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# Leaving Someone Behind: Coal Phase-Out in South Korea

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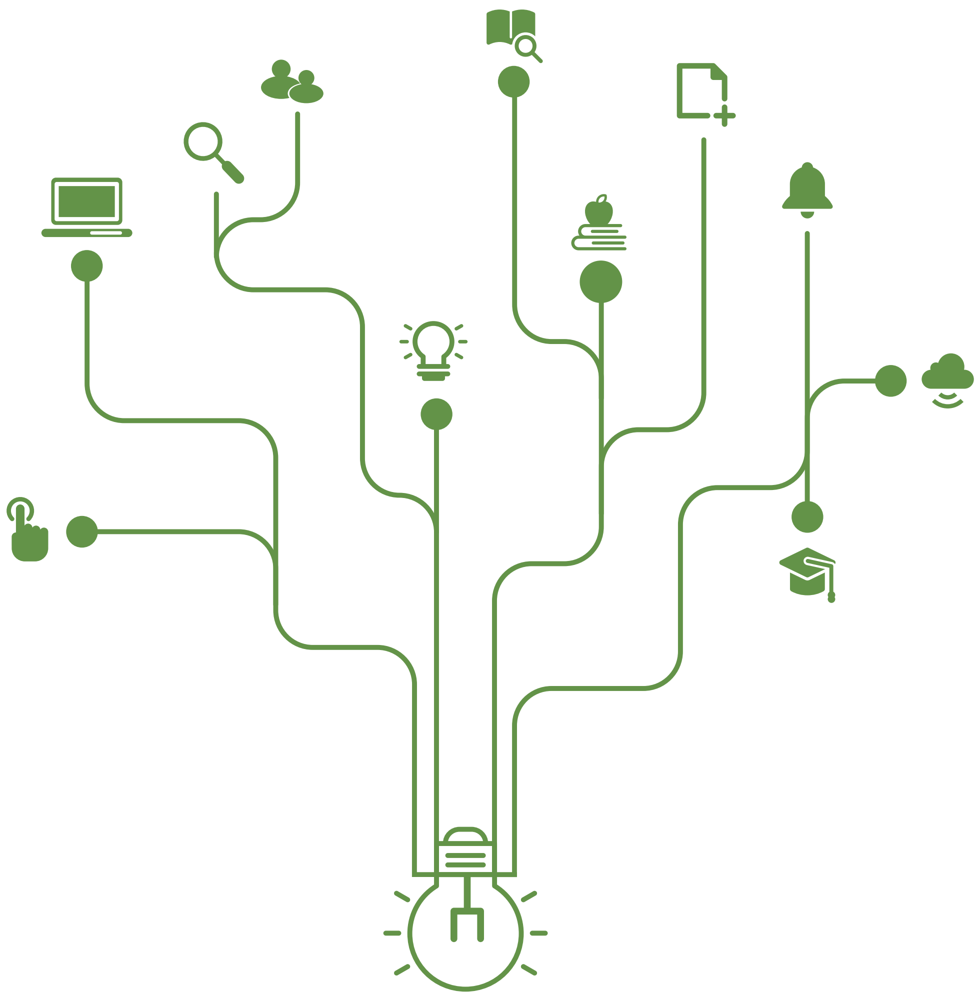

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# Leaving Someone Behind: Coal Phase-Out in South Korea

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This study estimates the effect of coal power plant phase-out on employment in South Korea. We employ the difference-in-difference design to infer causality. We find that the phase-out does not affect displaced workers at coal power plants in Seocheon. However, the changes had an unequal impact across industries. We also find a decrease in female and less educated manufacturing workers and an increase in male construction workers. These ripple effects highlight the winners and losers of the coal phase-out in Seocheon. The policy must be inclusive to ensure that no one is left behind.

***Keywords***— Coal phase-out; Employment; South Korea; Difference-in-differences

***JEL***— Q4, L1, L5, H4

# 1 Introduction

The combustion of coal for electricity generation is one of the major contributors to greenhouse gas (GHG) emissions and air pollution. To reduce these harmful gases, there is a growing movement toward the reduction and phase-out of coal-based electricity and the transition to low-carbon energy technologies. However, this phasing out effort poses challenges that would be unevenly borne by various stakeholders (e.g., Diluiso et al., 2021; Johnson et al., 2015; Ohlendorf et al., 2022), notably including potential job losses during the transition that would be more severe for workers in the affected region. In recognition of this concern, the International Labour Organization calls for social protection for job losses and displacement, which is crucial for just transition (ILO, 2015).

Several studies have documented the effects of coal phase-out on employment (Jolley et al., 2019; Oei et al., 2020; Pai et al., 2021) and the welfare consequences of unemployment (Haywood et al., 2024; Rud et al., 2024).[1] Other studies show that phasing out coal leads to substantial reallocation of workers across sectors (Beatty and Fothergill, 1996; Beatty et al., 2007). In addition, the potential benefits and costs of the withdrawal from coal use are not distributed equally. For example, Aragón et al. (2018) finds that the collapse of the coal industry in the United Kingdom disproportionately impacted female workers, while Haywood et al. (2024) highlighted that the welfare costs of job loss vary between different age-education groups. These findings have advanced our understanding of the direct and indirect employment impacts of coal phase-out, enabling policymakers to identify potential 'winners' and 'losers' and design safeguards for achieving a just transition to renewable energy sources.

However, evidence in this area remains limited, and further research is needed to fully understand the implications of coal phase-out, particularly across diverse international contexts. This study contributes to the growing yet still nascent body of evidence by examining the impact of coal power plant closures on employment in South Korea. In July 2016, the Ministry of Trade, Industry and Energy (MOTIE) announced the phased closure of ten 30-year-old power plants. As part of this plan, two coal power plants in Seocheon were permanently closed in September 2017, creating a quasi-experimental setting.[2] This case study offers the first causal evidence of coal phase-out effects on employment in Korea, a country characterized by high labor market rigidity and relatively low job mobility. By adding this case to the growing body of literature, we attempt to enhance the understanding of how coal phase-out policies operate in different labor market

[1] Existing studies report mixed results about the employment effects of environmental policy. For instance, Berman and Bui (2001) report ambiguous results from an analysis of California plant-level data. While Morgenstern et al. (2002) concluded that the regulated industries did not see significant employment changes, Curtis (2018) identifies negative employment impacts of cap-and-trade and NOx budget trading policies. Other research on the Clean Air Act Amendments (CAAA) found that failure to meet the National Ambient Air Quality Standards (NAAQS) led to job and income losses (Greenstone, 2002; Kahn and Mansur, 2013; Walker, 2011, 2013).

[2] While there are other cases of closure (e.g., Boryeong units 1 and 2, Honam units 1 and 2, Samcheonpo units 1 and 2, Yeongdong units 1 and 2), it is difficult to estimate the effect of coal power plant phase-out on employment with our data because the closure timing was too late, or they converted to environmentally friendly power plants (e.g., replacement of coal with natural gas). Thus, we consider them less suitable for a quasi-experimental study.

contexts.

We employ the difference-in-differences (DD) design to compare the average employment status of Seocheon residents with those living in the surrounding areas, before and after the closure of the coal power plant. The key identifying assumption is that employment trends would have been similar in both areas without the closure, a hypothesis we validate using an event-study specification. To strengthen our analysis, we include additional robustness checks, such as using regions with power plants as alternative control groups and employing the synthetic control method (SCM) that does not require the parallel trends assumption.

Our findings indicate that the coal phase-out in Korea had little overall impact on regional employment, but significantly affected various sectors and demographic groups. While employment in the power generation industry remained stable, the likelihood of working in manufacturing declined, and employment in construction increased. These sectoral shifts align with prior studies suggesting that plant closures create ripple effects across related industries (Black et al., 2005).

We also find heterogeneous effects across demographic groups. The closure increased employment opportunities for men but reduced them for women, similar to patterns observed in the United Kingdom's coal industry (Aragón et al., 2018). Furthermore, permanent employment, serving as a proxy for job quality, declined more among women, less-educated workers, and older individuals. These findings suggest that workers with limited skills face greater difficulty adapting to employment changes, underscoring the need for targeted support within just transition policies.

This study makes three contributions. First, it provides the first causal evidence on the labor market effects of coal phase-out in Korea, addressing a significant research gap. While there has been extensive literature on the effects of environmental regulation on employment (e.g., Berman and Bui, 2001; Walker, 2013), there has been a lack of research on coal phase-out on the labor market in the Korean context. Second, it highlights the *ripple effects* of coal plant closures, consistent with prior findings in other contexts, such as Germany (Thomas, 2002). Finally, our research informs the policy debate on just transition by illustrating the unintended employment consequences of coal phase-out and the importance of holistic support for affected workers. Our findings also contribute to the body of literature on just transition (e.g., Healy and Barry, 2017; Sharma and Banerjee, 2021), a concept that originates from the discourses of environmental justice (e.g., Agyeman et al., 2016) and climate justice (e.g., Kalt, 2021).

The remainder of the paper is organized as follows. In Section 2, we review the empirical contexts and describe the data. Section 3 presents our estimation strategy. In Section 4, we present our estimation results and robustness checks. In Section 5, we conclude and suggest future research directions.

## 2 Background and Data

## 2.1 Background

Coal was the largest power source in Korea's total electricity production during the 2010s (KEEI, 2023). To reduce GHG emissions and improve air quality, the Korean government has implemented policies aimed at phasing out coal and expanding low-carbon energy sources (Hyun et al., 2023). For example, in July 2016, the MOTIE announced the phase-out of 10 coal power plants older than 30 years.[3]

Among these were two coal power plants in Seocheon, Units 1 and 2 (the old units), that were originally built in 1983 to reduce the country's reliance on imported oil. Together, these plants had a total power generation capacity of 400 MW and utilized anthracite, the coal type with the highest carbon content (Mobley, 2001). Initially slated for closure in 2018, their decommissioning was accelerated after the inauguration of a new administration in May 2017, which prioritized transitioning away from coal and nuclear energy. Both units were permanently closed in July 2017 after following a one-month trial shutdown, as shown in Figure 1.

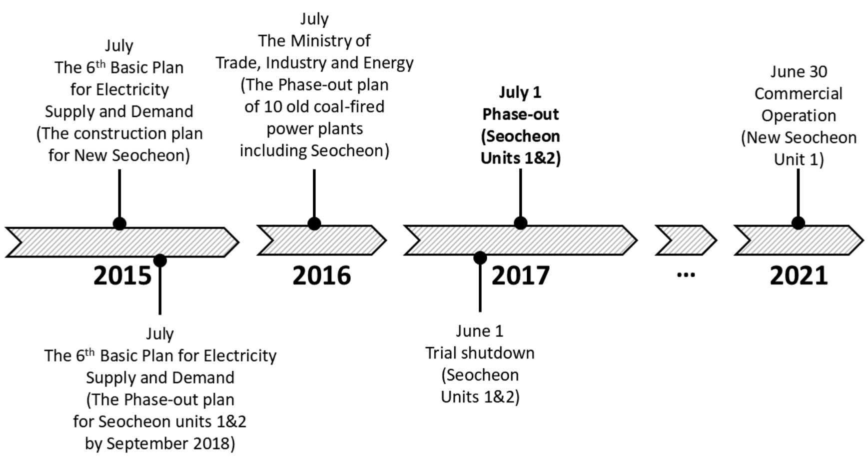



Figure 1: Timeline of Coal Phase-out in Seocheon

Meanwhile, in 2016, the government approved the construction of the New Seocheon Power Plant Unit 1 (the new unit) in the same area. This decision was based on the sixth Basic Plan for Long-Term Electricity Supply and Demand, announced in February 2013 (KEEI, 2023). The new unit began its operation on June 30, 2021. It is an ultra-supercritical plant fueled by bituminous coal with a maximum capacity of 1,000 MW. Compared to the old units, the new plant is expected to achieve higher production efficiency while producing fewer GHG emissions.

During the energy transition, ensuring employment of the worker from the old units emerged as a significant policy concern (Ecoview, 2017). The workforce at the old plant included permanent employees hired by

[3]The Korean government decided to shut down 10 coal power plants that are over thirty years old, including Seocheon Power Plant Units 1 and 2, Samcheonpo Power Plant Units 1 and 2, Honam Power Plant Units 1 and 2, Boryeong Power Plant Units 1 and 2, and Yeongdong Power Plant Units 1 and 2.

Korea Midland Power, a state-owned enterprise, as well as workers employed by primary and secondary subcontractors. Although permanent employees were guaranteed a complete reassignment to other power plants, some of their subcontracted counterparts faced job losses due to the closure of the old units (Oh et al., 2022). Recognizing the vulnerability of these workers, the Ministry of Employment and Labor announced the *Measures to Support a Just Labor Transition in Response to Changes in the Industrial Structure* in July 2021. This initiative includes reeducation and training programs designed to support workers transitioning from the coal power sector (MOEL, 2021). However, it does not extend to workers in other related sectors, which motivates this study to explore the direct and indirect costs associated with the closure of coal plants.

## 2.2 Data

We use data from the Local Area Labor Force Survey to estimate the employment impact of the Seocheon coal power plant on the plant itself and related industries across multiple regions, including Seocheon and its surrounding areas (KOSTAT, 2024). Collected biannually by Statistics Korea in April and October, this repeated cross-sectional survey provides individual-level data on household members aged 15 or older, covering demographics, employment status, and job-related details such as industry classification, wages, and workplace location.

