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## Estimating the effects of nuclear power facilities on local income levels: A quasi-experimental approach

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*Estimating the effects of nuclear power  
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A quasi-experimental approach*

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ESTIMATING THE EFFECTS OF NUCLEAR POWER FACILITIES ON LOCAL INCOME LEVELS:  
A QUASI-EXPERIMENTAL APPROACH

MICHIHITO ANDO

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# Estimating the effects of nuclear power facilities on local income levels: A quasi-experimental approach\*

Michihito Ando<sup>#</sup>

January 27, 2013

## *Abstract*

This paper studies how the establishment of Nuclear Power Facilities (NPF) in the 1970s and 1980s has affected local per capita income levels in NPF-located municipalities in Japan by using the synthetic control method (SCM). Eight quantitative case studies using the SCM clarify that the effects of NPF establishment on per capita taxable income levels are highly heterogeneous, but often economically meaningful and in some cases huge: an 11 % increase on average, a 62 % increase in Rokkasho village in 2002 and a 30 % increase in Tomioka town in 2002. On the other hand, a few NPF-located municipalities receive weak or negligible effects from NPF establishment. I also examine the statistical significance of individual treatment effects with several placebo tests and find that the treatment effects of 4 out of the 8 NPF locations are larger than 95% of placebo effects.

*Keywords:* local economic growth, nuclear power facilities, synthetic control method

*JEL codes:* H71, O18, R53

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*You know, municipalities where nuclear power plants are located are all poor areas. Okuma town has a mild climate and it's comfortable to live there. But the main industry was agriculture and many people looked for jobs in urban cities during the winter. In the winter, fathers had to leave home. Families had to live apart. "If nuclear power plants come, we won't have to leave home during the winter. We could get better jobs with steady incomes, instead of relying on volatile agriculture. We can receive education in nice school buildings. Grants will make the town rich." Nuclear power was called "the energy of the future".*

-Toshitsuna Watanabe, the mayor of Okuma town, Fukushima prefecture<sup>1</sup>

## 1. Introduction

Since the Fukushima Daiichi nuclear disaster in 2011, it has been widely recognized in Japan that municipalities which have accepted the location of nuclear power facilities (NPF) receive large employment opportunities and NPF-related fiscal benefits such as central grants and revenues from local property taxes. It is, however, not clear how the establishment of NPF promotes local economic and income growth. Several official reports point out that the benefit of NPF to the local community is generally weak<sup>2</sup>. On the other hand, there is a stereotype that the economy of NPF-located municipalities depends heavily on the nuclear power industry. Then the question arises: does NPF establishment really lead to a significant increase in local income levels?

In order to tackle this question, I examine the impact of the location of nuclear power facilities (NPFs) in the 1970s and 1980s on local per capita taxable income in Japan. This study will contribute to the following two research strands in economics. First, this study is closely related to recent literature on the effects of specific economic shocks on local and regional economies, such as the effects of pipeline construction on the local labor market (Carrington, 1996), the effects of terrorist conflict on regional per capita GDP (Abadie and Gardeazabal, 2003), the effects of military base closures on local employment (Dardia et al., 1996, Hooker and Knetter, 2001, and Poppert and Herzog Jr., 2003), the effects of coal boom and bust on local employment and earning (Black et al., 2005), and the effects of large plant openings on total factor productivity of incumbent plants (Greenstone et al., 2010)<sup>3</sup>.

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<sup>1</sup> This passage is quoted from an interview with Toshitsuna Watanabe in Japanese at *Diamond Online* <http://diamond.jp/articles/-/16605>. The article was published on March 15, 2012. The sentences are translated into English by the author. All the citizens in Okuma town were evacuated from their homes after the accident at Fukushima Daiichi Nuclear Power Plants on March 11, 2011.

<sup>2</sup> For example, see the introduction of METI (2011).

<sup>3</sup> Another partly related research field is the growing literature on how particular historical events affect local or regional economic growth in the long run, either directly or indirectly. This literature tends to focus on the very long-term impact of colonial or historical legacies such as Banerjee and Iyer (2005), Dell (2010), Acemoglu, et al. (2011), and Acemoglu et al. (2012) and differs from my study in the sense that they study persistent effects of *past* events while NPF operation is *ongoing* business activity. They are, nevertheless, relevant to my study because the focus of these studies is the effects of a peculiar monumental event on local or regional economic development.

The findings of this study are in particular comparable with results in studies that estimate the impact of economic shocks with explicit quasi-experimental designs. For example, Abadie and Gardeazabal (2003), using the Synthetic Control Method (SCM), estimate that terrorist conflict in the Basque Country causes 10% loss in per capita GDP. The baseline estimation in Black et al.(2005), whose research design is similar to a conventional difference-in-differences (DID) approach, find that earnings per worker grew around 3 % faster during the coal boom and 2.8% slower during the bust. Greenstone et al. (2010), also exploiting several DID approaches, estimate that a large plant opening in a “winning” county leads to 12 % higher total factor productivity in incumbent plants five years after the opening.

In this study, using the SCM, I find that the NPF establishment makes per capita taxable income in NPF-located municipalities around 61.7 % higher as an maximum and about 11.1 % higher on average. Although the outcome variables and the “shocks” differ in the literature and cannot be compared directly, the economic impact of NPF establishment seems large in several NPF-located municipalities and on average.

Second, this study contributes to the literature on economic analysis of NPF locations. To my knowledge, previous studies on the socio-economic impact of NPF location largely fall into two groups. The first group studies the effect of NPF establishment on property prices around NPFs, mostly using a hedonic approach such as Nelson (1981), Gamble (1982), Clark and Nieves (1994), Clark et al. (1997) and Folland and Hough (2000). The second group examines the impact on local industry and employment, using descriptive statistics or Keynesian income multiplier models such as Pijawka and Chalmers (1983), McGuire (1983), Lewis (1986), Glasson et al. (1988), Metz (1994) and Cumbria et al. (2012). When it comes to Japanese NPFs, several reports by the Japan Atomic Industrial Forum (JAIF) such as JAIF (1984) provide detailed descriptive statistics and some simulation studies about the impact of an NPF location on the local economy. Nishikawa (2000) studies the fiscal impact of NPFs in Japan using simple regression analysis.

From an econometric point of view, it is not an easy task to estimate the impact of NPF establishment on local income levels. As in Black et al. (2005) and Greenstone et al. (2010), estimation strategies based on DID approaches may be applicable, but there are several challenges when I apply DID estimation in this study.

First, because NPF sites are not randomly assigned but determined by various geographical, political and socio-economic factors, the common trend assumption of simple DID may not be plausible. In addition, it is hard to control for confounding time-varying covariates because NPF establishment changes local socioeconomic situations in various ways and controlling for these endogenous factors may cause a “bad control” problem (Angrist and Pischke, 2008).

Second, the number of “treated” municipalities is small: in Japan, there are only 22 NPF-located municipalities and my limited dataset allowed me to examine only 8 NPF location events. Although the time dimension of the dataset is relatively large (from 1972 to 2002), the small number of treated units could make it difficult to consistently estimate an average effect of NPF establishment and

implement plausible statistical inference.

Third, heterogeneity of the treatment could also result in misleading conclusions: the timing of NPF establishment, periods of construction and operation, numbers and scales of NPFs differ considerably in each NPF-located municipality. Impacts of NPFs are also not uniform across years because construction and operation involve different economic activities and the huge revenue from local property tax based on NPF-related assets decreases gradually due to depreciation once NPF operation starts. Then estimated average treatment effect of the small number of NPF locations could be hard to interpret without taking into account this treatment heterogeneity.

To deal with these problems, I adopt the synthetic control method (SCM) which was firstly proposed by Abadie and Gardeazabal (2003) and then further developed by Abadie et al. (2010). The idea underlying the SCM is intuitively clear: a combination of non-NPF-located municipalities is used to construct a “counterfactual” unit (called synthetic control unit) of an NPF-located municipality and then the per capita income of this counterfactual unit is compared with the actual per-capita income of the NPF-located municipality. One notable feature of the SCM is that the required number of treated units is only one. That is, using the SCM, I can investigate the effect of NPF establishment on per capita income, focusing on *individual* NPF-located municipalities. As is mentioned in Section 4, the common trend assumption in DID can also be relaxed with the SCM. In addition, by extending placebo tests suggested by Abadie et al. (2010), I propose two simple inference methods to explicitly test the statistical significance of SCM estimates.

The rest of the paper is organized as follows. In Section 2, I briefly describe the historical background of Japan’s NPF locations and possible causal pathways from NPF establishment to local income level. Section 3 describes the dataset that I use for estimation and then show simple difference in differences (DID) estimation. Section 4 explains identification issues in the synthetic control method, presents estimation results and discusses implications. In Section 5, the results of placebo tests are presented. I also provide two statistical significance tests using the distributions of average placebo effects. Section 6 concludes.

## **2. Nuclear power facilities in Japan**

### ***2.1 Historical background***

According to a report from the Japan Atomic Industrial Forum, JAIF (1984), NPF locations were in general welcomed and accepted by local municipalities and local people during the 1960s, when the constructions and operations of the oldest nuclear power plants started in Tokai, Tsuruga, Mihama, and Fukushima.

NPF locations became more controversial for local communities in the early 1970s, when several NPF-related accidents happened in Japan. Since then, the perception that NPFs pose risks to those living in their vicinity has become stronger<sup>4</sup>.

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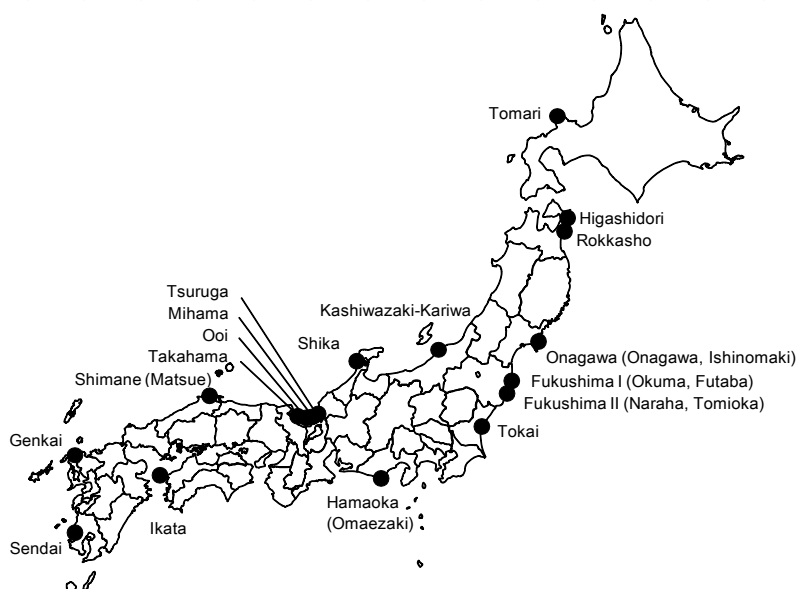
<sup>4</sup> For example, people may believe that NPFs could potentially damage health through exposure to low-level radiation, ruin health in the event of severe nuclear accidents, contaminate agricultural and fishery products through

In addition, it became more apparent that it was not clear to what extent NPFs made an economic contribution to local communities. New jobs created by NPF locations and their indirect effects were often attractive for local residents, but even in the late 1960s and early 1970s, when only one NPF was operating in Japan, several official reports of a governmental committee pointed out that the economic impact of NPFs on the local economy was relatively small and unsustainable<sup>5</sup>: First, NPF-sited regions are usually unsuitable for industrial development and it is hard to expect that other factories or business offices will move into regions with new NPFs. Second, demand for local labor during plant construction is not high, if it exists at all, and is limited to relatively low-skilled work.

Recognizing the perceived risks and limited direct benefits of NPFs, the committee suggested that several fiscal measures were necessary to encourage the development of NPF-sited municipalities. With a strong political initiative by then prime minister Kakuei Tanaka, this suggestion led to the famous power source siting laws in 1974<sup>6</sup>.

Since these laws were implemented, the central government and energy companies have been equipped with strong fiscal compensation schemes which help to subdue local anti-NPF movements. Although it is not clear how these laws contribute to the promotion of NPF locations, there were 54 nuclear plants located in 21 municipalities and several nuclear fuel recycling facilities in one municipality (Rokkasho village) in 2010 (Figure 1).

**Figure 1. Location of Nuclear power facilities in Japan, 2010**



Notes: When the names of NPFs are not identical with the names of municipalities, the latter are shown in parentheses.

radiation, and cause consumers to boycott local agricultural and fishery products due to fears of contamination. Considerable uncertainty about the likelihood and magnitude of these risks is another negative aspect of NPFs.

<sup>5</sup> Shimizu (1991a, 1991b) reviews the committee's findings.

<sup>6</sup> Act on Tax for Promotion of Power-Resources Development, Law on Special Accounts for Electric Power Development Acceleration Measures, and Act on the Development of Areas Adjacent to Electric Power Generating Facilities. Shimizu (1991b) discusses early development and amendment of these laws.



## ***2.2 NPF establishment and local economic growth***

Although it is hard to observe the precise mechanism of NPF effects on the local income level, a simple local production function  $Y = F(A, L, K, G)$  or its per capita notation  $y = f(A, l, k, g)$  provides some useful implications<sup>7</sup>. The latter equation with per capita variables implies that NPF establishment is expected to affect all the variables on the right-hand side of the equation. Equipment investment for NPFs increases private per capita private capital  $k$ . NPF-related public investment raises per capita public capital  $g$ . The ratio of employment to total population  $l$  can be increased by NPF-related job opportunities and worker inflow from other areas. Structural change in local industry could also affect productivity  $A$ . All of these impacts can lead to an increase in per capita income  $y$ . In the following subsections, I briefly discuss these potential causal pathways from NPF establishment to local economic growth and local per capita income.

### ***Equipment Investment in NPF***

According to the above local production function, equipment investment in NPF leads to an increase in local production and therefore local per capita income through accumulated private capital. This is simply due to electricity production and the allocation of its business benefits to local people. One caveat is that this paper studies changes in local income levels and uses per capita taxable income, not per capita local GDP, as an outcome variable. Hence the leakage of the benefits to other areas might be significant because electricity generation from nuclear power plants are managed by large electricity firms whose headquarters and many affiliated organizations are located in other large cities.

### ***NPF-related public investment***

In addition to the direct investment in plants or facilities, NPF location affects local public investment through NPF-related grants and tax revenues. Figure 2 illustrates the amounts of fiscal transfers and property tax revenues in a model municipality before and after NPF construction and operation based on the 2003 fiscal year. This figure shows that the total amount of grants increases sharply when an NPF construction starts. Then, just after the NPF begins its operation, local property taxes start to flow into municipality's coffers while several grants expire or shrink. Revenue from property taxes gradually decreases year by year because of the depreciation of NPF-related property.

