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# Closures of coal-fired power stations in Australia: local unemployment effects*

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Around one-third of Australia's coal-fired power stations closed between 2012 and 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, 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 on average there has been an increase in local unemployment of around 0.7 percentage points after closures of coal-fired power stations, an effect that tends to persist beyond the months immediately after closures. The findings raise questions about appropriate policy responses for dealing with local structural adjustment issues facing coal-reliant communities.

**Key words:** coal, electricity, labour, structural change, unemployment.

## 1. Introduction

At the turn of this century, coal-fired power supplied more than four-fifths of Australia's electricity. Since then, coal's contribution to Australia's electricity mix has fallen steadily, declining to 61 per cent in 2017 (Figure 1). An ageing coal-fired fleet, increased use of natural gas, policies to bring renewables onto the grid, the disadvantages associated with coal's emissions footprint, and slow progress in reducing the cost of carbon capture and storage (Arranz 2016) have each contributed to coal's decline. 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's (2018) list of committed projects does not include any coal-fired power stations.

As of 2010, Australia had 34 coal-fired power stations in operation or under refurbishment, as listed in Table 1. These ranged in size from Eraring

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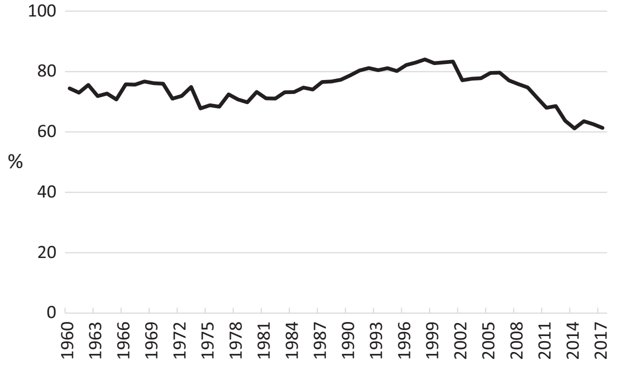


**Figure 1** Coal's contribution to Australia's electricity mix, 1960–2017. Source: World Bank (2017). Data for 2016 and 2017 are from the Department of the Environment and Energy (2018).

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 closures represented more than one-fifth of Australia's coal-fired power capacity. The largest to close was the Hazelwood power station (1,760 MW) in the Latrobe Valley, Victoria, in March 2017. No new coal-fired power station has opened since Bluewaters 2 power station in Western Australia (WA) in 2010.

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 cease operations 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.

Cutting carbon dioxide emissions in the electricity sector is typically at the heart of any overall decarbonisation strategy (Williams *et al*. 2012), with a transition to lower-carbon energy sources being necessary in order to have a chance of restricting global warming to 2°C or below (Figueres *et al*. 2017; Spencer *et al*. 2018). 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 the 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 relied on emissions-intensive industries. Coal-dependent regions are particularly exposed, especially the Latrobe Valley in Victoria, the Hunter Valley in NSW, and the Mackay and Fitzroy regions of Queensland.

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

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**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 |
| Millmerran | 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 Oxyfuel Project 2018). The list does not include Kwinana Cogeneration Plant in WA, which switched to primarily being fuelled by natural gas (ENGIE 2017). NSW, New South Wales; QLD, Queensland; SA, South Australia; VIC, Victoria; WA, Western Australia; —, em-dash.

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, aluminium 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 appears to be predominantly due to increased unemployment among males. Our method could in

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**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. [Colour figure can be viewed at wileyonlinelibrary.com]

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 of potential interest not only within Australia, 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).

Coal-mining regions have undergone structural declines that have led to social disadvantage in some key coal-mining countries overseas, including the United Kingdom (Johnstone and Hielscher 2017) and the United States (Carley *et al.* 2018). Spencer *et al.* (2018) concluded 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 adjustment.

Our paper adds to a literature on factors affecting unemployment in Australia. Among prior contributions, Dixon *et al.* (2001) reported that state-level disparities in unemployment rates tend to be largest when the national unemployment rate is low. Heaton and Oslington (2002) concluded that interindustry shocks have been the primary cause of changes in

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Australia's unemployment rate. 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 exacerbate local unemployment. Our paper is the first to examine the effects of coal-fired power station closures.