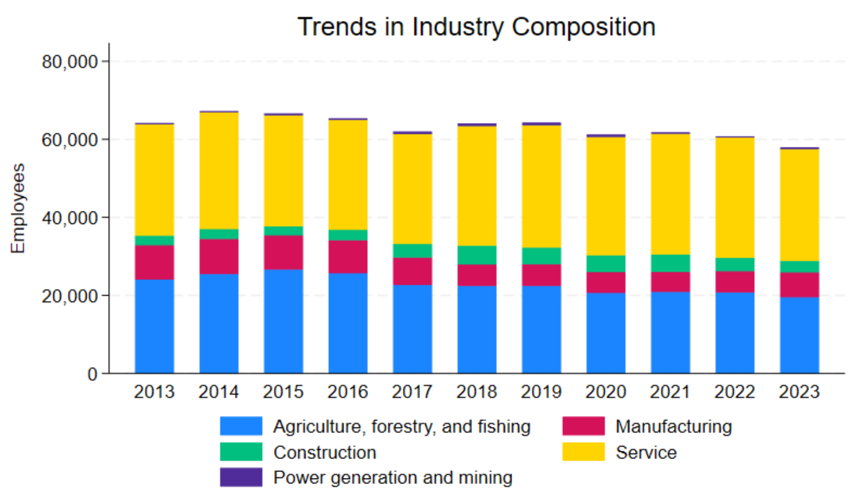



Figure 2: Industry Composition in Seocheon

Figure 2 highlights Seocheon's industrial composition, revealing that it is predominantly agricultural, with a large share of local workers employed in agriculture, forestry, and fishing. Other industries (e.g., manufacturing, construction, and services) are present but comparatively smaller. This distribution underscores the region's heavy reliance on primary sectors and provides context for examining how coal plant closures may generate ripple effects on a largely agriculture-based economy.

Our analysis draws on comparing Seocheon, directly hit by the closure, and neighboring cities and counties.

Observations are grouped into three categories based on the place of residence: the treatment group, the first control group (Control 1), and the second control group (Control 2), as shown in Figure 3. Seocheon, where the coal power plant is located, is the treatment group. Control 1 consists of nearby areas, such as Boryeong, Buyeo, Nonsan, Gunsan and Iksan. Control 2 covers a broader area, encompassing Hongseong, Cheongyang, Gyeryong, Wanju, Jeonju, Gimje, Buan and the regions within Control 1.

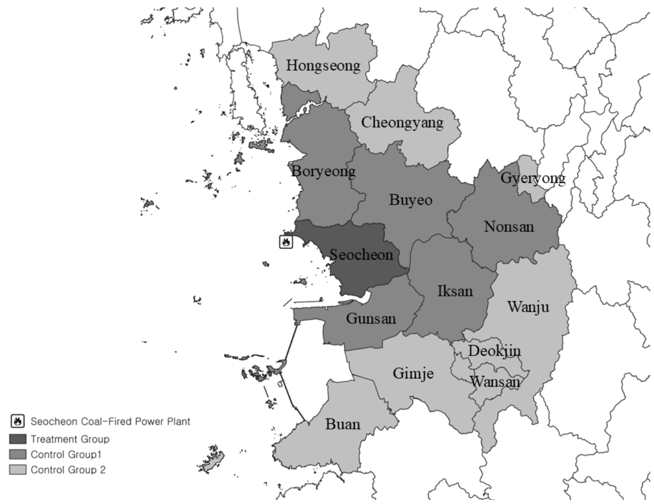



Figure 3: Map of Treatment and Control Areas

We define the treated and control areas based on their distance from the Seocheon power plant, following Kahn and Mansur (2013), which recommends a range of 45-65 km for establishing causality. Other studies have used different radii to identify treated and control areas. For example, Jofre-Monseny et al. (2018) employs a 10 km radius in Spain, where 8,122 municipalities exist in a relatively compact geography. In contrast, Korea, though half the size of Spain, has 260 municipalities, making a 45-65 km range reasonable for defining control groups. Similarly, Zhang et al. (2022) uses a 16 km radius to study health effects, reflecting the need to capture exposure to air pollutants within close proximity. Drawing on these contexts, we adopt a larger radius to ensure that our analysis captures broader labor market impacts.

Table 1 presents summary statistics for Seocheon (treatment) and its two control groups. The treatment area features a higher labor force participation rate and a notably older, less-educated population. Compared to the controls, Seocheon also has a larger share of workers in agriculture and fewer in manufacturing and services. These differences highlight the region's distinctive labor market characteristics and underscore the need to account for demographic and industry composition in our analysis.

## Table 1: Summary Statistics

Panel A. Before the Coal Power Plant Phase-out

| | Treatment | | Control 1 | | Control 2 | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| ***Labor Market Outcomes*** | | | | | | |
| Labor Force Participation (=1) | 0.660 | 0.474 | 0.594 | 0.491 | 0.611 | 0.487 |
| Employment Status (=1) | 0.653 | 0.476 | 0.587 | 0.492 | 0.604 | 0.489 |
| Monthly Wage (10,000 won) | 198.468 | 130.305 | 193.312 | 121.044 | 197.159 | 130.928 |
| ***Personal Characteristics*** | | | | | | |
| Male (=1) | 0.457 | 0.498 | 0.469 | 0.499 | 0.461 | 0.499 |
| Age | 57.621 | 18.313 | 52.253 | 18.833 | 52.684 | 19.091 |
| ***Education*** | | | | | | |
| Elementary School or Below (=1) | 0.416 | 0.493 | 0.288 | 0.453 | 0.298 | 0.458 |
| Middle School (=1) | 0.145 | 0.352 | 0.133 | 0.339 | 0.126 | 0.331 |
| High School (=1) | 0.275 | 0.447 | 0.323 | 0.467 | 0.308 | 0.462 |
| College or Above (=1) | 0.163 | 0.370 | 0.257 | 0.437 | 0.268 | 0.443 |
| ***Industry Share*** | | | | | | |
| Agriculture, forestry, and fishing (%) | 43.2 | 49.5 | 28.3 | 45.1 | 32.3 | 46.8 |
| Manufacturing (%) | 11.7 | 32.1 | 14.0 | 34.7 | 11.5 | 31.9 |
| Construction (%) | 3.5 | 18.4 | 6.1 | 24.0 | 6.1 | 24.0 |
| Service (%) | 41.2 | 49.2 | 51.1 | 50.0 | 49.8 | 50.0 |
| Power generation, and mining (%) | 0.5 | 6.8 | 0.5 | 7.0 | 0.3 | 5.5 |
| Observations | 14,326 | | 86,346 | | 202,737 | |

Panel B. After the Coal Power Plant Phase-out

| | Treatment | | Control 1 | | Control 2 | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| ***Labor Market Outcomes*** | | | | | | |
| Labor Force Participation (=1) | 0.653 | 0.476 | 0.594 | 0.491 | 0.614 | 0.487 |
| Employment Status (=1) | 0.650 | 0.477 | 0.585 | 0.493 | 0.604 | 0.489 |
| Monthly Wage (10,000 won) | 211.720 | 156.700 | 236.022 | 141.687 | 238.034 | 148.805 |
| ***Personal Characteristics*** | | | | | | |
| Male (=1) | 0.447 | 0.497 | 0.466 | 0.499 | 0.460 | 0.498 |
| Age | 62.162 | 17.560 | 55.291 | 18.868 | 55.326 | 19.132 |
| ***Education*** | | | | | | |
| Elementary School or Below (=1) | 0.405 | 0.491 | 0.261 | 0.439 | 0.267 | 0.442 |
| Middle School (=1) | 0.135 | 0.342 | 0.127 | 0.333 | 0.121 | 0.326 |
| High School (=1) | 0.297 | 0.457 | 0.333 | 0.471 | 0.312 | 0.463 |
| College or Above (=1) | 0.162 | 0.369 | 0.280 | 0.449 | 0.300 | 0.458 |
| ***Industry Share*** | | | | | | |
| Agriculture, forestry, and fishing (%) | 39.9 | 49.0 | 27.1 | 44.4 | 30.0 | 45.8 |
| Manufacturing (%) | 7.6 | 26.5 | 12.6 | 33.1 | 10.5 | 30.6 |
| Construction (%) | 5.8 | 23.3 | 6.5 | 24.6 | 6.2 | 24.2 |
| Service (%) | 46.1 | 49.9 | 53.0 | 49.9 | 52.8 | 49.9 |
| Power generation, and mining (%) | 0.6 | 7.9 | 0.8 | 9.1 | 0.5 | 6.9 |
| Observations | 16,837 | | 109,357 | | 253,567 | |

## 3 Empirical Design

To estimate the causal impact of the Seocheon coal power plant closure on regional employment, we employ a DD strategy combined with an event-study approach. This design leverages spatial and temporal variation in the closure to compare changes in employment in Seocheon against those in otherwise similar municipalities.

Formally, let $y_{ist}$ indicate whether an individual $i$ in municipality $s$ is employed at time $t$. We estimate:

$$y_{ist} = \beta \text{Post}_t \times \text{Treat}_s + X_i\gamma + \theta_s + \delta_t + \varepsilon_{ist} \tag{1}$$

where $\text{Post}_t$ is a dummy for periods after September 2017 (the closure date), $\text{Treat}_s$ identifies the treated municipality Seocheon, and $X_i$ includes controls such as age, sex, and education. We include municipality fixed effects $\theta_s$, half-year fixed effects $\delta_t$, and cluster all standard errors at the municipality level to account for unobserved municipal-level shocks and heteroskedasticity.

Since most Seocheon coal-sector workers were guaranteed reemployment (Oh et al., 2022), we do not necessarily expect a significant negative effect on direct power generation jobs. However, adjacent industries might have ripple effects if displaced subcontractors and their communities are not fully compensated.

Our identifying assumption is that Seocheon and the control municipalities would have followed parallel trends in employment if the plant had not closed. To validate the assumption, we also estimate the following event study regression equation, following the recommendation of Roth et al. (2023):

$$y_{ist} = \Sigma_{j \neq 2017H1} \beta_j (I[j = t] \times \text{Treat}_s) + X_i\gamma + \theta_s + \delta_t + \varepsilon_{ist} \tag{2}$$

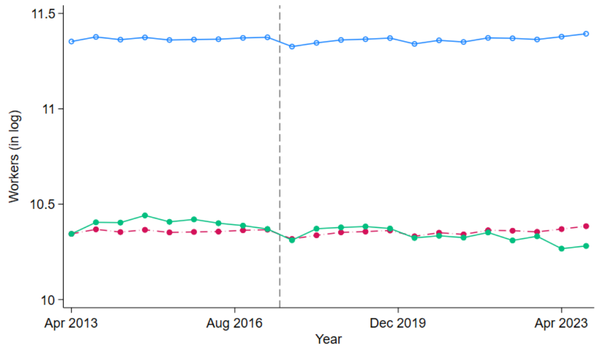
In equation 2, we replace the *post* dummy variable with a set of dummy variables for each half-year period, $t \in \{2013H1, 2013H2, \ldots, 2022H2\}$. All other notation remains as in the preceding equation 1. If the estimates for $\beta_j$'s for $j \in \{2013H1, 2013H2, \ldots, 2016H2\}$ are not statistically significant, it suggests that the employment in Seocheon and the control regions followed similar trends before the power plant closure.

The next section shows our baseline estimates, followed by heterogeneity analyses across industries and demographic groups.

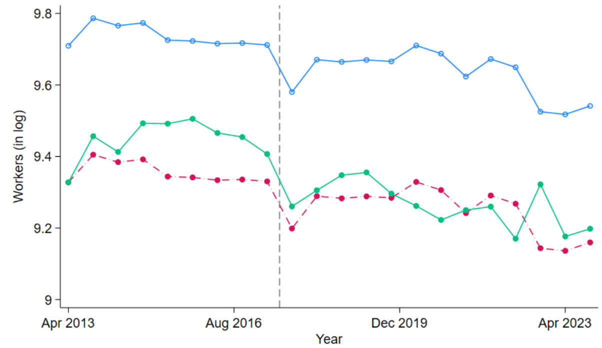
## 4 Results

This section examines how the coal phase-out in Seocheon affected local employment. We first describe baseline employment trends across industries before turning to sectoral shifts and heterogeneous effects.

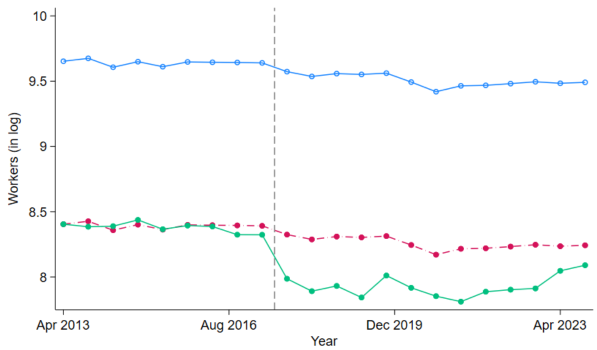
Figure 4 shows the employment trends across industries between 2013 and 2023. The green line represents the



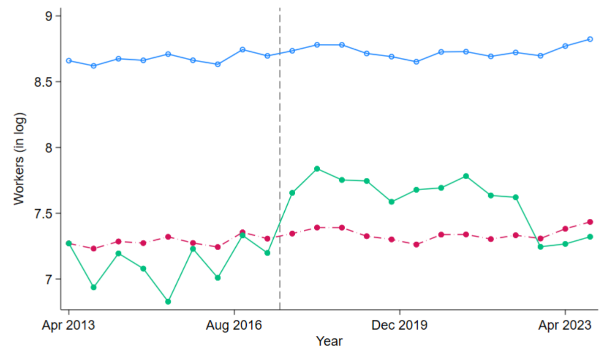

**(a)** Total



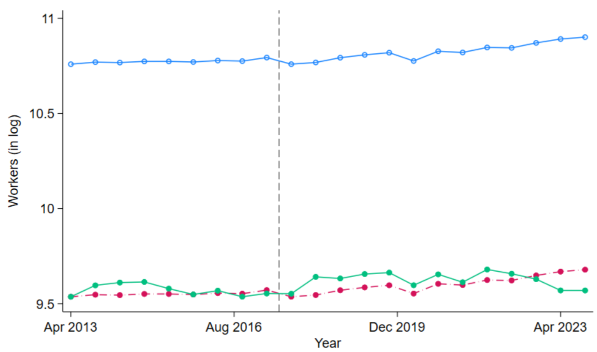

**(b)** Agricultural, forestry, fishing



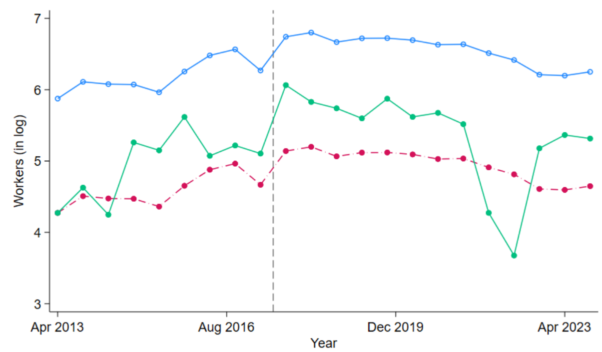

**(c)** Manufacturing




**(d)** Construction




**(e)** Service




**(f)** Power generation and mining

Control
Control (adjusted)
Treat

*Notes*: The figure shows the trends in the number of workers (in log) across industries between 2013 and 2023. The green line represents the actual employment level in Seocheon and the blue line shows the actual employment level for the control group. The red line represents an adjusted employment value, calculated to account for initial differences.

