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# Fukushima Daiichi nuclear power plant impact on regional economies from 1960 to 2010

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ABSTRACT

Understanding the economic and social impact of nuclear power on a region is crucial; this is particularly important for Fukushima because the region relies on nuclear power and its sustainable recovery following the nuclear accident at Fukushima Daiichi. However, existing studies do not reveal any consensus on the economic impact of nuclear power plants. Further, long-term time-series data for conducting such an analysis are lacking; so, for this study, a long-term database from 1960 to 2010 was constructed (before the earthquake and nuclear power plant accidents happened in 2011). The data were analyzed to evaluate the effects of the nuclear power plants on employment in various sectors in Fukushima, using the difference-in-differences (DID) and staggered DID methods. Unlike previous studies, this study revealed that nuclear power surprisingly increased agricultural employment (892.62 more jobs) while reducing manufacturing employment (−466.40 fewer jobs) due to crowding-out effects. Furthermore, although employment in the construction sector also increased, the impact was temporary. These findings highlight the complex economic dynamics triggered by the presence of a nuclear power plant, which may have significant implications for long-term recovery strategies in the region. Despite the positive impacts on certain sectors, the negative effects on manufacturing underscore the need for careful consideration in future economic planning and recovery efforts. The study's findings provide valuable insights into the challenges and opportunities faced by regions hosting nuclear power plants, which must be considered for long-term recovery.

## 1. Introduction

More than a decade after the Fukushima Daiichi (No.1) nuclear power plant accident in 2011, the area continues to recover from the damage. More than 160,000 people living in the surrounding areas were forced to take emergency shelter, including those who had to evacuate because of radiation leaks and whose homes were damaged by the earthquake and tsunami. One day after the earthquake on March 12, 2011, the evacuation order was issued within a 20-km radius. The residents of a 30-km radius were instructed to take shelter inside.

In typical disasters, even if not always possible, at least some images of recovery are shared among people upon returning to their communities, such as before the disaster [1–4]. However, this was not the case for Fukushima. Recovery efforts are more complicated because there is no way to return to the way things used to be with an operational nuclear power station.

In Fukushima, efforts have been made to increase employment and encourage evacuated residents to return to their hometowns for reconstruction. For example, Futaba Town has attracted Asano Nenshi (Twisted Silk) Co. and Naraha Town has attracted Shirohato Food Co. However, these efforts have been limited and have not generated sufficient industry or employment. Several issues have been identified, including a lack of interaction between decommissioning work and local industries [5–8].

Looking back at history, in the mid-1960s, when the nuclear power plant was in its development stage, there was a plan to develop industrial parks around the nuclear power plant to promote the manufacturing sector [9–11]. Construction on Fukushima Daiichi (No.1) began in 1965, and operations commenced in 1971. Emphasis was placed on the manufacturing industry, which usually generates the most employment opportunities. However, Fukushima's manufacturing sector has neither grown nor created jobs. Was this because of the nuclear power plant? The nuclear power stations have changed the society and economy of the surrounding area, but to what degree and by how much?

However, the existing studies do not reach a consensus on the economic impact of nuclear power plants. Further, there are issues of analytical methodology and the lack of long-term time-series data for such an analysis, as will be seen in the next section.

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**Abbreviations:**

| | |
|---|---|
| ATET | (Average Treatment Effect on the Treated) |
| DID | (Difference-in-Difference) |
| GDP | (Gross Domestic Product) |
| IPCC | (Intergovernmental Panel on Climate Change) |
| NEA | (Nuclear Energy Agency) |
| PSM | (Propensity Score Matching) |
| TEPCO | (Tokyo Electric Power Company Holdings, Inc.) |

*Nomenclature*

| | |
|---|---|
| $i$ | municipality |
| $g$ | cohort |
| $t$ | time |
| $\gamma_g$ | the cohort fixed effect |
| $\gamma_t$ | the fixed effect of time |
| $z_{igt}$ | the covariate |
| $d_{igt}$ | a binary or continuous variable representing the treatment |
| $\epsilon_{igt}$: | the error term |

This study examines the impact of the Fukushima Daiichi nuclear power station on the regional economy and society from the beginning of the power station's construction until the earthquake and nuclear power plant accidents in 2011. For this purpose and also to tackle the issues of methodology and data, this study constructed long-term panel data on employment by the municipality in the Fukushima Prefecture from the National Census conducted from 1960 to 2010. Using these data, a difference-in-differences (DID) analysis, which is a quantitative method, is conducted to compare the locations of nuclear power plants with other areas.

## 2. Literature review and research gap

After the Fukushima Daiichi (No.1) nuclear power plant accident in 2011, much has been discussed about its social and economic impacts since the commencement of its operations in 1971. Most studies have discussed whether nuclear power is financially and economically viable considering the risks and uncertainties associated with the Fukushima Daiichi (No.1) accident [12–14]. This discussion of financial and economic feasibility has been conducted since the introduction of nuclear power, even before the Fukushima accident [15–17]. The impacts on society and the environment have also been discussed extensively [18–23].

However, only a few studies have examined the impact of nuclear power plants on local economies, and there is no consensus on these impacts. Some studies have concluded that the impact on the local economy is positive. For instance, the Nuclear Energy Agency (NEA) and International Atomic Energy Agency (IAEA) [24], and the Nuclear Energy Institute (NEI) [25] discussed the positive employment impacts of nuclear power plants.

Against these studies, there are a number of negative studies on the impact of nuclear power plants on the local economy. Based on Japan's case, Suzuki [26] concluded that nuclear power plants had created a "monoculture-type economic structure" with nuclear power plant-related industries such as construction, electricity, gas, and water supply.

Morotomi [27] also critically reviewed this impact by arguing that the operation of the Fukushima Daiichi nuclear power plant led to the "destruction of the endogenous development" of the local society where the plant is located. His reasons were twofold: the impact on employment and the massive inflow of money from outside. Let us look at these two reasons closely.

First, he analyzed the impacts of nuclear power plants on industries, such as the decline of agriculture and the increase in the retail and wholesale sectors. The concentration of employment in these industries destroys a region's endogenous development. He attributed this to the fact that employment at the construction sites of nuclear power plants increased. As it increased, the labor force increasingly shifted from the agricultural sector to the construction sector. It has been argued that part-time farmers move to construction sites as a workforce. The construction sector attracts the best talent from wholesale and local businesses.

His argument did not stop there; he even discussed how other talented people in local businesses, such as local shops, moved to the nuclear power plant industry. As the nuclear power plant requires specialized and advanced technology, only external contractors and engineers can handle power plants. After the plant was built, they remained in the region, removing construction businesses from local firms. These factors move the local economy in the opposite direction of self-reliance and endogenous development. A complete lack of linkage with the industrial structure of local businesses characterizes it.

The second point, Morotomi [27] pointed out, was the dependency on subsidies for accepting proximity to nuclear power plants. In Japan, municipalities receive massive subsidies if they accept nuclear power plants as nuisance facilities. He argued that nuclear power plants moved the local economy in a direction opposite to self-sufficiency. This is because the subsidies brought by nuclear power plants are attractive to local governments suffering from financial difficulties. The local economy was completely mobilized by the nuclear power plant and deprived of its vitality. This resulted in a complete disconnect between a nuclear power plant and the region's industrial structure.

