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Tohoku University, Kyoto University, CTI Engineering Co., Ltd., Ministry of Land, Infrastructure, Transport and Tourism

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The effects of hazard risk information on locations of firms by industry in tsunami-prone coastal areas

Tatsuhito Kono[1*], Hirokazu Tatano[2], Kenji Ushiki[3], Daisuke Nakazono[3] and Fumihito Sugisawa[4]

[1] Tohoku University, Aoba 09, Aoba-ku, Sendai 980-0879, Japan

[2] Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan

[3] CTI Engineering Co., Ltd., 3-21-1 Nihonbashi Hama-cho Chuo-ku, Tokyo, 103-8430 Japan

[4] Ministry of Land, Infrastructure, Transport and Tourism, 1100 Misonodaira, Fujimiya, Shizuka, 418-0004, Japan

Abstract. The construction of seawalls changes the risk of tsunami inundation and the locations of firms behind the seawalls. In order to estimate the benefits of seawalls and to design land use planning behind seawalls, it is necessary to know the impact of risk reduction on the location of firms. To capture such impacts, we estimate the effects of changes in tsunami inundation risk information on the number of firms behind the seawalls. The data is from Japanese areas with a high possibility of a tsunami. There are regional fixed effects by industry and spatial heterogeneities in risks due to the topographic conditions. We first rigorously derive a fixed-effects model in uncertain situations with expected profits of firms, and theoretically find that, unlike in situations of certainty, we should factor in the interaction between regional fixed effects and the change in risks besides the usual regional fixed effects. Our empirical estimation finds that awareness of a high inundation risk has a negative impact on industries with demand in a wide range of areas, such as manufacturing and wholesale, but no impact on industries with localized demand, such as education and clinics.

Key Words: Difference-in-differences, Relocation of firms, Tsunami hazard map

JEL classification: R1; R3

[*] Corresponding author. E-mail: kono@tohoku.ac.jp

1. Introduction

There are many areas with tsunami risk all over the world. According to hazard maps provided by UNESCO[1], since 1610 BCE, there have been 259 fatal tsunamis. According to UNESCO[2], the countries hit by a tsunami causing more than 2,000 or more deaths during the last 500 years spread all over the world, which are Chile, Indonesia, Italy, Japan, Jamaica, Pakistan, Papua New Guinea, Peru, Portugal, Sri Lanka, Russia, and the Philippines. In addition, as Koshimura et al. (2020) point out, tsunami events are rare but can be extremely devastating. Sixteen recent major tsunamis between 1996 and 2015 killed a remarkable 250,900 people in 21 countries in total. It implies that it averages more than 15,600 deaths per event.

The construction of seawalls can reduce the risk of tsunami inundation drastically. This further enables us to use land efficiently behind the seawalls, which is important for densely-populated countries. If the benefit of the efficient land use outweighs the cost of the seawalls, the construction is justified. In order to estimate the benefit of inundation-risk reduction by seawalls and to design land use planning behind seawalls, it is necessary to understand the impact on the location of firms and residents. The current paper focuses on firms.

If the scale of seawalls frequently changes, we can estimate how land-use changes according to the scale. However, because it takes a long time to complete seawalls, there are no such data. Thus, instead of changes in the scale of seawalls, we use the change in the scale of an expected tsunami publicly released in the hazard maps. Most people have no sufficient information and knowledge to estimate what level of tsunami is expected in the areas where they reside or work by themselves, so they rely on the publicly-released scale estimations of tsunamis. Actually, even experts do not know the scale of an expected tsunami and the

1 The url is http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=1672&Itemid=2698.

2 The url is http://itic.ioc-unesco.org/images/stories/about_tsunamis/tsunami_glossary/DeadlyRegionalLocal_morethan2000.jpg

inundation depth at each location without finely-tuned simulations of tsunamis because the scale of a tsunami as well as its inundation depth depends on various complex factors. Indeed, regarding the seismic risk, which is also difficult for people to estimate, Hidano et al. (2015) and Ikefuji et al. (2022), respectively, have shown that apartment prices and property values are significantly affected by seismic hazard risk information. So we suppose that people believe the expected scale announced in the hazard maps and change their behavior according to the expected inundation depth.

The treatment group is areas with a high possibility of a large tsunami in prefectures in Japan, while the control group is the other areas in the same prefecture. In the Nankai Trough in the south of Japan, there is an estimated 90% probability of a large-scale (magnitude 8-9 class) earthquake occurring within the next 40 years according to the Earthquake Research Committee of the headquarters for Earthquake Research Promotion. In this area, hazard maps are published to promote disaster prevention and mitigation. The first of these maps were published around 2004, and the scale estimates used in the first hazard maps were increased in the second hazard maps due to the experience of the Great East Japan Earthquake in 2011, which recorded a magnitude of 9.0.

It is known that, due to a wide recognition of tsunami risk, land values in flooded areas may decrease because the land demand decreases. In fact, many previous studies have shown that the publication of hazard information due to potential flooding has lowered land prices. Bin and Polasky (2004), Bin and Kruse (2006), and Hallstrom and Smith (2005) have confirmed that flood risk information or records cause land prices to decline. Teramoto et al. (2008), Okagawa et al. (2011), Bin and Landry (2013), and Inoue et al. (2018) indicate that the actual damage caused by a hurricane reduces land prices. Votsis and Perrels (2016) analyze flood risk and house prices in Finland by the difference-in-differences method, and show a decrease in house prices. Saito (2005) shows that land prices in places with previous floods have decreased more than those in places without previous floods.

These previous studies have captured the impact on land prices, but have not analyzed this by industry. To design land use policies from the viewpoint of industry policies, we should know the impact of the construction of seawalls on each industry. Since the impact of inundation on businesses is different across industries, it is necessary to grasp the influence on the location of each industry. Furthermore, tsunami risk varies spatially depending on the distance from the coast and the topographic conditions.

To reflect these characteristics for analyses, we apply the difference-in-differences approach to the location data by industry. We first rigorously derive a fixed-effects model from firms' expected profit maximization behavior in uncertain situations reflecting tsunami risk, and show that, unlike in situations of certainty, we should take account of the interrelationship of regional fixed effects or regional heterogeneity (e.g., existence of nearby transport nodes) and the risks, in addition to the conventional regional fixed effects, because the change in risk affects regional fixed effects as well as other factors through the change in the occurrence probabilities. No previous papers have derived a fixed-effects model in such an uncertain world.

Next, applying the derived approach to the data, we empirically find that awareness of a high inundation risk has a negative impact on industries with demand in a wide range of areas, such as manufacturing and wholesale, but no impact on industries with localized demand, such as education and health.

The rest of our paper is as follows. Section 2 explains what data are used, and Section 3 analyzes the data using the descriptive statistics. We summarize the results of interviews regarding the actual situation of the change in the number of firms. Section 4 constructs a theoretical locational model of firms, and derives a fixed-effect approach for an uncertain situation. Section 5 estimates parameters of the approach, and shows how firms' locations change by prefecture and by industry, based on the estimation results.

2. Hazard maps and locations of firms

2.1 Tsunami inundation prediction map published by each prefecture

The analysis target areas are five prefectures[3] where a large tsunami is expected due to earthquakes of magnitude 8-9 in the Nankai Trough, south of Japan. The target prefectures are shown in the first column of Table 1, and a map of them is shown in Figure 1. In this area, hazard maps are published by each prefecture to promote disaster prevention and mitigation. Tsunami hazard maps show where inundation is expected and how deep the inundation is expected to be. Actually, in our target area and period, hazard maps were published twice. The publication years are shown by prefecture in Table 1. We use the publication of these hazard maps to estimate the effects on the location of firms.[4]

Table 1 Public release years of tsunami hazard maps by prefecture

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Shizuoka Pref.		○												○	
Mie Pref.					○								○		
Wakayama Pref.						○								○	
Tokushima Pref.					○								○		
Kochi Pref.			△			○							○		
Locational data		●					●			●			●		●

Note: Kochi published three hazard maps. But the method used to produce the 2002 map denoted by △ in the table was too simplistic. Indeed, it does not show the inundation depth by grid square. So we regard the 2005 map as the first map. Actually, the locational data related to these hazard maps are obtained from only 2001 and 2006. Accordingly, the choice of the 2002 or 2005 map for the first map is not so important. Tokushima published a provisional hazard map in 2011. But the information was incomplete, so we do not use this map.