These fiscal changes increase productive public investment and possibly per capita income in NPF-sited municipalities<sup>8</sup>. In particular, before 2003, major NPF-related subsidies were restricted to

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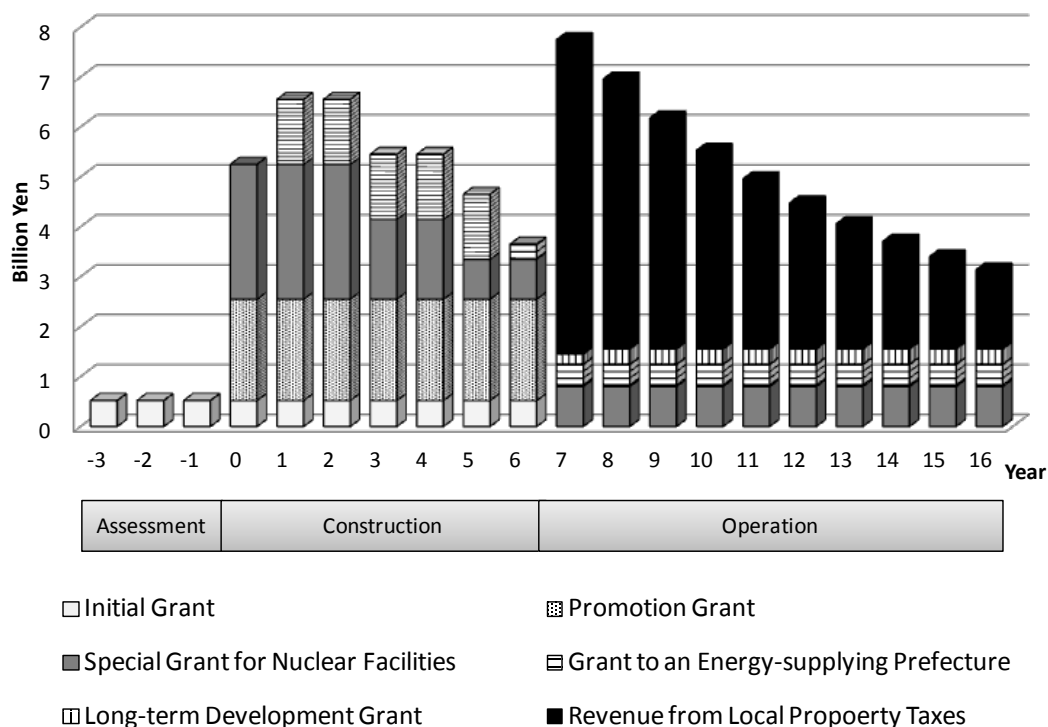
<sup>7</sup> As in the textbook setting,  $Y$  is a local production or local income level,  $L$  is labor,  $K$  is private capital,  $G$  is public capital,  $A$  is an indicator of productivity such as technology and knowledge, A small letter  $x$  corresponds to per capita values,  $X/N$ , where  $N$  is population size. It is common to divide production function by  $L$  or  $AL$ , not  $N$ , to obtain an equation with per worker or per effective labor terms, but I derive per capita terms since my empirical analysis use per capita income  $Y/N$  as a main outcome variable.

<sup>8</sup> The impact of public investment on local or regional economic growth has been extensively studied using the framework of local production function and other approaches. See seminal works by Aschauer (1989), Gramlich (1994) and Holtz-Eakin (1994) and recent literature review by Romp and Haan (2007). Romp and Haan (2007)

the construction of municipal public facilities and some of them were designed to be used for the promotion of local business activities. Even if they did not have a long-term positive contribution to local business productivity, these grants at least should have contributed to increasing local employment in the short run through public investment projects.

On the other hand, if these revenues are used in inefficient or growth-impeding ways, local income levels may not change significantly. In addition, a large part of the increase in local tax revenue is in general canceled out by a decrease in fiscal equalization grants, so called ordinary Local Allocation Tax (LAT) grants<sup>9</sup>. It is therefore not certain whether increases in NFP-related revenues always increase local per capita taxable income.

**Figure 2. NPF-related grants and property taxes in a model case**



Notes: Estimates are based on a model case (Output = 1.35 GW, Construction cost = 450 billion yen, construction period=7 years). Institutional and budgetary settings are based on the 2003 fiscal year. Grants for neighboring municipalities and a prefecture are included, but property taxes and long-term development grants are estimated only for a NPF-located municipality. Some other NPF-related grants and tax revenues are not considered here.

Source: Ministry of Economy, Trade and Industry: METI (2004)

conclude that the recent literature finds more evidence of a growth-enhancing effect of public capital, but the magnitude of the impact is much lower than found by Aschauer (1989), though they review both regional and national growth. They also indicate that many studies report heterogeneous effects, depending on the characteristics of investment regions and the types of investment.

<sup>9</sup> In Japan, 75% of revenue-capacity increase in major taxes is taken into account in the fiscal equalization scheme and the LAT grants are reduced instead. Roughly speaking, tax revenue increase by 100 in LAT-received municipalities will lead to total revenue increase by 25 due to decrease in the LAT grants by 75. Exceptions are rich municipalities which do not receive any LAT grants. For no-LAT-received municipalities, increase in tax revenue means one-to-one increase in total revenue.

### ***NPF-related Employment***

NPF-related private and public investments also create large employment opportunities. For example, JAIF (1984) surveys the three oldest NPF location cases in Japan and finds certain economic contributions of NPF construction and operation to local employment. It is difficult to know the exact number of total jobs generated by NPF location, because indirect impacts on retail, accommodation and other service sectors are hard to measure. In the most recent literature, Miyoshi (2010) points out that around one third of workers belong to the NPF industry in Tsuruga city in Fukui prefecture and Kainuma (2011) mentions that approximately one out of three or four households have a family member who works for NPF-related businesses in NPF-sited municipalities in Fukushima.

### ***Some restraining factors***

NPF establishment is not a simple investment project. NPF location is often a controversial political agenda due to NPFs' NIMBY (Not-in-My-Back-Yard) characteristics. NIMBY features could generate peculiar incentive and distributional effects on the local politics and industries because political compromise and fiscal compensation are crucial in order for affected groups to reach an agreement on NPF location<sup>10</sup>.

As is implied in Murphy et al. (1993), the rent-seeking activities that arise from these political and fiscal environments may be costly for sustainable economic growth through more productive and innovative activities. Persson and Tabellini (2002) also review possible causality from special interests and political rents to economic growth. In this perspective, NPF establishment could hinder sustainable local economic growth through efficient investment, human capita development and innovation which would have been realized if NPPs had not been located there. Although it is hard to identify the effect of incentive changes on local economic growth, there is some possibility of negative causal channels from NPF location to local growth.

In addition, NPF establishment might not cause industrial accumulation because of low economic spillovers and a small number of NPF-related businesses. NPF-related public investment may also be ineffective from local growth perspective since the allocation of funds to these projects is based on neither market mechanism nor cost-benefit analysis. Furthermore, NPF-located regions are generally less developed areas whose economic potential could be low. These characteristics imply that NPF-related public investment could have little impact on long-term local development.

### ***2.3 Heterogeneous treatment***

It can also be expected that NPF locations have larger or smaller effects on local income levels, depending on different characteristics of their NPF locations. For example, Rokkasho village in Aomori prefecture has several nuclear fuel recycling facilities, not nuclear power plants. The

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<sup>10</sup> See Lesbirel (1998) , Aldrich, (2004, 2005, 2008a, 2008b) and Dusinger and Aldrich, (2011) for NIMBY facility siting in Japan, including NPF location.

locations of these facilities have caused the inflows of affiliated companies and high-skilled workers, which municipalities with nuclear power plants have not experienced<sup>11</sup>. Then the overall impact of NPF establishment on Rokkasho can be larger than the impact of nuclear-plants establishment on another municipality.

Table 1 presents basic information about the 8 NPF-located municipalities which I use as treated units in the following analysis. The selected municipalities are the NPF-located municipalities in which the first NPF construction took place during 1975 to 1988<sup>12</sup>. This table shows very heterogeneous patterns of NPF establishment. Timing of the first NPF construction, the number of NPFs and total power are considerably different in each NPF site. In Section 4, I estimate the effects of these heterogeneous NPF locations on per capita taxable income levels in the NPF-located municipalities respectively, using coastal non-neighbor municipalities within a certain region as the set of control units<sup>13</sup>. In the next section, before moving to the estimation part, I firstly describe my dataset and then implement simple difference-in-differences estimations to motivate the use of the SCM.

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<sup>11</sup> Akimoto (2003) provides detailed statistics which show the changes of local industry and local public finance in Rokkasho before and after the NPF location. Rokkasho village (2008) presents a list of more than 80 companies that have moved to or have been established in Rokkasho, most of which are directly or indirectly related to NPF establishment.

<sup>12</sup> The reasons why we exclude the other 14 NPF-located municipalities from the analysis are: (1) the first NPF construction happened before 1972 and my dataset (from 1972 to 2002) has no pre-intervention period (Futaba, Okuma, Tokai, Hamamatsu, Tsuruga, Mihama, Takahama, Ooi, Kashima, and Genkai), (2) the first NPF construction started in 1973 and the pre-intervention period is only one year (Shikata), (3) the first NPF construction started in 1998 and the post-intervention period is only 4 years (Higashidori), (4) the first NPF construction took place in 1978 but the confounding effect of fossil fuel plants location in the 1970s could not be eliminated (Sendai) and (5) no tangible fixed assets such as nuclear reactors are located within area and a confounding idiosyncratic shock (the stagnation of a major industry, whaling, after the 1970s) cannot be controlled for (Oshika).

<sup>13</sup> See Section 4.2 for the setting of estimation with the SCM.

**Table 1. Municipalities treated in this study**

Municipality	Name of NPFs	Region	First NPF location year	Intervention year	Number of nuclear plants (2010.3)	Total power (MW) (2010.3)
1.Rokkasho	Nuclear Fuel Cycle*	Tohoku	1986	1986	-*	-
2.Tomari	Tomari	Hokkaido	1984	1984	3	2070
3.Onagawa	Onagawa	Tohoku	1979	1979	3	2174
4.Naraha	Fukushima II	Tohoku	1975	1975	2	2200
5.Tomioka	Fukushima II	Tohoku	1980	1975	2	2200
6.Kashiwazaki	Kashiwazaki-Kariwa	Hokuriku	1978	1978	4	4400
7.Kariwa	Kashiwazaki-Kariwa	Hokuriku	1983	1978	3	3812
8.Shika	Shika	Hokuriku	1988	1988	2	1746

\*In Rokkasho, four nuclear fuel cycle facilities have been located so far. That is, Uranium Enrichment Plant, Reprocessing Plant, Vitrified Waste Storage Center, and Low-level Radioactive Waste Disposal Center. See Rokkasho Village (2008) for further details.

Notes: The Japanese fiscal year is from April to March. Rokkasho's "Fiscal NPF location year" is the year when land reclamation for nuclear fuel cycle facilities started. For the other municipalities, "Fiscal NPF location year" is the first year of NPF construction based on official records. "Intervention year" is identical with the "Fiscal NPF location year" for most municipalities, but Tomioka's and Kariwa's intervention years are defined as Naraha's and Kashiwazaki's intervention years respectively. It is because Tomioka and Naraha share the Fukushima II nuclear plants around their border and it is expected that Tomioka is influenced by Naraha's first NPF location. In a similar way, Kariwa should be affected by Kashiwazaki's first NPF construction. Each "total power (MW)" is calculated based on METI (2011).

### 3. Data and DID analysis

#### 3.1 Descriptive statistics

The panel data that I use for the following analysis cover all the municipalities across Japan and consist of three types of variables, that is, per capita taxable income based on registration data (1972-2002, fiscal year), socio-economic variables based on Census data (1960, 1965, 1970, ... , 2000), and fiscal variables based on municipality fiscal statistics (1975-2002, fiscal year)<sup>14</sup>. My outcome variable of interest is per capita taxable income<sup>15</sup>. As will be discussed in Section 4, Census data before the first NPF location is used for pre-determined covariates in the SCM. Fiscal variables

<sup>14</sup> The municipality list of my dataset is arranged based on 1998.4.1. I do not use the data after 2002 because huge municipality amalgamation (so called Heisei Amalgamation) took place in the 2000s and the number of municipalities decreased from 3,232 (1999.3.31) to 1730 (2010.3.31). I also excluded all the 55 municipalities which experienced amalgamation between 1973.4.1 and 2002.3.31 from the sample.

<sup>15</sup> As is mentioned before, a certain amount of business income in electric power companies should go outside of NPF-located municipalities. Therefore per capita taxable income is a better indicator of the average income level of local people than per capita local GDP because the latter includes business income, which does not necessarily result in income for local people. One fault of using taxable income as a proxy for local income level is that it may not properly reflect income levels of those who have more discretion in reducing the amount of taxable incomes by using income deduction, such as the self-employed. Another defect in this variable is that the range of "taxable" income varies depending on years due to policy changes, but it should not seriously affect the cross-municipality income variation.

are not used for estimation, but it is useful to see how they change after NPF location because public investment and other expenditure could be a major source of local income growth.

The left-hand side of Table 2 shows the summary statistics of these variables in the 1970s and 2000 for the 8 NPF-located municipalities which I use as treated units in the analysis with the SCM. The right-hand side of this table presents the counterpart statistics for the coastal municipalities which do not have NPFs in their areas. The reason why I limit the sample to coastal municipalities is that all the nuclear power plants in Japan are located along the sea and nuclear fuel cycle facilities are also sited in a coastal municipality, Rokkasho village<sup>16</sup>. It is therefore reasonable to assume that all the “comparable” municipalities are along coastal areas.

When I compare the variables of NPF-located and non-NPF-located municipalities, there are some noticeable differences between them. First, average per capita taxable income in NPF-located municipalities is lower than in non-NPF-located municipalities in 1972, but it exceeds the counterpart in 2000. Growth rate in per capita taxable income during 1972-2000 in NPF-located municipalities is around 129 % and it is about 38.1 percentage points higher than in non-NPF-located municipalities.

Second, NPF-located municipalities have smaller populations and lower Densely Inhabited Districts population<sup>17</sup> ratios than non-NPF-located municipalities both in 1970 and in 2000. Population growth during 1972-2000 in the NPF-located is slightly positive on average but it is also smaller than that of the no-NPF-located. Average population ratios in all age cohorts (Age 0~15, 16~64, and 65~) are very similar in both 1970 and 2000. When it comes to ten-year population growth rates in 1970, the growth rates in the population of the age groups of 0~15 years and 16~65 years are more negative in the NPF-located municipalities, but, the same ten-year growth rates in 2000 do not show clear differences between the NPF-located and the non-NPF-located.

Third, the industrial structure of NPF-located municipalities is more dependent on the primary sector in 1970, but the growth rates from 1970 to 2000 of the secondary sector ratio and the tertiary sector ratio for these municipalities are higher than in the non-NPF-located<sup>18</sup>. The ten-year growth rates of the secondary and tertiary industries in 1970 are stagnant in the NPF-located compared with the non-NPF-located.

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<sup>16</sup> Only one NPF-located municipality, Kariwa village in Niigata prefecture, is not a coastal municipality. However, Kariwa village is very close to the sea and provides the land for the Kashiwazaki-Kariwa nuclear power plants, which is located across Kashiwazaki city and Kariwa village.

<sup>17</sup> The Densely Inhabited Districts population ratio is an index of urbanization and calculated as the ratio of population in Densely Inhabited Districts to total population. In general, Densely Inhabited Districts are defined as groups of contiguous unit blocks which satisfy the following two requirements: 1. each of contiguous unit blocks has a population density of 4,000 inhabitants/km<sup>2</sup> or more and 2. the total population of contiguous unit blocks is 5,000 or more within a municipality.

<sup>18</sup> The industrial classification here follows the Japan Standard Industrial Classification. The primary sector consists of agriculture, forestry, fisheries and mining. The secondary sector includes construction and manufacturing. The remaining industries such as wholesale trade, retailing, finance, insurance, transportation, communication, other services, public service, etc. belong to the tertiary sector.

Fourth, when I focus on more detailed sectoral ratios of industry<sup>19</sup>, many NPF-located municipalities are more dependent on fishery both in 1970 and 2000 and less on wholesale, retail and other services. The most rapidly growing sector in its sectoral ratio for the NPF-located is other services<sup>20</sup> and its average sectoral ratio increases from 10% % in 1970 to 26% in 2000. The sectoral ratio of construction also doubles from 9% to 19% in the NPF-located municipalities.

Fifth, when it comes to fiscal variables, the most noticeable feature is a high growth rate (1141 % on average) in per capita tax revenue from 1975 to 2000 in NPF-located municipalities while the counterpart of the non-NPF-located is only 160%. A growth rate in per capita expenditure is more moderate due to a decrease in the fiscal equalization grants (the LAT grants<sup>21</sup>), but it is still 296%, compared with 159% in the non-NPF-located municipalities.