Currently, there is an accelerating trend toward restarting nuclear power. The trend is found not only in Japan but also all over the world. Tackling climate change is one of the reasons [28–32], and the Ukrainian conflict is the other. For instance, in 2023, the Chugoku Electric Power Company approached Kaminoseki Town, Yamaguchi Prefecture, to temporarily investigate the construction of an interim storage facility to store spent nuclear fuel. The town was willing to accept the proposal, but the people were divided during the debate. This is because subsidies brought by nuclear power plants are attractive to local governments suffering from financial difficulties.

Shibata [33–35] studied the economic impacts on Futaba Town, where Fukushima Daiichi (No.1) in Fukushima Prefecture is located, and Mihama, where the Mihama Nuclear Power Plant in Fukui Prefecture is located. Fukushima Daiichi is located between Okuma Town and Futaba Town (Fig. 1). He concluded that with the construction of the nuclear power plant, the "retail and wholesale sector" and "services" sectors have grown significantly. At the same time, the local agriculture, forestry, and fishing industries have declined considerably. He also studied the impact on this population. The population increased in both Futaba Town and Mihama after the construction of the nuclear power plant, which brought about an inflow of workers from outside the prefecture. However, this cannot be said to have prevented an outflow of population. After the plant started operating, the population began to decline as the nuclear power plant construction ended. In other words, the impact on the population is temporary.

Against these opposing views, a study by the Japan Atomic Industrial Forum found positive impacts [9–11]. In the past, their Japanese organization name was Nihon Genshiryoku Sangyo Kaigi, and it became Nihon Genshiryoku Sangyo Kyokai in 2005. In this study, "Japan Atomic Industrial Forum" is used as the English translation for this name. The 1984 report was titled "Local Communities and Nuclear Power Plants." This report is based on field surveys conducted in the areas surrounding the Fukushima Daiichi (No.1), Mihama (Fukui Prefecture), and Genkai (Saga Prefecture) nuclear power plants.

According to this 1984 report, "the siting of nuclear power plants has increased production and job opportunities in local communities." While emphasizing that the siting of nuclear power plants had

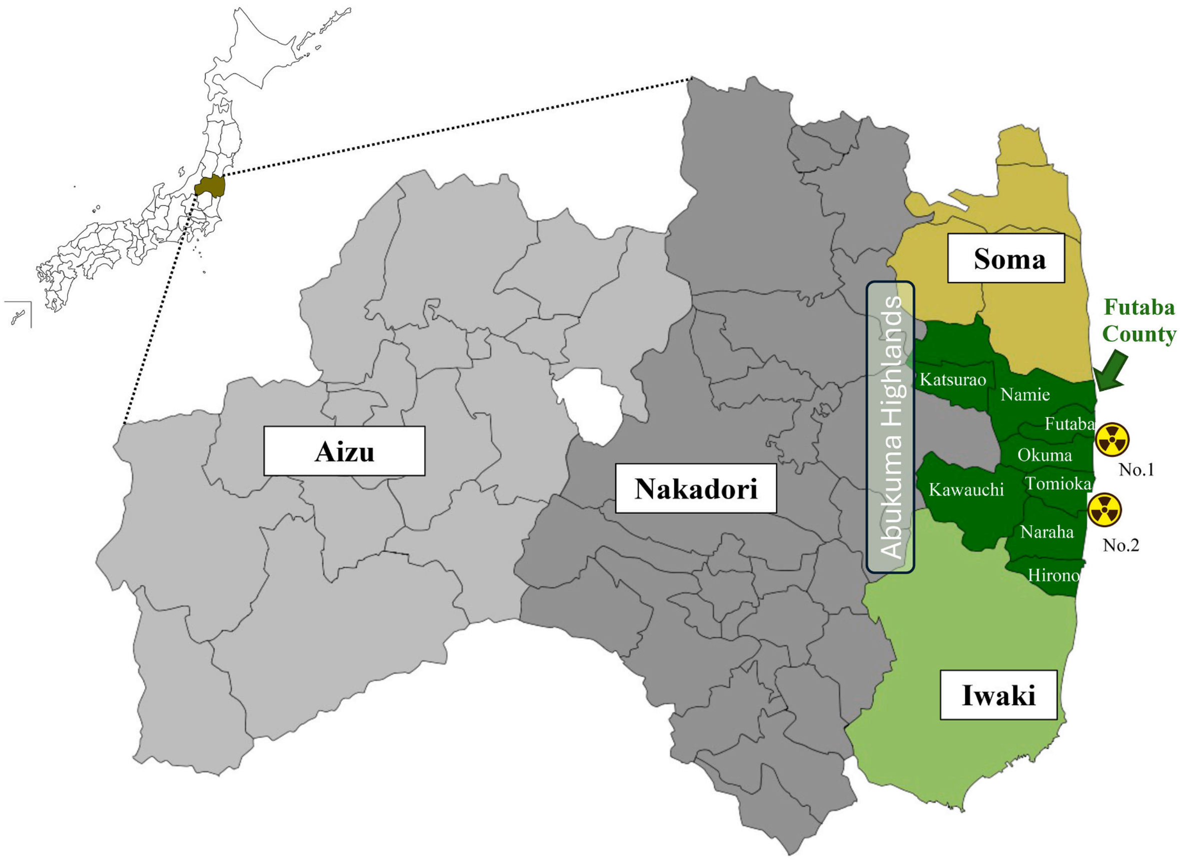


**Fig. 1.** Map of Fukushima.

contributed significantly to the development of local communities, the report also stated that "many of the economic benefits are highly time-limited" and that regional development and improvement plans were necessary based on these new findings.

The study is based on a simulation to compare the "if-located" nuclear power plant and "if-not-located" scenarios (with and without evaluation). The report concluded that their study found that in Town, 17.8 % more jobs were created with the power plant than without. The reported number of employment created compared with and without the project is 9.4 % at Mihama, Fukui, and 17.9 % at Genkai, Saga. In addition, a shift in employment structure from primary to secondary and tertiary industries has been reported.

The report also concluded that the population of the three towns where power plants are located was assessed to have either increased or halted declining. In the case of Okuma Town, where the Fukushima Daiichi (No.1) plant is located, the population increase with the project was 15.7 % greater than that without the project. The report also concludes that the population increased by 8.2 % at Mihama, Fukui, and 5.3 % at Genkai, Saga. Kainuma [36] also supported the argument that nuclear power plants increase population. Shibata [33–35] found that the impact of population increase is temporal; therefore, views on the impacts are divided.

A review of existing studies clarified that agreements and disagreements exist. Regarding the agreement, there were positive effects on employment. The most positive piece of study on this topic is the Japan Atomic Industrial Forum [11]. Other studies indicated different effects, as shown in Table 1. A common agreement is that the construction sector increases employment. Views are divided on other sectors and their impact on the population.