Figure 4: Trend in Employment by Industries

actual employment level in Seocheon and the blue line shows the actual employment level for the control group. The red line represents an adjusted employment value, calculated to account for initial differences[4], allowing

[4]First, we calculated the employment difference between the treated group and the control group in April 2013. For all subsequent periods, we subtract this difference from the exact number of employment of the control group. As

for a more evident comparison with Seocheon's employment trends. Panel A of Figure 4 suggests no overall decline in total employment. However, Panels C and D of Figure 4 show a notable reduction in manufacturing employment and an increase in construction employment. These patterns imply that there are heterogeneous ripple effects across industries, despite the absence of a significant negative impact on overall employment.

The remainder of this section explores these effects in detail. Section 4.1 presents the main DD estimates for overall employment and an event study analysis. Section 4.2 investigates sectoral shifts, first in power generation and coal and then in other industries such as manufacturing and construction. Section 4.3 examines heterogeneous impacts by gender, education, and age. Section 4.4 evaluates changes in job quality, distinguishing between permanent and temporary employment, while Section 4.5 presents robustness checks to validate our findings.

## 4.1 The Effect of Power Plant Shutdown on Overall Employment

We begin by examining whether the coal phase-out caused a decline in total employment. Table 2 reports the DD estimates where the dependent variable is a dummy, indicating whether an individual is employed. All specifications include municipality and half-year fixed effects and controls for sex, age (and age-squared), and education. Standard errors are clustered at the municipality level.

Table 2: The Effect of Power Plant Shutdown on Overall Employment

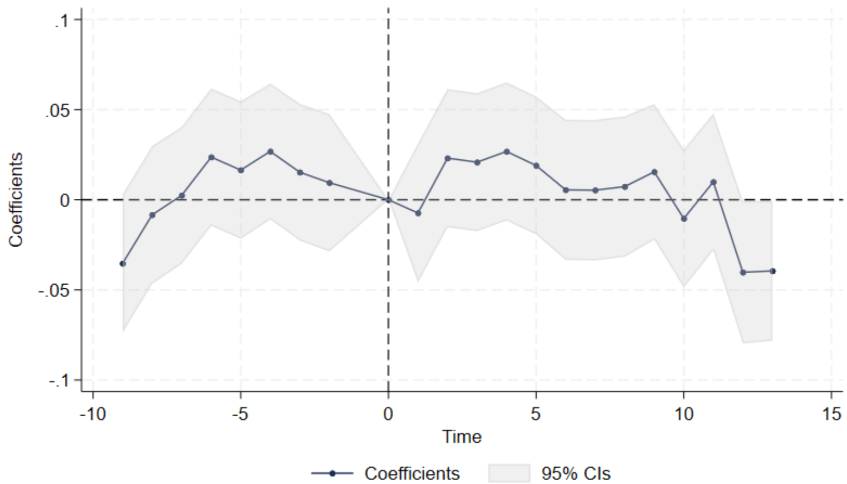
| | Being Employed | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| Treat × Post | -0.005 | -0.002 | 0.009* |
| | (0.006) | (0.006) | (0.005) |
| Municipality FEs | Yes | Yes | Yes |
| Year FEs | Yes | No | No |
| Half-year FEs | No | Yes | Yes |
| Individual characteristics | No | No | Yes |
| $R^2$ | 0.008 | 0.008 | 0.247 |
| Observations | 250,548 | 250,548 | 250,548 |

*Notes:* This table presents the DD estimates from equation (1), which measures the effect of coal phase-out on the likelihood of workers being employed. The dependent variable is a binary variable that equals 1 if the individual is employed and 0 otherwise. Control variables include sex, age, age squared, and a dummy variable for high school education or beyond. Standard errors in parentheses are clustered at the municipality level.
$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

In columns (1) and (2), where we progressively add municipality and half-year fixed effects, the coefficient on the interaction term $Treat \times Post$ is small and statistically insignificant, indicating no substantial overall decline in employment in Seocheon relative to the control group. The point estimate becomes slightly positive when we include individual controls in column (3), but it remains modest in magnitude, suggesting that the coal phase-out did not lead to a net decline in local employment. These results are consistent with the possibility that direct coal power plant workers were largely reassigned elsewhere (Oh et al., 2022), leading to limited net changes in total local employment.

a result, the difference between the green line and the red line was zero in April 2013.

Figure 5 displays event study coefficients for overall employment, providing further insight into dynamic or anticipatory effects. The coefficients remain near zero before the closure, supporting the assumption of parallel trends. Similarly, the estimates remain statistically indistinguishable from zero during the post-treatment period, reinforcing the conclusion that Seocheon's total employment did not undergo a large negative shock.




*Notes*: This figure plots the estimated coefficients from the event study in equation (2). All specifications control for sex, age, age squared, a dummy variable for high school education or beyond, and municipality and half-year fixed effects. Grey-shaded areas correspond to a 95 percent confidence interval. All coefficients are normalized such that the coefficient for 2017H, when the power plant closed, is zero. Event time is measured in half-year intervals, with time 0 corresponding to the power plant closure.

Figure 5: Event Study Estimates of Impact the Power Plant Closure: Overall Employment

## 4.2 Sectoral Heterogeneity

Having established that total employment did not change drastically, we now explore how the coal power plant closure affected specific industries. We begin by examining direct impacts on the power generation and coal sector, presenting DD estimates in Table 3 and event study results in Figure 6. These shed light on whether plant employees or related subcontractors faced immediate displacement. We then turn to indirect effects in other industries in Table 4, investigating how the closure may have reshaped employment in manufacturing, agriculture, construction, and services. This step-by-step approach highlights both the direct labor market outcomes in the plant itself and the ripple effects across the broader local economy.

### Coal and Power Generation Industry

Table 3 reports the DD estimates for employment in power generation and the coal sector using three different specifications. In all columns, the effect of the coal plant shutdown on the likelihood of working in these industries remains statistically insignificant, indicating no measurable decline in direct coal-related jobs.

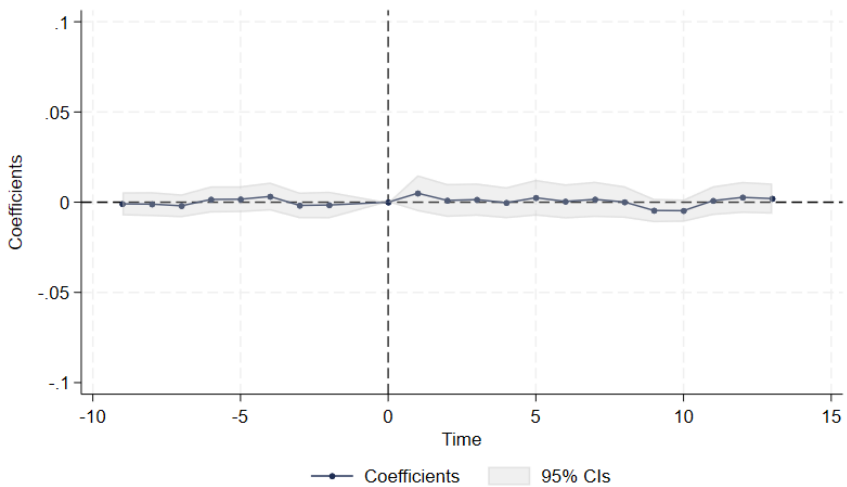
Figure 6 presents the event study estimates for the likelihood of workers being employed in the power generation and coal sector. This confirms our earlier regression findings and indicates no violation of the

Table 3: The Direct Employment Effect of the Power Plant Closure: Power Generation and Mining

| | (1) | (2) | (3) |
|---|---|---|---|
| Treat × Post | 0.001 | 0.001 | 0.001 |
| | (0.001) | (0.001) | (0.001) |
| Municipality FEs | Yes | Yes | Yes |
| Year FEs | Yes | No | No |
| Half-year FEs | No | Yes | Yes |
| Individual characteristics | No | No | Yes |
| $R^2$ | 0.006 | 0.006 | 0.012 |
| Observations | 149,263 | 149,263 | 149,263 |

*Notes:* This table presents the DD estimates from equation (1). The dependent variable is a binary variable that equals 1 if the individual is employed and 0 otherwise. Control variables include sex, age, age squared, and a dummy variable for high school education or beyond. Standard errors in parentheses are clustered at the municipality level.
$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

common trends assumption. The regression and event study results suggest that the coal plant shutdown did not reduce employment in industries directly tied to coal power generation.




*Notes*: This figure shows the outcomes of the event study described in equation (2). Specifically, the figure shows the dynamic effects of the coal phase-out on the likelihood of workers being employed in the power generation and mining industry. Grey-shaded areas correspond to 95 percent confidence intervals that allow for clustering over municipality areas. Event time is measured in half-year intervals, with time 0 corresponding to the power plant closure.

Figure 6: Event Study Estimates of Impact of Coal Phase-Out: Being Employed in Power Generation and Mining

These results primarily reflect the reassignment of all 139 incumbent Seocheon power plant workers to other power generation facilities (Oh et al., 2022). Because the coal sector comprises such a small share of Seocheon's overall economy (see Figure 2), its fluctuations minimally affect total employment. Consequently, we observe no significant changes in power generation or coal-mining jobs.

Overall, our findings indicate that the coal phase-out did not reduce the likelihood of being employed, either at the regional level or in directly related industries. While this outcome aligns with the policy's just transition aims, recent literature (e.g., Lee, 2022) underscores the need to broaden that concept. Merely preserving jobs in coal-related sectors does not ensure a truly inclusive, just transition; policymakers must also address the broader ripple effects on other industries.

### Other Industries

We now turn to whether the coal power plant shutdown produced ripple effects beyond the directly affected power and coal sector. Table 4 reports the likelihood of working in agriculture, manufacturing, construction, and services, with columns (2) and (4) reflecting our preferred specifications (including individual characteristics and fixed effects).

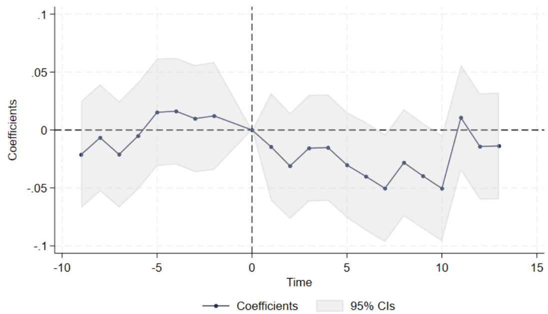
Table 4: The Indirect Employment Effect of Plant Shutdown: Other Industries

| | Agriculture, Forestry, and Fishing | | Manufacturing | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Treat × Post | -0.026*** | -0.033*** | -0.021*** | -0.021*** |
| | (0.007) | (0.006) | (0.006) | (0.005) |
| Municipality FEs | Yes | Yes | Yes | Yes |
| Half-year FEs | Yes | Yes | Yes | Yes |
| Individual characteristics | No | Yes | No | Yes |
| $R^2$ | 0.096 | 0.314 | 0.017 | 0.077 |
| Observations | 149,263 | 149,263 | 149,263 | 149,263 |
| | Construction | | Service | |
| | (1) | (2) | (3) | (4) |
| Treat × Post | 0.024*** | 0.022*** | 0.022*** | 0.032*** |
| | (0.004) | (0.004) | (0.008) | (0.007) |
| Municipality FEs | Yes | Yes | Yes | Yes |
| Half-year FEs | Yes | Yes | Yes | Yes |
| Individual characteristics | No | Yes | No | Yes |
| $R^2$ | 0.002 | 0.053 | 0.022 | 0.139 |
| Observations | 149,263 | 149,263 | 149,263 | 149,263 |

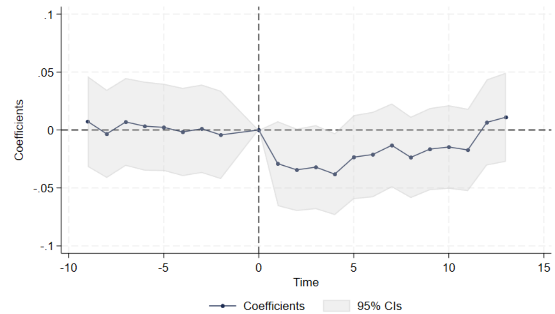
*Notes:* This table presents the DD estimates from equation (1), which measures the effect of coal phase-out on the likelihood of workers being employed in other industries. The dependent variable is a binary variable that equals 1 if the individual is employed and 0 otherwise. Control variables include sex, age, age squared, and a dummy variable for high school education or beyond. Standard errors in parentheses are clustered at the municipality level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In agriculture and manufacturing, the coal plant shutdown exerts a significant negative impact, with coefficients of -0.033 and -0.021, respectively—equivalent to declines of 3.3 and 2.1 percentage points in the probability of working in these sectors. By contrast, construction and services show positive shifts, as the phase-out raises the likelihood of employment by about 2.2 and 3.2 percentage points, respectively. These results signal that although the number of jobs remains relatively stable, labor is reallocated across industries after the plant's closure.