Our results complement estimates of multiplier effects from localised job losses. Black *et al*. (2005) used data for four states of the United States in the 1980s, finding that 0.35 jobs tended to be lost in local construction and services for every job lost 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 data from the Australian census, Fleming and Measham (2014) estimated that each new mining job leads to around seven jobs in other sectors in the same local government area (LGA). Fleming *et al*. (2015) also found evidence of positive local spillovers from jobs growth in mining.

Closures of coal-fired power stations are of particular interest because these stations are in some cases among the largest local employers. All of Australia's coal-fired power stations are located outside capital cities. The adaptive capacities of these regions are often weaker than is the case in capital cities (Productivity Commission 2017).

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

Approximately 64,300 people were employed in supplying electricity in Australia as of November 2017 (based on their main job; ABS 2018b). This accounted for only 0.5 per cent of the total number of employed people nationwide.[1] Most are employed at the transmission, distribution and retail levels. Around 94 per cent have full-time jobs, and almost three-quarters are male. Across Australia, another 51,500 people are employed in coal mining (Australian Bureau of Statistics 2018b), many working to supply coal for export.

Australia's seasonally-adjusted unemployment rate was 5.5 per cent in December 2017. This is below the 1978–2017 average of 6.9 per cent, but above the preglobal financial crisis low of 4.0 per cent (see Figure 3). It is also higher than the unemployment rates of New Zealand (4.5 per cent as of December 2017; StatsNZ 2018) and the United States (4.1 per cent; Bureau of Labor Statistics 2018). National data hide substantial variation among SA4 regions (Figure 4); the average monthly unemployment rate over the year to December 2017 ranged from 2.2 per cent in Sydney's Eastern Suburbs to 12.2

[1] The number is also small relative to the annual flow of people from employment to unemployment (Chapman and Lounkaew 2013) or the annual number of involuntary retrenchments across the national economy (around 355,000 in the year to February 2013; Productivity Commission 2014).

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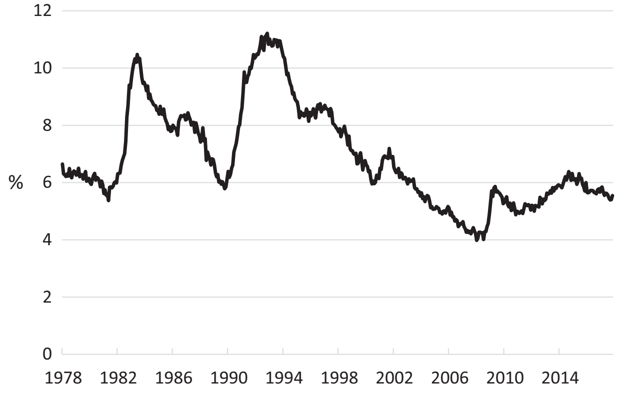


**Figure 3** Australia's unemployment rate, February 1978–December 2017. *Note:* Shows seasonally adjusted monthly series. Source: ABS (2018c).

per cent 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 approximately 88 per cent of employment (based on individuals' main job; Australian Bureau of Statistics 2018b), up from <55 per cent in 1900 (Connolly and Lewis 2010). Manufacturing employs 17 per cent fewer people than in the mid-1980s (Australian Bureau of Statistics 2018b). More than 12.4 million people were employed nationwide as of late 2017, more than ever before (Australian Bureau of Statistics 2018b). Historically, job losses in sunset occupations have thus been more than offset by new jobs.

From a national perspective, a transition from coal-fired electricity generation does not necessarily involve fewer jobs in electricity generation,

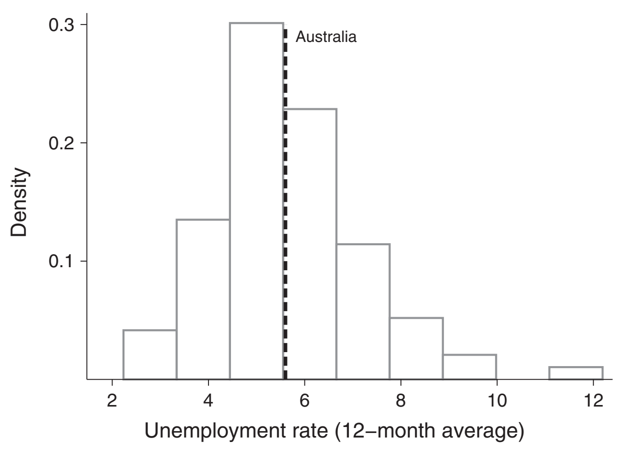


**Figure 4** Histogram of unemployment rate (12-month average) by SA4 region, December 2017. Data are for 87 SA4 regions. The Australian unemployment rate is also shown. Source: Australian Bureau of Statistics (2018a).