In spite of these disagreements, there are common methodological issues for all existing studies throughout. Except for the Japan Atomic Industrial Forum [11], other studies have analyzed trends in the number

**Table 1**
Local economy impacts of the nuclear power plants.

| | |
|---|---|
| Japan Atomic Industrial Forum [11] | 17.8 % job increase |
| Suzuki [26] | Increases jobs in construction, electricity, gas, and water supply sector |
| Morotomi [27] | Declines employment in agriculture and retail and wholesale sectors increases employment in the construction sector |
| Shibata [33–35] | Grows the retail, wholesale, and services sectors: declines agriculture, forestry, and fishing sectors. |

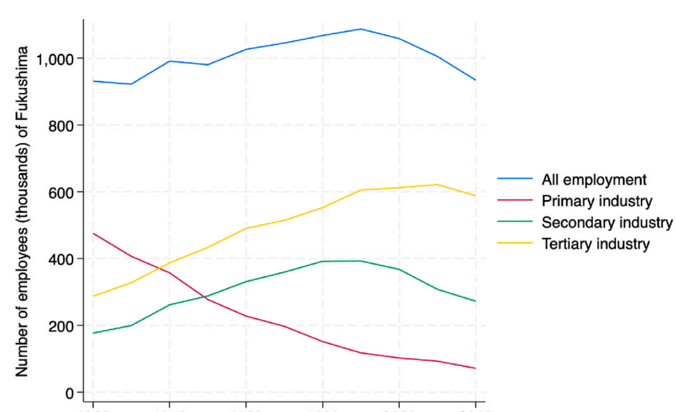


**Fig. 2.** Employment trends in Fukushima Prefecture (until before the earthquake).

of employees. The most crucial issue is that these trend analyses did not consider other economic factors. A notable example is the agricultural and service sectors. Fig. 2 shows long-term employment trends in Fukushima Prefecture. As the table shows, the primary industry, of which agriculture was the leading industry, declined even before the construction of the Fukushima Daiichi (No.1) nuclear power plant in the mid-1960s.

However, the tertiary industry has been increasing since the years before nuclear power plants. These trends are precisely what Petty-Clark's Law suggests for industrial structure changes: economic structure changes as economies develop from the primary sector to the secondary sector and eventually to the tertiary sector [37–42]. The main issue is distinguishing these long-term economic structural changes from the impact of nuclear power plants. Even without a nuclear power plant, the primary industry would decline, and the tertiary sector would increase employment. Without distinguishing between these overall effects, it is difficult to say whether power plants have a specific impact on these sectors. Therefore, it is necessary to control for these general trends in the analysis.

The Japan Atomic Industrial Forum [11] employed a with-without analysis. The with-without analysis compares outcomes between a group that experiences an intervention (the "with" group) and a group that does not (the "without" group). The with-without approach is much better for controlling external factors than the before-after analysis, which compares the conditions before and after the intervention. However, with-without analysis, there is also the issue of selection bias. This is because the groups with and without may not be comparable at baseline. Methodologically, there are other issues in the with-without approach. These issues are discussed in detail in the following sections.

This section reviews existing studies on the economic impact of the Fukushima Daiichi (No.1) power plant. As we have seen, there exists a research gap on the impact of nuclear power plants on local economies. There is also the issue of the analytical methodology employed in existing studies. To tackle these issues, in the next section, this study examines the impact of the Fukushima Daiichi (No.1) nuclear power station on the regional economy from the beginning of the power station's construction until the earthquake and nuclear power plant accidents in 2011. The following section will discuss the data and methodology used in the analysis.

## 3. Data and estimation method

### 3.1. Data

As the last section reviewed, there have been some studies on the impact of the Fukushima Daiichi (No.1) nuclear power plant on the local economy, based on national census data. However, they all used a dataset with a short time series (around 10–15 years, but the census was conducted every five years, meaning they had only two to three data points). Furthermore, most studies do not refer to data from the pre-treatment period of the 1960s. The Fukushima Daiichi (No.1) nuclear power plant was approved for construction in December 1966 and began construction in September 1967. The plant was completed, and commercial operations started in March 1971. Therefore, to understand these impacts, it is essential to have data from the 1960s′ pre-treatment period.

Therefore, this study sought data to show the impact over an extended period, starting in the early 1960s. Before 1980, the Japanese government's electronic data website did not provide data at the municipal level. Previously, the census was paper-based. For this reason, original municipal-level census data for Fukushima Prefecture from 1955 to 1960 were obtained from the National Diet Library [43]. Subsequently, several automatic scans of previous documents were performed. However, none were accurate enough to be useable, partly because the descriptions of census documents are complicated by style and differ year by year. Finally, all the data were manually entered. Several students were employed as research assistants: (1) four groups of two students entered the data into Excel, and (2) after entering the data, the same two students read the data together to ensure no errors. (3) This was further checked by two other students.

The census is conducted where the person usually lives on October 1, irrespective of the place of residence or any other notified place. The place of usual residence is where one has lived for more than three months or where the person knows he or she will live for more than three months. In the case of migrant workers (short-term employees), the destination is selected if they have lived there for more than three months; if they have lived there for less than three months, their hometown is selected.

It is hoped that time-series data on several critical variables can be obtained at the beginning of data collection. This is because this study initially aimed to examine the impact of social welfare aspects more broadly, such as taxable income rather than employment. However, even if this study attempted to generate a variety of long-term series data covering the 1960s, owing to the enormous changes in the census survey items, it was not possible to generate data on anything other than population and employment. For the analysis of DID, data from at least two pre-treatment time points, 1960 in this study's case, are required to carry out a parallel trend analysis, which will be discussed in detail later.

Even for the employment data, the classification of the employment sector changed over time; therefore, the data were processed to create panel data. For instance, in the finance and real estate sector, the data up to 1965 were treated as one section, "finance and real estate." The data from 1970 onwards were collected in separate sectors, the "finance" and "real estate" sectors. It was not possible to split the combined data "finance and real estate" into "finance" and "real estate." So, in these cases, "finance" and "real estate" are summed up and treated just as "finance and real estate."

Another difficulty encountered was the change in the boundaries or divisions of the municipality. While merging municipalities can be calculated by adding the municipalities being merged (e.g., old village A + old village B = new village C), boundary changes and splits cannot be calculated, as there is no way to split the employment data for old village D into new villages E and F. All these problematic changes were made in 1955. Therefore, the 1955 census could not be connected to the post-1960 municipal data). Therefore, it was decided to use data from 1960 onwards for the analysis in this study. Table 2 presents the descriptive statistics.