These simple comparisons between NPF-located and non-NPF-located municipalities in the 1970s and 2000 provide two implications. First, selection based on socio-economic factors should be an important consideration in choosing the location of NPFs and this endogenous location may be problematic for orthodox quasi-experimental strategies like difference in differences. Second, implications from the above comparison do not contradict the simple theoretical consideration in Section 2.2. That is, NPF location seems to affect per capita income positively by promoting industrial shift from low productive sectors to high productive sectors and increasing private and public investment.

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<sup>19</sup> These detailed industrial sectors are chosen based on the characteristics of NPF-located municipalities: Fishery is a major industry for some NPF-located municipalities and the stagnation of the mining sector could be one factor for a municipality to accept NPFs. Construction and manufacture are both important industries for local and peripheral economy. The ratio of whole sale and retail sectors indicates the presence of basic service sectors.

<sup>20</sup> “Other services” include various tertiary sectors of industries that are *not* categorized either as wholesale, retail, finance, insurance, transportation, communication, electricity, gas, heat supply, water business, real estate, and public service.

<sup>21</sup> See footnote 9 for a brief description of the LAT grants.

**Table 2. Descriptive statistics in the 1970s and 2000**

Variable	NPF-located municipalities							Non-NPF-located coastal municipalities							Diff. (1)-(2)
	1970s			2000			(1) Growth rate (70s-00)	1970s			2000			(2) Growth rate (70s-00)	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.		N	Mean	Std. Dev.	N	Mean	Std. Dev.		
<b>Per capita taxable income (Thousand yen)</b>	8	507.77	125.35	8	1162.09	139.34	128.9%	887	556.55	260.18	895	1061.83	290.58	90.8%	38.1%
<b>Demographic variables</b>															
Population	8	19438	25000	8	19923	28106	2.5%	895	46202	168284	895	52676	196161	14.0%	-11.5%
Densely Inhabited Districts population ratio	8	0.0994	0.1842	8	0.1167	0.2161	17.4%	895	0.1893	0.2714	895	0.2180	0.3097	15.2%	2.2%
Population ratio (Age 0~15)	8	0.2715	0.0528	8	0.1477	0.0197	-45.6%	895	0.2644	0.0451	895	0.1457	0.0236	-44.9%	-0.7%
Population ratio (Age 16~64)	8	0.6361	0.0423	8	0.6167	0.0461	-3.1%	895	0.6412	0.0495	895	0.6127	0.0517	-4.4%	1.4%
Population ratio (Age 65~)	8	0.0924	0.0270	8	0.2356	0.0576	155.0%	895	0.0944	0.0273	895	0.2416	0.0640	155.8%	-0.9%
Growth rate (Population, Age 0~15, 10 years)	8	-0.3912	0.1575	8	-0.2427	0.0721	-	845	-0.2633	0.3436	895	-0.2509	0.1219	-	-
Growth rate (Population, Age 16~64, 10 years)	8	-0.0735	0.2097	8	-0.0649	0.1551	-	848	0.0191	0.2118	895	-0.0874	0.1215	-	-
Growth rate (Population, Age 65~, 10 years)	8	0.1819	0.0908	8	0.3385	0.1452	-	845	0.2703	0.4340	895	0.3647	0.1406	-	-
<b>Basic industrial structure</b>															
Employment ratio to population	8	0.4973	0.0579	8	0.5093	0.0467	2.4%	895	0.4932	0.0553	895	0.4890	0.0461	-0.8%	3.3%
Sectoral ratio (Primary)	8	0.4475	0.1685	8	0.0974	0.0385	-78.2%	895	0.3756	0.1930	895	0.1591	0.1188	-57.6%	-20.6%
Sectoral ratio (Secondary)	8	0.2766	0.1243	8	0.3774	0.0713	36.4%	895	0.2551	0.1320	895	0.2899	0.0865	13.6%	22.8%
Sectoral ratio (Tertiary)	8	0.2758	0.1142	8	0.5252	0.0802	90.4%	895	0.3693	0.1247	895	0.5511	0.1096	49.2%	41.2%
Growth rate (Employment, Primary, 10 years)	8	-0.2857	0.1643	8	-0.3942	0.0647	-	848	-0.3175	0.1177	895	-0.2844	0.1882	-	-
Growth rate (Employment, Secondary, 10 years)	8	0.1443	0.4544	8	0.0118	0.5440	-	847	0.4362	0.6841	895	-0.0718	0.1751	-	-
Growth rate (Employment, Tertiary, 10 years)	8	0.1308	0.4110	8	0.1550	0.2039	-	848	0.3224	0.2898	895	0.0873	0.1281	-	-
<b>Detailed industrial structure</b>															
Sectoral ratio (Fishery)	8	0.0866	0.1253	8	0.0391	0.0589	-54.8%	895	0.0714	0.1137	895	0.0470	0.0749	-34.2%	-20.6%
Sectoral ratio (Mining)	8	0.0076	0.0096	8	0.0019	0.0012	-75.3%	895	0.0081	0.0396	895	0.0026	0.0120	-67.3%	-8.0%
Sectoral ratio (Construction)	8	0.0930	0.0874	8	0.1915	0.0776	105.8%	895	0.0817	0.0444	895	0.1248	0.0423	52.8%	53.0%
Sectoral ratio (Manufacturing)	8	0.1760	0.1068	8	0.1841	0.0948	4.6%	895	0.1654	0.1277	895	0.1624	0.0898	-1.8%	6.4%
Sectoral ratio (Wholesale/Retail)	8	0.1103	0.0354	8	0.1376	0.0299	24.7%	895	0.1313	0.0539	895	0.1754	0.0482	33.6%	-8.9%
Sectoral ratio (Other services)	8	0.1044	0.0367	8	0.2598	0.0535	148.9%	895	0.1313	0.0531	895	0.2492	0.0570	89.8%	59.2%
<b>Fiscal variables (Thousand yen)</b>															
Tax revenue per capita	8	38.52	12.86	8	478.18	282.42	1141.4%	895	38.83	27.55	895	100.92	57.07	159.9%	981.4%
Fiscal equalization grants (LAT)	8	84.26	45.71	8	7.82	18.49	-90.7%	895	74.94	62.91	895	227.72	197.87	203.9%	-294.6%
Central grants per capita	8	47.94	29.62	8	117.39	155.37	144.9%	895	46.96	51.23	895	59.21	173.20	26.1%	118.8%
Expenditure per capita	8	262.58	120.47	8	1040.03	1052.29	296.1%	895	244.25	143.83	895	632.73	539.42	159.0%	137.0%
Construction per capita	8	86.35	41.54	8	257.28	315.56	198.0%	895	84.51	75.43	895	173.06	226.73	104.8%	93.2%

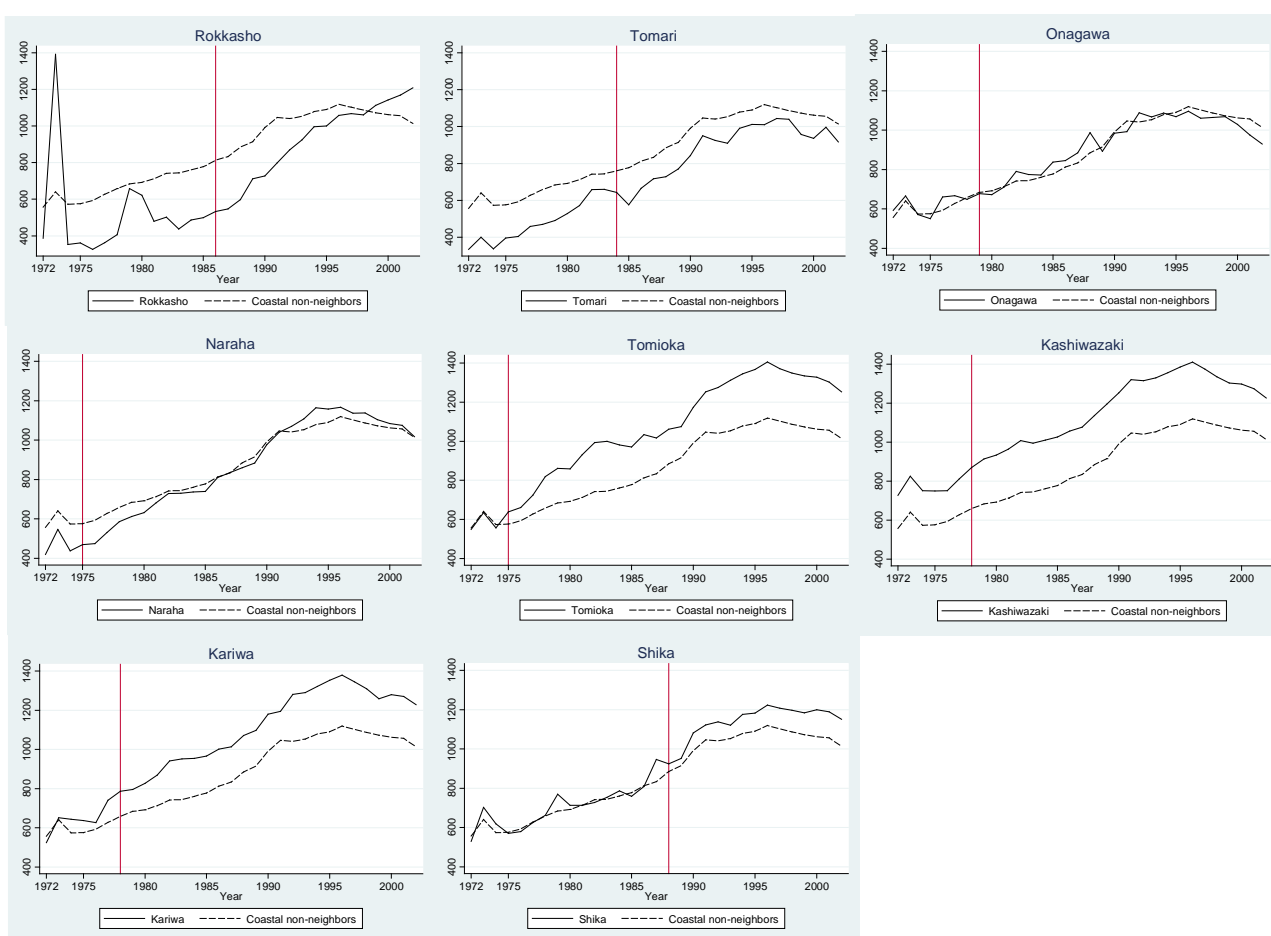
Notes: See Appendix A for the definitions and data sources of all the variables. Statistics in the 1970s are different due to data availability: per capita taxable income is based on 1972, demographic variables and industrial structure on 1970, fiscal variables except central grants on 1975, and central grants on 1977. The other 14 NPF-located municipalities, which are not listed in Table 2, are excluded from the sample. The neighboring municipalities of these excluded NPF-located municipalities are also eliminated from the sample. One exception is Yokohoama town in Aomori prefecture. This town is a neighboring municipality of both Rokkasho (a treated NPF-located municipality in this study) and Higashidori and kept in the sample as a neighboring municipality of Rokkasho. Miyake village in Tokyo prefecture is also dropped because of residents' evacuation from their island in 2000 due to a volcanic eruption. Finally, coastal special districts (called *ku*) in Tokyo are also not in the sample.



### 3.2 Trends and simple DID

In this subsection, I provide time-trend graphs and simple Difference-in-Difference (DID) estimates in order to consider what can be learned from a simple DID framework. First, Figure 3 shows the time trends of per capita taxable income in the 8 NPF-located municipalities with solid lines and the counterpart trend of control municipalities with dashed lines. The control municipalities consist of the coastal local bodies which do not have NPFs and also do not border on the NPF-located municipalities (called “coastal non-neighbors”). I exclude the coastal neighboring municipalities of the NPF-located from the control group because these municipalities are expected to gain some benefits from NPF establishment such as subsidies, employment, and other indirect effects<sup>22</sup>.

**Figure 3. Per capita taxable income in NPF-located municipalities (thousand yen)**



Notes: Solid lines represent per capita taxable income in the 8 NPF-located municipalities respectively. The dashed lines in all the graphs represent the same average per capita taxable income in coastal non-neighbors. A vertical line in each graph indicates the intervention year, which is presented in Table 1.

<sup>22</sup> JAIF (1984) provides detailed statistical survey on these neighbor effects at the three earliest nuclear power plant sites. See also Appendix B for some investigation into coastal neighboring municipalities. I assume that the effects of NPF location on nearby but not neighboring municipalities are negligible or geographically dispersed.

The comparison of the two trends in the eight graphs indicates that (I) the income trends in Rokkasho, Tomioka, and Kariwa are clearly shifted upward compared with the income trend in the coastal non-neighbors, implying that NFP establishment seems to positively affect per capita income in these municipalities<sup>23</sup>, (II) the trends in Naraha and Shika also show modest upward shifts after intervention, (III) the trend in Tomari is hard to interpret because the pre-intervention trend is apparently different from the coastal non-neighbors, and (IV) Onagawa and Kashiwazaki have similar trends to the coastal non-neighbors after intervention, suggesting no NFP impact.

Second, to clarify the graphical implications mentioned above, I implement OLS estimation with the following simple DID model :

$$Y_{it} = \gamma_i + \pi_t + \alpha D_{it} + \varepsilon_{it}, \quad (1)$$

where  $Y_{it}$  is per capita income in municipality  $i$  in period  $t$ ,  $\gamma_i$  is municipality fixed effects,  $\pi_t$  is a common time effect,  $\varepsilon_{it}$  is the unobservable random error term, and  $D_{it}$  is a dummy variable which takes value one for NFP-located municipalities in and after the intervention years and zero otherwise. I use the same data as in Figure 3 to obtain DID estimates for the 8 location events respectively by setting only one NFP-located municipality as a treated group and excluding other NFP-located from the sample<sup>24</sup>.

Results are shown in Table 3. DID estimates for respective NFP establishment are compatible with the implications from Figure 3. For example, DID estimates for Rokkasho, Tomioka, and Kariwa are larger than estimates for the others. In sum, DID estimates are mostly positive and suggest that the NFP location could have some positive “effect” on NFP-located municipalities.

**Table 3. DID estimates for per capita income (thousand yen)**

Treated municipalities	(1) Rokkasho	(2) Tomari	(3) Onagawa	(4) Naraha	(5) Tomioka	(6) Kashiwa-zaki	(7) Kariwa	(8) Shika
DID estimate	164.67*** (38.30)	61.5*** (17.10)	-17.18 (14.67)	115.02*** (15.51)	222.43*** (12.19)	82.07*** (6.18)	157.36*** (20.90)	78.94*** (12.61)
Adjusted R-squared	0.9166	0.9169	0.9168	0.9168	0.9169	0.9169	0.9169	0.9168
Observations	19,305	27,161	27,161	27,161	27,161	27,161	27,161	27,161
No. of municipalities	878	878	878	878	878	878	878	878
No. of the treated municipalities	1	1	1	1	1	1	1	1
Sample period	1981-2002	1972-2002	1972-2002	1972-2002	1972-2002	1972-2002	1972-2002	1972-2002

Notes: Heteroskedasticity-robust standard errors are in parentheses. In column (1), observations before 1981 are excluded for Rokkasho because per capita taxable income in Rokkasho during this period fluctuates considerably. \*\*\*, \*\*, \* denote significance at the 1%, 5% and 10% level respectively.

<sup>23</sup> Income fluctuation in Rokkasho before 1980s is huge, but in the first half of the 1980s Rokkasho has more or less a similar income trend to the trend in coastal non-neighbor municipalities.

