme, Media Release, https://www.actu.org.au/actu-media/media-releases/2017/government-unions-and-power-station-operators-reach-agreement-on-historic-latrobe-valley-worker-transfer-scheme.

Alberta Government (2017). *Advisory Panel on Coal Communities*, https://www.alberta.ca/coal-communities.aspx.

Alcorn, G. (2017). Gloom in the valley as Hazelwood fades to black, *The Guardian*, 28 March, https://www.theguardian.com/australia-news/2017/mar/28/gloom-in-the-valley-as-hazelwood-fades-to-black.

AlphaBeta (2017). *The Automation Advantage*, Sydney and Singapore.

Andersen, J. (2017). Power plant at Collinsville, south-east of Townsville, could reopen, *Townsville Bulletin*, 14 February, http://www.townsvillebulletin.com.au/news/power-plant-at-collinsville-southeast-of-townsville-could-reopen/news-story/6b398d67680b3d2c0232034ca69901de.

Arranz, A.M. (2016). Hype among low-carbon technologies: Carbon capture and storage in comparison, *Global Environmental Change* 41, 124–141.

Arup, T. and Willingham, R. (2015). Alcoa to shut Anglesea coal mine and power plant, *The Age*, 12 May, http://www.theage.com.au/victoria/alcoa-to-shut-anglesea-coal-mine-and-power-plant-20150512-ggzgw9.html.

Australian Bureau of Statistics (2018a). *6291.0.55.001 - Labour Force, Australia, Detailed - Electronic Delivery, June 2018*, http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/6291.0.55.001June%202018?OpenDocument.

Australian Bureau of Statistics (2018b). *6291.0.55.003 - Labour Force, Australia, Detailed, Quarterly, May 2018*, http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/6291.0.55.003May%202018?OpenDocument.

Australian Bureau of Statistics (2018c). *6202.0 - Labour Force, Australia, Jul 2018*, http://www.abs.gov.au/ausstats/abs@.nsf/mf/6202.0.

Australian Bureau of Statistics (2018d). *6102.0.55.001 - Labour Statistics: Concepts, Sources and Methods, Feb 2018*, http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/6102.0.55.001~Feb%202018~Main%20Features~Unemployment~6.

Australian Bureau of Statistics (2018e). *Australian Statistical Geography Standard (ASGS)*, http://www.abs.gov.au/websitedbs/D3310114.nsf/home/Australian+Statistical+Geography+Standard+(ASGS).

Australian Energy Market Operator (2018). *Generation Information Page*, https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information.

Australian Government (2014). *Australian Energy Resource Assessment*, 2nd Edition, Canberra.

Australian Senate (2017). *Retirement of Coal Fired Power Stations: Final Report*, Environment and Communications References Committee, Commonwealth of Australia.

Black, D., McKinnish, T. and Sanders, S. (2005). The economic impact of the coal boom and bust, *Economic Journal* 115(503), 449–476.

Blakers, A., Lu, B. and Stocks, M. (2017). 100% renewable electricity in Australia, *Energy* 133, 471–482.

Blanchard, O. and Katz, L.F. (1992). Regional evolutions. *Brookings Papers on Economic Activity* 1.

Borland, J. (2015). The Australian labour market: The more things change …, *Australian Economic Review* 48(3), 225–242.

Bureau of Labor Statistics (2018). *Databases, Tables & Calculators by Subject*, https://data.bls.gov/timeseries/LNS14000000.

Callide Oxyfuel Project (2017). Callide A Power Station: A world first demonstration http://www.callideoxyfuel.com/Why/CallideAPowerStation/tabid/73/Default.aspx.

Carley, S., Evans, T.P. and Konisky, D.M. (2018). Adaptation, culture, and the energy transition in American coal country, *Energy Research & Social Science* 37, 133–139.

Chapman, B. and Lounkaew, K. (2013). How many jobs is 23,510, really? *Australian Journal of Labour Economics* 16(2), 259–275.

Connolly, E. and Lewis, C. (2010). Structural change in the Australian economy, *Bulletin*, Reserve Bank of Australia, September Quarter, 1–9.

Denis, A., Jotzo, F., Ferraro, S., Jones, A., Kautto, N., Kelly, R., Skarbek, A. and Thwaites, J. (2014). Pathways to deep decarbonisation in 2050: How Australia can prosper in a low carbon world, ClimateWorks Australia and ANU.

Department of Employment (2018). *Small Area Labour Markets Publication*, March, https://www.employment.gov.au/small-area-labour-markets-publication.