**Table 2**
Descriptive statistics.

| Variable | Obs | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|
| Total employment | 528.00 | 6334.46 | 6196.44 | 351.00 | 62294.00 |
| Primary industry | 528.00 | 2033.80 | 2107.62 | 8.00 | 19264.00 |
| Agriculture | 528.00 | 1935.21 | 2016.75 | 1.00 | 18656.00 |
| Forestry and hunting | 528.00 | 64.19 | 100.89 | 0.00 | 986.00 |
| Fisheries | 528.00 | 34.41 | 153.88 | 0.00 | 1290.00 |
| Secondary industry | 528.00 | 1932.20 | 2162.18 | 13.00 | 20360.00 |
| Mining | 528.00 | 23.08 | 56.90 | 0.00 | 803.00 |
| Construction | 528.00 | 675.78 | 737.03 | 9.00 | 7222.00 |
| Manufacturing | 528.00 | 1233.35 | 1518.58 | 4.00 | 13122.00 |
| Tertiary industry | 528.00 | 2406.09 | 3050.03 | 133.00 | 37802.00 |
| Wholesale and retail trade | 528.00 | 791.24 | 1012.76 | 12.00 | 10031.00 |
| Finance/Insurance/Real estate | 528.00 | 78.23 | 133.46 | 0.00 | 1719.00 |
| Transportation and Communication | 528.00 | 232.96 | 270.24 | 2.00 | 2618.00 |
| Electricity & Gas | 528.00 | 52.56 | 116.77 | 0.00 | 1064.00 |
| Service | 528.00 | 1015.22 | 1364.99 | 66.00 | 19099.00 |
| Public Service | 528.00 | 174.03 | 175.64 | 16.00 | 1868.00 |
| Unclassifiable | 528.00 | 13.79 | 74.47 | 0.00 | 849.00 |

### 3.2. Methodology

As discussed in the previous section, employment data from 1960 to 2010 enabled us to analyze the long-term impacts of nuclear power plants. Most existing studies have examined employment data trends by comparing before and after the start of the operation of the Fukushima Daiichi (No.1) nuclear power plant (before-after evaluation method).

It is well known that there are limitations to causality inference before and after evaluation. One of the significant limitations is the lack of a control group, as discussed in the last section; therefore, it is impossible to determine whether the changes resulted from the intervention, the nuclear power plant in this study's context, or other factors. For instance, as shown in Fig. 2, the agricultural sector has declined over the years in all areas of Japan. This decline cannot be attributed entirely to the construction of nuclear power plants, which is the overall trend in Japan.

Another method used in research is the with-without evaluation method proposed by the Japan Atomic Industrial Forum [11]. There are three significant issues associated with this method. As pointed out in the existing studies review section, selection bias is the first issue with the with-without approach, which has already been highlighted in the previous section. The second concerns the confounding effect of external shocks. If an external shock affects the "with" group but not the "without" group (or vice versa), it can lead to biased results in the case of the with-without analyses. Third, it is not easy to account for the effects of dynamic treatment. The with-without approach does not capture treatment effects that change over time.

This study employed the DID and staggered DID approaches. This is because the DID and staggered DID can tackle the issues of past studies, establishing causal inferences. This point will be discussed after discussing the DID and staggered DID methods. Fig. 3 illustrates the operation of the DID. DID is used when randomized controlled trials are not possible, as in this study [44,45]. The DID aims to estimate the causal effects of policy interventions. This was performed by comparing outcome changes between the treatment and control groups over time. Here, the control group serves as a proxy for the counterfactual because it shows what would have happened to the treatment group if the intervention had not occurred. The DID estimator measures the difference between the pre-and post-intervention changes in the outcome for the treatment group, subtracting any changes in the control group, as shown in Fig. 3.

By isolating the impact of an intervention from other factors that could affect the outcome, this approach compared the differences in outcomes between the two groups before and after the intervention. Thus, DID can be used to estimate the causal impact of the intervention. This helps to control time-invariant unobserved heterogeneity, which could bias the results if not adequately accounted for.

The DID estimates the Average Treatment Effect on the treated (ATET), which is the average effect of the intervention in the group that received the treatment (group with intervention). ATET can be written as:

$$ATET = E(Y_1 - Y_0|D=1) = E(Y_1|D=1) - E(Y_0|D=1)$$

The model used in this study can be expressed as follows:

$$y_{igt} = \gamma_g + \gamma_t + {}_{zigt}\beta + {}_{digt}\delta + \varepsilon_{igt}$$

$i$: municipality, $g$: cohort, $t$: time
$\gamma_g$: the cohort fixed effect
$\gamma_t$: the fixed effect of time
$z_{igt}$: the covariate
$d_{igt}$: a binary or continuous variable representing the treatment.
$\epsilon_{igt}$: the error term.

There are two critical assumptions for DID. These are the "parallel trend assumption" and "no anticipation assumption." In the former, the changes in outcomes were parallel in the treatment and target groups before treatment. Therefore, selection bias was not observed. Without the intervention, the treatment group would not have had different outcomes from those of the control group. This means that before the intervention, the paths of the outcomes for both groups were expected to follow similar trends over time. This assumption is crucial because it establishes that any difference in the post-treatment period can be attributed to the intervention rather than to preexisting differences or trends. To confirm this assumption, it was appropriate to compare it with the control group. The parallel trend test confirmed that the estimation satisfied this assumption. Once this test is satisfied, conducting the Propensity Score Matching (PSM) to confirm if the control group satisfies the assumption to compare is unnecessary.

The latter assumption is that no event affects the outcome before treatment (no effect on the treatment group occurs in anticipation of the treatment, or the same effect occurs across the treatment and control groups). The Granger causality test examines whether factors other than the intervention affect the outcomes.

This study also conducted a staggered DID analysis. Fukushima has two nuclear power plants: the first (Fukushima Daiichi), which failed, and the second (Fukushima Daini), which did not. Fig. 1 in the first section shows that both are in Futaba County. To be precise, the first nuclear power plant straddled the towns of Okuma and Futaba. The Fukushima Daini (No.2) nuclear power plant is located 16 km south of the Fukushima Daiichi (No.1) nuclear power plant and straddles the towns of Tomioka and Naraha.

The DID can only analyze an intervention. Therefore, in the case of the DID, the intervention is considered to begin at the operational start of the first nuclear intervention (Fukushima Daiichi (No.1)). As shown in