<sup>24</sup> In Appendix B, I provide a more standard DID estimation where all 8 NFP-located municipalities are included in a treated group. In addition, in order to see whether NFP location has a spillover effect on neighboring areas, I also implement a DID analysis with which 18 coastal neighboring municipalities are used as a treated group.

### 3.3 Limitations of the DID analysis

Although the graphical analysis and the simple DID estimation provide useful information about what happened to the income levels of NPF-located municipalities, reliable causal interpretation is difficult due to the following restrictions.

First, the key identifying assumption behind the graphical analysis and DID estimation is that the trend of per capita income would be the same in the treated and the untreated in the absence of treatment. This common trend assumption might not be plausible because NPF assignment is not random but somewhat endogenously determined by various factors such as geographic and socio-economic environments, which should be correlated with income trends. Although Figure 3 shows that the common trend assumption is not entirely implausible, it is hard to verify the assumption clearly because of relatively short pre-intervention periods.

One common way to solve or mitigate this problem is to add time-varying covariates  $X_{it}$  to the equation (1). This strategy, however, does not work well in this case because the impact of NPF location is diverse and many time-varying covariates could be affected by the treatment. In this case, so-called “bad control” problem arises and the identification of the treatment effect fails<sup>25</sup>.

Another approach is to implement DID estimation conditional on pre-determined covariates  $X$  or propensity score  $P(X) = Pr(D = 1|X)$ , where  $D$  is the binary variable which indicates whether a municipality accepts NPF location or not<sup>26</sup>. For example, it is possible to obtain  $P(X)$  with cross-sectional logit and relogit (rare-events logit) using pre-determined socio-economic variables as dependent variables<sup>27</sup>. In fact, when I implement logit and relogit estimations, pre-determined socio-economic variables in the early 1970s seem to explain some variation of NPF location<sup>28</sup>. However, these estimations ignore the fact that the actual NPF locations in the 9 municipalities happened in different periods and it is not sure to what extent DID analysis is improved by conditioning on covariates  $X$  or propensity score  $P(X)$ . In addition, the small number of treated units can make it problematic to obtain a consistent estimate and implement valid statistical inference<sup>29</sup>. Finally, a standard DID approach with an average treatment effect cannot provide a straightforward empirical implication to the consequences of highly heterogeneous NPF location.

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<sup>25</sup> See Angrist and Pischke (2008), Chapter 3.

<sup>26</sup> See, among others, Heckman, Ichimura, and Todd (1997), Heckman, Ichimura, and Smith (1998), Smith and Todd (2005), and Abadie (2005) for the advantages of DID estimators conditional on propensity score.

<sup>27</sup> Relogit is a so called “rare events logistic regression” developed by King and Zeng (2001), which corrects the standard logistic regression when binary outcomes have much more zeros (“nonevents”) than ones (“events”).

<sup>28</sup> The results of logit and relogit estimation are not shown. The dependent variable is the binary variable which indicates one for the 8 NPF-located municipalities and zero otherwise. As independent variables, I use 13 socio-economic variables in the pre-intervention period such as per capita taxable income, employment ratio to population, the ratio of Densely Inhabited Districts population, sectoral shares of industry (primary and tertiary employment ratios), demographic composition (population ratios of age 15-64 and 65 and over), and ten-year growth rates of employment (primary, secondary and tertiary sectors) and population size (age 15 and under, age 15-64, and age 64 and over). I use the data in 1972 for per capita taxable income and in 1970 otherwise. Pseudo R<sup>2</sup> in logit estimation is 0.226.

<sup>29</sup> Conley and Taber (2011) argue that a DID estimate can be inconsistent and classical inference can be misleading when the number of treated units is small and the time span is fixed.

## 4. Estimation with the SCM

In this paper, instead of refining the DID approach, I use the Synthetic Control Method (SCM) developed by Abadie and Gardeazabal (2003) and Abadie et al. (2010)<sup>30</sup>. The SCM is the data-driven procedure which is suitable for comparative case studies that focus on the impact of a particular event or intervention. The SCM is a useful econometric tool to take into account the diversity of NPF establishment as individual historical events and to avoid some limitations of the DID approach mentioned above.

Intuitively speaking, the SCM constructs a “counter-factual” control unit by weighing control-group municipalities such that the weighted average of outcomes and relevant covariates in the pre-intervention period will be close to the counterparts of a treated unit. Because the SCM is able to focus on each NPF-located municipality respectively, heterogeneity of NPF impact can be also addressed.

### 4.1 Identification<sup>31</sup>

Define  $\alpha_{it}$  as the effect of an NPF location  $\alpha$  on municipality  $i$  at year  $t$ . Let  $D_{it}$  be a treatment indicator which satisfies

$$D_{it} = \begin{cases} 1 & \text{if NPF are located in municipality } i \text{ in year } t, \\ 0 & \text{otherwise.} \end{cases}$$

Then an observed outcome variable  $Y_{it}$ , per capita taxable income for municipality  $i$  at year  $t$ , is

$$Y_{it} = Y_{it}^N + \alpha_{it}D_{it}, \quad (2)$$

where  $Y_{it}^N$  is a “counterfactual” outcome which would be realized if there were no intervention by the NPF location. Let’s focus on one NPF-located municipality as a “treated” unit and assume that only municipality  $i = 1$  is exposed to the NPF location after year  $t = T_o$ . Then  $D_{it} = 1$  if  $i = 1$  and  $t > T_o$  and  $D_{it} = 0$  otherwise.

The objective is to estimate  $\alpha_{1t}$  after  $t = T_o$ , that is,

$$\alpha_{1t} = Y_{1t} - Y_{1t}^N, \text{ for } t > T_o. \quad (3)$$

Because  $Y_{1t}$  is observed, only  $Y_{1t}^N$  needs to be estimated to obtain  $\alpha_{1t}$ . Abadie and Gardeazabal (2003) and Abadie et al. (2010) define a “synthetic control unit” as a weighted average of the control units in the donor pool and use these weights to construct  $Y_{1t}^N$ . That is, a synthetic control can be represented by a  $(J \times 1)$  vector of weights  $\mathbf{W} = (w_2, \dots, w_{J+1})'$  for municipalities  $j = 2, \dots, J + 1$ , which satisfy  $0 \leq w_j \leq 1$  and  $w_2 + \dots + w_{J+1} = 1$ . Using some optimal weights  $\mathbf{W}^* = (w_2^*, \dots, w_{J+1}^*)'$ ,  $Y_{1t}^N$  is estimated as the weighted average of  $Y_{jt}$ . Then  $\alpha_{1t}$  is estimated as follows:

<sup>30</sup> Other recent applications of the synthetic control method include Fitzpatrick (2008), Cavallo et al. (2011), Coffman and Noy(2011), Montalvo (2011), Hinrichs (2012), Pinotti (2012) and Abadie et al.(2012)

<sup>31</sup> The explanation in this section follow the instructions of Abadie et al. (2010) and Abadie et al.(2012). See Abadie et al. (2010) for a more formal discussion about the properties of the SMC.

$$\hat{\alpha}_{1t} = Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt}. \quad (4)$$

When it comes to optimal weights optimal weights  $\mathbf{W}^*$ , Abadie and Gardeazabal (2003) and Abadie et al. (2010) choose  $\mathbf{W}^*$  so that  $\mathbf{W}$  minimizes:

$$\sum_{m=1}^k v_m (\mathbf{X}_{1m} - \mathbf{X}_{0m} \mathbf{W})^2, \quad (5)$$

where  $\mathbf{X}_1$  is a  $(k \times 1)$  vector which contains the values of the pre-intervention characteristics (called predictors<sup>32</sup>) of the treated unit,  $\mathbf{X}_0$  is a  $(k \times J)$  matrix that includes the values of the same predictors for the control units in the donor pool, and  $v_m$  is a weight that reflects the relative importance that is assigned to the  $m$ -th variable.

In other words,  $\mathbf{W}^*$  is selected to minimize the difference between  $\mathbf{X}_1$  and  $\mathbf{X}_0 \mathbf{W}$ , where each  $m$ -th variable is weighted by  $v_m$ . When it comes to the weight  $v_m$  ( $m = 1 \sim k$ ), Abadie and Gardeazabal (2003) and Abadie et al. (2010) suggest that the set of  $v_m$  is chosen such that the mean squared error of the outcome variable is minimized for the pre-intervention periods. Intuitively, weights  $\mathbf{W}^*$  and  $v_m$  are determined so that the outcome variable and covariates of the synthetic unit are as similar as possible to those of the treated unit in pre-intervention periods.

Using a linear factor model, Abadie et al. (2010) formally show that the identifying assumption of the SCM is less restrictive than that of DID in the sense that the SCM allows time-varying confounding unobserved characteristics. In addition, using an autoregressive model with time-varying coefficients, Abadie et al.(2010) also argue that the synthetic control estimator is unbiased even if data for only a single pre-intervention period is available.

#### 4.2 Settings in the SCM

I apply the SCM to estimate the effects of NPF location on per-capita taxable income in 8 NPF-located municipalities<sup>33</sup>. Various settings in the SCM in this paper are summarized in Table 4 and can be described as follows.

First, the timing of intervention  $t = T_o + 1$  is defined as in Table 1. Second, I restrict a donor pool to geographically similar municipalities to NPF-located municipalities in order to set up a more plausible “comparable” donor pool<sup>34</sup>. First of all, the donor pool is geographically limited to the municipalities that belong to the same regional category, which in general consist of several

<sup>32</sup> Typically, predictors contain average values of the outcome variable and observed covariates in the pre-intervention periods, but they can be flexibly chosen based on economic theory and some empirical evidence as long as they are not affected by the treatment.

<sup>33</sup> In the estimation, I use the `synth, nested` command in STATA, which is developed by Jens Hainmueller, Alberto Abadie, and Alexis Diamond.

<sup>34</sup> Abadie et al. (2010) suggest that a donor pool may be restricted to regions with similar characteristics to the region exposed to the intervention of interest.

contiguous prefectures<sup>35</sup>. Then, as in the previous DID analysis, I use only coastal municipalities for the donor pool and also exclude other NPF-located municipalities and the neighboring municipalities which border on the NPF-located municipalities.

Third, for observed predictors  $X_1$  and  $X_0$ , I use the outcome variable and 18 demographic variables in the pre-intervention periods: per capita taxable income, employment ratio to population, Densely Inhabited Districts population ratio, basic sectoral ratios of employment (primary and tertiary), detailed sectoral ratios (fishery, mining, construction, manufacture, wholesale & retail, and other services), and population ratios (age 16-64, age 65 and over), growth rates of employment over ten years (primary, secondary, and tertiary sectors), and finally, growth rates of population over ten years (age 0-15, age 16-64, and age 65 and over)<sup>36</sup>. The summary statistics of these variables in the 1970s and 2000 are already listed in Table 2.

Employment ratio to population is a variable that appears in the local production function in Section 2.2. Densely Inhabited Districts population ratio should reflect municipalities' urbanization and production capacity. Basic and detailed sectoral ratios are used in order to capture both fundamental and subtle industrial structures of NPF-located municipalities before NPF location. It would be best if I could use per capita private and public capitals at pre-intervention period for predictors but they are not available. Nonetheless, regressions of per capita taxable income  $Y$  on 18 demographic covariates with a pooled OLS model and fixed-effect model show that adjusted R-squared are around 0.8, so my covariates can predict per capita taxable income well<sup>37</sup>.

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<sup>35</sup> Tomari is in the Hokkaido region. Rakkasho, Onagawa, Naraha, and Tomioka belong to the Tohoku region, Kashiwazaki, Kariwa and Shika are included in the Hokuriku region. Kashiwazaki and Kariwa in Niigata prefecture are sometimes categorized in the Tohoku region, but I include them to Hokuriku due to geographical proximity.

<sup>36</sup> Growth rate of  $X$  over ten years is expressed as  $(X_t - X_{t-10})/X_{t-10}$ .

<sup>37</sup> In these regressions, I use demographic covariates in both pre-intervention and post-intervention periods. That is, I use the data in 1975, 1980, 1985, 1990, 1995, and 2000 because all demographic variables are based on Census data, which is collected every fifth year. As in the DID estimation in Section 3, I use only the data of coastal municipalities and exclude the other 14 NPF-located municipalities and their neighbors. The estimation results can be provided upon request.

**Table 4. Setting of the synthetic control method**

Outcome variable	• Real per capita taxable income (1972-2002, deflated by CPI 2005)
Treated municipality	• 8 NPF-located municipalities
Intervention year	For Rokkasho (See also the notes of Table 1.) • Year when land reclamation for NPF started For Tomari, Onagawa, Naraha, Kashiwazaki, Shika • Year when the first NPF construction started For Naraha (See also the notes of Table 1.) • Year when the first NPF construction started in Tomioka For Kariwa (See also the notes of Table 1.) • Year when the first NPF construction started in Kasiwazaki
Donor pool (the set of control units)	• Coastal municipalities within the same region • Excludes neighboring municipalities and other NPF-located municipalities
Predictors (averages over the pre-intervention period)	• Real per capita taxable income (deflated by CPI 2005) • Employment ratio to population • Densely Inhabited Districts population ratio • Population ratios (age 16~64, age 65 and over) • Sectoral ratios of employment (primary, tertiary) • Detailed sectoral ratios of employment (fishery, mining, construction, manufacture, wholesale & retail, other services) • Growth rates of population ratios and basic sectoral ratios (from 10 years ago)

### 4.3 Results

First, in order to see how similar a treated unit and a synthetic unit are before intervention, per capita taxable income and covariates in pre-intervention period are compared between the treated unit and the synthetic unit. Figure 4 graphically shows that the levels and trends of per capita taxable income are similar before intervention between the treated and the synthetic control in all the cases. Predictor balances in the pre-intervention period in Appendix C also indicate that the values of most pre-determined covariates of the synthetic units are close to those of the treated. These results suggest that the treated units and the synthetic units are reasonably “comparable” in post-intervention period<sup>38</sup>.

Second, when it comes to the impact of NPF location, Figure 4 shows that per capita taxable income in Rokkasho, Tomari, Naraha, Tomioka, and Kariwa diverge upward from their synthetic counterparts after NPF location. Estimated effects (income gaps between the treated and synthetic units) in the 1990s and 2000s are often more than 200,000 yen in Rokkasho and Tomioka and around 100~200,000 yen in Tomari, Naraha and Kariwa. On the other hand, no noticeable positive divergence is observable in Onagawa, Kashiwazaki, and Shika.

Table 5 provides some summary statistics about outcome gaps between the treated units and the

<sup>38</sup> Weights on donor-pool municipalities in synthetic units are also presented in Appendix D. Although it is difficult for those who are not familiar with listed municipalities to find useful implications from these weights, it appears that municipalities that get higher weights tend to be at least geographically close to treated municipalities.

synthetic units<sup>39</sup>. According to this table, the gaps in Rokkasho indicates that per capita taxable income in Rokkasho is 26.2% higher than in the synthetic unit on average and 61.7% higher in 2002. Tomioka's income is also 23.6% higher on average and 30.2% higher in 2002. On the other hand, the gaps in Onagawa, Kashiwazaki and Shika are all small (on average 1.1%, -0.8%, and 1.4% respectively). These average gaps with the SCM have a more or less similar tendency to DID estimation results in Table 3, but the values of estimates differ in many cases. Since similarity between the treated and the control in pre-intervention period is more plausible in the SCM than in the DID, it can be argued that the estimates in the SCM are less biased.

In Table 5, I also present the averages of outcome gaps. First, per capita taxable income level in all 8 NPF-located municipalities is 11.1 % higher on average than in the counterparts in synthetic control units after NPF establishment. Second, when I exclude Rokkasho from averaging and focus on the effect of nuclear power plants location, the average income level in the treated units is still around 9% higher than the average income level in the synthetic controls.