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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 needed to operate solar and wind farms, 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 the local community. Approximately 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 were retained for site decommissioning (Alcorn 2017), and some were transferred to other power stations. Net job losses represented around 0.4 per cent of the labour force of the Latrobe-Gippsland SA4 region and around 5 per cent of the total number of unemployed people in the region (Australian Bureau of Statistics 2018a).

In addition to direct job losses, indirect job losses might also be expected. These might occur elsewhere in the supply chain, such as at local coal mines, and also in industries supplying locally consumed goods and services (Black *et al.* 2005).[2] 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 in the same location. If there are limitations to geographical mobility, and if alternative employment is slow to emerge, local unemployment rates may rise.

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; sulphur dioxide; nitrogen oxide; lead, and mercury. These are the cause of health problems such as asthma, stroke, and cancer (Environmental Justice Australia 2017). The closure of coal-fired power stations will likely reduce these problems.[3] Some local industries – such as tourism and agriculture – may benefit, although this will likely take time to play out and may not lead to a reduction in the unemployment rate.[4] Our estimates will measure the net short-run effect of power station closures on the local unemployment rate.

[2] For example, the Angus Place coal mine in NSW was closed after the decommissioning of the Wallerawang C power station (Pearce 2014).

[3] See Yang and Chou (2018) for a case study from the United States.

[4] Reductions in pollution likely have employment effects that vary by sector and may also have implications for the labour force participation rate.

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## 3. Method and data

### 3.1 Estimation method

Our basic estimation model is:

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

where $U$ is the unemployment rate; $C$ is a binary variable equal to 0 prior to a coal-fired power station closure and 1 thereafter; $\boldsymbol{X}$ is a vector of controls; and $\varepsilon$ 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 key structural and time-specific factors that may affect 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, which 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 shocks to unemployment that are common across regions in any state in any month. The state-specific month dummies also deseasonalise the data. The Northern Territory and the Australian Capital Territory are handled as 'states', which means there are eight 'states' in our data set.[5]

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, as made available by the World Bank (2018). We use the 2-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 by splitting it into separate binary variables for subperiods. 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, which would require the use of five-yearly census data.

[5] Australia has six states and two territories.

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We avoid specific priors about the size of the effect of closures of coal-fired power stations *vis-à-vis* the effects of closures of other industrial 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'. It should be expected that unemployment effects are larger for closures of larger plants; closures that are more sudden; and closures in regions with fewer adaptation possibilities.

### 3.2 Data

Our analysis uses monthly labour force estimates by labour market region from the Australian Bureau of Statistics (2018a). These are available for 87 Statistical Area Level 4 (SA4) regions. The data are based on where people live rather than where they work, with 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 closure to an SA4 region is detailed in Appendix S1.[6]

The ABS data come from a monthly survey of approximately 26,000 dwellings, stratified by region. This represents around 0.3 per cent of the Australian civilian population aged 15 years and over (Australian Bureau of Statistics 2018a). The surveys are subject to sampling error, which introduces some data volatility, particularly for regions with small populations. As a consequence, the Australian Bureau of Statistics (2018a) recommends that analysis of regional labour force data should use 12-month averages. We heed this advice when presenting summary statistics in Figures 4–8. Our main estimates do not use 12-month averages, as there is no reason to think that sampling error for the dependent variable would be correlated with closures of coal-fired power stations. We find a similar result using the 12-month moving average, as will be documented.

The definition of unemployment in Australia is in line with the international definition; the unemployed are '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.

[6] An 88th SA4 spatial unit ('Other territories') exists, but labour force data are not available for this region. We use the terms 'local' and 'regional' interchangeably when referring to the SA4 level.

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The Department of Employment (2018) provides finer-grained estimates of unemployment rates by statistical area level 2 (SA2). Data are available for 2,090 SA2 regions on a quarterly basis, commencing in the final quarter of 2010. SA4-level data are better suited to our purposes given that they are available on a monthly basis and that SA4 regions are designed to approximate local labour markets (ABS 2018e). We do not study spillover effects across regions.