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[3] The prefectures which are expected to be affected are these five prefectures and Aichi Prefecture. In the current paper, we analyzed the effects of two hazard maps published around 8 years apart. However, in Aichi Prefecture, on the first map, only 1.5% of the area was expected to suffer inundation. Accordingly, we cannot capture the effect of the first map on the locations of firms in Aichi. So, we excluded Aichi Prefecture.

[4] The same authors have estimated the effects of only the first publication of hazard maps on the location of firms in Kono et al. (2021).

Figure 1 Target areas and the Nankai Trough

Each prefecture has published hazard maps for itself, so the publication years are different. The hazard maps we use are shown by circles in Table 1. The first hazard maps are calculated based on the record of the past three real large earthquakes after 1850: the Tokai, Tonankai, and Nankai earthquakes. But since the Great East Japan Earthquake in 2011 was the largest in 1,000 years, these hazard maps were revised based on the largest possible seismic forces for the area. As a result, the expected depth and area of inundation have increased significantly on the second hazard maps in all prefectures.

Table 2 Expected inundation area ratio in terms of the number of 500m^2 grid squares

		First hazard map		Second hazard map	
	No. of grid squares in total	No. of inundation grid squares	Inundation percentage	No. of inundation grid squares	Inundation percentage
Shizuoka Pref.	8,481	809	9.5%	1,454	17.1%
Mie Pref.	6,140	1,447	23.6%	1,876	30.6%
Wakayama Pref.	3,048	723	23.7%	989	32.4%
Tokushima Pref.	2,666	589	22.1%	986	37.0%
Kochi Pref.	2,623	840	32.0%	1,077	41.1%

Table 2 counts the number of 500 m^2 grid squares in total and in the inundation areas by prefecture. This shows that the inundation area ratios in the first hazard maps are about 10% in Shizuoka, about 20% in Mie, Wakayama, and Tokushima, and more than 30% in Kochi. In the second hazard map, the ratios increase to about 20% in Shizuoka, about 30%

or more in Mie, Wakayama, and Tokushima, and about 40% in Kochi.

2.2 Number of firms in inundation areas

The numbers of firms by industry classification are collected from grid data from the Economic Census in 2006, 2009, 2012, and 2014. The black circles in the last line of Table 1 show the publication years of the Economic Census. We use all these data. The industry classification follows the Japan Standard Industrial Classification in the 2014 version.

Some grid squares have zero values during our analysis period. For these grid squares, even if changes in tsunami risk affect the firms' location behavior, the number of locations will be subject to the zero constraint. Since such zero values distort the change trend, we ignore the grid squares that have zero values even in a single year during the analysis period.

This 'non-zero' sample selection may distort the estimates of the parameters in the following way, unless firms in the same category are regarded as being homogenous across grid squares. Taking the commercial industry sector as an example, this sector includes large supermarkets with a large trade area and small supermarkets with a small trade area. In the case of large supermarkets, the number of locations within the grid square is smaller than that of small supermarkets. In this case, the number of locations of large supermarkets and small supermarkets may differ due to the effect of the inundation depth. But if the composition of the number of locations of large and small supermarkets in each grid square is the same, there is no heterogeneity between grid squares in the sense of composition. On the other hand, if a grid square with a large supermarket has an unbalanced distribution of locations, such as no small supermarkets in the grid square with a large supermarket, the parameter estimates in this study cannot be representative of the entire commercial area. The degree of heterogeneity is reduced by subdividing the industry classification. So we have classified industries into as many as possible in consideration of the number of samples.

When, due to the heterogeneity of firms within a sector, the parameter may not be representative of the sector, the parameter can be interpreted as that of the firms located in the grid square that was adopted as the sample among the industries. The existence and degree of heterogeneity between firms that have zero firms in the grid square and those that do not may vary from industry to industry. However, there is no way to know this.

Table 3 compares the number of grid squares excluded from the analysis with the number of grid squares used in order to consider the degree of influence when there is heterogeneity among grid squares. The number of grid squares excluded is considerably smaller than the number of grid squares included in the analysis in many sectors but large in several sectors. For example, in the manufacturing sector, 6,056 grid squares are excluded while 15,951 grid squares are used for our analysis. The sectors where the number of excluded grid squares is more than the number of target grid squares are mining, and quarrying of stones; electricity, gas, heat supply, and water supply; and information and communication.

Furthermore, since the decision-making unit for firms' location behavior is the firm, we show the number of firms in the excluded grid square as of 2001, and the number of firms in the grid square to be analyzed are shown in the rightmost two columns of Table 3. The table shows that the number of firms in most sectors is less than 10% or 20% of the number of excluded firms, except for three sectors: mining, quarrying of stones; electricity, gas, heat supply, and water supply; and compounded services. Therefore, as long as the difference between the excluded firms and the target firms is not large, there seems to be no major problem in considering the location behavior of the analyzed firms as representative of their industries.

In the following sections, we will interpret the parameter estimates as representative values for each industry classification. However, as mentioned above, precisely speaking, our study is an analysis of the location behavior of the firms located in the analyzed grid square. Indeed, it is conceivable to apply the Tobit model and incorporate grid squares with zero number of firm locations. However, because our paper uses panel data, not a cross-sectional analysis, fixed effects are included as explanatory variables. It is known that fixed effects are not a consistent estimation in a panel analysis where the number of time points covered is limited. Furthermore, in the Tobit model, the parameters related to the inundation depth, which is the focus of this study, are not estimated in a consistent manner because the values of other parameters are not determined independently of the fixed effects. Although estimation methods have been developed to solve or alleviate this problem (e.g., Heckman and MaCurdy (1980)'s iterative methods and Honor´e (1992)'s semiparametric method), these methods have also shown shortcomings. For these reasons, we do not use panel Tobit analysis in this study.

Table 3. Number of grid squares and firms

Industry	No. of grid squares			No. of firms at 2001	
	No. of firms at 2001>0		Zero firms at 2001	No. of firms at 2001>0	
	Zero firms later than 2001	Positive no. of firms in all years		Zero firms later than 2001	Positive no. of firms in all years
Mining and quarryiing of stone	280	54	143,231	252	55
Construction	5,646	17,222	120,697	5,892	69,019
Manufacturing	6,056	15,951	121,558	6,801	91,962
Electiricty, gas, heat supply and water	829	211	142,525	893	274
Information and communications	1,671	844	141,050	1,600	3,755
Transport and postal services	3,214	4,516	135,835	3,227	10,842
Wholesale and retail trade	5,685	18,247	119,633	6,880	223,096
Finance and insurance	1,595	2,986	138,984	1,466	9,838
Real estate and goods rental and leasing	2,553	7,172	133,840	2,647	35,135
Scientific research, professional and technical services	2,650	5,778	135,137	2,500	21,923
Accommodations, eating and drinking services	4,932	11,730	126,903	5,427	104,302
Living-related and personal services and amusement services	3,470	12,154	127,941	3,417	62,385
Education, learning support	5,232	7,020	131,313	6,356	23,672
Medical, health care and welfare	2,789	9,469	131,307	3,003	31,221
Compound services	2,407	2,651	138,507	2,391	3,894
Services	4,534	11,800	127,231	4,588	35,485

For every prefecture, we suppose that the latest hazard map before the publication year of the Economic Census, which provides location data, is the hazard map affecting the location of firms. Every prefecture has published two hazard maps affecting our location data. We capture the effects of the two hazard maps.

3. Location behavior of firms

3.1 Trend of locations of firms according to interview

Before analyzing the locational data statistically, we conducted interviews for local governments in the coastal areas in December, 2018, and asked about the actual situations of the change in the number of firms. Table 3 shows the major interview results. As Table 4 in section 3.2 shows, the number of firms in inundation areas along the coast decreases relative to other areas after the tsunami hazard maps are released. However, according to the public servants in charge of industrial locations, in most cases, firms do not move their locations. But the number of firms in the inundation areas decreases compared to that in the other areas because no new firms come into the tsunami risk areas while some existing firms close down due to the owners' retirement or other reasons.