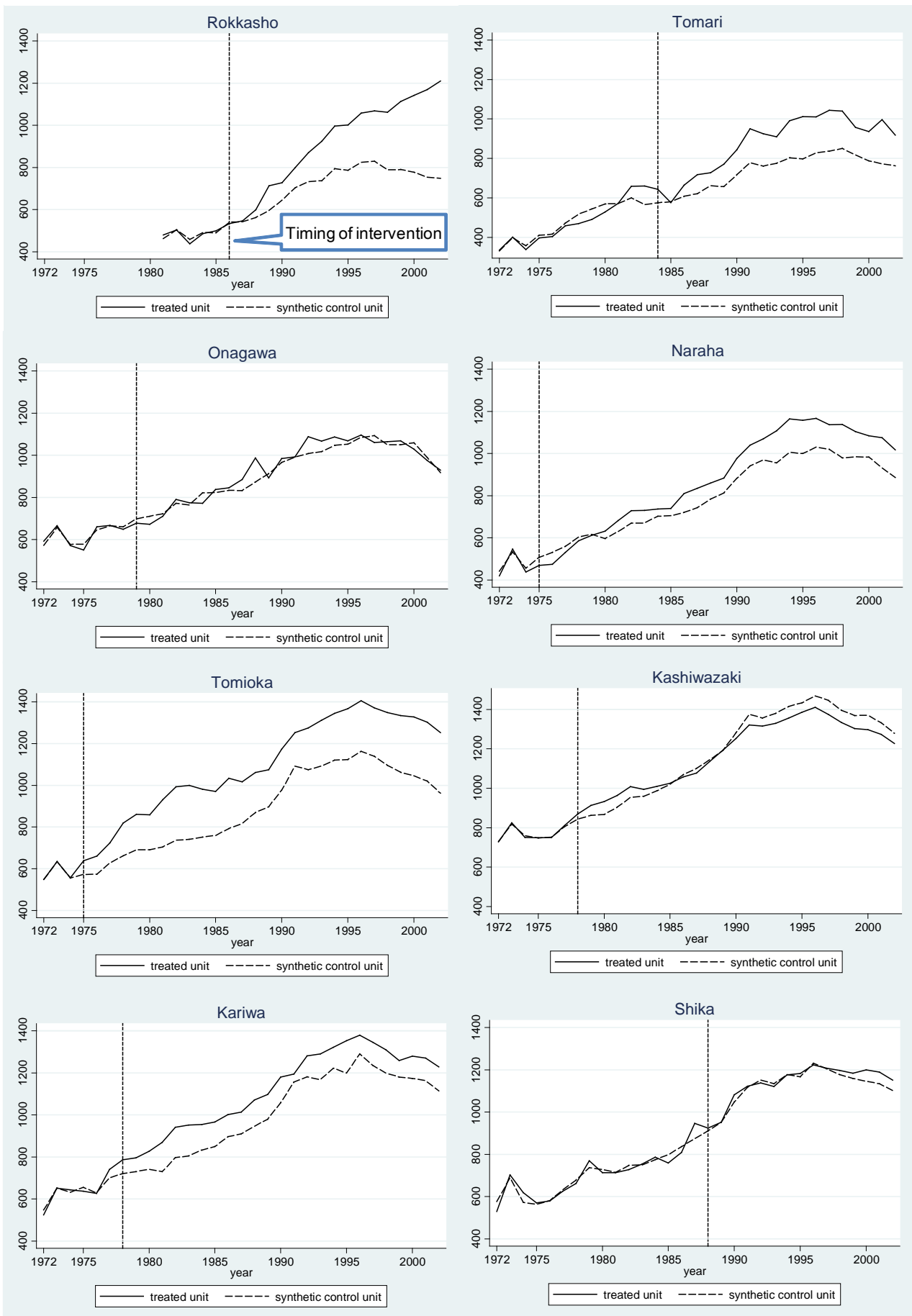
Finally, Figure 5 presents the trends of average per capita income gap between the treated units and the synthetic control units, based on the normalized years in which the intervention year is set as zero. The bold line represents the average income gap in all 8 NPF-located municipalities and the thin line indicates the average income gap in nuclear-plants-located municipalities. According to this graph, the average income gap between the NPF-located municipalities and the synthetic controls diverge from around zero a few years after the NPF location and then keep increasing.

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<sup>39</sup> More detailed outcome statistics can be provided by the author on request.



**Figure 4. Per capita taxable income: treated municipalities and synthetic control units**



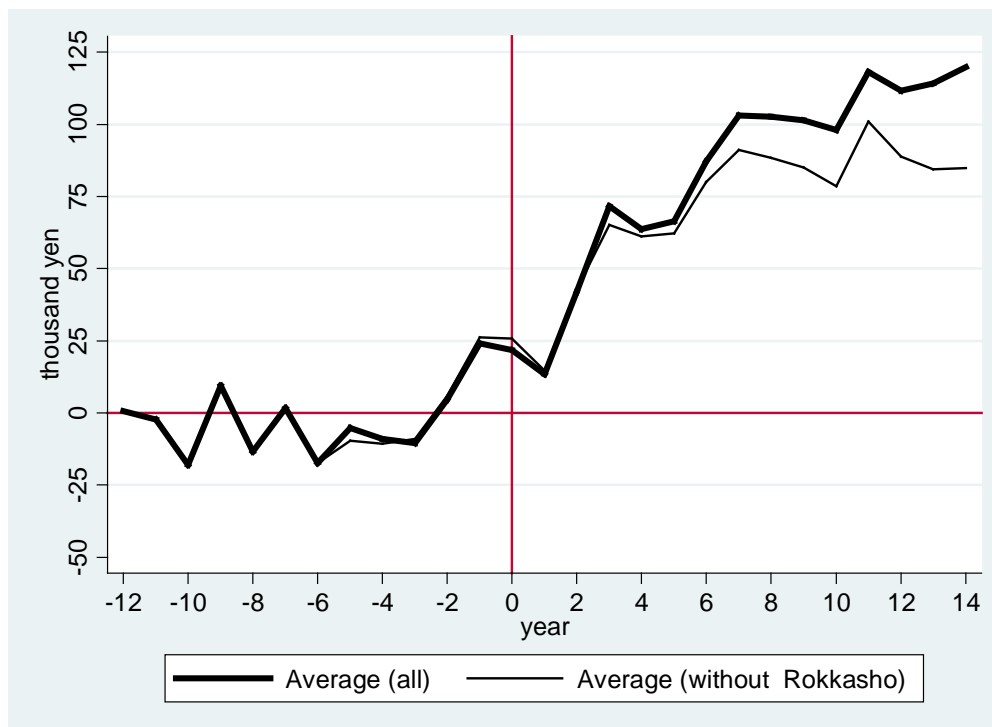
Notes: In Rokkasho, the pre-intervention period is limited from 1981 because per capita taxable income in Rokkasho fluctuates in the 1970s. In Tomari, one municipality, Atsuma town, is excluded from the donor pool due to extreme outliers for its per capita taxable income in 1972 and 1973.

**Table 5. Summary of results in the SCM**

Municipality	Average		Maximum		In 2002	
	Gap	Percent	Gap	Percent	Gap	Percent
Rokkasho	198.83	26.19%	461.34	61.67%	461.34	61.67%
Tomari	138.90	18.21%	223.81	28.98%	154.35	20.23%
Onagawa	10.79	1.07%	114.08	13.06%	10.65	1.16%
Naraha	75.82	8.22%	158.51	16.16%	132.14	14.92%
Tomioaka	208.42	23.63%	290.74	34.91%	290.74	30.22%
Kashiwazaki	-17.87	-0.83%	66.20	7.64%	-52.76	-4.12%
Kariwa	107.44	11.06%	153.63	19.10%	113.78	10.21%
Shika	15.72	1.42%	54.22	4.78%	48.49	4.40%
Average	92.26	11.12%	190.32	23.29%	144.84	17.34%
Average (without Rokkasho)	77.03	8.97%	151.60	17.80%	99.63	11.00%

Notes: "Gap" is "Per capita taxable income in a treated unit - Per capita income in a synthetic control unit" and the unit is 1,000 yen. "Percent" is calculated by dividing "Gap" by per capita taxable income in the synthetic control. "Average" is averaged over the post-intervention period. "Maximum" is a maximum gap or percent in the post-intervention period.

**Figure 5. Trends of average per capita income gap with the SCM**



Notes: Income gaps are averaged across the 8 NFP-located municipalities between the normalized year -3 and 14. Average gaps in normalized years before -3 are based on a smaller number of income gaps because only Tomari and Shika have 12 years of the pre-intervention period or more. Nonetheless the average gaps are shown during this period because average gaps in the pre-intervention period are supposed to be close to zero with the SCMs in all the cases. Average gaps after 14 are not shown because the number of income gaps that can be used for calculating an average is decreasing.

#### **4.4 Discussions**

It seems like that there are quite heterogeneous NPF effects on local per capita taxable income while the average effect is strongly positive. It is beyond the scope of this paper to examine detailed factors and exact mechanisms of heterogeneous NPF effects, but a few comments can be provided based on the comparison of socio-economic variables of the treated units and synthetic control units.

First, estimated NPF effects in Rokkasho and Tomioka are remarkably higher than NPF effects in other municipalities. As is shown in Appendix E, Rokkasho and Tomioka have experienced higher increases in population and the sectoral ratios of construction and other services after NPF establishment when compared with their synthetic control units. Rokkasho's employment ratio has also increased sharply after the intervention. These comparisons suggest that the NPF establishment in Rokkasho and Tomioka have caused the inflow of workers and have made the local industrial structure more dependent on construction and other (NPF-related) service industries. It can be argued that these economic changes lead to considerable increases in per capita taxable income in these municipalities.

Second, the SCMs with Tomari, Naraha, and Kariwa show modest positive NPF impacts. According to graphs in Appendix E, these effects can also be explained by the growth of employment in construction and other services. Unlike Rokkasho and Tomioka, remarkable population increase is not observed in these municipalities.

Third, little NPF effects on Onagawa, Kashiwazaki and Shika could also be related to trends in the sectors of construction and other services. Although the sectoral ratios of construction have increased after the NPF location in these municipalities, the ratios are still relatively small compared with the municipalities that gain positive NPF effects<sup>40</sup>. In addition, trends in sectoral ratios of other services do not change in Onagawa and Shika after NPF establishments. These statistics imply that NPF locations in these municipalities have relatively small effects on local employment and the shift of industrial structures.

Finally, in order to investigate how the above estimation results are robust for different settings of the SCM, I implement the SCM with a smaller number of covariates and/or limited donor pools. Estimation results are in general similar to the ones presented here.

## **5. Placebo tests**

### **5.1 Placebo effects**

To evaluate the significance of the estimated treatment effects that are obtained in the last section, I also conduct placebo tests as suggested by Abadie et al. (2010). In these placebo tests, the same SCM is applied to every control municipality in an original donor pool one by one, instead of a

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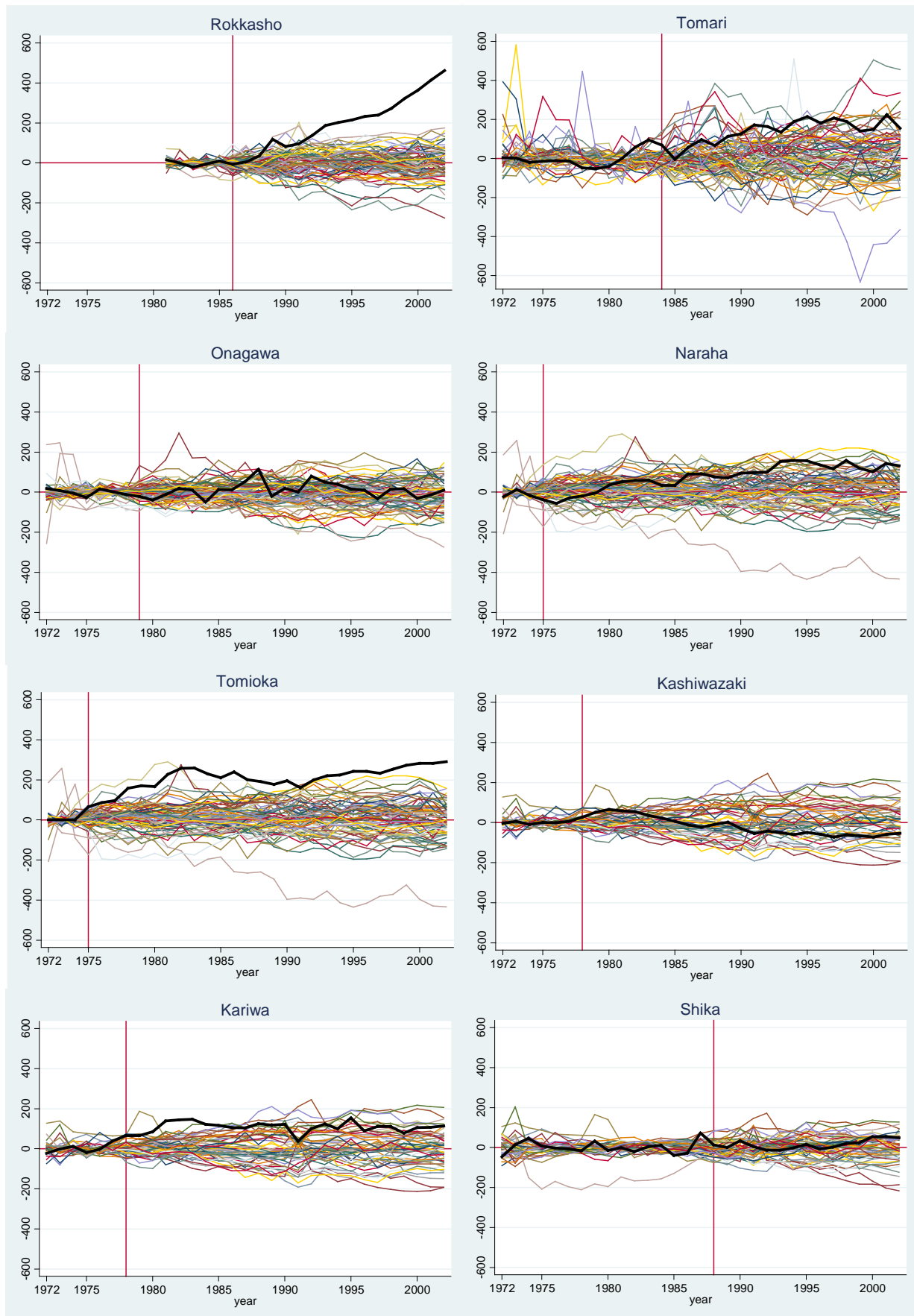
<sup>40</sup>In Onagawa, Kashiwazaki, and Shika, the maximum sectoral ratios of construction are around 15% after intervention whereas the maximum ratios in Tomioka and Rokkasho are more than 30 % and the corresponding ratios in Tomari, Kariwa, and Naraha are around 25~30%. See Appendix E.

NPF-located municipality. That is, like a permutation test, one control unit is used as a treated unit in the SCM as if this control unit had experienced NPF location in the intervention year. Then this procedure is repeated for all the control units in the original donor pool. In these placebo tests, remaining donor-pool municipalities are used as a new donor pool and the NPF-located municipality is excluded from the sample. In each trial, placebo effects are calculated as gaps between the outcome values of a placebo unit and its synthetic control.

In these placebo tests, estimated treatment effects should not be extreme compared with estimated placebo effects under the null hypothesis of no intervention effect. In other words, if the treatment effects for a NPF-located municipality are larger than most placebo effects, the treatment effects may be considered as plausible.