Department of the Environment and Energy (2018). *Australian Energy Statistics*, https://www.energy.gov.au/publications/australian-energy-statistics-table-o-electricity-generation-fuel-type-2016-17-and-2017.

Dickey, D.A., and Fuller, W.A. (1979). Distribution of the estimators for autoregressive time series with a unit root, *Journal of the American Statistical Association* 74(366), 427–431.

Diesendorf, M. (2004). Comparison of employment potential of the coal and wind power industries, *International Journal of Environment, Workplace and Employment* 1(1), 82–90.

Dixon, R., Shepherd, D. and Thomson, J. (2001). Regional unemployment disparities in Australia, *Regional Studies* 35(2), 93–102.

ENGIE (2016). Hazelwood power station in Australia to close at the end of March 2017, Press Release, 3 November, http://www.engie.com/en/journalists/press-releases/hazelwood-power-station-australia/.

Environmental Justice Australia (2017). *Toxic and Terminal: How the Regulation of Coal-Fired Power Stations Fails Australian Communities*, Carlton, Victoria.

Evans, G. (2007). A just transition from coal to renewable energy in the Hunter Valley of New South Wales, Australia, *International Journal of Environment, Workplace and Employment* 3(3-4), 175–194.

Fankhauser, S., Sehlleier, F. and Stern, N. (2008). Climate change, innovation and jobs, *Climate Policy* 8(4), 421–429.

Field, E., Lazzaro, K. and ABC Gippsland staff. (2018). Life in the Latrobe Valley one year on from Hazelwood power station shutdown, *ABC News*, 29 March, http://www.abc.net.au/news/2018-03-29/latrobe-valley-a-year-after-hazelwood-power-station-closure/9592346.

Figueres, C., Schellnhuber, H.J., Whiteman, G., Rockström, J., Hobley, A. and Rahmstorf, S. (2017). Three years to safeguard our climate, *Nature* 546(7660), 593–595.

Fleming, D.A. and Measham, T.G. (2014). Local job multipliers of mining, *Resources Policy* 41, 9–15.

Fleming, D.A. and Measham, T.G. (2015). Local economic impacts of an unconventional energy boom: The coal seam gas industry in Australia, *Australian Journal of Agricultural and Resource Economics* 59(1), 78–94.

Fleming, D.A., Measham, T.G. and Paredes, D. (2015). Understanding the resource curse (or blessing) across national and regional scales: Theory, empirical challenges and an application, *Australian Journal of Agricultural and Resource Economics* 59(4), 624–639.

Freebairn, J. (2003). Economic policy for rural and regional Australia, *Australian Journal of Agricultural and Resource Economics* 47(3), 389–414.

Georgeson, C. and Harrison, A.W. (2015). Regional impacts of the accelerated decline of the manufacturing sector in Australia, Research Paper 1/2015, Office of the Chief Economist, Department of Industry and Science, Australian Government.

Grudnoff, M. and Denniss, R. (2014). Will we let the sun shine in? Trends in the Australian solar industry, Policy Brief No. 65, Australia Institute.

Heaton, C. and Oslington, P. (2002). The contribution of structural shocks to Australian unemployment, *Economic Record* 78(243), 433–442.

Henry, K., Harmer, J., Piggott, J., Ridout, H. and Smith, G. (2009). *Australia's Future Tax System*, Commonwealth Treasury, Canberra.

Holmes à Court, S. (2017). Australian coal-fired power in free-fall, but they making off like bandits, *RenewEconomy*, http://reneweconomy.com.au/australian-coal-power-in-free-fall-but-they-making-off-like-bandits-2012/.

Investor Group on Climate Change (2017). *Coal, Carbon and the Community: Investing in a Just Transition*, October.

Johnstone, P. and Hielscher, S. (2017). Phasing out coal, sustaining coal communities? Living with technological decline in sustainability pathways, *Extractive Industries and Society* 4(3), 457–461.

Ker, P. (2016). The coal wheel turns in Collinsville, *Financial Review*, 12 October, http://www.afr.com/business/mining/coal/the-coal-wheel-turns-in-collinsville-20161012-gs0qj7.

Louie, E.P. and Pearce, J.M. (2016). Retraining investment for US transition from coal to solar photovoltaic employment, *Energy Economics* 57, 295–302.

McCarthy, J. (2014). Jobseekers swamp Collinsville coal mine which is set to reopen after 300 were laid off when it closed, *news.com.au*, 9 January.