Table 3 Major results of interviews conducted in three municipalities along the coast

City/town	Public sector action	Firms' reactions to hazard maps
Town A	Since the Great East Japan Earthquake in 2011, police stations and kindergartens have been moved out of the flood zone. In addition, public evacuation facilities, such as evacuation towers, have been constructed in the flood areas.	Due to the age of owners, some firms have gone out of business. There have been no new businesses coming into the flood areas.
City B	Tsunami risks and measures for risks have been publicly announced. Preparation of a business continuity plan has been promoted for firms.	No new firms have come into the flood areas. The locations which firms have moved out of have not been sold, so most of them are used for warehouses. Retail stores and restaurants have gone out of business, rather than relocating their locations.

Town C	The town has tried to encourage firms to move out of the flood areas as measures against an expected tsunami. The town has had meetings sharing tsunami risks and measures for them with firms.	Firms relocating are rare. Many firms have gone out of business due to the high ages of owners. Currently, there is a lot of vacant land, so some firms might come in to use some large areas.

Note that we do not have permission to reveal the city names.

3.2 Numbers of firms in predicted inundation areas

Combining the tsunami inundation prediction map with the data of the number of firms, we counted the number of firms in the inundation areas and the no-inundation areas on the two hazard maps by prefecture (see Table 4). In most prefectures, after the first hazard map, the number of firms in the inundation areas decreases more than the prefecture average rate. For example, in Shizuoka, the share of the number of firms in the inundation area decreases from 12.7% to 12.3%, and in Tokushima, the share decreases from 31.1% to 31.0% after the first hazard map while the shares had increased up to the publication of the first hazard map.

However, in Wakayama and Kochi, there are no clear decreases in the number of firms after the first hazard map, compared to the past trend up to the first hazard map announcement. For Wakayama, this is probably because the hazard map is announced in 2005, soon before the year 2009. Indeed, in 2012, the share decreases greatly, possibly meaning that a decrease due to the first hazard map comes in slowly. In Kochi, even in 2012, the share does not decrease. This might be partly because Kochi has a large predicted inundation area (as shown in Table 2) so that it is hard to find land in no-inundation areas if firms look for suitable locations. The above-denoted tendency might be different among industries. So, we will check them statistically by industry in the following sections.

Looking at the effects of the second hazard maps published between 2012 and 2014, in all prefectures except for Kochi, the number of firms drops due to the publication of the hazard maps. Although the changes seem different between the two areas in Tokushima, there are no clear differences in the other prefectures. These tendencies might be different among industries, so we will check them statistically in the following sections.

Table 4 Number of firms in inundation and no-inundation areas

Prefecture	Year	Whole area (a)	Inundation area on 1st hazard map (b)	b/a	Inundation area on 2nd hazard map			
					Inundation area on 1st hazard map (c)	c/a	No-inundation area on 1st hazard map (d)	d/a
Shizuoka	2001	205,968	26,205	12.7%	25,583	12.4%	18,350	8.9%
	2006	189,851	23,274	12.3%	22,698	12.0%	16,816	8.9%
	2009	192,076	22,583	11.8%	22,032	11.5%	17,068	8.9%
	2012	176,123	20,270	11.5%	19,771	11.2%	15,575	8.8%
	2014	179,969	20,153	11.2%	19,634	10.9%	15,795	8.8%
Mie	2001	91,442	31,124	34.0%	31,076	34.0%	14,293	15.6%
	2006	84,160	28,084	33.4%	28,039	33.3%	12,730	15.1%
	2009	86,147	28,312	32.9%	28,277	32.8%	12,910	15.0%
	2012	77,092	25,139	32.6%	25,106	32.6%	11,650	15.1%
	2014	80,755	25,946	32.1%	25,914	32.1%	12,072	14.9%
Wakayama	2001	57,499	24,338	42.3%	24,338	42.3%	9,870	17.2%
	2006	53,363	22,051	41.3%	22,051	41.3%	9,075	17.0%
	2009	53,496	22,005	41.1%	22,005	41.1%	9,040	16.9%
	2012	47,981	19,491	40.6%	19,491	40.6%	8,311	17.3%
	2014	48,882	19,621	40.1%	19,621	40.1%	8,292	17.0%
Tokushima	2001	44,020	13,589	30.9%	13,436	30.5%	13,323	30.3%
	2006	40,188	12,490	31.1%	12,351	30.7%	12,215	30.4%
	2009	40,923	12,705	31.0%	12,555	30.7%	12,480	30.5%
	2012	36,463	11,336	31.1%	11,197	30.7%	11,396	31.3%
	2014	37,950	11,675	30.8%	11,521	30.4%	11,652	30.7%
Kochi	2001	44,734	25,408	56.8%	24,844	55.5%	2,938	6.6%
	2006	40,584	22,260	54.8%	21,730	53.5%	2,709	6.7%
	2009	40,279	22,116	54.9%	21,594	53.6%	2,704	6.7%
	2012	35,689	19,824	55.5%	19,379	54.3%	2,399	6.7%
	2014	37,165	20,427	55.0%	19,975	53.7%	2,537	6.8%

Note: The dashed lines in the table indicate the year of publication of the first hazard map, and the solid lines in the table indicate the year of publication of the second hazard map. The exact years of publication are shown in Table 1.

4. A fixed-effect model in a risk situation

4.1 Model

One advantage of a fixed-effects model is that it can easily consider regional fixed effects, which are composed of uneasily observed specific factors. This advantage is in common with difference-in-differences approaches. Most difference-in-differences approaches, however, have been applied to a situation of certainty.

In our tsunami risk situation[5], we have to suppose that firms determine their locations based on the expected profit, which is the weighted average of profits in normal situations and tsunami situations. Indeed, both normal situations and tsunami situations affect regional fixed effects. So, we show that since the weights, i.e., the probability of inundation, is the policy variable in our case, the fixed-effects model should consider how much the risk affects regional fixed effects, by rigorously deriving the model.

When the number of locations in location *r* at time *t* is set as Nr (t), it can be set as a function of profit which can be obtained in location *r* as,

$$N_r(t) = f(\pi_r(\boldsymbol{X_r}, \boldsymbol{Y_r}(t), t, D_r(t), P(t))) \tag{1}$$

where $\boldsymbol{X_r} = [X_{r1}, \dots, X_{ri}, \dots, X_{rI}]$, and $\boldsymbol{Y_r} = [Y_{r1}, \dots, Y_{rj}, \dots, Y_{rJ}]$.

Here, f is a monotonic function, π_r is an annual expected profit when locating in location *r*, Xri is a factor that does not change during the analysis period for location *r* and industry *i* in both normal and disaster times, Yrj is a factor that changes during the analysis period for location *r* and industry i in normal times and disaster times, *t* represents the time trend, for example, to represent the trend of demand for the industry as a whole. $Dr(t)$ is the subjective inundation depth in region *r* at time *t,* and $P(t)$ is the subjective probability that a tsunami will come in one year[6].

In a situation of certainty, vector $\boldsymbol{X_r}$ (e.g., the existence of a nearby port) can be

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[5] In some fields studying risk environments specifically, risk and uncertainty are used differently. In our study, agents are supposed to set some subjective probabilities for tsunamis. In this sense, we only consider risk environments, not uncertain environments. But in our study, we use these words interchangeably.

[6] Dr can be set as a vector, setting an element Drk (t) as the subjective inundation depth due to the *k*-level tsunami in region *r* at time *t*. In addition, we can set Pr as the probability that a *k*-level tsunami will come in one year. However, in our situation, residents and firms only know the latest hazard map. The hazard map provides one level of inundation depth, supposing a certain level of large earthquake. So, the current paper sets only one level of inundation depth.

captured as regional fixed effects, which is the combination of the effects of $\boldsymbol{X_r}$, in a fixed effect approach. On the other hand, $\boldsymbol{Y_r}$ (e.g., a new opening of a highway interchange) should be considered as explanatory variables even in a situation of certainty. However, as we show below, in an uncertain situation, vector $\boldsymbol{X_r}$ needs to be considered as in $\boldsymbol{Y_r}$.