The results of placebo tests are shown in Figure 6. It suggests that the effect of NPF location seems particularly plausible in Rokkasho and Tomioka because their income gaps become explicitly larger than almost all placebo gaps a few years after the intervention. The validity of NPF effects on Tomari, Naraha, and Kariwa are less significant in the sense that some placebo effects are larger than the treatment effects, but nevertheless the treatment effects are larger than most placebo effects. When it comes to Onagawa, Kashiwazaki and Shika, it is hard to distinguish the estimated NPF gaps from placebo gaps.

**Figure 6. Per capita taxable income gaps in the treated municipalities and placebo municipalities**



Notes: Bold lines are per capita taxable income gaps for treated municipalities. The other lines are gaps for placebo municipalities. Placebo gaps in Naraha and Kashiwazaki are identical with those in Tomioka and Kariwa respectively, because donor pools and intervention timings are the same. Placebo gaps for Sarufutsu village (a well-known “rich” municipality with a successful scallop business) in the case of Tomari are all excluded due to their extreme values both in pre- and post-intervention periods. Placebo gaps for Notojima town cannot be estimated in the cases of Kashiwazaki and Kariwa due to an optimization failure.

## 5.2 Statistical significance

The graphs of placebo tests in the last subsection provide straightforward implications on whether the estimated treatment effects are comparatively larger than placebo effects. Outstanding examples are Rokkasho and Tomioka, where most placebo effects are smaller than estimated treatment effects a few years after intervention. It suggests that NPF establishment should have statistically significant effects on local per capita taxable income in these municipalities. However, some other placebo tests yield more ambiguous figures. For example, the estimated effects in Tomari, Naraha and Kariwa are often among the largest after the intervention, but there are some placebo effects that exceed their effects. In addition, these individual placebo tests in 9 NPF location events do not tell whether the overall impact of NPF establishment is significantly different from zero from some statistical criteria.

In order to complement these insufficiencies in the graphical placebo tests in the last subsection, I propose the two statistical significance tests that can be easily applied to other analyses with the SCM when the number of case studies and placebo units are not so small. The first approach can be utilized to test whether each intervention has a statistically significant impact and the second approach can examine whether the overall average of all treatment effects is significantly different from zero.

The first approach is based on the placebo tests developed by Abadie et al. (2010), but I further convert all placebo gaps, which are usually presented with graphs like Figure 5, into one distribution by averaging them across years. Then the statistical significance of *average* treatment effects are tested by this placebo distribution. In other words, I construct the distribution of the *average* placebo effects of all placebo units in all case studies, assuming that these test statistics follow the same distribution under the null hypothesis. More precisely, a placebo distribution is obtained and used as follows.

1. Estimate all treatment effects  $\hat{\alpha}_{g,t}$  and placebo effects  $\hat{\eta}_{g,i,t}$  in all case studies, where  $g$  indicates one case study<sup>41</sup>,  $i$  represents a control unit in donor pools,  $t$  is a year which satisfies  $t > T_0$ .
2. Calculate average treatment effects  $\bar{\alpha}_g$  and average placebo effects  $\bar{\eta}_{g,i}$  across years for all treated units and control units.
3. Use the distribution of  $\bar{\eta}_{g,i}$  for statistical significance tests on  $\bar{\alpha}_g$ , assuming that  $\bar{\alpha}_g$  and  $\bar{\eta}_{g,i}$  follow the common distribution under the null hypothesis.

In the same way to the original placebo test above, this test is plausible if an average treatment effect is not expected to stand out from the distribution of average placebo effects under the hypothesis of no intervention effect.

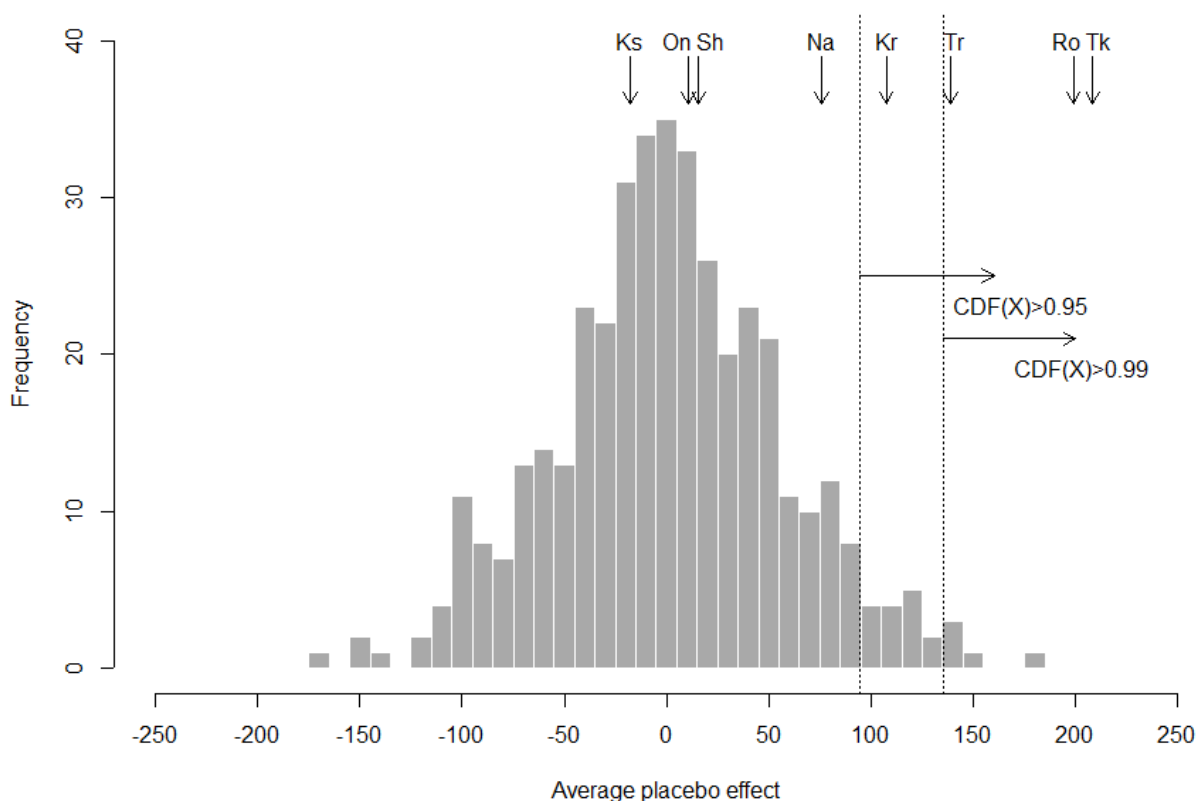
The result is graphically presented in Figure 7. First of all, the distribution of average placebo

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<sup>41</sup> For example, in this paper,  $g = 1\sim 8$ , that is, Rokkasho, Tomari, Onagawa, Naraha, Tomioka, Kashiwazaki, Kariwa, and Shika.

effects is more or less bell-shaped with a peak around 0, indicating that “placebos” do not cause systematic impacts on control units. When it comes to the statistical significance of average treatment effects, Figure 7 shows that the estimated average effects in Tomioka (Tk), Rokkasho (Ro) and Tomari (Tr) are larger than 99% of placebo effects ( $CDF(X)>0.99$ ) and the average effect in Kariwa (Kr) are larger than at least 95% of average placebo effects ( $CDF(X)>0.95$ ). These two thresholds can be considered as 1% and 5% significance levels at a one-sided test. On the other hand, the average effects in other NPF-located municipalities are smaller than 5% of average placebo effects. It implies that their estimated effects are statistically not different from zero at the 5% significance level, while Naraha (Na) is somewhat close to the threshold of the 5% significance level.

**Figure 7. Histogram of average placebo effects (N=407)**



Notes: Arrows on the upper side indicate the magnitude of average treatment effects in 8 NPF-located municipalities: from the left-hand side, Ks=Kashiwazaki, On=Onagawa, Sh=Shika, Na=Naraha, Tr=Tomari, Kr=Kariwa, Tk=Tomioka and Ro=Rokkasho. The values of average treatment effects are presented in the first column of Table 5.  $CDF(X)$  is the cumulative distribution function of average placebo effects. Because the placebo gaps of Naraha and Kashiwazaki are identical with the placebo gaps of Tomioka and Kariwa, I can use only 6 sets of placebo gaps out of 8 case studies. As in Figure 5, I exclude an average placebo gap for Sarufutsu village in the case of Tomari due to its extreme value.

Although the first approach provides informative inference about the statistical significance of the respective average treatment effects, it does not answer the question whether an *overall* average treatment effect is significantly different from zero<sup>42</sup>. The second approach, therefore, tests the *overall* average treatment effect by constructing a distribution of *overall* average placebo effects. My approach is similar to a statistical test with the SCM proposed by Cavallo et al. (2011), but there are two noticeable differences between Cavallo et al. (2011) and this paper.

First, Cavallo et al. (2011) test the statistical significance of average treatment effects across different case studies on an annual basis, but I examine a *single* overall average treatment effect in order to answer the question “whether the magnitude of intervention effects as a whole is statistically significant”. Second, Cavallo et al. (2011) construct a distribution of all possible placebo averages with the selective placebos which are chosen based on the goodness of pre-intervention fits in their placebo trials. On the other hand, I construct a distribution of overall average placebo effects by a resampling method, utilizing all placebos in all case studies.

My approach is more transparent and easier to apply to different studies because no arbitrary selection criterion for placebos is required to construct a statistical distribution for a significance test. In addition, when the number of case studies is relatively large, the resampling method mentioned below can generate a sufficiently large amount of overall average placebo effects.

In practice, the distribution of overall average placebo effects can be computed and utilized as follows:

1. Calculate an overall average treatment effect  $\tilde{\alpha} = (\sum_{g=1}^G \tilde{\alpha}_g)/G$ , where  $G$  is the number of case studies<sup>43</sup>.
2. Calculate an overall average placebo effect  $\tilde{\gamma} = (\sum_{g=1}^G \tilde{\gamma}_{i,g})/G$  by randomly choosing a municipality  $i$  in each  $g$ .
3. Repeat Step 2  $M$  times<sup>44</sup> and make a distribution of overall average placebo effects  $\tilde{\gamma}$ .
4. Use the distribution of  $\tilde{\gamma}$  for a statistical significance test on  $\tilde{\alpha}$ , assuming that  $\tilde{\alpha}$  and  $\tilde{\gamma}$  follow the common distribution under the null hypothesis that all  $\tilde{\alpha}_g$  and  $\tilde{\eta}_{g,i}$  are equal to zero.

Intuitively speaking, I randomly pick up one placebo trial from every graph in Figure 6 and calculate an overall average treatment effect by averaging the average placebo effects of the randomly chosen placebo trials. Then I repeat this procedure  $M$  times to construct a distribution of overall average

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<sup>42</sup> The wording here could be a little bit confusing. I use the term “*average* treatment/placebo effect” as an *average* of treatment/placebo effects across years in a treated/untreated municipality and the term “*overall* average treatment/placebo effect” as the *average* of “average treatment/placebo effects” across treated /untreated municipalities.

<sup>43</sup> For example,  $G=8$  in this study because I have 8 cases of NPF locations.

<sup>44</sup>  $M$  can be set by researchers based on the number of possible overall average placebo effects. For instance, the number of possible overall average placebo effects in this study is  $\prod_{g=1}^8 N_g = 74 \times 82 \times 74 \times 74 \times 74 \times 74 \times 51 \times 51 \times 52$ , where  $N_g$  is the number of placebo trials in an NPF location event  $g$ . Then  $M$  can be any number which is sufficiently large but less than  $\prod_{g=1}^8 N_g$ .

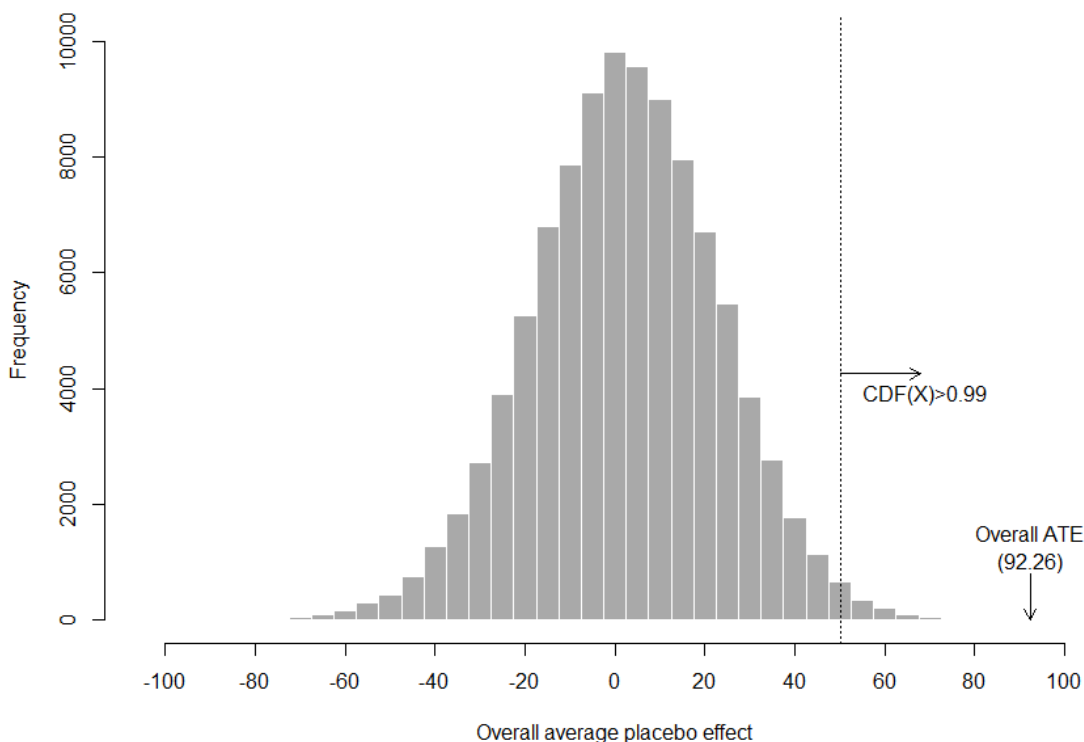


treatment effects. In this study,  $G=8$  and I set  $M=100,000$ .

The result with the second test is graphically presented in Figure 8. It shows that the overall average treatment effect  $\tilde{\alpha} = 92.26$  is far larger than the threshold line at  $CDF= 99\%$ , which is obtained by the distribution of overall average placebo effects. That is, the overall average treatment effect is significantly different from zero at the 1% significance level of the one-sided test. This result is somewhat expected from Figure 7, which indicates that 4 out of 8 average treatment effects are larger than 95% of average placebo effects.

Both Figure 7 and Figure 8 imply that it is very rare to accidentally obtain the set of average treatment effects  $\tilde{\alpha}_g$  or the overall average treatment effect  $\tilde{\alpha}$  from the placebo distributions. Thus, it can be concluded that NPF establishment has statistically significant effects on local per capita taxable income levels while the size of the effects is quite heterogeneous.

**Figure 8. Histogram of overall average placebo effects (M=100,000)**



## 6. Conclusion

This paper studied how NPF establishment has influenced local income levels using an explicit quasi-experimental approach. Estimation with the SCM clarifies that the NPF effects on per capita taxable income levels are highly heterogeneous but statistically significant in many cases and on average. The size of impact on per capita taxable income is often economically meaningful and huge in some cases: 11.1 % increase on average, 61.7% increase in Rokkasho in 2002, and 30.2 % increase in Tomioka in 2002. On the other hand, several NPF-located municipalities receive weak or negligible effects from NPF establishment.

Findings in this paper contribute to evaluating NPF-related local development and development policies. First of all, NPF establishment has a clear positive impact on local income levels in several municipalities. In this sense, NPF location can work as a trigger for local income growth while the development may heavily rely on NPFs. In particular, Rokkasho and Tomioka have experienced outstanding income growth and have joined the richest groups in their prefectures after NPF location<sup>45</sup>. On the other hand, negligible or weak effects in some municipalities and unpredictable risks of NPFs make it hard to conclude that this possible income growth outweighs the cost of NPF location in the long run.