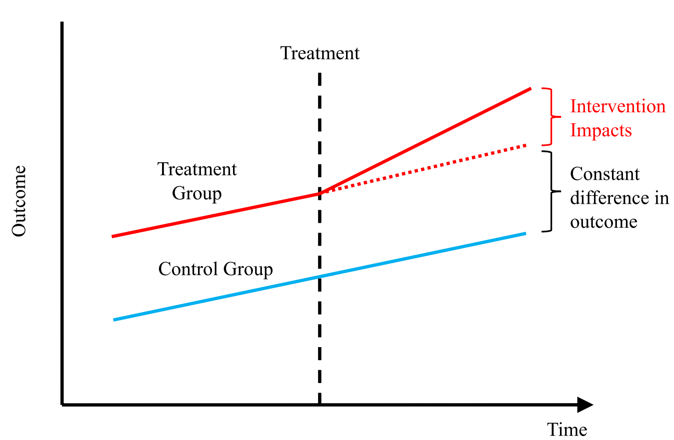


**Fig. 3.** Difference-in-Difference.

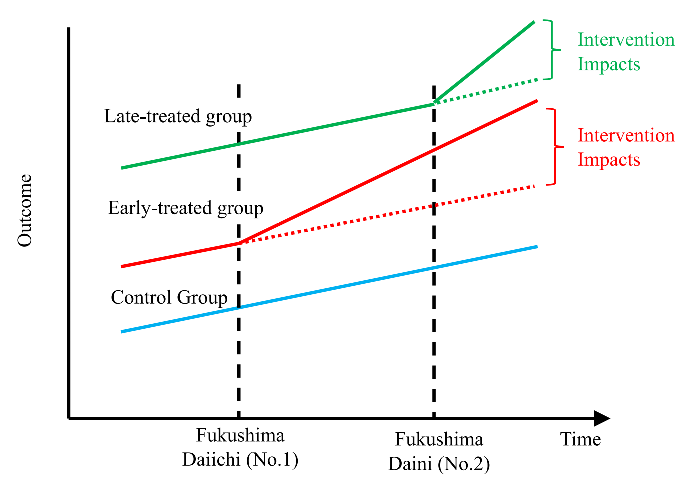


**Fig. 4.** Staggered difference-in-difference.

Fig. 4, staggered DID can analyze cases with two interventions [46,47]. Therefore, the staggered DID analysis separates Fukushima 1 and 2, which have different operational start points and municipalities (Fukushima Daiichi (No.1) started operations in 1971 in Okuma and Futaba towns, and Daini (No.2) started operations in 1982 in Naraha and Tomioka towns).

Regarding the treatment group for the DID analysis, as shown in Table 3, Futaba County (the County is called "gun" in Japanese) served as the treatment group. Futaba County, where the nuclear power plant is located, consists of six towns and two villages and has an area of 865.71 $km^2$, which is slightly larger than that of Singapore. These towns and villages are Hirono Town, Naraha Town, Tomioka Town, Kawauchi Village, Okuma Town, Futaba Town, Namie Town, and Katsurao Village. Futaba County and the Soma area are called Hamadori. Please note that, as Fig. 1 illustrates, Futaba Town is a part of Futaba County. The nuclear power plant (No.1) is located in Futaba Town of Futaba County. These eight towns and villages are within commuting distance and close to nuclear power plants. Thus, they can be said to have been affected similarly. The similarity was checked by the parallel test, Granger causality test, and DID itself between towns in Futaba County with nuclear power plants and towns and villages without nuclear power plants. All the tests and the DID found no difference between the two groups of towns and villages in Futaba County. So, it can be safely said that the influence of the nuclear power plant is similar in this County, which serves as the treatment group.

The towns and villages of Nakadori and Aizu were used as the control group. The suitability of the control group was checked using the parallel trend test to determine whether the parallel assumption was satisfied. Fig. 1 shows these areas and Futaba County juxtaposed horizontally, from east to west. Importantly, Futaba County is physically separated from Nakadori and Aizu by the Abukuma Highlands. The highlands also separated Futaba County economically because commuting was limited. Owing to this plateau, no trains directly connect Futaba County to other regions from east to west, although the distances are small. One must make a significant detour by train from Futaba County to Nakadori and Aizu. Trains and highways run north to south in Futaba County, Nakadori, and Aizu. As a result, despite being in the same prefecture, Futaba County is said to be quite different from the Nakadori and Aizu counties. As the towns and villages of Futaba County are small, the cities of Fukushima Prefecture are excluded from the control group because they have a much larger population and different industrial structures.

## 4. Results

### 4.1. DID analysis

Table 4 presents the results of the DID analysis. As mentioned, Futaba County was the treatment group, and the municipalities of Naka Dori and Aizu were the control groups. Parallel trend tests were conducted to verify these parallel assumptions. Because all *p*-values are greater than 0.10, this test supports the parallel trend hypothesis.

Another test, the Granger causality test, was conducted to evaluate whether the control or experimental groups could be used to estimate changes in trends for the other group. Again, the results of all tests are

**Table 3**
Treatment Group and Control Group divided by Abukuma Highlands.

| | Treatment Group | Control Group | Method |
|---|---|---|---|
| Estimation 1 | Futaba County, where nuclear power plants are located | Municipalities of Naka Dori and Aizu | DID |
| Estimation 2 | Towns where nuclear power plants are located (Okuma, Futaba, Naraha, and Tomioka Town) | Towns and villages of Naka Dori and Aizu | Staggered DID |

above 0.10; therefore, there is insufficient evidence to reject the null hypothesis that the trends do not change before the intervention. Combined with the results of the parallel trend tests, this suggests that the ATET estimates can be trusted.

Looking at the coefficients for all industries that show total employment in Model 1, the results are positive and statistically significant. This means that since its operation at Fukushima Daiichi (No.1) in 1972, the nuclear power plant has generated 984.56 more jobs in Futaba County. Before the nuclear power accident, the county's population was approximately 74,000. Therefore, the impact of power plants can be considered significant.

The left panel of Fig. 5 shows the observed means, and the right panel shows a linear trend model that sets the same starting point. As the figure shows, employment in the control group declined rapidly, and employment in Futaba County did not increase significantly. It increased until 2000 and started declining after that but was not as fast as that of the control group.

Further, looking into each sector in Table 4, manufacturing became strongly negative, −506.27. This indicated a significant decline. Fig. 6 shows the figural diagnosis for the parallel trend in the manufacturing sector and shows that the mean number of employees in Futaba County in 2010 was just above 500. The number of employees initially dropped in Futaba County but then increased. Considering the observed means in the right-hand panel of Fig. 6, employment in the treatment in 2010 is almost the same as in 1970 before the intervention. The mean number of employees in 2010 increased in the control group compared with 1970. Later in the discussion and conclusion sections, the reason for this negative impact will be discussed.

Several sectors have become significantly positive, as shown in Table 4. One such sector is the construction sector. This result is precisely what the existing studies point out, which is unsurprising and confirms what it is supposed to be.

However, a surprising result is agriculture (and primary industry), which has been argued to have declined due to the start of nuclear power plant operations. These results were positive and statistically significant. By contrast, 704.90 more employment is generated according to the coefficient. This is higher than that of the construction sector (401.07). Fig. 7 shows a figure-specific diagnosis of the parallel trends in agriculture. As can be seen, the number of employees has not increased; it has declined but not as fast as the control group. Instead, employment in agriculture continued to stay stable. The reason for this surprising positive impact will also be discussed in the discussion and conclusion section.

In Table 4, the electricity, gas, and water sectors are positive, as predicted. There is a crucial point to note here. For this sector and other sectors, such as wholesale retail and local government, the outcome of the intervention is considered to show the 1970 round of census data rather than the 1975 census data. The Fukushima Daiichi (No.1) nuclear power plant was approved in December 1966, and all the preparation work began. Therefore, TEPCO (Tokyo Electric Power Company Holdings, Inc.) had already begun hiring, and people from other cities settled in Futaba County. The local governments also began to receive support funds from TEPCO once the project was approved. The wholesale and retail sectors also increased their employment. Therefore, changes began earlier in these sectors than in other sectors.

The *p*-values of the parallel trend tests in Table 4 suggest that they satisfy our assumptions and are comparable. In addition to the intervention reported in 1970, the 1975 intervention was tested. In this case, the *p*-values of the parallel trend tests were less than 0.10, indicating that changes occurred in these sectors and were not comparable at that point. Therefore, the 1970 intervention period was employed for these sectors.