The expected profit is

$$\Pi_r(\boldsymbol{X_r}, \boldsymbol{Y_r}(t), t, D_r(t), P(t)) = (1 - P(t))\pi_{ro} + P(t)\pi_{rd}, \quad (2)$$

where π_{ro} is an annual disaster-free profit and π_{rd} is an annual profit in a year with a tsunami (tsunami year, hereafter). Here, π_{ro} is specified as

$$\pi_{r0}(t) = \alpha + \sum_{i=1}^{I} \beta_{Xi} X_{ri} + \sum_{j=1}^{J} \beta_{Yj} Y_{Yj}(t) + \gamma(t)\delta(t), \quad (3a)$$

where $\delta(t)$ takes one at time t, and zero otherwise, and α, β_{Xi}, β_{Yj}, γ_t are parameters.

Here, the influence on the operation after a tsunami differs by factor, and the degree of the expected influence is expressed by λ_Z ($Z = \alpha, X_1, ..., X_i, ..., X_{ZI}, Y, ..., Y_i, ..., Y_{ZI}$, or t). So, π_{rd}, annual profit in a tsunami year is

$$\pi_{rd}(t) = \lambda_\alpha \alpha + \sum_{i=1}^{I} \lambda_{Xi} \beta_{Xi} X_{ri} + \sum_{j=1}^{J} \lambda_{Yj} \beta_{Yj} Y_{rj}(t) + \lambda_t \gamma(t)\delta(t), \quad (3b)$$

It should be noted that λ_Z is generally 1 or less, i.e., when it is 1, it means that the factor contributes as in normal times. Naturally, λ_Z decreases as the inundation depth increases. So, the current paper sets $\lambda_Z = 1 - \kappa_Z(D_r)$, where $\kappa_Z(D_r)$ is the effect of the inundation depth on variable Z. Using this, the expected profit can be rewritten as

$$\begin{aligned}
\pi_{r0}(t) &= (1 - P(t))[\alpha + \sum_{i=1}^{I} \beta_{Xi} X_{ri} + \sum_{j=1}^{J} \beta_{Yj} Y_{Yj}(t) + \gamma(t)\delta(t)] \\
&\quad + P(t)[\lambda_\alpha \alpha + \sum_{i=1}^{I} \lambda_{Xi} \beta_{Xi} X_{ri} + \sum_{j=1}^{J} \lambda_{Yj} \beta_{Yj} Y_{rj}(t) + \lambda_t \gamma(t)\delta(t)] \\
&= \alpha + \sum_{i=1}^{I} \beta_{Xi} X_{ri} + \sum_{j=1}^{J} \beta_{Yj} Y_{rj} + \gamma(t)\delta(t) \\
&\quad + P(t)[(\lambda_\alpha - 1)\alpha + \sum_{i=1}^{I} (\lambda_{Xi} - 1)\beta_{Xi} X_{ri} + \sum_{j=1}^{J} (\lambda_{Yj} - 1)\beta_{Yj} Y_{rj} + (\lambda_t - 1)\gamma(t)\delta(t)] \\
&= \alpha + \sum_{i=1}^{I} \beta_{Xi} X_{ri} + \sum_{j=1}^{J} \beta_{Yj} Y_{rjt} + \gamma_t \delta_t
\end{aligned}$$

$$-P[\kappa_\alpha(D_r)\alpha + \sum_{i=1}^{I}\kappa_{Xi}(D_r)\beta_{Xi}X_{ri} + \sum_{i=1}^{I}\kappa_{Yj}(D_r)\beta_{Yj}Y_{rjt} + \kappa_t(D_r)\gamma_t\delta_t], \qquad (4a)$$

where $P(t)$ is the subjective probability of a tsunami occurring in year *t*. This subjective probability is revised by a new hazard map.

Since we need not capture the details of regional fixed effects on the expected profit basis, we can represent the combination of multiple fixed effects as one scalar variable, as

$$\begin{aligned}\pi_{rt} &= \alpha + B_r + \sum_{j=1}^{J}\beta_{Yj}Y_{rj} + \gamma_t\delta_t \\ &-[\kappa_\alpha(D_r)\alpha' + \sum_{i=1}^{I}\kappa_{Xi}(D_r)\beta'_{Xi}X_{ri} \\ &+ \sum_{i=1}^{J}\kappa_{Yj}(D_r)\beta'_{Yj}Y_{rjt} + \kappa_t(D_r)\gamma'_t\delta_t]\end{aligned}, \qquad (4b)$$

where $B_r \equiv \sum_{i=1}^{I}\beta_{Xi}X_{ri}$, $\alpha' \equiv P(t)\alpha$, $\beta'_{Xi} \equiv P(t)\beta_{Xi}$, $\beta'_{Yj} \equiv P(t)\beta_{Yj}$, $\gamma' \equiv P(t)\gamma$.

In (4b), we make new parameters α', β'_{Xi}, β'_{Yj} and γ' by combining the subjective probability P(t) with parameters because the subjective probability is unknown to analyzers. The term $\kappa_{Xi}(D_r)X_{ri}$ in (4b) is a cross term of the policy variable $\kappa_{Xi}(D_r)$ (i.e., changes in inundation level) and regional fixed effects on the situation basis, X_{ri}. This implies that a fixed effect approach cannot remove regional fixed factors from explanatory variables, unlike in a situation of certainty. This point might be useful for other uncertain situations, so we summarize this in Proposition 1.

Proposition 1 (a fixed effect (or difference-in-differences) approach in an uncertain situation).

As shown in (4b), when a policy changes the probability of occurrence of some situations, a difference-in-differences approach in uncertain situations cannot ignore regional fixed effects, which can be ignored in a difference-in-differences approach in a situation of certainty (i.e., only one situation). We need to consider a cross term of policy variable (e.g., changes in inundation levels) and regional fixed effects on the situation basis (e.g., the existence of a nearby port).

The inundation degree function, $\kappa_\alpha(D_r)$, $\kappa_{Zi}(D_r)$ ($Z = X$ or Y), $\kappa_t(D_r)$ can be linear or nonlinear. In the current paper, we specify this in the following two manners.

Specification 1:

$\kappa_\alpha(D_r) = \mu_\alpha D_r$, $\kappa_{Zi}(D_r) = \mu_{Zi} D_r$, $\kappa_t(D_r) = \mu_t D_r$

Specification 2:

For $D_r = 0$, $\kappa_\alpha(D_r) = \kappa_{Zi}(D_r) = \kappa_t(D_r) = 0$

For $D_r > 0$, $\kappa_\alpha(D_r) = \mu_\alpha$, $\kappa_{Zi}(D_r) = \mu_{Zi}$, $\kappa_t(D_r) = \mu_t$

where $\mu_\alpha, \mu_X, \mu_Y, and\ \mu_t$ are positive parameters.

The idea of Specification 1 is that the effect of the inundation depth is linear. That is, as the depth increases, the effect of the depth increases linearly. On the other hand, Specification 2 implies that whether the depth is zero or positive is important. Even if the depth is very small, a positive depth affects the locational behavior[7].

As shown in Section 2, the first hazard maps are revised during our target period. So, $D_r(t)$ changes twice in our target period. The effects of the revised hazard maps might be different from the effects of the first hazard maps. So, we use different parameters $\mu_\alpha, \mu_X, \mu_Y, and\ \mu_t$ for the depths D_r in the first and second hazard maps.

Next, we specify $f(\pi_r)$, which is used to determine the number of locations as $N_r(t) = f(\pi_r)$.

Specification A:

$N_r(t) = \theta\pi_r(t)$, and all the explanatory variables are used as they are. (5a)

Specification B:

$N_r(t) = \theta\pi_r(t)$, and all the explanatory variables are log-transformed. (5b)

θ in eqs. (5a) and (5b) are ultimately multiplied by the parameters in eq. (4) and are estimated

[7] Actually, we suppose another function, which assumes multiple-step effects by dividing the inundation depth into multiple steps, using the data up to 2012. The results are not so valuable for the specification for the complexity of the analysis. So, we ignore this case.

as one parameter, so even if we set $\theta = 1,$ there will be no problems.