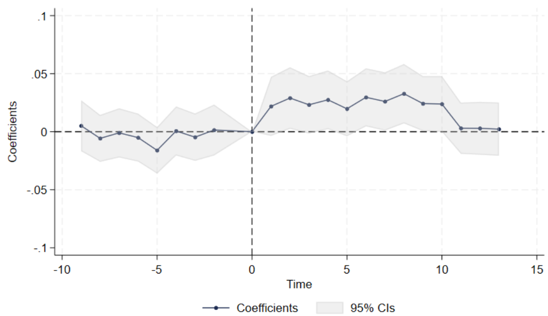
Figure 7, the event study results for other industries, reinforce these findings. Panel B shows a significant drop in manufacturing employment, while Panel C reveals a corresponding uptick in construction. By contrast, Panels A and D indicate no statistically significant effects for agriculture, forestry, fishing, or services. Moreover, the coefficients in these latter sectors are not consistently near zero before the closure, making it difficult to attribute any observed changes to the phase-out itself.



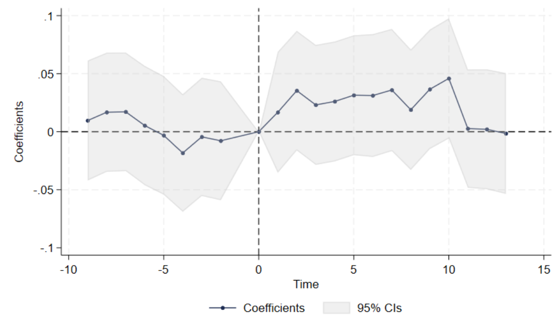

**(a)** Agricultural, forestry, and fishing




**(b)** Manufacturing




**(c)** Construction




**(d)** Service

*Notes*: This figure shows the outcomes of the event study described in equation (2). Specifically, the figure shows the dynamic effects of the coal phase-out on the likelihood of workers being employed in other industries. All estimates contain sex, age, age squared, high school, and municipality and half-year fixed effects. Grey-shaded areas correspond to 95 percent confidence intervals that allow for clustering over municipality areas. Event time is measured in half-year intervals, with time 0 corresponding to the power plant closure.

Figure 7: Event Study Estimates: Other Industries

Our results suggest that workers reallocated from manufacturing to construction after the coal plant closure. The manufacturing decline may reflect disruptions in energy supply and related production processes (Missbach et al., 2024). In contrast, the construction boom likely stems from the government's 2016 decision to build a new power plant nearby. Although this expansion created local opportunities in Seocheon, it remained temporary and ended once construction concluded in 2021.

## 4.3 Gender Difference

In the previous subsection, we confirm that the coal phase-out has ripple effects on the manufacturing and construction sectors. We also observe that three key industries (power generation and mining, manufacturing, and construction) are male-dominated, suggesting potential gender-specific impacts (Aragón et al., 2018). Accordingly, this subsection examines whether the phase-out has heterogeneous effects across gender, education, and age, highlighting which groups may be more vulnerable to labor market shifts.

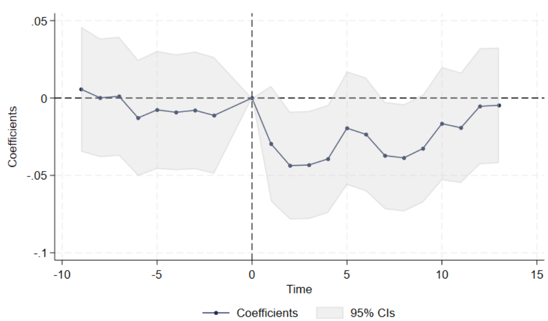
Table 5 shows how the coal plant shutdown affected the employment likelihood across gender, education, and

Table 5: The Employment Effect of Plant Shutdown by Demographics

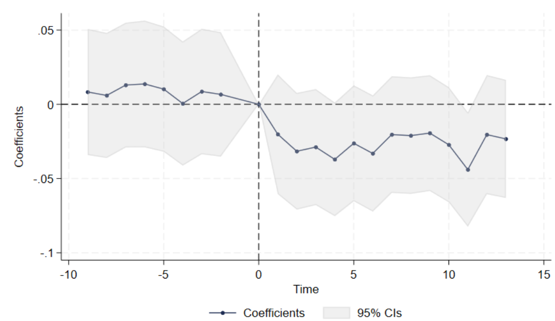
| | (1) Female | (2) Male | (3) Low education | (4) High education | (5) Under 50 | (6) Over 50 |
|---|---|---|---|---|---|---|
| Treat × Post | -0.043*** | 0.037*** | 0.004 | 0.003 | 0.003 | -0.007 |
| | (0.008) | (0.008) | (0.008) | (0.009) | (0.012) | (0.007) |
| Municipality FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| Half-year FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.012 | 0.008 | 0.026 | 0.010 | 0.008 | 0.011 |
| Observations | 134,126 | 116,422 | 105,289 | 145,259 | 90,981 | 159,567 |

*Notes:* This table presents the DD estimates from equation (1), which measures the effect of coal phase-out on the likelihood of workers being employed by demographic characteristics. The dependent variable is a binary variable that equals 1 if the individual is employed and 0 otherwise. Standard errors in parentheses are clustered at the municipality level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

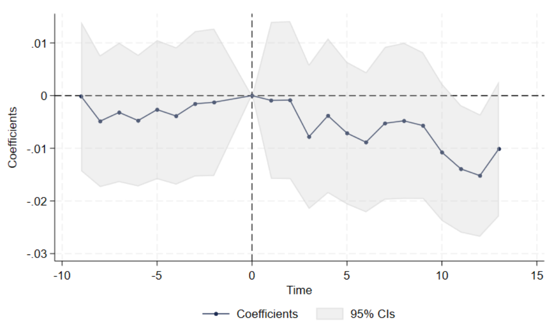
age groups. In Column (1), the coefficient is negative and statistically significant, whereas in Column (2), it is positive and significant, indicating heterogeneous effects by gender. By contrast, Columns (3) to (6) reveal no substantial heterogeneity across education levels or age groups.



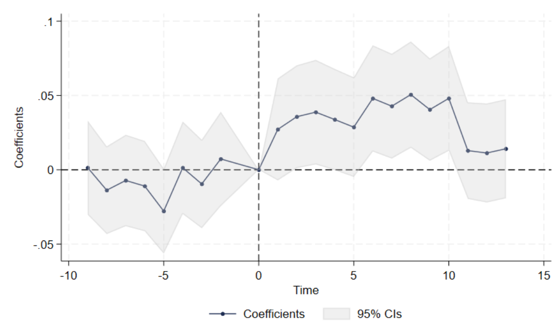

**(a)** Female, Manufacturing




**(b)** Male, Manufacturing




**(c)** Female, Construction




**(d)** Male, Construction

*Notes*: This figure shows the outcomes of the event study described in equation (2).

Figure 8: Event Study Estimates by Gender: Being Employed in Manufacturing, Construction

We further explore these male-female differences using an event study approach in Figure 8. The evidence corroborates the gender-differentiated patterns observed in Table 5. Panels A and B indicate a pronounced decline in manufacturing employment for both men and women, yet Panel A shows that female employment rebounds slowly following the closure. By contrast, Panels C and D illustrate that only men experience a marked uptick in construction employment, while female construction employment remains largely unchanged. These results suggest that men are more likely to transition from manufacturing to construction, whereas women face greater barriers to benefiting from emerging opportunities.

Importantly, these trends do not vary significantly by educational attainment, implying that the key driver of uneven labor reallocation is gender rather than differences in schooling. Overall, the data underscore that while both men and women lose manufacturing jobs post-closure, men gain a comparatively larger share of newly created construction roles, leaving women disproportionately affected by the coal power plant shutdown.

### 4.4 Job Quality: Effects on Permanent Employment

In Section 4.2, we showed that the coal plant shutdown barely affected overall employment. Building on Jhujhunwala et al. (2024), we explore how the shutdown influenced job quality (permanent vs. temporary). Since most workers prefer stable to temporary or contract jobs, we interpret that a decline in permanent employment indicates a deterioration in job quality. A permanent job typically refers to a type of employment that provides greater job security, long-term contracts, and benefits than a temporary or contract-based job. Thus, people generally perceive permanent jobs as being superior to temporary ones.

Table 6: The Effect of Power Plant Shutdown: Permanent Jobs

| | Being a Permanent Employee | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| Treat × Post | -0.108*** | -0.110*** | -0.068*** |
| | (0.010) | (0.010) | (0.009) |
| Municipality FEs | Yes | Yes | Yes |
| Year FEs | Yes | No | No |
| Half-year FEs | No | Yes | Yes |
| Individual characteristics | No | No | Yes |
| $R^2$ | 0.004 | 0.005 | 0.210 |
| Observations | 78,294 | 78,294 | 78,294 |

*Notes:* This table presents the DD estimates from equation (1), which measures the effect of coal phase-out on the likelihood of being a permanent employee. The dependent variable is a binary variable that takes 1 if the individual is permanent worker and 0 otherwise, conditional on being employed. Control variables include sex, age, age squared, and a dummy variable for high school education or beyond. Standard errors in parentheses are clustered at the municipality level.
$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

We demonstrate that there are ripple effects across the industries and gender, even though the coal phase-out seems to have no impact on employment. In this section, we suggest another interesting result related to the effect of the coal phase-out on the labor market is not confined to making winners and losers across industries and genders. The coal phase-out also affected the share of permanent employment.

In Table 7, we present the DD estimators for the probability of permanent jobs.[5] Table 7 consistently indicates a statistically significant negative effect of the coal phase-out on the likelihood of being a permanent

[5] The dependent variable is a binary variable indicating whether a resident is a permanent worker.

Table 7: The Employment Effects by Demographics: Permanent Jobs

| | (1) Female | (2) Male | (3) Low education | (4) High education | (5) Under 50 | (6) Over 50 |
|---|---|---|---|---|---|---|
| Treat × Post | -0.133*** | -0.094*** | -0.124*** | -0.066*** | -0.041*** | -0.132*** |
| | (0.015) | (0.014) | (0.021) | (0.011) | (0.013) | (0.016) |
| Municipality FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| Half-year FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.005 | 0.005 | 0.018 | 0.004 | 0.007 | 0.008 |
| Observations | 37,050 | 41,244 | 17,637 | 60,657 | 40,693 | 37,601 |

*Notes:* This table presents the DD estimates from equation (1), which measures the effect of coal phase-out on the likelihood of being a permanent employee by demographic characteristics. The dependent variable is a binary variable that takes 1 if the individual is a permanent employee and 0 otherwise, conditional on being employed. Standard errors in parentheses are clustered at the municipality level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

employee. In Columns (1) and (2), the negative effect is more pronounced for females compared to males. Similarly, in Columns (3) and (4), less-educated individuals are more adversely affected than their highly educated counterparts. In Columns (5) and (6), older workers experience a greater decline in permanent employment probability compared to younger workers.

Table 7 shows that there is a decline in permanent jobs because of coal phase-out. The coal phase-out disproportionately impacts female workers, less educated workers, and older workers compared to other groups. These findings highlight the disproportionate impact of the coal phase-out on specific demographic groups. Given that these groups are more vulnerable to economic shocks, it is crucial to consider measures to protect them from the ripple effects of the coal phase-out.

## 4.5 Robustness Checks

There are concerns that neighboring counties could potentially be influenced by the coal phase-out through the spillover effect. To address this concern, we conduct two additional analyses. First, we conduct the same analysis using control group 2, which is broader than the area of the control group 1. Second, we conduct the same analysis using alternative control groups where coal power plant is located. Third, we employ a synthetic control method to check the robustness of our findings.

### 4.5.1 Effects of Coal Plant Shutdown with Control Group 2

We conduct the same analysis using Control Group 2 to confirm that the results are consistent. Table A.1 shows the results for DD estimators for the likelihood of being employed in total and each industry. We include half-year fixed effects and controls the individual characteristics.

First, in Columns (1) and (2) of Table A.1, the coal phase-out shows no significant effect on the total employment and power and coal-related industries. In Columns (3) and (4), the effects of coal phase-out show a negative statistically significant effect on the likelihood of workers being employed in manufacturing and agriculture, forestry, and fishing. But Columns (5) and (6) exhibit a positive and statistically significant effect on the likelihood of workers being employed in construction and service. Specifically, the coal phase-out is associated with a 2 percentage point decrease in the likelihood that workers are employed in manufacturing and a 2 percentage point increase in construction. Despite the magnitude of coefficients being half of our main results in Table A.1, it shows that the affected industries and the direction of coefficients are the same, which is shown in Table 4.

We conduct the heterogeneity analysis to examine how the likelihood of workers being employed differs depending on individual characteristics. Columns (1) and (2) of Table A.2, we observe that the coal phase-out has a negative effect on the employment likelihood of females and a positive effect on males, which is consistent with the previous finding shown in Table 5.

We implement a heterogeneity analysis for the likelihood of being permanent workers. Table A.3 shows that all individual characteristics show statistically significant and negative effects. Column (1) of Table A.3 shows that the coal phase-out reduces the likelihood of being permanent workers. More specifically, the negative impact was greater for females compared to males, for lower educated compared to high educated, and aged over 50 compared to under 50. This consequence is on the same line with the disparities observed in the Table 7, thereby reinforcing the robustness of our main findings. Similarly, Figure A.1, Figure A.2, and Figure A.3 show consistent results.

### 4.5.2 Effects of Coal Plant Shutdown on Employment with Alternative Control Group: Municipalities with Coal Power Plant

We consider the alternative control group where the coal power plant is located. This idea came from the assumption that the characteristics of the counties where the coal power plants are located are likely to be similar. Using this framework, we find seven power plants (Yeongheung, Taean, Dangjin, Yeosu, Hadong, Honam, and Yeongdong) that existed before 2013 and have not been expanded since then, which is when our data started. As shown in Figure A.4, the alternative control group includes Dangjin, Taean, Hadong, Yeosu, and Gangneung. Although Incheon has a power plant in Yeongheung, given that it is a metropolitan city, its demographic and industry structure are significantly different from those of other counties. Thus, we decide to exclude Incheon from the alternative control group. Although our dataset extends to 2023, we restrict the analysis to data through 2021, as most power plants were closed and replaced with new facilities due to government policy after this year - thereby potentially introducing biases to our estimates.