Fig. 8 shows the diagnosis, and the rate of increase for Futaba County is very high. The vertical line is shown for 1965, as this was the last pretreatment period, and the post-treatment period began in 1970. There was a stark difference compared with the control group. The left panel

**Table 4**
DID analysis.

| Model No. | Dependent Variable (Number of people employed in the following sectors) | coefficeint | (p-value) | Robust HC2 Std. Err. | *N* | Number of clusters | Parallel-trends test (p-value) | Granger causality test (p-value) |
|---|---|---|---|---|---|---|---|---|
| 1 | All industries | 984.56 ** | (0.04) | 472.83 | 480 | 48 | 0.53 | 0.53 |
| 2 | Primary industry | 704.90 * | (0.10) | 450.71 | 480 | 48 | 0.14 | 0.14 |
| 3 | Secondary industry | −77.96 | (0.79) | 297.34 | 480 | 48 | 0.15 | 0.15 |
| 4 | Tertiary industry | 290.51 | (0.47) | 396.39 | 480 | 48 | 0.64 | 0.64 |
| 5 | Agriculture | 734.26 * | (0.08) | 409.67 | 480 | 48 | 0.13 | 0.13 |
| 6 | Fisheries | −1.15 | (0.65) | 2.56 | 480 | 48 | 0.70 | 0.70 |
| 7 | Mining | 27.24 *** | (0.01) | 9.80 | 480 | 48 | 0.14 | 0.14 |
| 8 | Manufacturing | −506.27 *** | (0.00) | 144.07 | 480 | 48 | 0.14 | 0.14 |
| 9 | Construction | 401.07 ** | (0.04) | 190.20 | 480 | 48 | 0.72 | 0.72 |
| 10 | Wholesale retail industry (1970) | 21.53 | (0.22) | 98.43 | 480 | 48 | 0.21 | 0.21 |
| 11 | Electricity, gas and water (1970) | 182.78 ** | (0.01) | 69.43 | 528 | 48 | 0.40 | 0.40 |
| 12 | Service | 118.14 | (0.58) | 213.01 | 480 | 48 | 0.47 | 0.47 |
| 13 | local government (1970) | 14.26 | (0.40) | 16.93 | 528 | 48 | 0.47 | 0.47 |