Furthermore, the inundation area in the second hazard maps can be separated into two areas: the first area, which is also expected to be inundated in the first hazard maps, and the second area, which is expected not to be inundated in the first hazard maps. The effects of the expected depth in the second hazard maps can be different between the two areas. So, we differentiate the parameters related to the areas. Adding subscripts to the above specification forms to express these differentiated parameters, we can express our final mathematical form as

$$\begin{aligned} N_{rt} \equiv \theta\pi_t &= \alpha + B_r + \textstyle\sum_{j=1}^{J} \beta_{Yj} Y_{rj} + \gamma_t \delta_t \\ &+ \delta_1[\kappa_{\alpha 1}(D_r)\alpha' + \textstyle\sum_{i=1}^{I} \kappa_{X1i}(D_r)\beta'_{X1i} X_{ri} + \sum_{i=1}^{I} \kappa_{Y1j}(D_r)\beta'_{Y1j} Y_{rjt} + \kappa_{t1}(D_r)\gamma'_1\delta_t] \\ &+ \delta_{21}[\kappa_{\alpha 21}(D_r)\alpha' + \textstyle\sum_{i=1}^{I} \kappa_{X21i}(D_r)\beta'_{X21i} X_{ri} + \sum_{i=1}^{I} \kappa_{Y21j}(D_r)\beta'_{Y21j} Y_{rjt} + \kappa_{t21}(D_r)\gamma'_{21}\delta_t] \\ &+ \delta_{22}[\kappa_{\alpha 22}(D_r)\alpha' + \textstyle\sum_{i=1}^{I} \kappa_{X22i}(D_r)\beta'_{X22i} X_{ri} + \sum_{i=1}^{I} \kappa_{Y22j}(D_r)\beta'_{Y21j} Y_{rjt} + \kappa_{t22}(D_r)\gamma'_{22}\delta_t], \end{aligned} \tag{4c}$$

where δ_1 is a dummy variable representing whether a sample $N_r\ (t)$ is affected by the first hazard map (if yes, $\delta_1 = 1$; if no, $\delta_1 = 0$), and δ_{2j} is a dummy variable signifying that a sample $N_r\ (t)$ is affected by the 2nd hazard map if δ_{2j} is not zero, and whether the zone was expected to be inundated in the first hazard map or not (if yes, δ_{21}=1 and δ_{22}=0; if no, δ_{21}=0 and δ_{22}=1). The number in subscript indicates the hazard map (1^{st} or 2^{nd}).

Note that, when estimating parameters, we do not identify the parameters including $\kappa_Z(D_r)$ from other parameters such as $\alpha_1{}'$ and β'_{X1}. Actually, identifying differentiated parameters is impossible, and useless for our purpose. We denote the combination of the parameters as just 'parameter' for each explanatory variable from now on.

5. Estimation results

5.1 Explanatory variables

As we explain in Proposition 1, we have to use all the factors affecting firms' profits in uncertain situations. As explanatory variables including X_{ri} and Y_{ri} in eq. (4c), we consider 1) whether the location is within 500m of the coast or not, 2) the number of firms in 8 grid squares adjacent to the location grid square, 3) population in 8 grid squares adjacent to the location grid square, 4) whether the zone is publicly designated as a 'densely inhabited district' or not, 5) public and transport infrastructures (highway interchange, stations, freight rail stations, port, fishery port)[8].

We estimate parameters of (4c) with ordinary least squares. However, all the parameters for X_{ri} and Y_{ri} are not statistically significant because these explanatory variables are fairly correlated with regional fixed effects B_r, time factor t, or $\kappa_t(D_r)t$. So, our final functions do not include these explanatory variables. For our current case, we can conclude that an exact derivation finds that we need to consider X_{ri} for an uncertain situation unlike for a situation of certainty, but at least for our case, these variables do not affect the results.

5.2 Comparisons between Specifications

Regarding the degree function of the inundation effects, Specifications 1 and 2 show the same tendencies in their estimation results, but Specification 2 has statistically better results. Regarding function *f*(), Specifications A and B have the same tendencies in the estimation results, but Specification A, which is a linear function, has statistically better results[9]. As a

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[8] The GIS data published in the National Land Numerical Information, which is published by the Ministry of Land, Infrastructure, Transport and Tourism, are used for the data on public and transportation infrastructures. We collected the locations and the opening dates of highway interchanges, ports, fishing ports, passenger railway stations, and freight stations for railways.

[9] The authors can show the results in other Specifications upon request.

result, we basically explain Specification 2-A results in the following.

5.3 Examination of parallel trend (placebo test)

In the difference-in-differences approach, it is necessary to assume that a parallel trend holds for the treatment group and the target group when there are no hazard maps. In order to confirm that our data meet parallel trend assumptions, we used data from 1996 to 2001, during which time no hazard maps were published, but hypothetically set a false publication year of the first hazard map up to 2001 from 1997. This is a placebo test[10]. In reality, the first hazard map was published in 2001.

Table 5 shows the estimation results of this placebo test. The t-values for the parameters for the false hazard map dummy were very low except for the 'Academic research, specialized and technical services' industry, and they are not significant even at a level of 10%. This indicates that they are likely to satisfy a parallel trend when there is no hazard map. Indeed, as shown in Section 5.4, the parameters for the hazard map dummies are estimated to be statistically significant[11] when the timing of the hazard map announcement is right.

The same analyses were performed for all other prefectures, showing similar trends. In Mie, only the 'Scientific research, professional and technical services' industry has a significance parameter (1.0% level). In Wakayama and Tokushima, only the 'compound services' industry has a significance parameter (10.0% level). In Kochi, the 'Mining and quarrying of stone' and 'Finance and insurance' industries have 10.0% significance parameters, the 'living-related and personal and amusement services' industry has a 5.0% significance parameter, and the 'Scientific research, professional and technical services' industry has a 1.0% level significance parameter. The above-denoted industries in the prefectures might not

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[10] It is difficult to collect the location data in grid squares before 1996, so we use only 1996 and 2001 data.

[11] Since the analysis of panel data usually has heteroscedasticity, we use robust t-values for checking the statistical significance of parameters in all estimations.

have parallel trends. But for other industries, we can assume that parallel trend assumptions hold.

Table 5 Placebo test (Shizuoka, Specification 2-A)

Industry category	Mining and quarrying of stone	Construction	Manufacturing	Electricity, gas, heat supply and water	Information and communications	Transport and postal services	Wholesale and retail trade	Finance and insurance	Real estate and goods rental and leasing	Scientific research, professional and technical services	Accommodations, eating and drinking services	Living-related and personal services and amusement services	Education, learning support	Medical, health care and welfare	Compound services	Services
Constant term	1.000	0.968	1.973	1.000	1.096	0.872	1.997	2.663	2.766	24.179	1.479	1.357	1.054	3.286	1.467	1.389
dummy variable for Inundation	-0.250	-0.554	-1.188	0.136	-0.187	0.127	-0.206	-0.816	0.000	-10.22**	-0.106	-0.057	-0.272	-0.429	-0.839	0.578
Fixed effect																
time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
each mesh	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
t value																
dummy variable for Inundation	-0.509	-0.347	-0.540	0.855	-1.265	0.671	-0.386	-0.554	0.002	-2.491	-0.381	-0.230	-0.334	-0.287	-0.509	1.115
R-squared	0.759	0.530	0.545	0.887	0.893	0.822	0.789	0.677	0.889	0.639	0.902	0.849	0.552	0.968	0.501	0.622
Number of Samples	18	4,676	4,594	54	2,042	288	380	1,492	2,288	4,974	628	2,162	660	16	220	28

Note: ***P<0.01, **P<0.05, *P<0.10

5.4 Estimation results

The parameter estimation results are all shown in the Appendix. There are many industries which have sufficient t-values of estimated parameters, although industries with small samples, e.g., mining and quarrying of stone, have statistically insufficient results. In particular, important parameters are ones for dummy variables for inundation on the two hazard maps. The signs of these parameters are supposed to be negative, which implies that the number of firms in the inundation area decreases compared to the other areas. As explained before, we estimate differentiated parameters for inundation areas on the second map with no-inundation on the first map and with inundation on the first map. Indeed, the two parameters are estimated to be different in most cases. We examine the detail of these parameters below.

In this section, based on the empirical results, we summarize the average change in the number of firms in response to the two hazard maps, using bar figures. To illustrate these figures, we only use the parameters for inundation dummies with more than 10% significance level in Specifications 2-A. As already denoted, the tendency of the results does not depend on the specifications.