Our sample commences in January 2010 and extends to December 2017. The data set consists of 8,352 observations (87 regions * 96 months), making it a balanced panel. Only ten regions experienced a coal-fired power station closure during our study period. Descriptive statistics are in Appendix S2. Definitions of our explanatory variables are in Appendix S3. Our data set and estimation codes are available online.

Figure 5 presents initial evidence on the local unemployment effects of closing coal-fired power stations. A year prior to the closures, 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 on average similar to their state's (6 per cent, in 12-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 2 years. Our estimates show the effect of closures on local unemployment rates after conditioning on our controls and allow us to formally evaluate statistical significance.

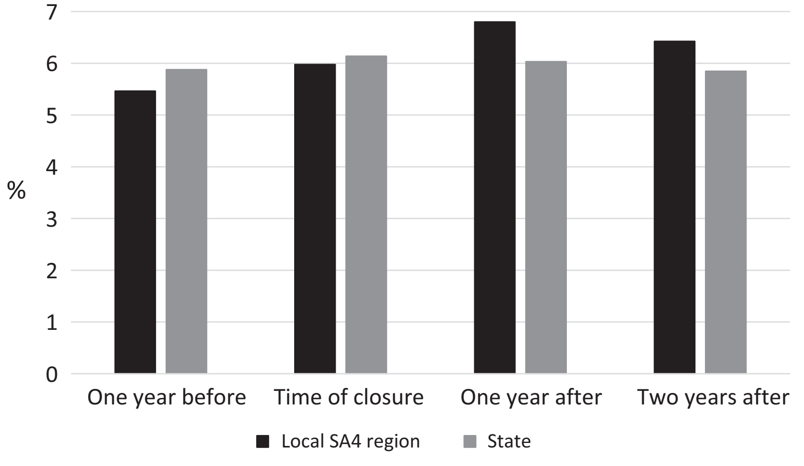


**Figure 5** Local versus state 12-month average unemployment rates following closures of coal-fired power stations. *Note:* Shows the 12-month average unemployment rate (Australian Bureau of Statistics 2018a). The data are averages for the twelve closures of coal-fired power stations listed in Table 1. The 'one year after' calculations are for only eleven closures, as at the time of analysis 1 year had yet to pass after the Muja power station closure. The 'two years after' calculations are for only 10 closures (excluding Hazelwood and Muja). The underlying data are in Appendix S1.

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### 3.3 Estimation issues

One issue is that some of the coal-fired power stations were mothballed prior to formal closure (e.g. Munmorah), operated below capacity (e.g. Morwell), and/or 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 make it 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 as indicative. An alternative would be to use the timings of mothballing decisions, although some staff are retained to maintain (and potentially operate) mothballed plants.

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. However, it is possible 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 possible that decisions to close power stations have been influenced by local economic conditions, which would introduce a potential endogeneity challenge. For example, reduced local demand for electricity might have induced a power station closure, or a station might have been squeezed by tight local labour market conditions. We expect this issue to be relatively slight given: (a) the stations supplied electricity to the broader grid; and (b) firms can 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, which are relatively exogenous. In some cases, however, 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 aluminium 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 rates. Instead, we seek to estimate average conditional effects of coal-fired power station closures as accurately as we can. Data availability issues lead us to focus on labour market implications rather than effects on income or well-being. Our estimates will be net of any ameliorating influence of government interventions.

Prior to running our estimations, we carried out Dickey and Fuller (1979) tests on the unemployment rates of 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

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criterion (with a maximum of four) and included a time trend. The results pointed to an absence of unit roots. We thus proceed to estimate our models in levels.

We also carried out a Hausman test to evaluate our choice of fixed effects over 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 are not overly concerned about degrees of freedom and wish to control for time-invariant factors, we continue to use fixed effects. Wooldridge (2006, p. 497) concludes that fixed effects are '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. The effect differs from zero at the 1 per cent significance level. The $R^2$ indicates that the variable explains only around 1 per cent of the variation in the unemployment rate. A low $R^2$ makes sense, as many other factors influence SA4-level unemployment rates.