***, **, and * indicate statistical significance at the 1 %, 5 %, and 10 % levels, respectively.

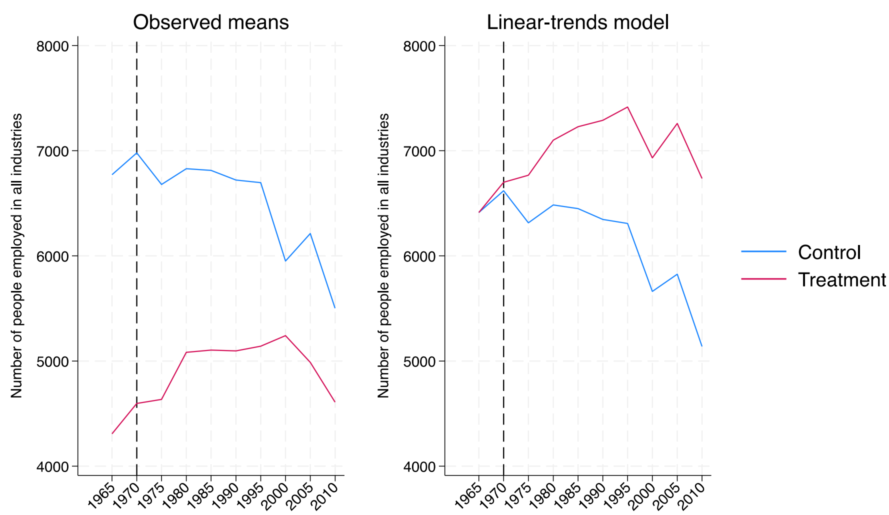


**Fig. 5.** Diagnosis for parallel trend (total employment).

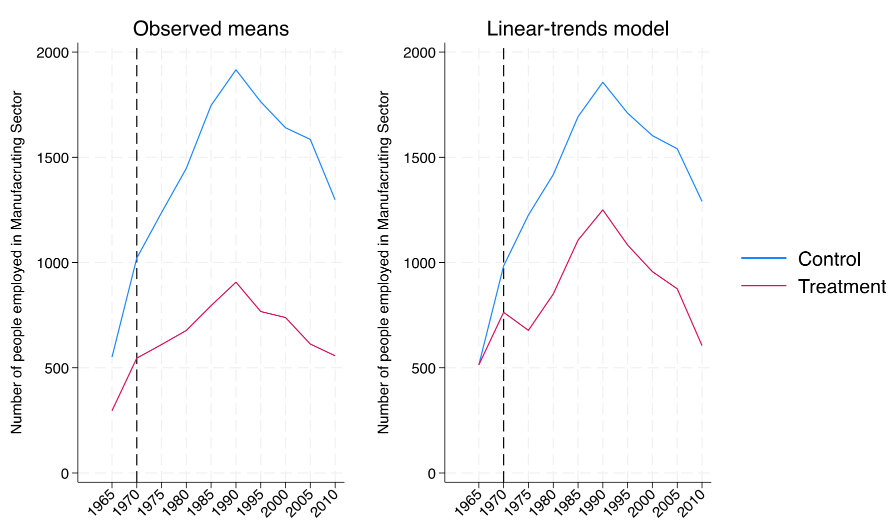


**Fig. 6.** Diagnosis for parallel trend (manufacturing).

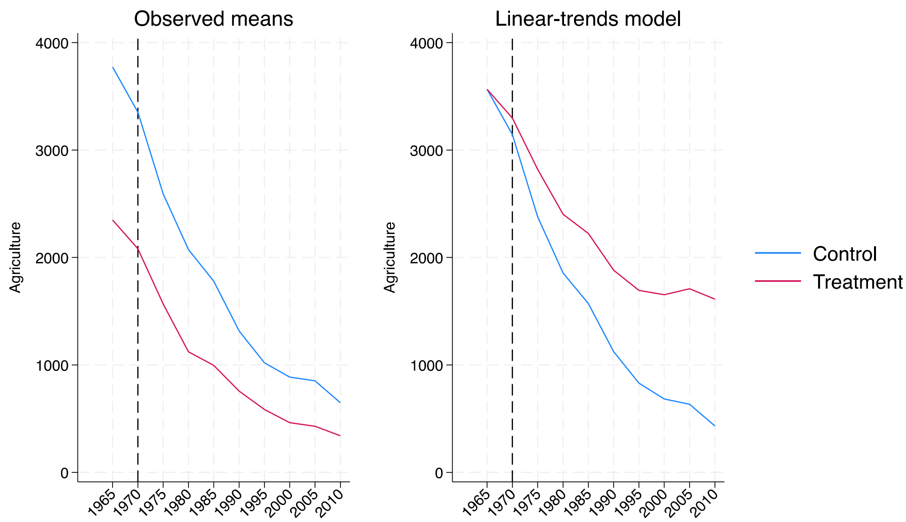


**Fig. 7.** Diagnosis for parallel trend (agriculture).

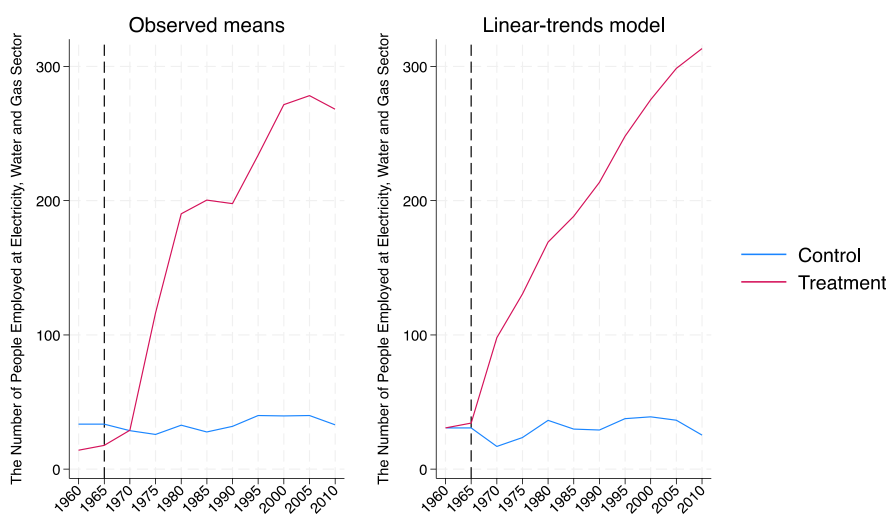


**Fig. 8.** Diagnosis for parallel trend (electricity, gas, and water).

(observed means) shows that the marginal increase gradually decreases over time.

The wholesale retail and service sectors do not become positive, while the existing studies claim a positive impact on these sectors. There was an increasing trend in the treatment group, but this was the same as that observed in the control group. As discussed, this is what Petty-Clark's Law suggests, and even without a nuclear power plant, the industrial structure shifts to the tertiary sector, such as wholesale retail and services. Mining also became positive, but the coefficient was small (only 27 employees increased).

### 4.2. Staggered DID analysis

Table 5 presents the results of the staggered DID analysis. For this analysis, the intervention periods of Fukushima Daiichi (No.1), located in Okuma and Futaba Towns, and Daini (No.2), located in Naraha and Tomioka Towns, were considered separately. As mentioned in the Methodology section, this analysis involved multiple intervention periods.

Some of the results were the same as those of the DID analysis and confirmed these results. In model 1, employment has a positive effect on all industries. The coefficient (1631.33) was larger than that of the DID analysis (984.56). This means that power plants create significant employment opportunities in this area. The same applies to primary industry and agriculture; the coefficient is larger than that in the DID analysis. Thus, contrary to the existing studies, this study found that nuclear power plants increase employment in agriculture. Construction, electricity, gas, and water are all positive, although the coefficients differ slightly.

The manufacturing sector is also negative (−466.40 fewer jobs), and the coefficients are almost the same. The most worrying result is the negative impact on the manufacturing sector, as this sector usually absorbs laborers and provides the necessary income for their families. The benefit of a staggered DID analysis is that this approach enables us to see how the intervention affects over time.

Fig. 9 shows the aggregated impacts of the two power plants on the manufacturing sector. As shown, until 1995 there was a declining trend, after which it started to increase. Therefore, the impact changed over time. These changes are shown in Table 6. The negative impacts persisted until 1995 when the coefficients became less negative but

**Table 5**
Staggered DID analysis.

| Model No. | Dependent Variable (Number of people employed in the following sectors) | coefficeint | (p-value) | Robust HC2 Std. Err. | *N* | Number of clusters |
|---|---|---|---|---|---|---|
| 1 | All industries | 1631.33 *** | (0.00) | 540.24 | 528 | 48 |
| 2 | Primary industry | 902.90*** | (0.01) | 287.14 | 528 | 48 |
| 3 | Secondary industry | −36.42 | (0.89) | 255.85 | 528 | 48 |
| 4 | Tertiary industry | 741.80 * | (0.08) | 408.99 | 528 | 48 |
| 5 | Agriculture | 892.62 *** | (0.00) | 256.42 | 528 | 48 |
| 6 | Fisheries | 0.84 | (0.64) | 1.82 | 528 | 48 |
| 7 | Mining | 16.9 | (0.22) | 13.62 | 528 | 48 |
| 8 | Manufacturing | −466.40 *** | (0.00) | 133.64 | 528 | 48 |
| 9 | Construction | 413.07 ** | (0.02) | 172.24 | 528 | 48 |
| 10 | Wholesale retail industry | 58.43 | (0.58) | 103.75 | 528 | 48 |
| 11 | Electricity, gas and water | 319.08 *** | (0.00) | 66.95 | 528 | 48 |
| 12 | Service | 396.35 * | (0.10) | 233.89 | 528 | 48 |
| 13 | local government (1970) | −1.94 | (0.88) | 12.47 | 528 | 48 |

***, **, and * indicate statistical significance at the 1 %, 5 %, and 10 % levels, respectively.

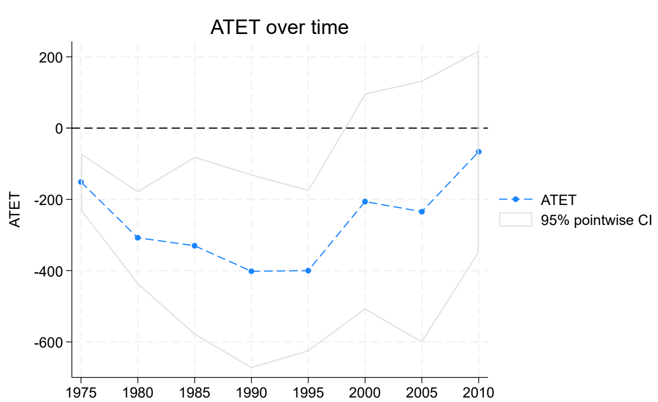


**Fig. 9.** Aggregated impacts of the two power plants on manufacturing sector.

statistically insignificant. This indicates that the adverse effects of nuclear power have disappeared in decades. In other words, there is a hangover effect from the nuclear power plant. These findings have significant implications for the future recovery of this region following the 2011 nuclear accident. This is discussed in the conclusion section.

Contrastingly, as Tables 5 and 6 show, the impacts on agriculture are surprisingly consistent and positive (892.62 more jobs). The impact on the construction sector is positive (413.07 more jobs), as the existing studies and the DID analysis show. However, as shown in Table 6, these effects were temporal. No local economy can sustain itself by relying on this type of industry. What policy implications can be drawn from this analysis?