Figures 2-6 show the average change in the number of firms per grid square by industry in each prefecture. The results differ among the prefectures, but as a whole, the number of firms has largely decreased inversely with the risk of inundation in ‘Construction’, ‘Manufacturing’, ‘Wholesale and retail trade’, and ‘Accommodation, eating and drinking services’. On the other hand, the number of firms has not responded to the inundation information in ‘Education, learning support’, and ‘Medical, health care and welfare’. ‘Scientific research, professional and technical services’ also has low effects from the inundation information, but this industry has no parallel trend, which is examined in Section 5.3. Considering these propensities from the views of their demand characteristics, this point can be summarized as follows.

Major observation 1 (industries). Awareness of a high inundation risk has a negative impact on the location of industries with demand in a wide range of areas, such as construction, manufacturing, wholesale and retail trade, and lodging, but no locational impact on industries with localized demand, such as education, and health care.

In other words, firms with demand in a wide range of areas are basically footloose. So, they need not locate in tsunami-risk areas. On the other hand, firms with localized demand continue locating around residents. So, if residents move out from the areas, they might move. To examine this, it is important to examine the effects of the hazard maps on residential locations next.

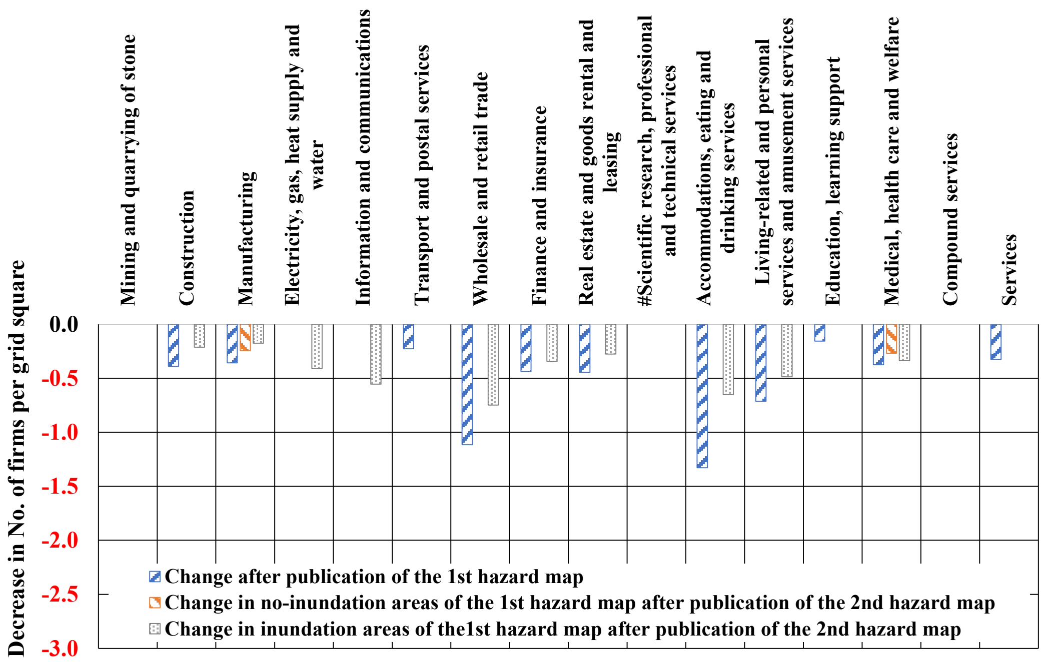
Next, we compare prefectures. Shizuoka, Wakayama, and Kochi have many industries which have been greatly affected by the inundation information. Mie and Tokushima have fewer industries affected by the inundation information than the other prefectures. But, even in Mie and Tokushima, seven industries are affected. The coast of Shizuoka, Wakayama, and Kochi faces the Pacific Ocean relatively directly compared to Mie and Tokushima. If a tsunami occurs, tsunami waves come into Shizuoka, Wakayama, and Kochi at an almost 90-degree angle with the coast, while they come into Mie and Tokushima parallel to the coast. We can summarize this in the following manner.

Major observation 2 (prefectures). Shizuoka, Wakayama, and Kochi have more industries which have been affected by the inundation information than Mie and Tokushima. Geographically, Shizuoka, Wakayama, and Kochi face the Pacific Ocean relatively directly compared to Mie and Tokushima.

Next, we focus on the difference between the first hazard map and the second hazard map. As a whole, if the effects of the first hazard map are observed, the effects of the second hazard map are lower than the effects of the first hazard map. These tendencies are observed in many industries in Shizuoka, and ‘Construction’ and ‘Manufacturing’ in Mie, ‘Manufacturing’ and ‘Wholesale and retail trade’, ‘Living-related and personal services and amusement services’ and ‘Education, learning support’ in Wakayama, in ‘Manufacturing’ in Tokushima, and in many industries in Kochi. In particular, we can clearly see this tendency in manufacturing, which has large samples. However, exceptional industries are observed, including ‘Wholesale and retail trade’ in Mie, and multiple industries in Tokushima. In particular, in Tokushima, the effects of the first hazard map are not significant in many industries. But the effects of the second hazard map are observed in the inundation areas announced by the first map. So, in Tokushima, the effect of the first map might have lagged. We can summarize this in the following manner.

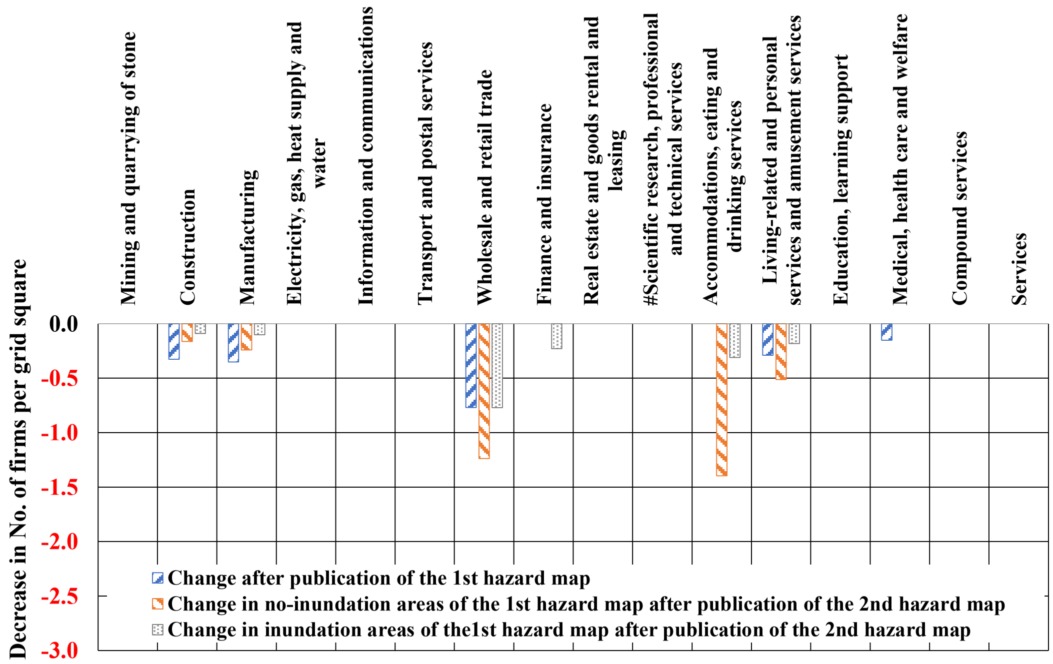
Major observation 3 (first hazard map vs. second hazard map). As a whole, if the effects of the first hazard map are observed, the effects of the second hazard map are lower. In particular, this tendency is clearly seen in manufacturing. But some industries do not have this tendency. In particular, in Tokushima, the appearance of the effects of the first hazard map might have lagged.

The first hazard map and the second map have different inundation depths and different occurrence probabilities. Probably, residents and workers recognize the highest devastation levels of an upcoming tsunami on the second map in addition to the information on the first hazard map. The time interval is around 8 years between the first and the second hazard maps. Nevertheless, many industries moved out of the inundation areas after the second hazard map. In several industries, the decrease in the number of firms after the second hazard map is even greater than the decrease after the first map. They are listed as 'Construction' in Wakayama and Tokushima; 'Wholesale and retail trade' in Mie and Tokushima; 'Real estate and goods rental and leasing' in Wakayama, 'Accommodations, eating and drinking services', and 'Living-related and personal services and amusement services' in Tokushima. This implies that hazard map information strongly affects industrial locations.