Column 2 of Table 2 includes our controls. The coefficient for the coal-fired power station binary variable reduces to 0.7, significantly different from zero at the 5 per cent level. This is our headline result. The estimation also provides a strong positive coefficient (+1.8) for the closure of a nickel refinery, significant at the 1 per cent 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 jobs lost in these industries. Positive point estimates are obtained for the vehicle and aluminium plant variables, but they are not precisely estimated. The closures of vehicle manufacturing plants were in urban areas, which have larger SA4 populations and generally better prospects for switching to other jobs. A negative coefficient is obtained for the steel closure variable. Additional specifications (see Stata code) reveal an increase in the local unemployment rate in the first year after the single closure of a steel blast furnace in our sample, and that the unemployment rate fell after that. We find a negative coefficient for the coal export price, providing evidence that local unemployment in coal-exporting regions is directly affected by commodity price cycles. With the inclusion of control variables the $R^2$ increases to 0.44. The remaining estimations retain the full set of controls.

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**Table 2** Effects on the unemployment rate

Dependent variable: Unemployment rate$_{r,m}$

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| Closed coal-fired power station (binary)$_{r,m}$ | 0.89*** | 0.74** | | | | | | 0.71* |
| | (0.33) | (0.34) | | | | | | (0.38) |
| Closed coal-fired power stations (cumulative)$_{r,m}$ | | | 0.63** | | | | | |
| | | | (0.24) | | | | | |
| Closed coal-fired power stations (180 MW or larger; binary)$_{r,m}$ | | | | 0.86** | | | | |
| | | | | (0.42) | | | | |
| Closed coal-fired power station within last 6 months (binary)$_{r,m}$ | | | | | 0.64* | | | |
| | | | | | (0.34) | | | |
| Closed coal-fired power station 6–12 months ago (binary)$_{r,m}$ | | | | | 1.09** | | | |
| | | | | | (0.51) | | | |
| Closed coal-fired power station ≥1 year ago (binary)$_{r,m}$ | | | | | 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) | |
| The year in advance of closure of a coal-fired power station (binary)$_{r,m}$ | | | | | | | | −0.09 |
| | | | | | | | | (0.39) |
| Closed vehicle manufacturing plant (binary)$_{r,m}$ | | 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) |

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**Table 2** (*Continued*)

Dependent variable: Unemployment $rate_{r,m}$

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| Closed nickel refinery $(binary)_{r,m}$ | | 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) |
| Closed alumina refinery or aluminium smelter $(binary)_{r,m}$ | | 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) |
| Closed steel blast furnace $(binary)_{r,m}$ | | −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 $ton)_{r,m-2}$*Coal export region $(binary)_r$ | | −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 |

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. No. of observations: 8,352. No. of regions: 87. No. of months: 96. Time period: January 2010–December 2017.

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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 SA4 regions each had two closures. The coefficient reduces to 0.6. Column 4 uses a binary variable 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 the 5 per cent level. This suggests that our findings are not driven by the smallest closures.

Column 5 of Table 2 splits our coal-fired power station closure binary variable into three: one for the first 6 months after closure; one for the next 6 months; and one for thereafter. We obtain positive coefficients for each, with the largest and most statistically significant being for the second 6-month period (+1.1). We are thus able to conclude that the effect persists beyond the first 6 months postclosure (see also Figure 5). The effect is unlikely to be permanent, but we do not have an adequate time-series to explore long-run 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. A positive coefficient is obtained, but the 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, which is again not significant. Column 8 tests for an increase in the unemployment rate during the year prior to closures. We do not find a significant coefficient.

Table 3 uses alternative dependent variables. We revert to our initial explanatory variable. Column 1 uses the 12-month moving average unemployment rate instead of the same-month unemployment rate. A coefficient of +0.55 is obtained. A smaller coefficient was expected, as it takes time to have a major influence on the 12-month moving average. 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 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 per cent level. Columns 7–9 estimate effects for the number of employed people, the participation rate and the size of the labour force. The estimates do not reveal significant effects. Additional robustness checks are discussed in Appendix S4.

Our results are more precise using unemployment rate data rather than count data. This may be due to the accuracy of the underlying data, as it is likely to be easier to measure rates than stocks. On average, the Australian Bureau of Statistics (2018a) surveys slightly <300 households per SA4 region per month.

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**Table 3** Effects on other labour market indicators

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Unemployment $\text{rate}_{r,m}$ | | | Unemployed total ('000)$_{r,m}$ | | | Employed total ('000 people)$_{r,m}$ | Participation $\text{rate}_{r,m}$ | Labour $\text{force}_{r,m}$ |
| | Twelve-month moving average | Male | Female | People | Males | Females | | | |
| Closed coal-fired power station (binary)$_{r,m}$ | 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 |

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. No. of observations: 8,352. No. of regions: 87. No. of months: 96. Time period: January 2010–December 2017.