Measham, T.G. and Fleming, D.A. (2014). Impacts of unconventional gas development on rural community decline. *Journal of Rural Studies* 36, 376–385.

Moretti, E. (2010). Local multipliers, *American Economic Review* 100(2), 373–377.

Morton, A. (2018). Life after coal: the South Australian city leading the way, *The Guardian*, 20 July, https://www.theguardian.com/environment/2018/jul/20/life-after-coal-the-south-australian-city-leading-the-way.

Pearce, M. (2014). Another coal mining blow for Lithgow: Angus Place mothballed, *ABC News*, 39 October, http://www.abc.net.au/news/2014-10-29/another-coal-mining-blow-for-lithgow3a-angus-place-mothballed/5850380.

Productivity Commission (2014). *Australia's Automotive Manufacturing Industry*, Inquiry Report, No. 70, Canberra.

Productivity Commission (2017). *Transitioning Regional Economies*, Study Report, Canberra.

Rosemberg, A. (2010). Building a just transition: The linkages between climate change and employment, *International Journal of Labour Research* 2(2), 125–161.

Spencer, T., Colombier, M., Sartor, O., Garg, A., Tiwari, V., Burton, J., Caetano, T., Green, F., Teng, F. and Wiseman, J. (2018). The 1.5°C target and coal sector transition: At the limits of societal feasibility. *Climate Policy* 18(3), 335–351.

State Government of Victoria (2012). *The Latrobe Valley Industry and Employment Roadmap*, Melbourne.

StatsNZ (2018). *Stats NZ*, http://www.stats.govt.nz/.

United Nations Framework Convention on Climate Change. (2015). *Paris Agreement*, https://unfccc.int/process/conferences/pastconferences/paris-climate-change-conference-november-2015/paris-agreement.

Vorrath, S. (2017). Another solar farm planned for Collinsville, as Blackrock buys in, *RenewEconomy*, 11 August, http://reneweconomy.com.au/another-solar-farm-planned-collinsville-blackrock-buys-40951/.

Watt Electrical News (2017). Muja AB set to close four units, https://www.wattelectricalnews.com/NEWS/Muja-AB-set-to-close-four-units/38785.

Wei, M., Patadia, S. and Kammen, D.M. (2010). Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?, *Energy Policy* 38, 919–931.

Weller, S. (2012). The regional dimensions of the 'transition to a low-carbon economy': The case of Australia's Latrobe Valley, *Regional Studies* 46(9), 1261–1272.

Williams, J.H., DeBenedictis, A., Ghanadan, R., Mahone, A., Moore, J., Morrow, W.R., Price, S. and Torn, M.S. (2012). The technology path to deep greenhouse gas emissions cuts by 2050: The pivotal role of electricity, *Science* 335(6064), 53–59.

Wiseman, J., Campbell, S. and Green, F. (2017). Prospects for a "just transition" away from coal-fired power generation in Australia: Learning from the closure of the Hazelwood Power Station, CCEP Working Paper 1708, November, Australian National University.

Wooldridge, J.M. (2006). *Introductory Econometrics: A Modern Approach*. 3rd edition. South-Western.

World Bank (2017). *World Development Indicators*, http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators.

Yang, M. and Chou, S.Y. (2018). The impact of environmental regulation on fetal health: Evidence from the shutdown of a coal-fired power plant located upwind of New Jersey. *Journal of Environmental Economics and Management* 89, 94–115.

Appendix A: SA4-level unemployment rates before and after the closures of coal-fired power stations