Table A.4 shows the results of DD estimators for total employment by industry. We follow the same specification in Column (3) of Table 2 for the analysis. Column (1) of Table A.4 shows the negative and statistically significant effect on total employment, which is not in line with our findings. This is potentially due to the rate of decline in employment being greater than the rate of job loss in alternative municipalities in Korea. The rest of the columns of Table A.4 show consistent results. According to Columns (3) and (4) in Table A.4, the coal phase-out is associated with a 4 percentage point decrease in the likelihood that workers are employed in manufacturing and a 3 percentage point increase in construction. These magnitudes of coefficients are quite similar to our main regression. Even though other sectors, such as Agriculture, forestry, and fishing, and Service, have statistically significant effects after the coal phase-out, the lack of evidence supporting the parallel trends assumption in these two sectors makes it hard to say these effects are solely attributed to the coal phase-out.

We also conduct heterogeneity analysis for the likelihood of workers being employed, and whether these effects are differentiated by individual characteristics. Table A.5 presents the results for heterogeneity analysis. In Columns (1), (3), and (6), we observe that the coal phase-out negatively affects the likelihood of employment for workers in groups vulnerable to economic shocks. These results extend our main findings, which indicate a negative effect on the employment likelihood of females, to other demographic groups. Moreover, given that the magnitude of the coefficients is larger than Column (1) in Table 5, it implies that the negative effects may be even greater than previously estimated.

We additionally conduct heterogeneity analysis for the likelihood of being permanent workers. Table A.6 reveals that all individual characteristics show statistically significant and negative effects. According to Column (1) of Table A.6, the effects of coal phase-out reduce the likelihood of being permanent workers. More specifically, the negative impact was greater for females compared to males, for lower educated compared to high educated, and aged over 50 compared to under 50. This consequence is on the same line with the disparities observed in Table 7, thereby reinforcing the robustness of our main analysis. Similarly, Figure A.5, Figure A.6, and Figure A.7 show consistent results.

### 4.5.3 Synthetic Control Method

We address the concerns of the violation of the common trends assumption by re-weighting municipalities to match their pretreatment outcomes (Abadie et al., 2010). To implement the SCM, we aggregate regional data by averaging our main dependent variable, which indicates whether individuals are employed. Thus, we regard it as an employment rate. We have another dependent variable indicating whether workers work in specific industries, such as power generation, manufacturing, construction, agriculture, and service. Since this specification excludes individuals who do not work, we call this variable the employment share of each industry.

Using data from all municipalities in Korea, we construct an artificial control municipality that represents counterfactual employment share trends — specifically, the trends we would expect if there were no coal phase-out. This allows us to estimate the impact of the coal phase-out by differencing Seocheon's employment share with the counterfactual.

Figure A.8 displays the trends in the employment rate and the employment share of each industry, both in

Seocheon and the synthetic control from 2013 to 2023. Here, we focus on panel C of Figure A.8, which shows significant changes in manufacturing employment share. The pre-trend fit shown in Panel C of Figure A.8 demonstrates that the synthetic control approximates the counterfactual outcome that would have evolved in Seocheon for the post-treatment period in the absence of the coal phase-out.

However, the results of the synthetic control method for employment share in other industries do not fit well from the pre-trend, and the effects are not significant for the post-treatment period. In addition, in Figure A.9 and Figure A.10, we find no evidence of heterogeneous effects of the coal phase-out on employment rates and the proportion of permanent employees across individual characteristics. These results are quite different from the findings we first presented in the main analysis.

## 5 Conclusions

This study empirically examines the effect of coal power plant phase-out on employment in Korea. Our difference-in-differences (DD) analysis shows that while government policies successfully mitigated direct employment losses in the power generation sector, the phase-out led to significant ripple effects across related industries, disproportionately affecting female and less-educated workers.

Our findings highlight that coal phase-out policies, driven by the motive to reduce local air pollutants and GHG emissions, may have unintended consequences. While the provincial government has supported power sector workers at risk of unemployment, broader labor market disruptions—such as declining manufacturing jobs and an increase in temporary construction employment—remain unaddressed. These findings emphasize the need for a more inclusive just transition framework that extends beyond directly impacted workers.

Although the construction of an alternative power plant could be a viable countermeasure to the closure, it benefits only a subgroup of the affected population. We argue that policy measures should additionally consider those indirectly affected, as they are often overlooked by the direct policy measures for just transition. Our analysis contributes to the growing body of literature advocating for a broader approach to evaluating climate policies for this transition, rather than limiting it to a narrow interpretation (Chan et al., 2024).

Several lessons emerge that are relevant to policymakers. First, our findings suggest that the effects of coal phase-out on local economies extend beyond the power generation sectors, producing spillover impacts across the broader local economy. To achieve a just transition, we call for an equitable distribution of the benefits and burdens associated with coal phase-out. We must support not only the workers and communities directly affected but also the other industries of the economy throughout their transition, addressing any negative impacts that arise. For example, Germany's Coal Commission developed broad support packages for affected communities as well as direct support for coal workers (Kommission Wachstum, Strukturwandel und Beschäftigung, 2019), and Spain's initiatives in Asturias encouraged economic diversification and promoted job opportunities in renewable energy (Ministerio para la Transición Ecológica, 2018). These international cases underscore the importance of going beyond narrowly defined compensation measures to foster inclusive regional development.

Second, our study highlights increasing inequality in labor demand in the coal phase-out region as a key challenge for policymakers to consider. Policymakers will need to identify the demographic characteristics of those indirectly affected and consider a policy with a wide-ranging impact on the entire local economy. Equity concerns due to the coal phase-out in Seocheon could exacerbate a regional economic crisis coupled with a low birth rate, which leads to an aging population. Canada's Task Force on Just Transition for Canadian Coal Power Workers and Communities demonstrates how tripartite collaboration among government, industry, and labor can help anticipate and mitigate such inequality by implementing well-designed retraining and relocation programs (Task Force on Just Transition for Canadian Coal Power Workers and Communities, 2019). At the same time, the European Union's Just Transition Mechanism illustrates a framework for systematically monitoring and addressing social and economic disparities over the course of a regional energy transition (European Commission, 2020).

Third, our findings suggest potential reemployment opportunities in Seocheon's manufacturing sector. For example, Poland's coal phase-out faced challenges with limited job opportunities for displaced workers in the 1990s. However, since the 2010s, sectors like manufacturing and construction have expanded, providing alternative reemployment pathways for former miners (Sokołowski et al., 2021). This highlights the importance of tailored retraining programs for at-risk workers. Similarly, municipalities in Korea could consider implementing similar training strategies for young workers in industries expected to grow following the coal phase-out.

There are several limitations to this study. First, because it only considers the shutdown of the Secheon power plant in September 2017, we cannot conclude that Korea's national coal phase-out policy would experience similar impacts on employment. Thus, caution should be taken to avoid overgeneralizing these results. Studying the impact of similar policies in other regions would provide a more comprehensive understanding of coal phase-out policies in Korea. Second, our analysis is limited to the local economic impact of coal power plant closure. Assessing the effects of the openings of renewable energy plants in response to the phasing out of coal power plants could be another fruitful area of future research (Fabra et al., 2024). Third, future studies could expand this work by exploring the mechanisms behind the winners and losers. Fourth, the investigation of the reallocation of workers within the province could be another avenue of future research.

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**For Online Publication**

# Appendix A Additional Information

Table A.1: Impact of Coal Power Plant Shutdown on Employment by Industries: Likelihood of Being Employed (Control Group 2)

| | (1) Total | (2) Power generation and mining | (3) Agriculture, forestry, and fishing | (4) Manufacturing | (5) Construction | (6) Service |
|---|---|---|---|---|---|---|
| Treat × Post | 0.005 | 0.002 | -0.035*** | -0.030*** | 0.023*** | 0.039*** |
| | (0.005) | (0.001) | (0.006) | (0.005) | (0.004) | (0.007) |
| Municipality FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| Half-year FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| Individual characteristics | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.249 | 0.008 | 0.345 | 0.068 | 0.062 | 0.175 |
| Observations | 537,607 | 327,386 | 327,386 | 327,386 | 327,386 | 327,386 |

*Notes:* This table presents the DD estimates from equation (1), which measures the effect of coal phase-out on the likelihood of being employed by industries. The treated group is Seocheon, and the control group is control group 2 in Figure 3. The dependent variable is a binary variable that takes 1 if the individual is being employed and 0 otherwise. Control variables include sex, age, squared age, and high school. Standard errors in parentheses are clustered at the municipality level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.2: Impact of Coal Power Plant Shutdown on Employment by Demographics: Likelihood of Being Employed (Control Group 2)

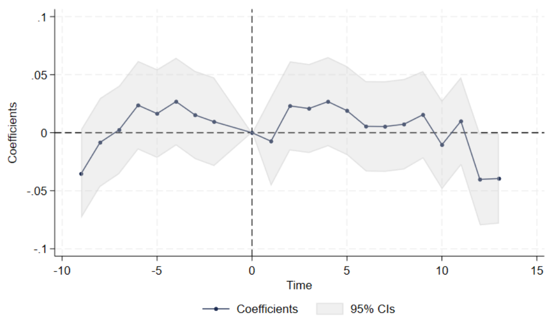
| | (1) Female | (2) Male | (3) Low education | (4) High education | (5) Under 50 | (6) Over 50 |
|---|---|---|---|---|---|---|
| Treat × Post | -0.053*** | 0.032*** | -0.012 | -0.002 | -0.005 | -0.016** |
| | (0.008) | (0.008) | (0.008) | (0.008) | (0.011) | (0.007) |
| Municipality FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| Half-year FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.015 | 0.008 | 0.045 | 0.009 | 0.006 | 0.018 |
| Observations | 290,135 | 247,472 | 220,089 | 317,518 | 200,445 | 337,162 |

*Notes:* This table presents the DD estimates from equation (1), which measures the effect of coal phase-out on the likelihood of being employed by demographic characteristics. The treated group is Seocheon, and the control group is control group 2 in Figure 3. The dependent variable is a binary variable that takes 1 if the individual is being employed and 0 otherwise. Standard errors in parentheses are clustered at the municipality level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

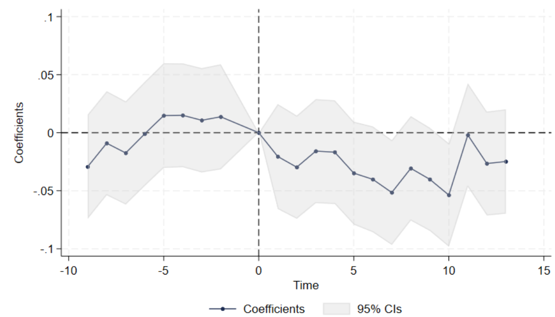
Table A.3: Impact of Coal Power Plant Shutdown on Employment by Industries: Likelihood of Being a Permanent Employee (Control Group 2)

| | (1)<br>Total | (2)<br>Female | (3)<br>Male | (4)<br>Low<br>education | (5)<br>High<br>education | (6)<br>Under<br>50 | (7)<br>Over<br>50 |
|---|---|---|---|---|---|---|---|
| Treat × Post | -0.088*** | -0.157*** | -0.118*** | -0.133*** | -0.092*** | -0.063*** | -0.152*** |
| | (0.009) | (0.015) | (0.014) | (0.020) | (0.011) | (0.013) | (0.015) |
| Municipality FEs | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Half-year FEs | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.212 | 0.009 | 0.008 | 0.023 | 0.008 | 0.011 | 0.013 |
| Observations | 168,430 | 80,990 | 87,440 | 35,573 | 132,857 | 89,491 | 78,939 |

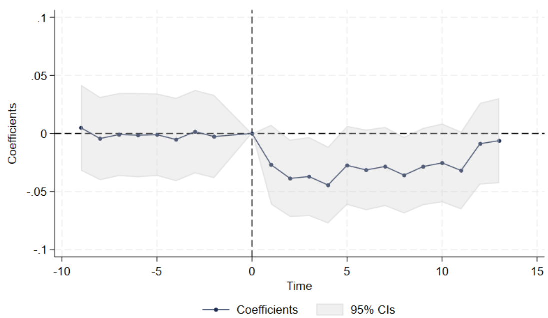
*Notes:* This table presents the DD estimates from equation (1), which measures the effect of coal phase-out on the likelihood of being a permanent worker by demographic characteristics. The treated group is Seocheon, and the control group is control group 2 in Figure 3. The dependent variable is a binary variable that takes 1 if the individual is a permanent employee and 0 otherwise, conditional on being employed. Standard errors in parentheses are clustered at the municipality level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$