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## 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 (Australian Bureau of Statistics 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 local 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 increase in the region's 12-month average unemployment rate from 2015, which rose to exceed the state average by more than 2 percentage points in the second half of 2016. Interestingly, the Latrobe-Gippsland unemployment rate fell after the closure of the Hazelwood power station, although 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 per cent, compared to 11 per cent in 2013 (Department of Employment 2018). This saw Morwell have the 8$^{th}$-highest unemployment rate among SA2 regions in Victoria in 2017,

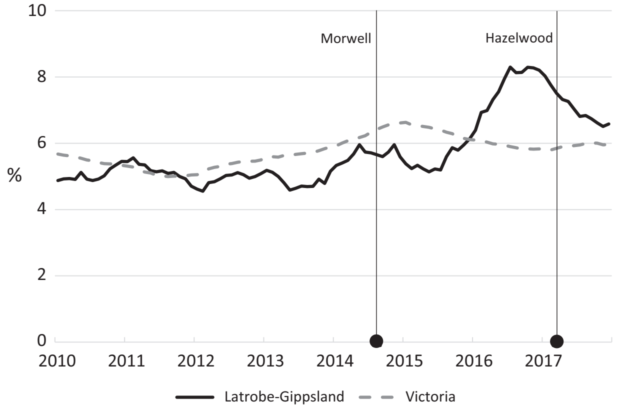


**Figure 6** Twelve-month moving average unemployment rate, Latrobe-Gippsland, January 2010–December 2017. Source: Australian Bureau of Statistics (2018a). The vertical lines represent closures of coal-fired power stations.

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compared to the 24th-highest unemployment rate in 2013. This is a fairly clear case of increased local unemployment in the period after coal-fired power station closures.

There are a number of possible explanations for why the Latrobe-Gippsland unemployment rate did not increase 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 power stations under a worker transfer scheme established by the state government, unions and the companies involved (ACTU 2017). Former employees reportedly received an average separation payment of $330,000, including leave payouts (Alcorn 2017), a large injection to the local economy. Concern about the fate of Hazelwood workers also saw the state and federal governments commit more than $300 million for infrastructure and other local initiatives (Wiseman *et al.* 2017). A Latrobe Valley Authority was established to manage the community's transition from coal. Nevertheless, some local impacts have been observable. For example, local retailers have suffered a loss of business, and some have closed (Field and Lazzaro 2018).

### 5.2 Wallerawang C, NSW

The second-largest coal-fired power station closure during our study 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. Approximately 300 people had been working at the plant (ABC News 2014). The closure precipitated the closure of the nearby Angus Place coal mine, which employed around 268 people. Around 100 of these workers were transferred to another mine (Pearce 2014).

Figure 7 indicates a substantial increase in the 12-month moving average unemployment rate in the local SA4 region (Central West NSW) following the closure of Wallerawang C. This only lasted around 1 year; the 12-month moving average unemployment rate fell back below the state average by late 2016. The SA2 pattern (Lithgow Region) is similar, with the 12-month moving average unemployment rate increasing from around 7 per cent before the closure to more than 8 per cent a year later, and then falling below 5 per cent by late 2016 (Department of Employment 2018). These data show just how quickly local unemployment rates can rise and fall.

### 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

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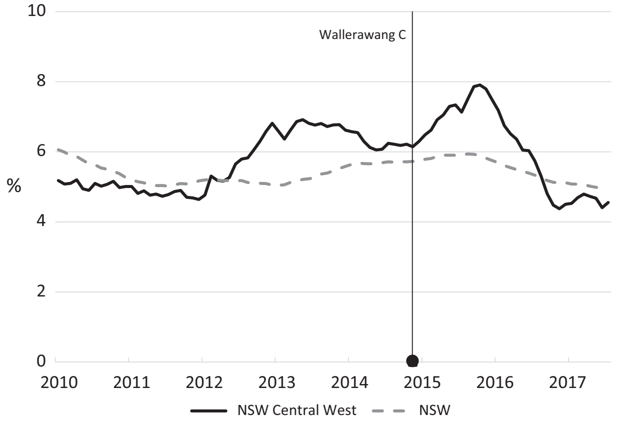


**Figure 7** Twelve-month moving average unemployment rate, NSW Central West, January 2010–December 2017. Source: Australian Bureau of Statistics (2018a). The vertical line represents a closure of a coal-fired power station.