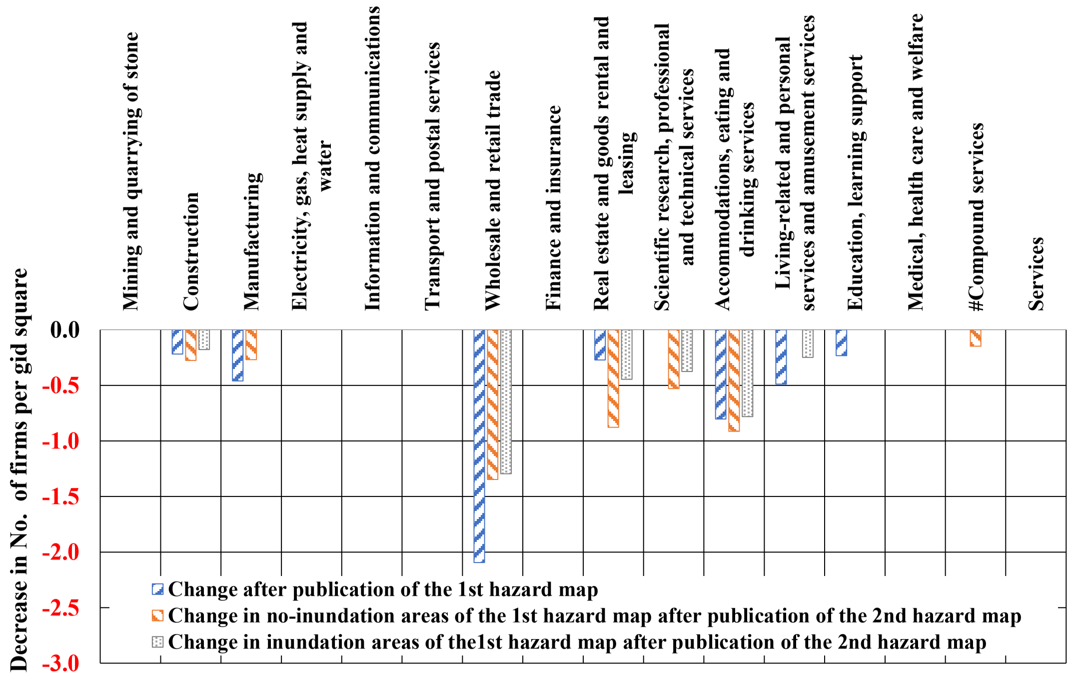
Note: '#' in front of the industry name indicates that this industry does not satisfy the parallel trend assumption (see Section 5.1).

Fig. 2 Change in the number of locations in the inundation area shown in each hazard map (Shizuoka, Specification 2 -A)



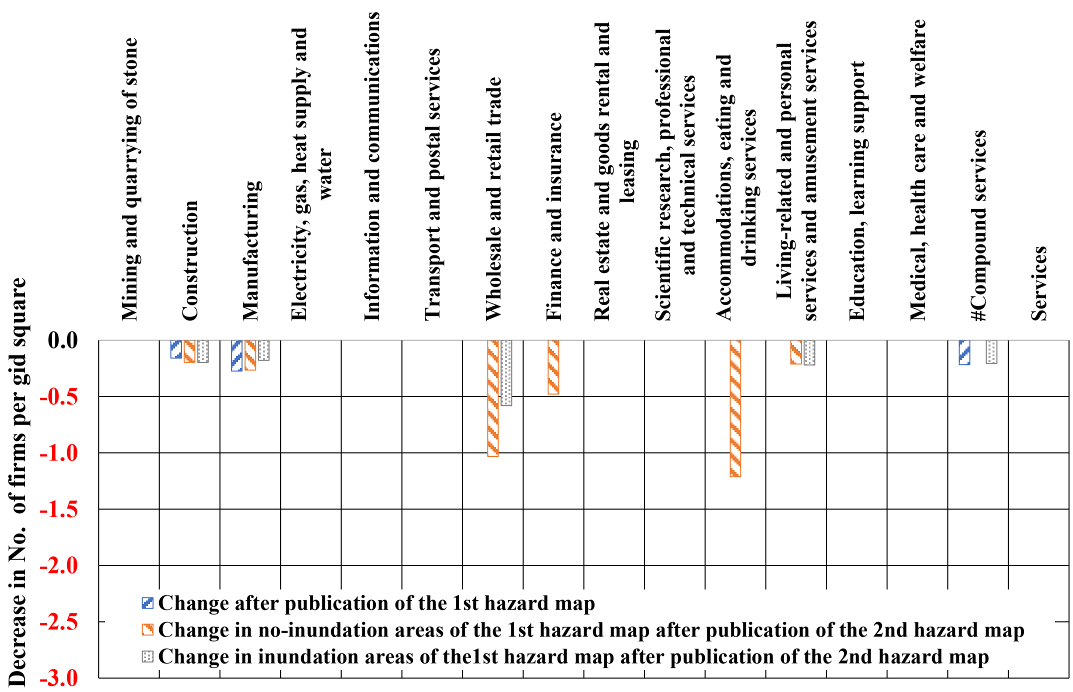
Note: '#' in front of the industry name indicates that this industry does not satisfy the parallel trend assumption (see section 5.1).

Fig. 3 Change in the number of locations in the inundation area shown in each hazard map (Mie, Specification 2-A)



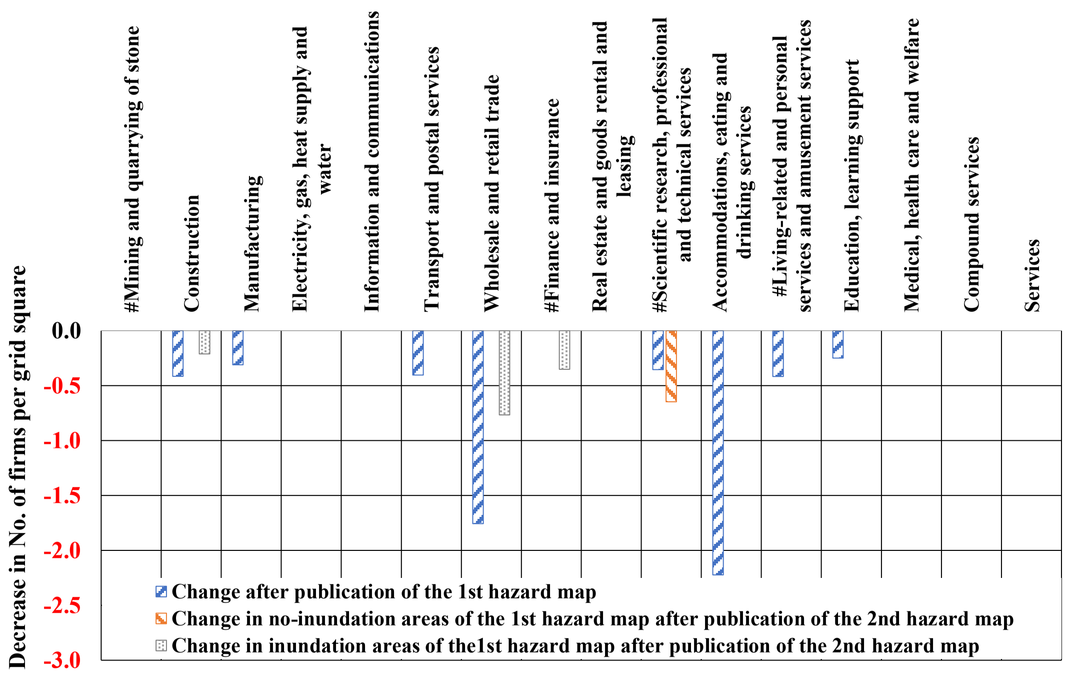
Note: '#' in front of the industry name indicates that this industry does not satisfy the parallel trend assumption (see section 5.1).

Fig. 4 Change in the number of locations in the inundation area shown in each hazard map (Wakayama, Specification 2 and A)



Note: '#' in front of the industry name indicates that this industry does not satisfy the parallel trend assumption (see section 5.1).

Fig. 5 Change in the number of locations in the inundation area shown in each hazard map (Tokushima, Specification 2 and A)



Note: '#' in front of the industry name indicates that this industry does not satisfy the parallel trend assumption (see section 5.1).