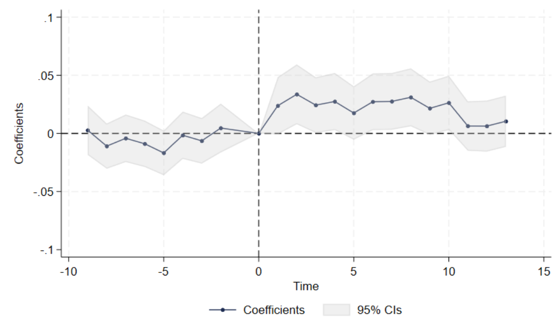

**(a)** Total



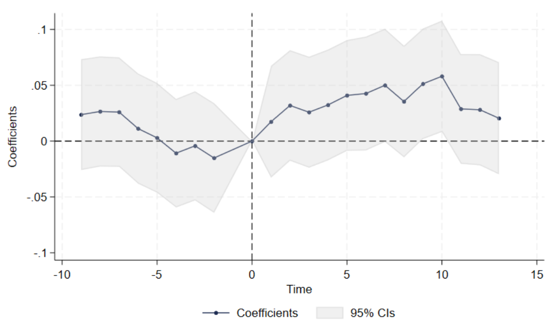

**(b)** Agriculture, forestry, and fishing



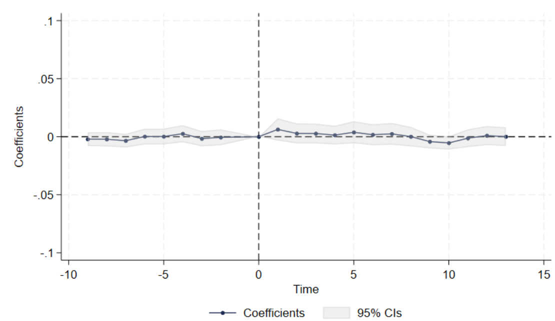

**(c)** Manufacturing




**(d)** Construction



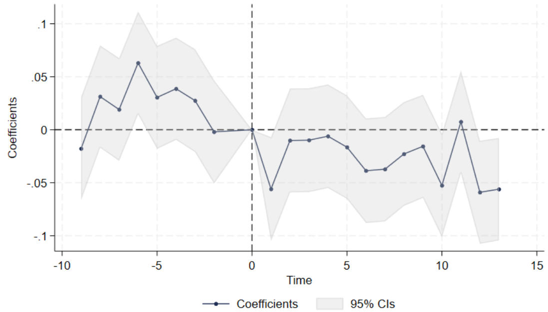

**(e)** Service



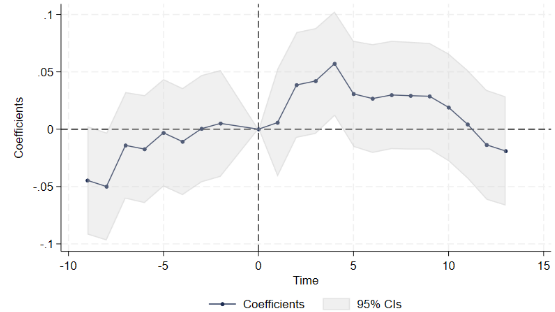

**(f)** Power generation and mining

*Notes*: This figure shows the outcomes of the event study described in equation (2). Specifically, the figure shows the dynamic effects of the coal phase-out on the likelihood of workers being employed by industry. The treated group is Seocheon, and the control group is control group 2 in Figure 3. All estimates contain sex, age, squared age, high school, and fixed effects for municipality and half-year fixed effects. Error bars correspond to 95 percent confidence intervals that allow for clustering over municipality areas. Time 0 represents the period when the coal phase-out occurred, and each unit of time refers to half-year. Each event study is normalized such that the coefficient corresponding to the time of the coal phase-out is zero.

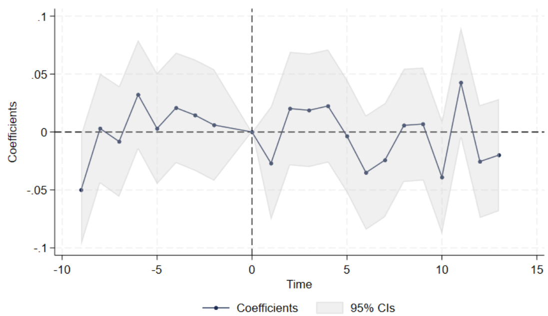
Figure A.1: Event-Study Estimates of Impact of Coal Power Plant Shutdown by Industries: Being Employed (Control Group 2)



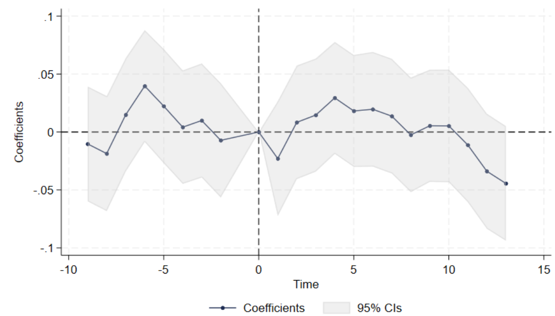

**(a)** Female



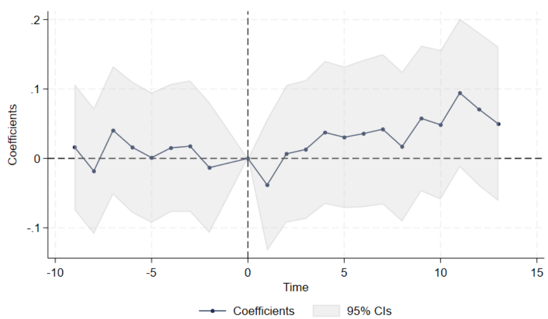

**(b)** Male



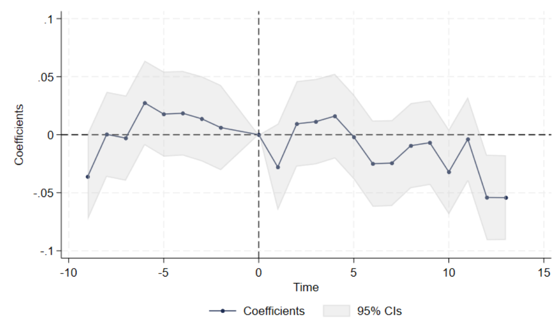

**(c)** Low Education




**(d)** High Education



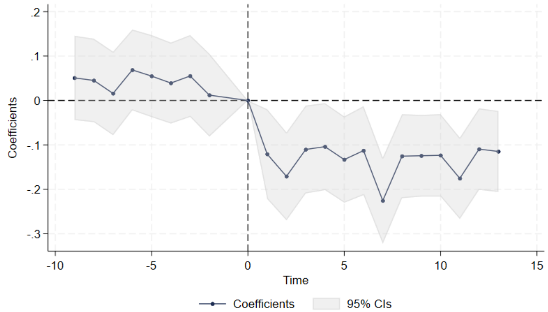

**(e)** Under 50



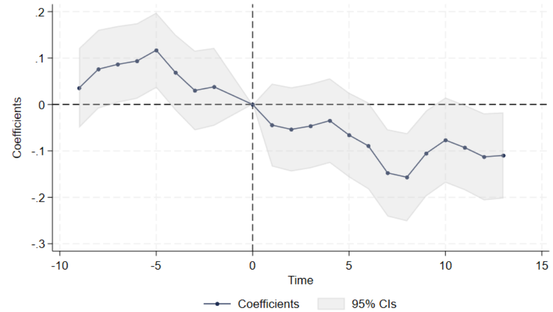

**(f)** Over 50

*Notes*: This figure shows the outcomes of the event study described in equation (2). Specifically, the figure shows the dynamic effects of the coal phase-out on the likelihood of workers being employed by demographic characteristics. The treated group is Seocheon, and the control group is control group 2 in Figure 3. All estimates contain fixed effects for the municipality and half-year fixed effects. Error bars correspond to 95 percent confidence intervals that allow for clustering over municipality areas. Time 0 represents the period when the coal phase-out occurred, and each unit of time refers to half-year. Each event study is normalized such that the coefficient corresponding to the time of the coal phase-out is zero.

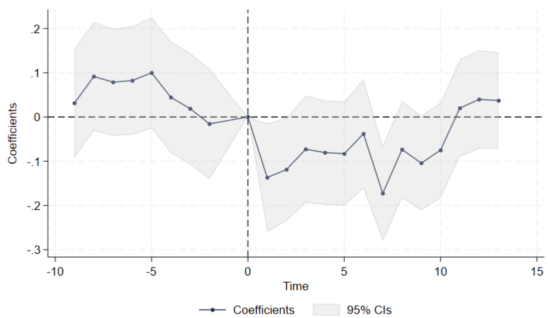
Figure A.2: Event-Study Estimates of Impact of Coal Power Plant Shutdown by Demographics: Being Employed (Control Group 2)



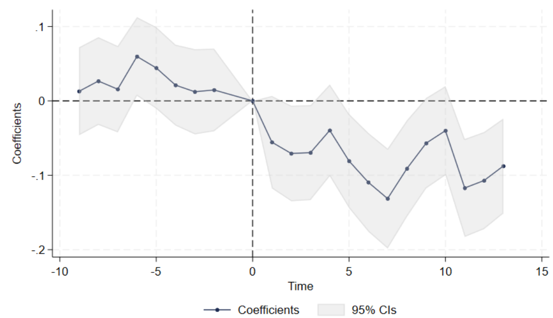

**(a)** Female



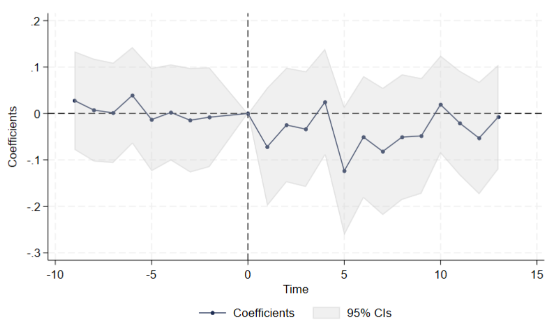

**(b)** Male



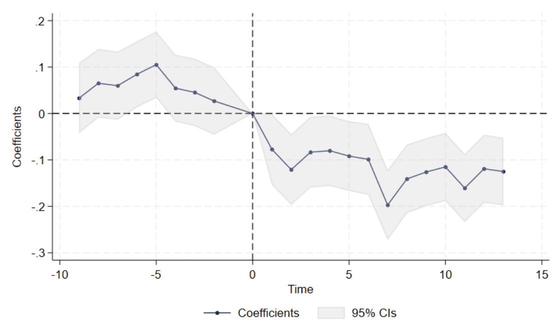

**(c)** Low education




**(d)** High education



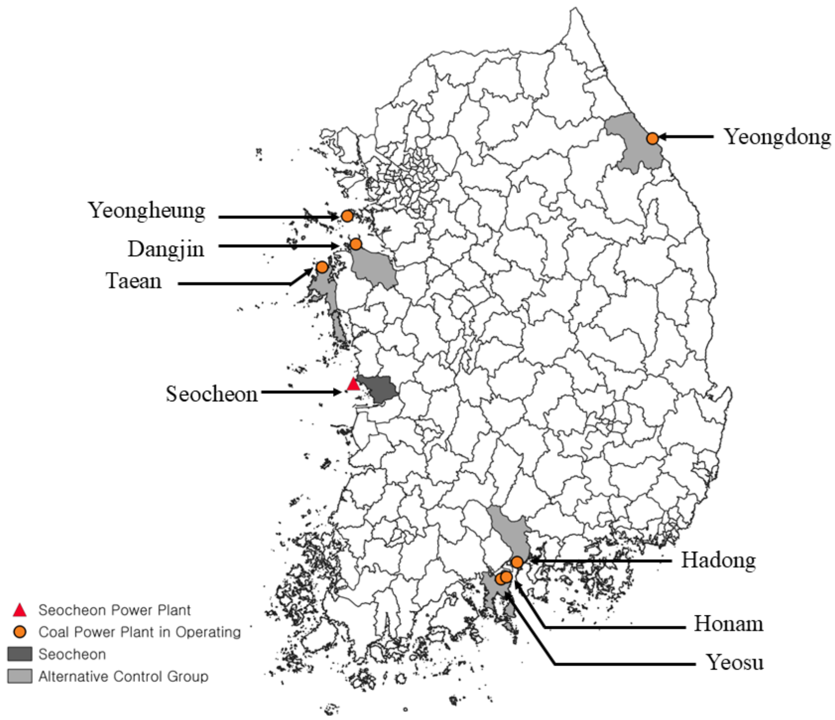

**(e)** Under 50




**(f)** Over 50

*Notes*: This figure shows the outcomes of the event study described in equation (2). Specifically, the figure shows the dynamic effects of the coal phase-out on the likelihood of being a permanent worker by demographic characteristics. The treated group is Seocheon, and the control group is control group 2 in Figure 3. All estimates contain fixed effects for the municipality and half-year fixed effects. Error bars correspond to 95 percent confidence intervals that allow for clustering over municipality areas. Time 0 represents the period when the coal phase-out occurred, and each unit of time refers to half-year. Each event study is normalized such that the coefficient corresponding to the time of the coal phase-out is zero.

Figure A.3: Event-Study Estimates of Impact of Coal Power Plant Shutdown by Demographics: Being a Permanent Employee (Control Group 2)




*Notes*: The map shows the locations of the treated and alternative control groups. The darkest-shaded municipality represents Seocheon. The second darkest-shaded counties represent alternative group. The control groups are defined based on proximity to Seocheon. The alternative group represents the coal power plant that was located before 2013 and has not been expanded since 2013. Alternative group includes Dangjin (Dangjin power plant), Taean (Taean power plant), Hadong (Hadong power plant), Yeosu (Honam and Yeosu power plant), and Gangneung (Yeongdong). Yeongheung (Yeongheung power plant). Incheon (Yeongheung power plant) is excluded given that it is a metropolitan city.