Coal-fired power station	SA4 region (2011 definition)	State	Month of closure	SA4-level unemployment rate after:				State unemployment rate after:			
				–1 years	0 years	1 year	2 years	–1 years	0 years	1 year	2 years
Swanbank B	Ipswich	QLD	May 2012	5.3	5.3	7.1	9.0	5.4	5.5	5.8	6.0
Munmorah	Central Coast	NSW	Jul. 2012	5.3	6.5	6.2	6.4	5.0	5.2	5.3	5.7
Collinsville	Mackay	QLD	Dec. 2012	3.9	3.1	4.6	5.2	5.5	5.8	5.8	6.4
Redbank	Hunter Valley excluding Newcastle	NSW	Aug. 2014	4.4	6.5	10.1	6.0	5.4	5.7	5.9	5.3
Morwell	Latrobe-Gippsland	VIC	Aug. 2014	4.7	5.7	5.6	8.1	5.7	6.4	6.3	5.9
Wallerawang C	NSW Central West	NSW	Nov. 2014	6.8	6.1	7.8	4.4	5.5	5.7	5.8	5.1
Callide A Unit 4	Fitzroy	QLD	Mar. 2015	6.2	5.6	6.8	6.6	5.9	6.5	6.1	6.2
Anglesea	Geelong	VIC	Aug. 2015	6.5	7.1	5.4	5.5	6.4	6.3	5.9	6.0
Northern	SA Outback	SA	May 2016	5.8	6.9	7.2	6.5	6.8	7.3	6.8	5.9
Playford	SA Outback	SA	May 2016	5.8	6.9	7.2	6.5	6.8	7.3	6.8	5.9
Hazelwood	Latrobe-Gippsland	VIC	Mar. 2017	7.0	7.5	6.7	-	6.0	5.8	5.8	-
Muja	Bunbury	WA	Sep. 2017	3.9	4.6	-	-	6.0	6.0	-	-
			Average	**5.5**	**6.0**	**6.8**	**6.4**	**5.9**	**6.1**	**6.0**	**5.8**

Note: Ordered by date of closure. Unemployment rate is the twelve-month average.

Appendix B: Definitions of explanatory variables

Dummy: Closed coal-fired power station: Equals 1 in the month of a region's first closure of a coal-fired power station during the study period, and thereafter. Otherwise, 0. A list of closures and regions is in Appendix A. Closure dates are in Table 1.

Closed coal-fired power stations (cumulative): The cumulative sum of coal-fired power station closures in our study period. Ranges from 0 to 2.

Dummy: Closed coal-fired power stations (180 MW or larger): Equals 1 if there has been cumulative closure of 180 MW or more of coal generation capacity in a region over our study period. Otherwise, 0.

Dummy: Closed coal-fired power station within last 6 months: Equals 1 if there has been a closure of a coal-fired power station within the last six months. Otherwise, 0.

Dummy: Closed coal-fired power station 6–12 months ago: Equals 1 if there was a closure of a coal-fired power station between six and 12 months ago. Otherwise, 0.

Dummy: Closed coal-fired power station ≥ 1 year ago: Equals 1 if there was a closure of a coal-fired power station in the region one year or more ago. Otherwise, 0.

Direct jobs lost in closed coal-fired power stations (and adjacent coal mines if part of same operation; '000; cumulative): Cumulative sum of direct job losses in coal-fired power stations and adjacent mines. Proxied by the number of people working in power stations and adjacent mines at the time of closure. It is important to note that some workers continued to be employed in decomissioning activities. Data gathered from newspaper reports. Jobs in adjacent mines only counted if they were part of the same operation.

Closed coal-fired power station capacity (cumulative; GW): Cumulative sum of closed coal-fired power station capacity in a region, in GW. Only increases upon full closure of a station. Calculated using data in Table 1.

Dummy: The year in advance of closure of a coal-fired power station: Equals 1 in the year prior to the closure of a coal-fired power station. Otherwise, 0.

Dummy: Closed vehicle manufacturing plant: Equals 1 if there has been a closure of a vehicle manufacturing plant since 2010. Otherwise, 0. Five occurred: Ford (Melbourne – North West), Ford (Geelong), Holden (Melbourne – Inner), Toyota (Melbourne – West), and Holden (Adelaide – North). We used the date of cessation of production.

Dummy: Closed nickel refinery: Equals 1 if there has been a closure of a nickel refinery since 2010. Otherwise, 0. One occurred: Palmer Nickel and Cobalt Refinery (Townsville). We used the date of entry into voluntary administration (January 2016).

Dummy: Closed alumina refinery or aluminium smelter: Equals 1 if there has been a closure of an alumina refinery or aluminium smelter since 2010. Otherwise, 0. Three occurred: Kurri Kurri (Hunter Valley excluding Newcastle), Gove (Northern Territory – Outback), Point Henry (Geelong). We used the date of cessation of production.

Dummy: Closed steel blast furnace: Equals 1 if there has been a closure of a steel blast furnace since 2010. Otherwise, 0. One occurred: Port Kembla (Illawarra).

Coal export price (US$ per metric ton): Equals 0 except in six regions with heavy reliance on coal exports: Hunter Valley excluding Newcastle, Newcastle and Lake Macquarie, NSW – Central West, Illawarra, Fitzroy, and Mackay. For these regions, the variable equals the average Newcastle/Port Kembla export price in US$ per metric ton from the World Bank (2018).