I conclude the paper with some comments on the potential and limitation of the research methods adopted in this study. By using the SCM, I was able to take into account treatment heterogeneity and obtained heterogeneous treatment effects, focusing on individual intervention cases. This paper, however, was able to provide only a few possible explanations for heterogeneous outcomes. The comparison of post-intervention trends in underlying socio-economic variables between a treated unit and a synthetic control unit was informative, but more detailed qualitative and quantitative case studies focusing on each NPF site will complement the findings of this study<sup>46</sup>.

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<sup>45</sup> Futaba and Okuma in Fukushima prefecture, which I could not investigate in this paper, were also two of the richest municipalities in Fukushima prefecture in the 2000s.

<sup>46</sup> As is advocated by Abadie et al. (2012), one advantage of the SCM is that this method provides a way to bridge a divide between quantitative studies and qualitative studies in empirical research.

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## Appendix A. Data description

Variable	Description	Period	Source
<b>Per capita taxable income (Thousand yen)</b>	Taxed income / Population	Fiscal years from 1972 to 2002	Survey on Local Government Taxation (Shi-Cho-Son Zei Kazei Jokyo tou no Shirabe)
<b>Demographic variables</b>			
Population	Population		
Densely Inhabited District population ratio	Population in Densely Inhabited Districts / Population. *In general, Densely Inhabited Districts are defined as groups of contiguous unit blocks which satisfy the following two requirements: 1.each of contiguous unit blocks has a population density of 4,000 inhabitants/km2 or more and 2.the total population of contiguous unit blocks is 5,000 or more within a municipality.	Every 5 years from 1970 to 2000	Census (Kokusei Chosa)
Population ratio (Age 0-15)	Population (Age 0-15) / Population		
Population ratio (Age 16-64)	Population (Age 16-64) / Population		
Population ratio (Age 65-)	Population (Age 65-) / Population		
Growth rate (Population, Age 0-15, 10 years)	[Population (Age 0-15) - Population (Age 0-15, 10 years ago)] / Population (Age 0-15, 10 years ago)		
Growth rate (Population, Age 16-64, 10 years)	[Population (Age 16-64) - Population (Age 16-64, 10 years ago)] / Population (Age 0-15, 10 years ago)		
Growth rate (Population, Age 65-, 10 years)	[Population (Age 65-) - Population (Age 0-15, 10 years ago)] / Population (Age 0-15, 10 years ago)		
<b>Basic industrial structure</b>			
Employment ratio to population	Number of employment / Population		
Sectoral ratio (Primary)	Number of employment in the primary sector / Number of employment *The primary sector consists of agriculture, forestry, fisheries and mining.		
Sectoral ratio (Secondary)	Number of employment in the secondary sector / Number of employment *The secondary sector includes construction and manufacturing.	Every 5 years from 1970 to 2000	Census (Kokusei Chosa)
Sectoral ratio (Tertiary)	Number of employment in the tertiary sector / Number of employment *The tertiary sector includes all the sectors that are not included in the primary and secondary sectors.		
Growth rate (Employment, Primary, 10 years)	[Employment (Primary)-Employment (Primary, 10 years ago)] / Employment (Primary, 10 years ago)		
Growth rate (Employment, Secondary, 10 years)	[Employment (Secondary)-Employment (Secondary, 10 years ago)] / Employment (Primary, 10 years ago)		
Growth rate (Employment, Tertiary, 10 years)	[Employment (Primary)-Employment (Primary, 10 years ago)] / Employment (Secondary, 10 years ago)		
<b>Detailed industrial structure</b>			
Sectoral ratio (Fishery)	Number of employment in the fishary sector / Number of total employment		
Sectoral ratio (Mining)	Number of employment in the mining sector / Number of total employment		
Sectoral ratio (Construction)	Number of employment in the construction sector / Number of total employment	Every 5 years from 1970 to 2000	Census (Kokusei Chosa)
Sectoral ratio (Manufacturing)	Number of employment in the manufacture sector / Number of total employment		
Sectoral ratio (Wholesale/Retail)	Number of employment in the wholesale&retail sector / Number of total employment		
Sectoral ratio (Other services)	Number of employment in the other service (tertiary) sectors		
<b>Fiscal variables (Thousand yen)</b>			
Tax revenue per capita	Tax revenue / Population	Fiscal years from 1975 to 2002	
Fiscal equalization grants (the LAT grants)	The LAT grants /Population	Fiscal years from 1975 to 2002	Local Government Finance Settlement (Shi-Cho-Son Betsu Kessan Jyokyo Shirabe)
Central grants per capita	Central grants / Population	Fiscal years from 1977 to 2002	
Expenditure per capita	Expenditure / Population	Fiscal years from 1975 to 2002	
Construction per capita	Expenditure on construction / Population	Fiscal years from 1975 to 2002	



## Appendix B. Additional DID estimates for the NPF-located and their neighbors

This appendix complements Section 3.2 in the main text and investigate how per capita taxable income changes *on average* after the intervention for 8 NPF-located municipalities and their 18 neighboring municipalities.

First, two average income gaps are provided in Figure B1 with a normalized horizontal axis in which the intervention year is set as zero. In this graph, the bold line presents the average of income gaps between the NPF-located and the coastal non-neighbors and the thin line indicates the average of income gaps between the coastal neighbors<sup>47</sup> and the coastal non-neighbors. This normalized graph shows straightforward implications<sup>48</sup>. When it comes to the NPF-located municipalities, the average per capita income gap is negative and has a little upward trend at the pre-intervention period, but it shows a steeper upward trend after intervention and turns positive three years after the NPF location. On the other hand, the average gap of the coastal neighbors is more or less around zero and indicates no trend both before and after the NPF location. This suggests that an NPF location seems to have a positive impact on the NPF-located municipalities whereas no spillover effect on coastal neighbors is observed.

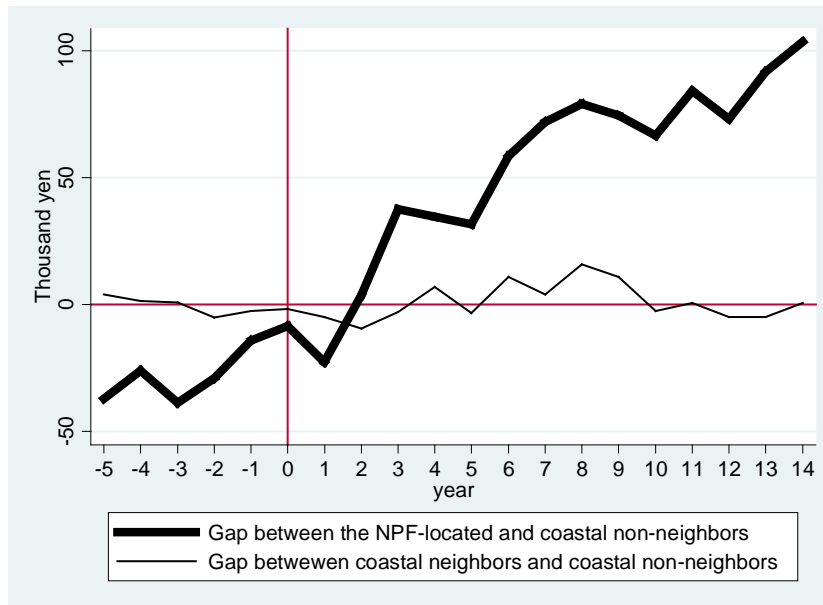
Second, Table B1 provides a DID estimate for all 8 NPF location events in Column (1) and a DID estimate for 18 coastal neighboring municipalities in Column (2). The same DID model with Equation (1) in the main text,  $Y_{it} = \gamma_i + \pi_t + \alpha D_{it} + \varepsilon_{it}$ , is used for estimation. The results show that an estimated average “effect” on the 8 NPF-located municipalities is around 93 thousand yen (930 dollars if 100 yen= 1 dollar) per year. On the other hand, the average “effect” on coastal neighboring municipalities is almost zero.

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<sup>47</sup> Coastal neighbors consist of the 18 seaside municipalities which border on the 8 NPF-located municipalities.

<sup>48</sup> The average income gaps in this graph are calculated as follows: First, annual per capita income gaps in an NPF-located municipality are calculated by subtracting the average per capita income of the coastal non-neighbors from the per capita income of a NPF-located municipality year by year. In other words, I calculate the annual gaps between the solid line and the dashed line for each graph in Figure 3. Then averaging these gaps across the 8 NPF-located municipalities based on normalized years. The same procedures are applied when I calculate average gaps between the coastal neighbors and the coastal non-neighbors and, in this case, the intervention year of a coastal neighbor is set as the intervention year of the NPF-located municipality on which this coastal neighbor borders.

**Figure B1. Gaps in average per capita taxable income**



Notes: Income gaps are averaged across the 8 NPF-located municipalities between the normalized year -3 and 14. In normalized year -5 and -4, two NPF-located municipalities (Naraha and Tomioka in Fukushima prefecture) and two coastal neighbors (Iwaki and Hirono in Fukushima prefecture) are dropped from averages because these municipalities have only three pre-intervention years (1972, 1973 and 1974). Average gaps in normalized years before -5 and after 14 are not shown because the number of income gaps that can be used for calculating an average is decreasing.

**Table B1. Gaps in average per capita taxable income**

	(1)	(2)
Treated municipalities	9 NPF-located	Coastal Neighbors
DID estimate	93.01	-0.86
Robust S.E.	(10.16)***	(6.29)
Clustered S.E.	(22.16)***	(19.22)
Adj. R-squared	0.9170	0.9169
Observations	27369.00	27,688
No. of clusters (municipalities)	885	895
No. of the treated municipalities	8	18
Sample period	1972-2002	1972-2002

Notes: “Clustered S.E.” is the cluster-robust standard errors that are clustered by municipality. Observations before 1981 are excluded for Rokkasho because per capita taxable incomes in Rokkasho during this period fluctuate considerably. In column (2), The 18 coastal neighbors of 8 NPF-located municipalities are set as the treated group and the timings of treatment are defined as the neighboring NPF-located municipalities' intervention years. The 18 coastal neighbors are excluded from the sample in Column (1) and the 8 NPF-located municipalities are excluded from the sample in Column (2). \*\*\*, \*\*, \* denote significance at the 1%, 5% and 10% level respectively.

## Appendix C. Predictor balance in pre-intervention period (average)

Variable	Rokkasho		Tomari		Onagawa		Naraha	
	Treated	Synthetic	Treated	Synthetic	Treated	Synthetic	Treated	Synthetic
Per capita taxable income	480.91	481.28	475.89	479.39	622.26	622.33	467.52	476.50
Employment ratio	0.4233	0.4680	0.4261	0.4377	0.4790	0.4951	0.4946	0.5102
DID population ratio	0.0000	0.0000	0.0000	0.0000	0.3775	0.0357	0.0000	0.0048
Sectoral ratio (Primary)	0.4094	0.4341	0.2564	0.3605	0.3564	0.4832	0.4408	0.5204
Sectoral ratio (Tertiary)	0.3701	0.3108	0.3800	0.3389	0.3554	0.2549	0.2742	0.2279
Sectoral ratio (Fishery)	0.1050	0.1407	0.2035	0.2461	0.3319	0.2615	0.0007	0.0493
Sectoral ratio (Mining)	0.0011	0.0004	0.0125	0.0022	0.0019	0.0051	0.0044	0.0064
Sectoral ratio (Construction)	0.1756	0.1755	0.2579	0.2363	0.0502	0.0698	0.0884	0.0944
Sectoral ratio (Manufacturing)	0.0438	0.0792	0.0933	0.0620	0.2360	0.1870	0.1922	0.1509
Sectoral ratio (Whole sale/Retail)	0.1033	0.0986	0.1098	0.1084	0.1558	0.0943	0.0852	0.0818
Sectoral ratio (Other services)	0.1612	0.1079	0.1806	0.1505	0.1003	0.0928	0.0748	0.0860
Population ratio (Age 16-64)	0.6406	0.6442	0.5933	0.6247	0.6649	0.6589	0.6313	0.6396
Population ratio (Age 65-)	0.0957	0.1176	0.1812	0.1185	0.0704	0.0843	0.0945	0.0930
Growth rate (Primary, 10 years)	-0.4280	-0.3626	-0.2057	-0.4683	-0.0583	-0.2745	-0.3012	-0.3092
Growth rate (Secondary, 10 years)	1.6955	0.4752	-0.3608	0.1530	0.0526	0.1776	0.2241	0.3908
Growth rate (Tertiary, 10 years)	0.6482	0.4012	-0.0346	0.0845	0.1436	0.3735	0.3246	0.3236
Growth rate (Age 0-15, 10 years)	-0.2346	-0.1896	-0.5631	-0.4440	-0.2290	-0.2629	-0.4147	-0.4003
Growth rate (Age 16-64, 10 years)	0.0403	-0.0205	-0.3210	-0.1761	0.0343	-0.0218	-0.0486	-0.0615
Growth rate (Age 65-, 10 years)	0.3947	0.3136	0.2879	0.0992	0.2916	0.3783	0.1994	0.2010

Variable	Tomioka		Kashiwazaki		Kariwa		Shika	
	Treated	Synthetic	Treated	Synthetic	Treated	Synthetic	Treated	Synthetic
Per capita taxable income	579.84	579.28	768.60	768.71	637.14	636.00	704.00	703.11
Employment ratio	0.4968	0.4962	0.5400	0.5590	0.5924	0.5557	0.5330	0.5510
DID population ratio	0.0000	0.1376	0.4044	0.3021	0.0000	0.0942	0.0000	0.0479
Sectoral ratio (Primary)	0.3861	0.3881	0.2650	0.2653	0.4578	0.4401	0.3107	0.3103
Sectoral ratio (Tertiary)	0.4061	0.3996	0.3948	0.3965	0.2218	0.2665	0.2852	0.3010
Sectoral ratio (Fishery)	0.0033	0.0410	0.0027	0.0110	0.0000	0.0111	0.0101	0.0404
Sectoral ratio (Mining)	0.0029	0.0029	0.0048	0.0038	0.0184	0.0025	0.0007	0.0016
Sectoral ratio (Construction)	0.0887	0.0912	0.0723	0.0733	0.0820	0.0956	0.0940	0.0810
Sectoral ratio (Manufacturing)	0.1161	0.1172	0.2630	0.2632	0.2200	0.1953	0.3094	0.3052
Sectoral ratio (Whole sale/Retail)	0.1331	0.1398	0.1581	0.1569	0.0808	0.0935	0.1168	0.0998
Sectoral ratio (Other services)	0.1487	0.1404	0.1424	0.1414	0.0836	0.1016	0.1223	0.1240
Population ratio (Age 16-64)	0.6433	0.6546	0.6778	0.6792	0.6750	0.6695	0.6356	0.6459
Population ratio (Age 65-)	0.0852	0.0844	0.0986	0.0981	0.1199	0.1056	0.1293	0.1207
Growth rate (Primary, 10 years)	-0.1806	-0.2270	-0.4064	-0.3835	-0.3972	-0.3633	-0.4189	-0.3901
Growth rate (Secondary, 10 years)	0.3942	0.4792	0.4460	0.4340	0.6219	0.7305	0.4308	0.4315
Growth rate (Tertiary, 10 years)	0.2966	0.3015	0.2269	0.2703	0.4112	0.3820	1.2923	0.3069
Growth rate (Age 0-15, 10 years)	-0.3258	-0.3251	-0.2749	-0.1924	-0.4168	-0.2940	-0.1823	-0.1766
Growth rate (Age 16-64, 10 years)	0.0413	0.0390	-0.0126	-0.0070	-0.0782	-0.0189	-0.0114	-0.0245
Growth rate (Age 65-, 10 years)	0.3289	0.3265	0.2739	0.4042	0.1776	0.2882	0.2296	0.2783

Notes: All variables are averaged over pre-intervention periods. Per capita taxable income is annual basis and other demographic covariates are 5-year basis (1970,1975,1980...). For example, in Rokkasho, the first pre-intervention year is 1981 and the intervention year is 1986, so per capita taxable income averaged for 1981-1985 and demographic covariates in 1985 are used as predictors. In the other cases, although the first pre-intervention year is 1972, I include demographic covariates in 1970 in predictors (otherwise no demographic covariates are available for Naraha and Tomioka.)