Figure A.4: Location of Coal Power Plant and Alternative Control Group in 2021

Table A.4: Impact of Coal Power Plant Shutdown on Employment by Industries: Likelihood of Being Employed (Alternative Group)

| | (1) Total | (2) Power generation and mining | (3) Manufacturing | (4) Construction | (5) Agriculture, forestry, and fishing | (6) Service |
|---|---|---|---|---|---|---|
| Treat × Post | -0.014** | 0.002* | -0.043*** | 0.030*** | -0.054*** | 0.064*** |
| | (0.005) | (0.001) | (0.005) | (0.004) | (0.006) | (0.007) |
| Municipality FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| Half-year FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| Individual characteristics | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.227 | 0.014 | 0.100 | 0.075 | 0.360 | 0.180 |
| Observations | 241,428 | 155,651 | 155,651 | 155,651 | 155,651 | 155,651 |

*Notes:* This table presents the DD estimates from equation (1), which measures the effect of coal phase-out on the likelihood of being employed by industries. The treated group is Seocheon, and the control group is the alternative group in Figure A.4. The dependent variable is a binary variable that takes 1 if the individual is being employed and 0 otherwise. Control variables include sex, age, squared age, and high school. Standard errors in parentheses are clustered at the municipality level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.5: Impact of Coal Plant Shutdown on Employment by Demographics: Likelihood of Being Employed (Alternative Group)

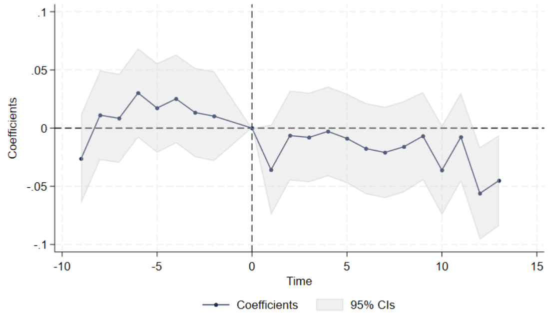
| | (1) Female | (2) Male | (3) Low education | (4) High education | (5) Under 50 | (6) Over 50 |
|---|---|---|---|---|---|---|
| Treat × Post | -0.065*** | 0.005 | -0.071*** | -0.008 | -0.012 | -0.048*** |
| | (0.008) | (0.008) | (0.008) | (0.009) | (0.012) | (0.007) |
| Municipality FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| Half-year FEs | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.016 | 0.019 | 0.044 | 0.010 | 0.006 | 0.027 |
| Observations | 128,019 | 113,409 | 103,107 | 138,321 | 87,437 | 153,991 |

*Notes:* This table presents the DD estimates from equation (1), which measures the effect of coal phase-out on the likelihood of being employed by demographic characteristics. The treated group is Seocheon, and the control group is the alternative group in Figure A.4. The dependent variable is a binary variable that takes 1 if the individual is being employed and 0 otherwise. Standard errors in parentheses are clustered at the municipality level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

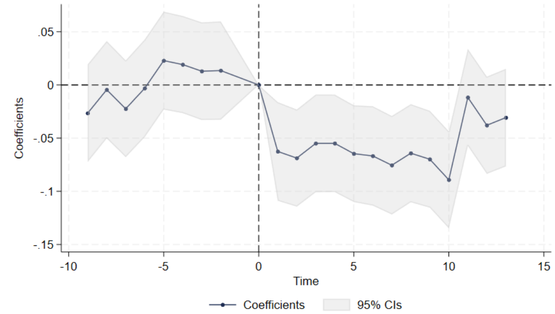
Table A.6: Impact of Coal Plant Shutdown on Employment by Demographics: Likelihood of Being a Permanent Employee (Alternative Group)

| | (1)<br>Total | (2)<br>Female | (3)<br>Male | (4)<br>Low<br>education | (5)<br>High<br>education | (6)<br>Under<br>50 | (7)<br>Over<br>50 |
|---|---|---|---|---|---|---|---|
| Treat × Post | -0.110*** | -0.131*** | -0.081*** | -0.099*** | -0.069*** | -0.041*** | -0.109*** |
| | (0.010) | (0.015) | (0.014) | (0.021) | (0.011) | (0.013) | (0.016) |
| Municipality FEs | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Half-year FEs | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.005 | 0.007 | 0.014 | 0.023 | 0.010 | 0.011 | 0.009 |
| Observations | 78,294 | 34,630 | 44,235 | 17,108 | 61,757 | 42,750 | 36,115 |

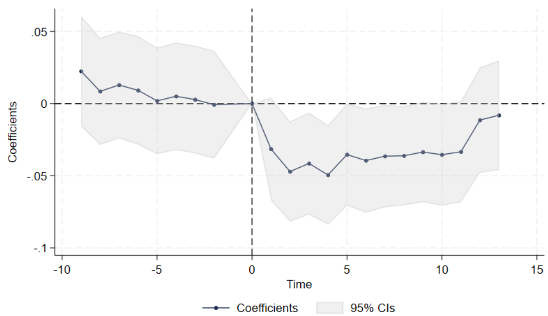
*Notes:* This table presents the DD estimates from equation (1), which measures the effect of coal phase-out on the likelihood of being a permanent employee by demographic characteristics. The treated group is Seocheon, and the control group is the alternative group in Figure A.4. The dependent variable is a binary variable that takes 1 if the individual is a permanent employee and 0 otherwise, conditional on being employed. Standard errors in parentheses are clustered at the municipality level. $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$



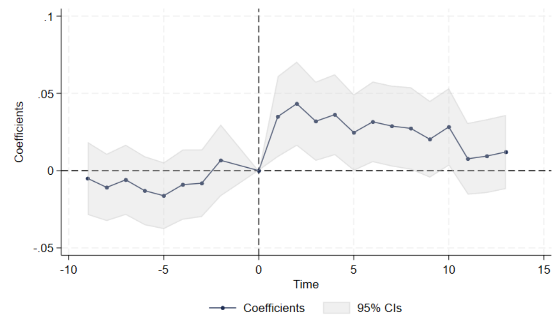

**(a)** Total



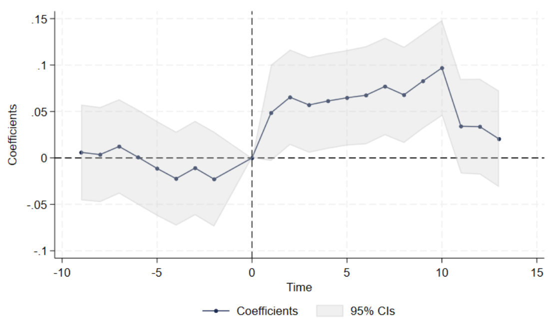

**(b)** Agriculture, forestry, and fishing



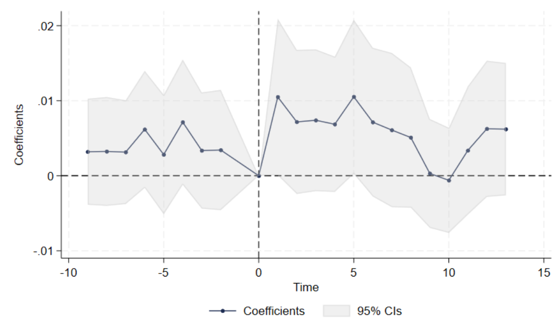

**(c)** Manufacturing




**(d)** Construction



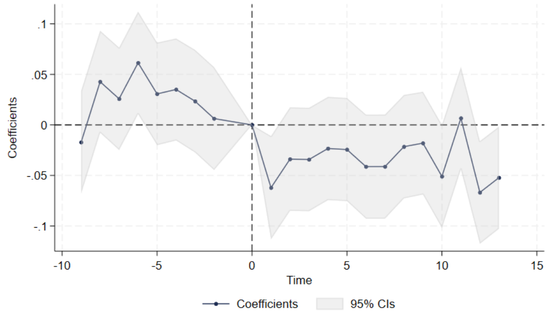

**(e)** Service



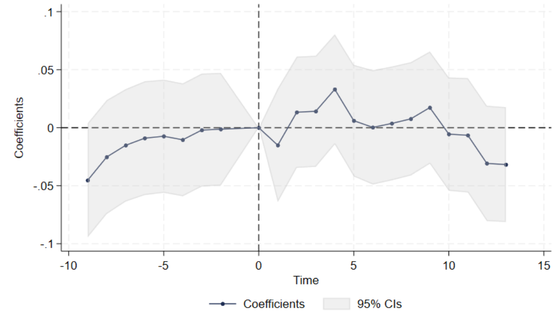

**(f)** Power generation and mining

*Notes*: This figure shows the outcomes of the event study described in equation (2). Specifically, the figure shows the dynamic effects of the coal phase-out on the likelihood of workers being employed by demographic characteristics. The treated group is Seocheon, and the control group is the alternative group in Figure A.4. All estimates contain sex, age, squared age, high school, and fixed effects for the municipality and half-year fixed effects. Error bars correspond to 95 percent confidence intervals that allow for clustering over municipality areas. Time 0 represents the period when the coal phase-out occurred, and each unit of time refers to half-year. Each event study is normalized such that the coefficient corresponding to the time of the coal phase-out is zero.

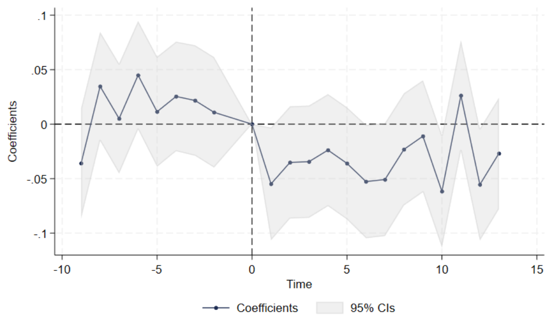
Figure A.5: Event-Study Estimates of Impact of Coal Plant Shutdown by Industries: Being Employed (Alternative Group)



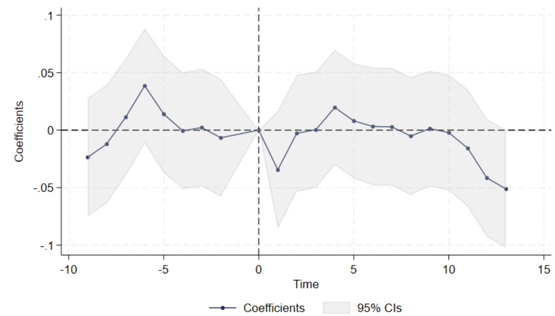

**(a)** Female



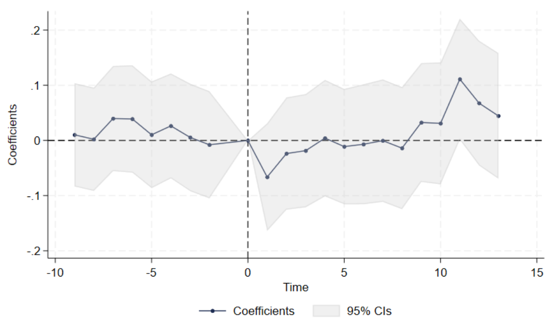

**(b)** Male



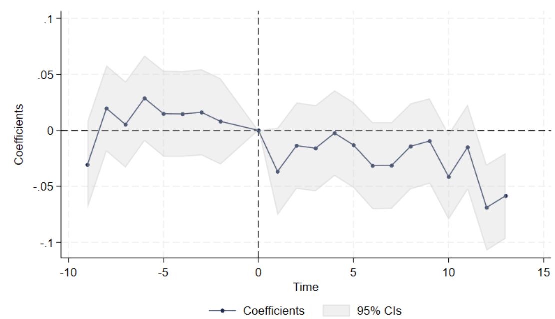

**(c)** Low Education




**(d)** High Education



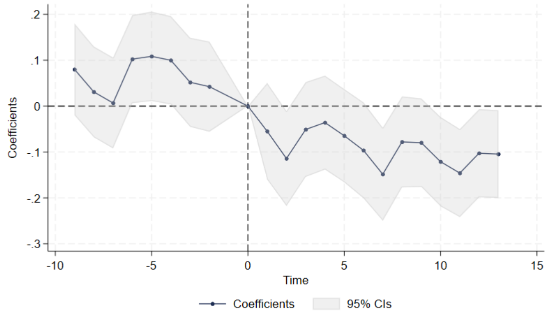

**(e)** Under 50



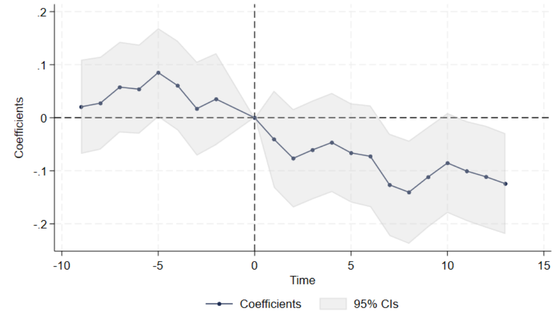

**(f)** Over 50

*Notes*: This figure shows the outcomes of the event study described in equation (2). Specifically, the figure shows the dynamic effects of the coal phase-out on the likelihood of workers being employed by demographic characteristics. The treated group is Seocheon, and the control group is the alternative group in Figure A.4. All estimates contain fixed effects for the municipality and half-year fixed effects. Error bars correspond to 95 percent confidence intervals that allow for clustering over municipality areas. Time 0 represents the period when the coal phase-out occurred, and each unit of time refers to half-year. Each event study is normalized such that the coefficient corresponding to the time of the coal phase-out is zero.