## 5. Discussion and conclusion

As discussed thus far, Fukushima's nuclear power plants have had mixed impacts on the local economy. Using newly constructed longitudinal time-series data, this study found positive impacts on agriculture and negative impacts on the manufacturing sector, which lasted for decades. These points have neither been discussed nor proven in previous studies. This study also confirmed some of the impacts of other studies, such as temporally positive impacts on the construction sector and positive impacts on the tertiary industry.

These results lead to the following question: Why did nuclear power plants have negative impacts on the manufacturing sector and positive impacts on agriculture?

One possible reason for the negative impact on the manufacturing sector is the high wages at nuclear power plants. Based on interviews with farmers and villagers in the local community, the Japan Atomic Industrial Forum [9,10] reported comments from local firms that the wages in the neighboring nuclear plant areas became too high for them to hire people. This is because the plant offers very high salaries, which attracts workers. This high wage at nuclear power plants made it necessary for other companies to raise wages to hire workers, but most commented that they were unable to do so. People working in the manufacturing sector must have found it easier to shift their work to nuclear plants than those from other sectors like agriculture and fisheries. In other words, the nuclear power plants crowded out the local manufacturing sector.

One possible reason for the puzzling positive impact on agriculture is that farmers have become more likely to stay in Futaba County. Before the nuclear power plant came to town, farmers used to migrate from Futaba County to Tokyo and other urban cities during the agricultural off-season. This changed when their household income improved once one of the family members began working for the nuclear power plants; they no longer needed to migrate. So, they stayed in town or continued to work in agriculture. Nuclear power plants provide some part-time work, such as security guards and other miscellaneous jobs. Therefore, they could continue farming even if other areas of Japan were forced to move to the secondary and tertiary sectors, away from the primary sector. Perhaps the industrial structure should have changed, as in other areas of the country, as suggested by Petty-Clark's Law for industrial structure changes. However, this was distorted and delayed.

In the current discussion on recovery, the agricultural sector seems to have been overlooked. During the interviews conducted after the nuclear accident in this region, some people expressed their sentiments regarding their farmland and crops. Any recovery effort must recognize the feelings of the people forced to evacuate. At the same time, the reality remains that it is not possible to return to the same state as during the days of nuclear power plants. This is the dilemma Fukushima has been facing.

In summary, the nuclear power plant distorted the economy, preserving agriculture, which should have become smaller in terms of employment as the economy grew, and crowding out the manufacturing sector, which would generally have been the absorber of these jobs. Instead, this sector relies on temporary construction and the tertiary sector.

Decommissioning of the Fukushima nuclear power plants by many companies is underway. However, it is unclear when the decommissioning will be completed; it is said this endeavor may take another 30 years. Decommissioning is also extremely dangerous owing to radiation, which is why the development of advanced technologies such as robots is being rapidly promoted. There is a disconnect between large companies developing these technologies and the local economy, whose economic structure is the same as that of decommissioning and nuclear power plants. Furthermore, the salaries paid were extremely high. Overall, wages are high because few people return to the area; they have been forced to evacuate owing to the 2011 nuclear power plant accident. If this is the case, it would be extremely difficult for industries other than the decommissioning industry to start and operate without government subsidies. This is what occurs in the towns and villages of Futaba County; however, the business model is unsustainable. This means that the crowding-out structure, which this study looked at, is ongoing and

**Table 6**
Impacts on agriculture, manufacturing, and construction.

| **Agriculture** | | | | | **Manufacturing** | | | | | **Construction** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **ATET** | **(p-value)** | **Robust Std. Err.** | | | **ATET** | **(p-value)** | **Robust Std. Err.** | | | **ATET** | **(p-value)** | **Robust Std. Err.** |
| Aggregate Effect | 1975 | 255.59** | (0.02) | 107.69 | Aggregate Effect | 1975 | −151.02 *** | (0.00) | 41.38 | | 1975 | 173.14 *** | (0.00) | 22.24 |
| | 1980 | 461.66 *** | (0.01) | 166.98 | | 1980 | −307.68 *** | (0.00) | 67.01 | Aggregate Effect | 1980 | 288.50 ** | (0.01) | 106.72 |
| | 1985 | 352.06 ** | (0.02) | 151.25 | | 1985 | −330.07 ** | (0.01) | 127.61 | | 1985 | −58.48 | (0.62) | 118.12 |
| | 1990 | 636.35 *** | (0.00) | 181.23 | | 1990 | −401.66 *** | (0.00) | 138.89 | | 1990 | −61.95 | (0.61) | 120.87 |
| | 1995 | 787.56 *** | (0.00) | 208.28 | | 1995 | −399.84 *** | (0.00) | 115.79 | | 1995 | −146.2 | (0.46) | 198.21 |
| | 2000 | 821.92 *** | (0.00) | 217.05 | | 2000 | −206.14 | (0.18) | 154.87 | | 2000 | 480.86 | (0.27) | 435.45 |
| | 2005 | 858.81 *** | (0.00) | 196.93 | | 2005 | −234.48 | (0.21) | 187.63 | | 2005 | 398.43 | (0.33) | 405.36 |
| | 2010 | 970.01 *** | (0.00) | 233.89 | | 2010 | −66.23 | (0.65) | 145.04 | | 2010 | 26.39 | (0.90) | 215.66 |
| | | Number of cohorts | | 3 | | | Number of cohorts | | 3 | | | Number of cohorts | | 3 |
| | | Number of obs | | 528 | | | Number of obs | | 528 | | | Number of obs | | 528 |
| | | Never treated | | 484 | | | Never treated | | 484 | | | Never treated | | 484 |
| | | Fukushima No.1 (1975) | | 22 | | | Fukushima No.1 (1975) | | 22 | | | Fukushima No.1 (1975) | | 22 |
| | | Fukushima No.2 (1980) | | 22 | | | Fukushima No.2 (1980) | | 22 | | | Fukushima No.2 (1980) | | 22 |

will continue.

It is difficult to recommend what local governments should do to promote recovery from accidents. However, any policy must be formulated based on the impacts of past policies. The impacts on agriculture and manufacturing industries are new, and the next step should be to recognize them. The government, local authorities, and civil society must continue dialogue and negotiation on what is sustainable while understanding such impacts.

This study has a data limitation. While it is desirable to examine other variables, such as taxable income and municipal-level GDP (Gross Domestic Product), there exist issues with the construction of the panel data on these variables, especially the changed definition of the variables. Due to data limitations, this study used only employment data. Ideally, the statistical authority should continue collecting original variable data and adding new variables rather than stopping data collection. Despite the limitation, the findings of this study bring us a step forward in understanding this area to promote industries to recover from the nuclear power plant accident.

Finally, many emerging economies and developing countries have begun considering building nuclear power plants. In Africa, South Africa already has an operational nuclear power plant and may have another one soon. Other countries, such as Kenya, Ghana, and Uganda, also plan to construct nuclear power plants. It is important to know the economic and social impacts that the nuclear power plants may have on local people. This is one of the possible future research directions.

## Credit author statement

The author (Go Shimada) confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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## Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author used Grammarly and DeepL to check for grammatical errors. After using this tool/service, the author reviewed and edited the content as needed and took full responsibility for the content of the publication.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Shimada Go reports financial support was provided by Japan Society for the Promotion of Science. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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