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 per cent at the time of closure of the power station to a peak of 8 per cent in late 2015. By late 2016, Mackay had returned to a 12-month moving average unemployment rate below the state average. At the SA2 level, there was a noticeable increase in the unemployment rate in Collinsville, from a 12-month moving average of less than 5 per cent in late 2012 to one that exceeded 10 per cent by late 2015. Collinsville's unemployment rate had reduced to around 6 per cent by the end of 2017, helped by a recovery in the coal export price (Ker 2016).

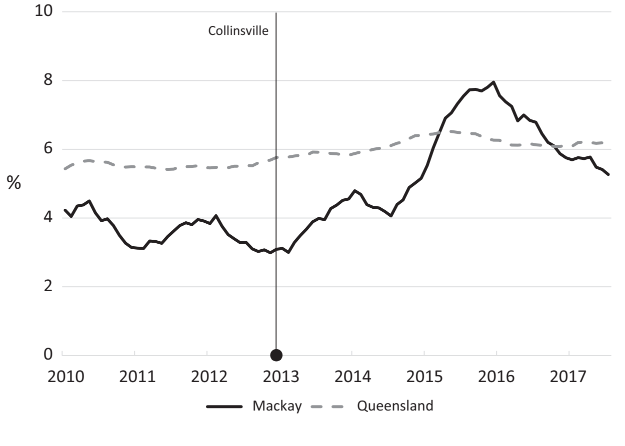


**Figure 8** Twelve-month moving average unemployment rate, Mackay, January 2010–December 2017. Source: Australian Bureau of Statistics (2018a). The vertical line represents a closure of a coal-fired power station.

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## 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 energy transition. We found 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*. An increase in unemployment rate is detectable beyond 6 months after closures, although some key regions have gone on to achieve reductions within a year or two. The relatively recent nature of the closures in our data set makes it difficult to study long-run effects. Blanchard and Katz (1992) found that shocks to state-level unemployment rates in the United States typically do not persist beyond 5–10 years.

To a local region, an additional 0.7 percentage points of unemployment is material. However, other factors explain most of the variation in unemployment rates across time and space. Among the six worst-performing SA4 regions in terms of 12-month average unemployment rate (as of December 2017), none had a closure of a coal-fired power station. This includes the Queensland Outback (12.2 per cent), Wide Bay (9.3 per cent) and Melbourne – West (9.1 per cent; Australian Bureau of Statistics 2018a). At the SA2 level, indigenous communities in Queensland such as Palm Island (50 per cent average unemployment rate in 2017) and Kowanyama – Pormpuraaw (48 per cent) 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 attention should primarily be paid to these regions.

It is 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. In 2014, the Productivity Commission (2014) estimated that up to 40,000 people would lose their jobs due to the closure of Australia's vehicle manufacturers. Millions of jobs are potentially at risk from automation over coming years (AlphaBeta 2017), although estimates of the effects of automation vary widely.

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 this 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). A number of other renewables projects are also planned for the area (Morton 2018). Collinsville will be home to several solar farms, including one at the site of the former coal-fired power station (Vorrath 2017).

While our results identify a legitimate concern over local outcomes after closures of energy-sector facilities, 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

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and households rather than *ad hoc* government initiatives on a region- or industry-specific basis. The Productivity Commission (2017) expressed concern about the effectiveness of regional initiatives, instead emphasising the need for a suitable overall environment for economic adjustment and growth. Nevertheless, recent experience shows that governments sometimes devote substantial resources to regional initiatives (Wiseman *et al*. 2017). It is important for any such funding to focus on boosting the productivity and economic prospects of individuals and communities.

One potential avenue for future research is to use individual-level data to track the labour market and other outcomes of retrenched workers over time. Another is to estimate the effects of coal-fired power station closures on local air quality and on migration patterns. It may also be feasible to explore the use of alternative estimation approaches such as the synthetic control method.

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## Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article:

**Appendix S1.** SA4-level unemployment rates before and after closures of coal-fired power stations.

**Appendix S2.** Descriptive statistics.

**Appendix S3.** Definitions of explanatory variables.

**Appendix S4.** Robustness checks.

**Table S1.** Excluding individual regions.

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