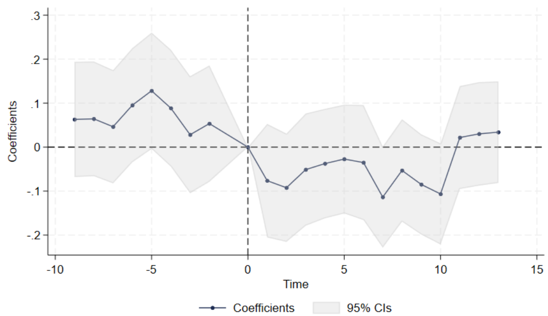
Figure A.6: Event-Study Estimates of Impact of Coal Plant Shutdown by Demographics: Being Employed (Alternative Group)



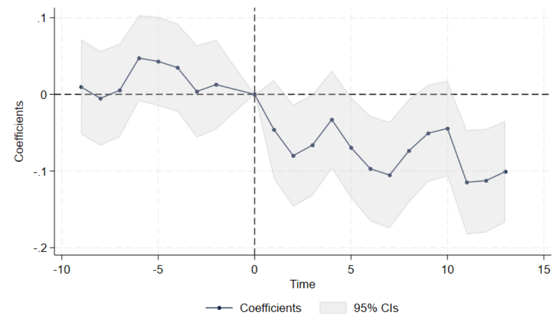

**(a)** Female



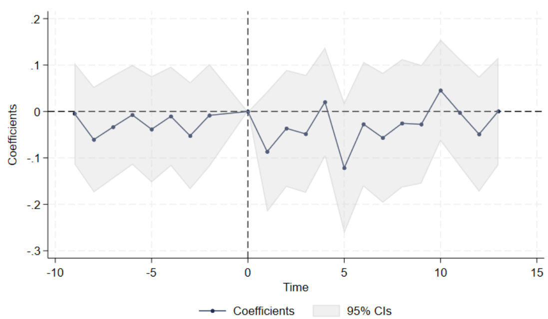

**(b)** Male



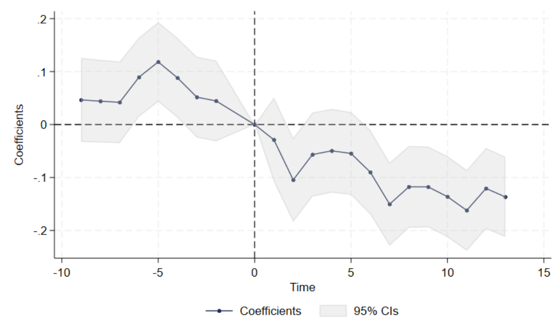

**(c)** Low education




**(d)** High education



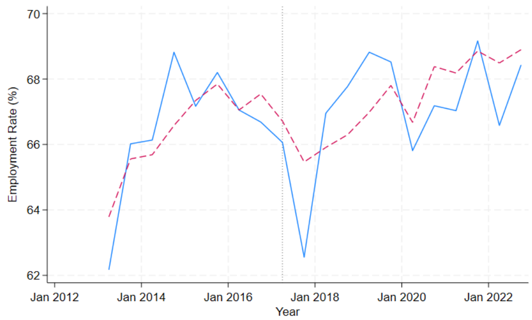

**(e)** Under 50



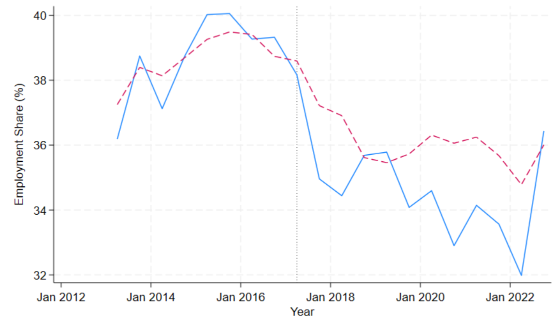

**(f)** Over 50

*Notes*: This figure shows the outcomes of the event study described in equation (2). Specifically, the figure shows the dynamic effects of the coal phase-out on the likelihood of being a permanent worker by demographic characteristics. The treated group is Seocheon, and the control group is the alternative group in Figure A.4. All estimates contain fixed effects for the municipality and half-year fixed effects. Error bars correspond to 95 percent confidence intervals that allow for clustering over municipality areas. Time 0 represents the period when the coal phase-out occurred, and each unit of time refers to half-year. Each event study is normalized such that the coefficient corresponding to the time of the coal phase-out is zero.

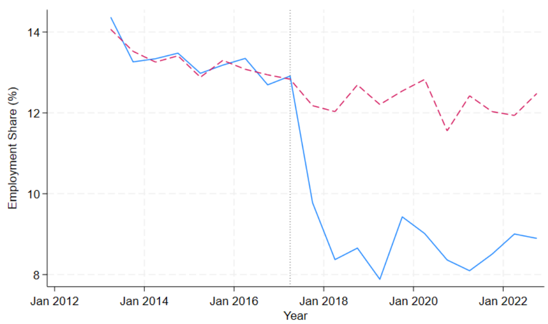
Figure A.7: Event-Study Estimates of Impact of Coal Plant Shutdown by Demographics: Being a Permanent Employee (Alternative Group)



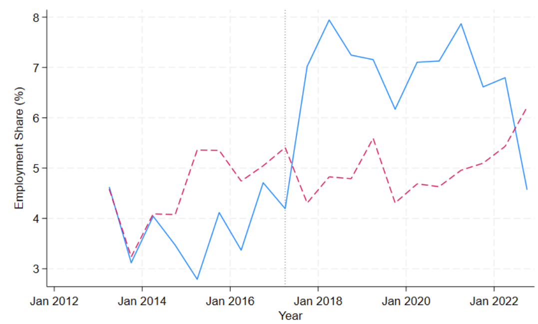

**(a)** Total



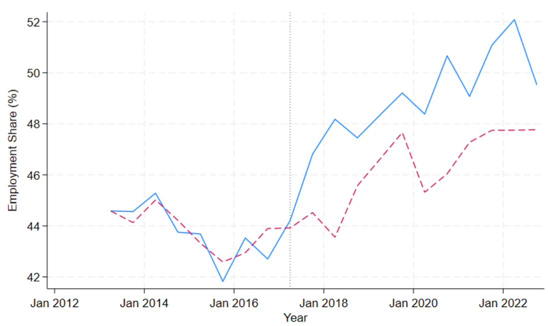

**(b)** Agriculture, forestry, and fishing



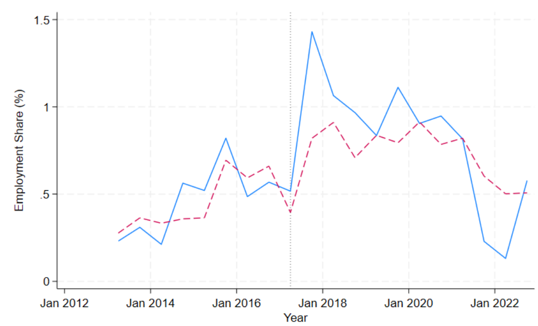

**(c)** Manufacturing




**(d)** Construction




**(e)** Service

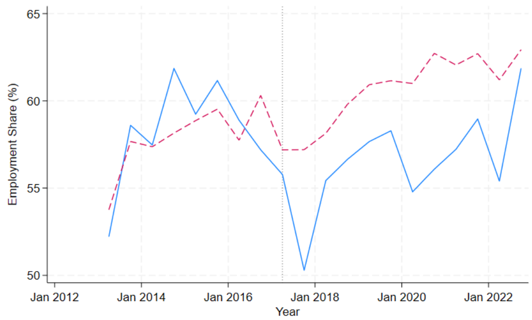



**(f)** Power generation and mining

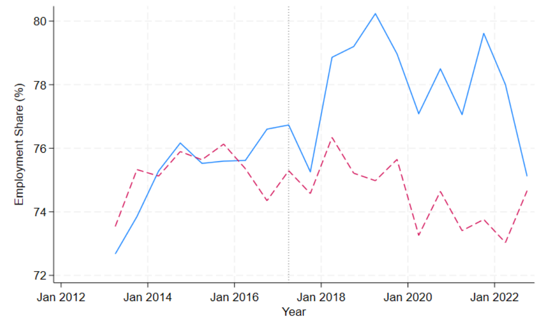
Actual — — — Synthetic

*Notes*: Synthetic control method results were derived by using pooled data from all of Korea's counties. We control the population and real gross regional domestic product. The red dotted line represents the trend in the counterfactual employment share of each industry, while the blue solid line represents the trend in the actual employment share of each industry in Seocheon. The difference between the two lines indicates the effect of the coal phase-out.

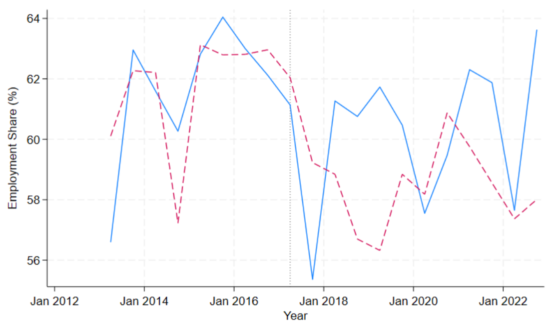
Figure A.8: Synthetic Control Method Results: Sectoral Employment



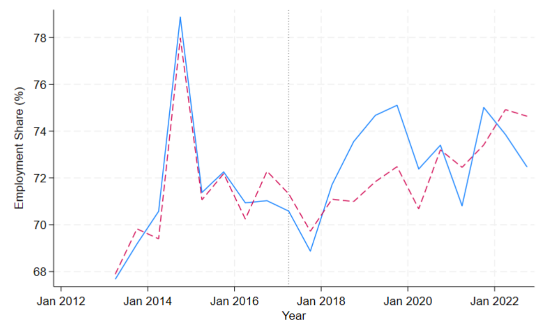

**(a)** Female



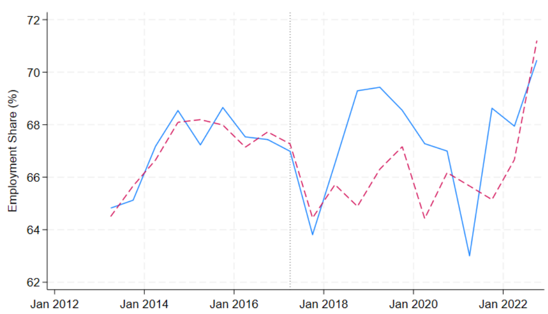

**(b)** Male



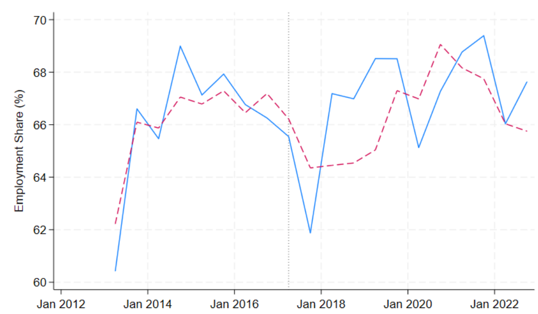

**(c)** Low education



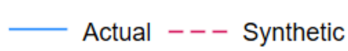

**(d)** High education




**(e)** Under 50

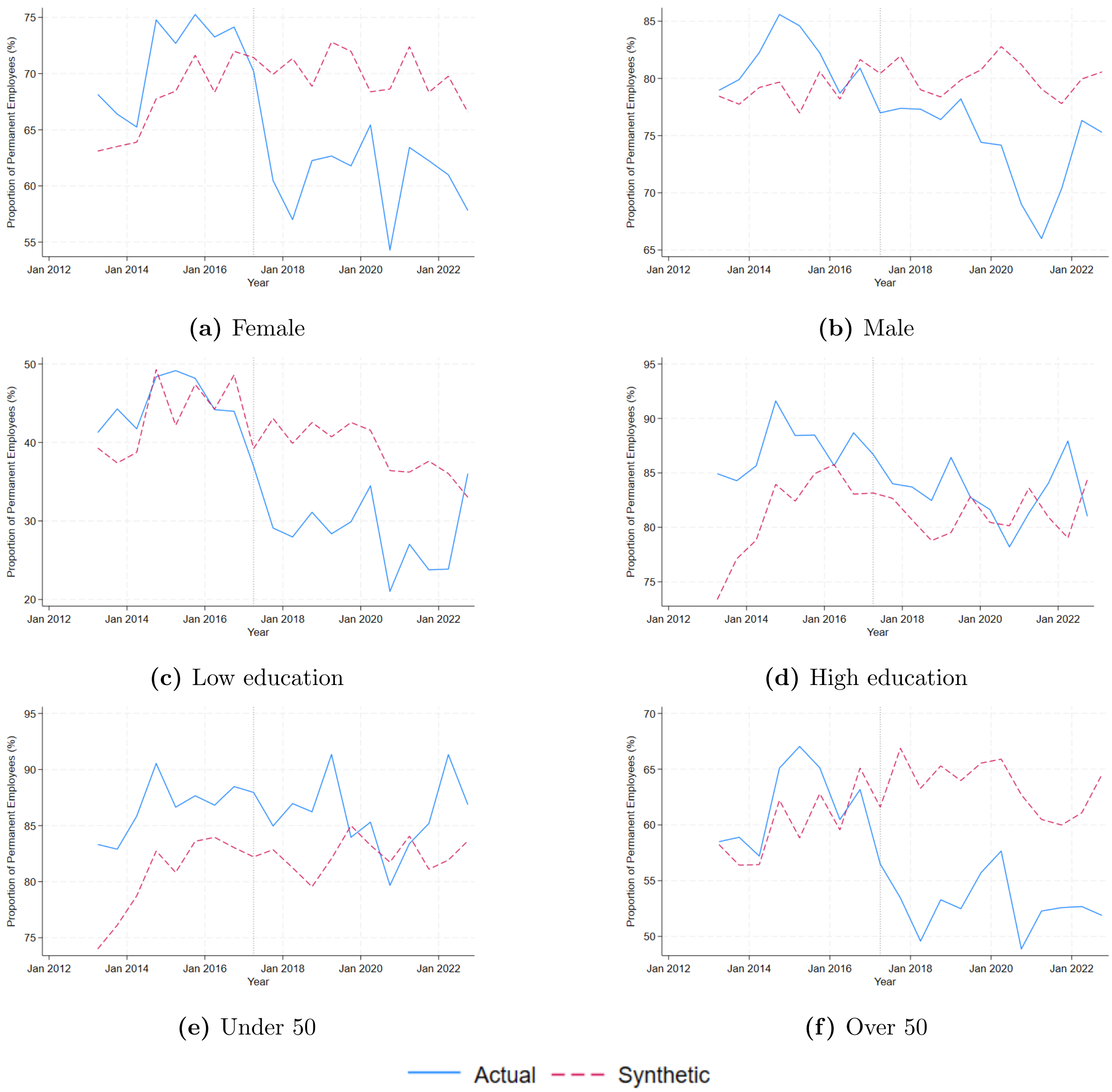



**(f)** Over 50




*Notes*: Synthetic control method results were derived by using pooled data from all of Korea's counties. We control the population and real gross regional domestic product. The red dotted line represents the trend in the counterfactual employment share of each industry, while the blue solid line represents the trend in the actual employment share of each industry in Seocheon. The difference between the two lines indicates the effect of the coal phase-out.

Figure A.9: Synthetic Control Method Results: Heterogeneity by Demographics




**(a)** Female

**(b)** Male

**(c)** Low education

**(d)** High education

**(e)** Under 50

**(f)** Over 50

*Notes*: Synthetic control method results were derived by using pooled data from all of Korea's counties. We control the population and real gross regional domestic product. The red dotted line represents the trend in the counterfactual employment share of each industry, while the blue solid line represents the trend in the actual employment share of each industry in Seocheon. The difference between the two lines indicates the effect of the coal phase-out.

Figure A.10: Synthetic Control Method Results: Permanent Employment