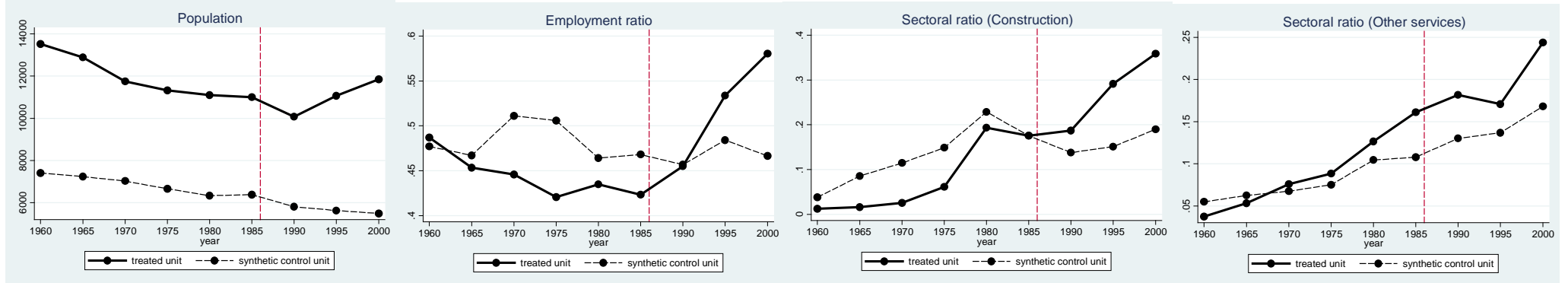
## Appendix D. Weights on donor-pool municipalities

Rokkasho (Aomori)			Tomari (Hokkaido)			Onagawa (Miyagi)			Naraha (Fukushima)		
Prefecture	Municipality	Weight	Prefecture	Municipality	Weight	Prefecture	Municipality	Weight	Prefecture	Municipality	Weight
Aomori	Minmaya	0.164	Hokkaido	Hamamasu	0.197	Aomori	Komadori	0.184	Aomori	Shiura	0.023
Aomori	Shariki	0.513	Hokkaido	Taisei	0.385	Miyagi	Shiogama	0.040	Iwate	Noda	0.051
Aomori	Ooma	0.236	Hokkaido	Shakotan	0.418	Miyagi	Karakuwa	0.323	Miyagi	Natori	0.035
Iwate	Noda	0.087	Other 80 municipalities		0	Akita	Nikaho	0.453	Miyagi	Naruse	0.018
Other 70 municipalities		0				Other 70 municipalities		0	Miyagi	Kitakami	0.389
									Akita	Hachimori	0.087
									Akita	Nikaho	0.132
									Fukushima	Odaka	0.265
									Other 66 municipalities		0
<b>Tomioka (Fukushima)</b>			<b>Kashiwazaki (Niigata)</b>			<b>Kariwa (Niigata)</b>			<b>Shika (Ishikawa)</b>		
Prefecture	Municipality	Weight	Prefecture	Municipality	Weight	Prefecture	Municipality	Weight	Prefecture	Municipality	Weight
Aomori	Shariki	0.035	Niigata	Oogata	0.013	Niigata	Kamihayashi	0.514	Niigata	Izumozaki	0.008
Iwate	Taro	0.007	Niigata	Oumi	0.046	Toyama	Nyuzen	0.486	Niigata	Kamihayashi	0.130
Miyagi	Natori	0.054	Toyama	Takaoka	0.015	Other 50 municipalities		0	Toyama	Nyuzen	0.244
Miyagi	Iwanuma	0.181	Toyama	Shinminato	0.048				Ishikawa	Nanatsuka	0.085
Miyagi	Matsushima	0.051	Toyama	Namerikawa	0.503				Ishikawa	Kashima	0.289
Miyagi	Yamoto	0.166	Toyama	Nyuzen	0.215				Ishikawa	Notojima	0.107
Miyagi	Naruse	0.008	Ishikawa	Kashima	0.009				Ishikawa	Uchiura	0.136
Miyagi	Motoyoshi	0.008	Ishikawa	Notojima	0.001				Other 45 municipalities		0
Akita	Tenno	0.005	Ishikawa	Monzen	0.030						
Akita	Nishime	0.061	Fukui	Awara	0.122						
Yamagata	Atsumi	0.423	Other 42 municipalities		0						
Other 63 municipalities		0									

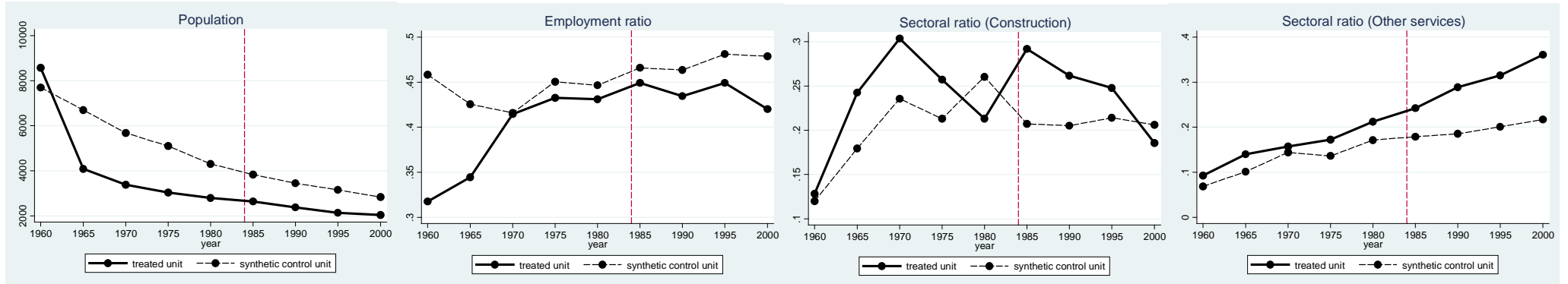
Notes: Sums of weights are not necessarily zero due to rounding off to three decimal places.

# Appendix E. Comparison of some socio-economic factors of treated units and synthetic control units

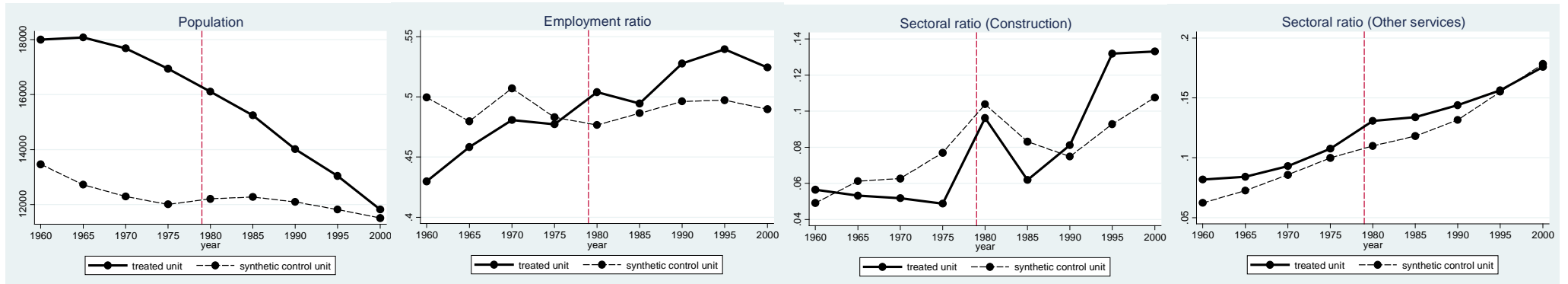
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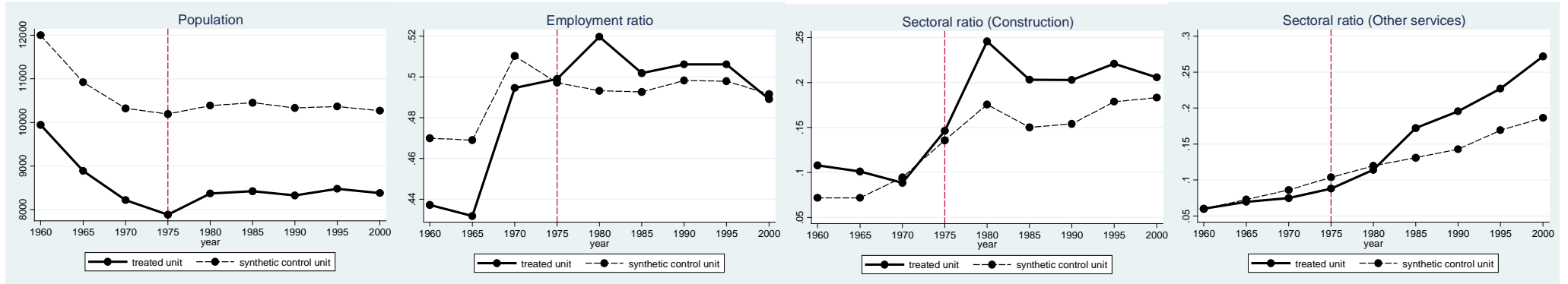
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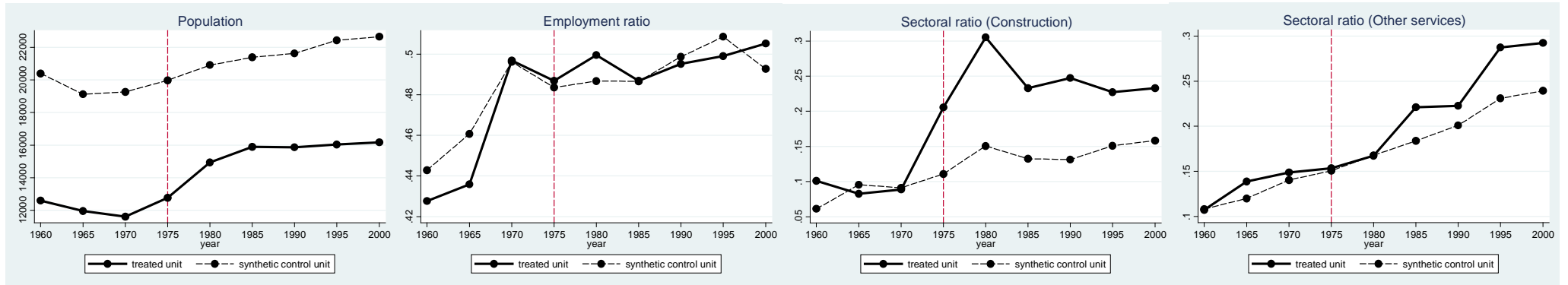
## Onagawa



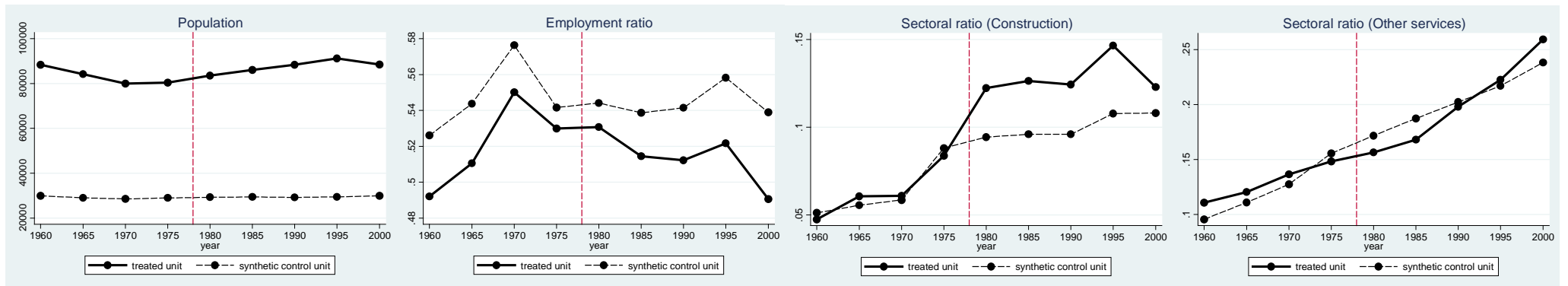
## Naraha



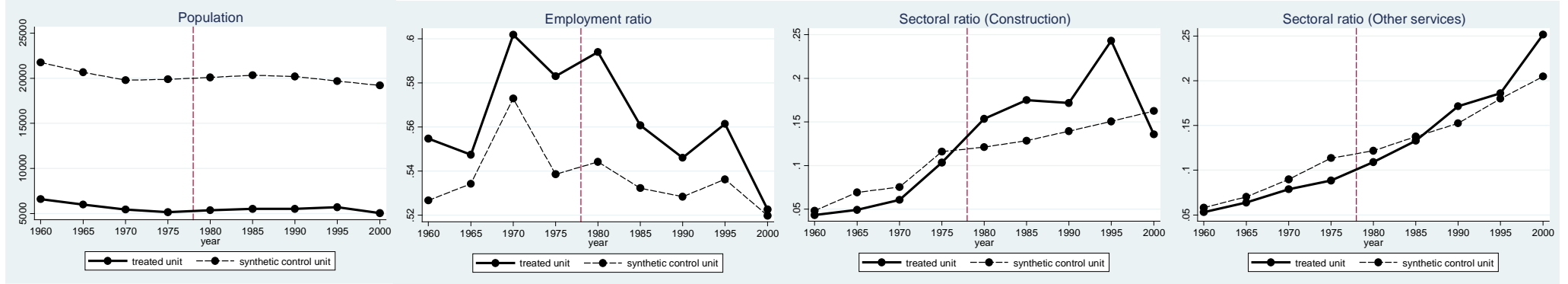
## Tomioaka



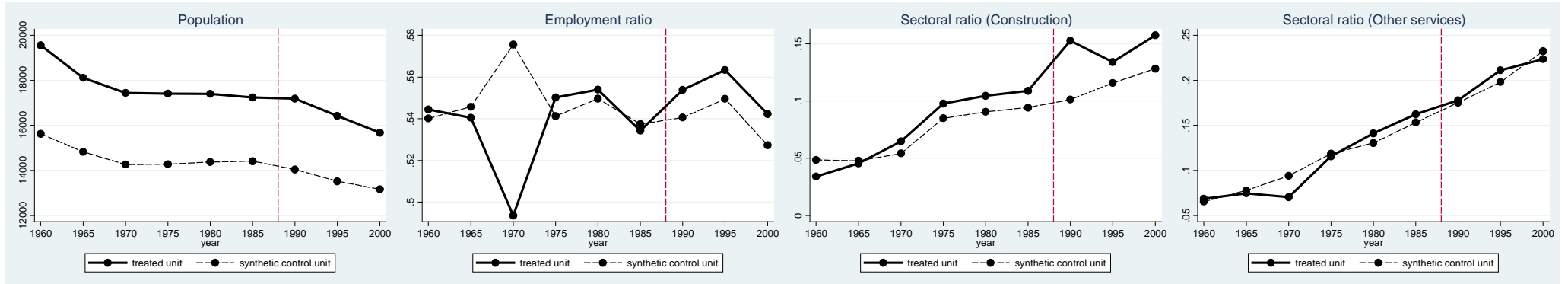
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