Fig. 6 Change in the number of locations in the inundation area shown in each hazard map (Kochi, Specification 2 and A)

6. Conclusion

In this study, in order to measure the influence of the inundation risk on the location, we constructed a location model based on expected profit, and derived an estimation formula to take a difference-in-differences approach. We find that we cannot ignore regional fixed effects unlike a situation of certainty. Finally, we quantitatively grasped changes in firms' locations by applying time series data to the estimation formula.

As a result of the analysis, the number of firms decreased significantly as a result of the publication of information regarding the risk of inundation in the construction, manufacture, wholesale and retail, accommodation, food and beverage, and life-related services industries other than in Kochi Prefecture, which has a large flood area. It is assumed that these industries with high sensitivity of the location change to these inundation risks have demand in a wide range of areas. On the other hand, education and learning, and medical welfare have almost no response to flood risk information. These low-sensitivity industries have localized demand.

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Appendix. Parameter estimation

Table A1(1) Estimation results (Shizuoka, Specification 1 and A)

Industry category	Mining and quarrying of stone	Construc-tion	Manufac-turing	Electric-ity, gas, heat supply and water	Informa-tion and communications	Transport and postal services	Wholesale and retail trade	Finance and insurance	Real estate and goods rental and leasing	Scientific research, professional and technical services	Accommoda-tion, eating and drinking services	Living-related and personal services and amusement services	Education, learning support	Medical, health care and welfare	Compound services	Services
Constant term	0.999	3.237	2.607	1.947	1.328	0.926	3.856	1.313	1.560	3.478	7.006	4.600	2.043	0.777	1.165	1.246
dummy variable for inundation on 1st map	-0.393	-0.216***	-0.020	-0.317**	-0.043	-0.134**	-0.152	-0.046	-0.308***	-0.051	-0.359***	-0.207***	-0.120	-0.167**	-0.072	-0.199***
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	0.025	0.004	-0.023	-0.123	-0.005	-0.002	0.010	-0.049	-0.093**	-0.039	-0.012	-0.006	-0.079**	0.026	-0.027
dummy variable for Inundation on 2nd map with inundation on 1st map	-0.008	-0.025**	-0.012	-0.065**	-0.074	-0.019	-0.070**	-0.056*	-0.056***	-0.025	-0.061***	-0.049***	-0.011	-0.062***	-0.004	-0.017
Fixed effect																
time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
each grid square	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
t-values																
dummy variable for inundation on 1st map	-0.488	-4.590	-0.326	-2.540	-0.122	-2.410	-1.029	-0.343	-3.178	-0.534	-2.650	-3.518	-1.596	-2.315	-1.518	-3.283
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	1.271	0.143	-0.533	-0.978	-0.193	-0.033	0.146	-1.485	-2.136	-0.730	-0.437	-0.222	-2.458	0.655	-1.059
dummy variable for inundation on 2nd map with inundation on 1st map	-0.095	-2.560	-0.918	-2.042	-1.329	-1.528	-2.388	-1.865	-2.937	-1.181	-2.586	-4.185	-0.838	-4.321	-0.488	-1.261
R-squared	0.412	0.911	0.934	0.593	0.944	0.856	0.962	0.954	0.957	0.945	0.975	0.964	0.891	0.918	0.596	0.936
Number of samples	95	24,505	23,500	265	1,325	6,360	23,875	4,125	10,570	8,360	16,465	16,240	9,235	11,825	3,200	15,065

Note: ***P<0.01, **P<0.05, *P<0.10

Table A1(2) Estimation results (Shizuoka, Specification 2 and A)

Industry category	Mining and quarrying of stone	Construc-tion	Manufac-turing	Electric-ity, gas, heat supply and water	Informa-tion and communications	Transport and postal services	Wholesale and retail trade	Finance and insurance	Real estate and goods rental and leasing	Scientific research, professional and technical services	Accommoda-tion, eating and drinking services	Living-related and personal services and amusement services	Education, learning support	Medical, health care and welfare	Compound services	Services
Constant term	—	3.479	2.865	1.944	1.226	0.913	4.327	1.287	1.266	3.346	7.890	5.067	2.139	0.950	1.189	1.216
dummy variable for inundation on 1st map	—	-0.390***	-0.359***	-0.189	-0.111	-0.229***	-1.115***	-0.438**	-0.446***	-0.163	-1.328***	-0.713***	-0.156*	-0.375***	-0.062	-0.324***
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	0.060	-0.244***	-0.087	-0.146	-0.036	-0.263	0.036	0.003	0.024	-0.049	-0.066	0.003	-0.268***	0.044	-0.081
dummy variable for Inundation on 2nd map with inundation on 1st map	—	-0.213***	-0.176**	-0.411*	-0.555*	-0.073	-0.749***	-0.345*	-0.277**	-0.100	-0.653***	-0.487***	-0.132	-0.338***	0.018	-0.126
Fixed effect																
time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
each grid square	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
t-values																
dummy variable for inundation on 1st map	—	-5.757	-4.089	-0.887	-0.360	-2.873	-4.912	-2.449	-3.754	-1.259	-6.007	-8.231	-1.693	-3.964	-0.909	-3.679
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	0.909	-2.843	-0.485	-0.448	-0.425	-1.102	0.212	0.023	0.220	-0.199	-0.728	0.027	-2.798	0.502	-0.890
dummy variable for inundation on 2nd map with inundation on 1st map	—	-3.105	-1.977	-1.916	-1.754	-0.900	-3.254	-1.909	-2.293	-0.762	-2.913	-5.549	-1.402	-3.498	0.260	-1.405
R-squared	—	0.911	0.934	0.578	0.944	0.856	0.962	0.954	0.957	0.945	0.975	0.964	0.892	0.918	0.596	0.936
Number of samples	95	24,505	23,500	265	1,325	6,360	23,875	4,125	10,570	8,360	16,465	16,240	9,235	11,825	3,200	15,065

Note: ***P<0.01, **P<0.05, *P<0.10

Table A2(1) Estimation results (Mie, Specification 1 and A)

Industry category	Mining and quarrying of stone	Construc-tion	Manufac-turing	Electric-ity, gas, heat supply and water	Informa-tion and communications	Transport and postal services	Wholesale and retail trade	Finance and insurance	Real estate and goods rental and leasing	Scientific research, professional and technical services	Accommoda-tion, eating and drinking services	Living-related and personal services and amusement services	Education, learning support	Medical, health care and welfare	Compound services	Services
Constant term	1.015	1.287	1.789	1.807	4.043	0.853	3.455	2.095	1.229	0.916	2.111	1.923	4.498	3.025	1.238	1.963
dummy variable for inundation on 1st map	0.019	-0.061***	-0.062***	0.047	-0.015	0.000	-0.116**	-0.010	-0.067	-0.034	0.060	-0.034*	-0.030	-0.056**	-0.032**	-0.016
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	-0.027	-0.076**	-0.166	0.046	0.067	-0.266***	0.077	-0.127*	0.003	-0.217**	-0.112***	0.014	0.082*	-0.091**	-0.003
dummy variable for Inundation on 2nd map with inundation on 1st map	-0.026*	-0.023***	-0.008	-0.036	-0.007	-0.004	-0.115***	-0.027	-0.013	0.000	-0.026	-0.033***	0.007	-0.040***	0.008	-0.009
Fixed effect																
time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
each grid square	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
t-values																
dummy variable for inundation on 1st map	0.734	-3.792	-3.396	0.766	-0.171	0.018	-2.546	-0.237	-1.569	-1.090	1.400	-1.843	-0.968	-2.353	-2.037	-1.059
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	-1.037	-2.032	-0.989	0.543	1.290	-3.128	1.001	-1.883	0.070	-2.262	-3.096	0.296	1.872	-1.995	-0.112
dummy variable for inundation on 2nd map with inundation on 1st map	-1.830	-2.824	-0.847	-1.091	-0.171	-0.321	-4.771	-1.285	-0.595	0.006	-1.083	-3.342	0.439	-3.331	0.904	-1.049
R-squared	0.543	0.867	0.899	0.611	0.917	0.824	0.945	0.954	0.934	0.951	0.973	0.946	0.881	0.910	0.612	0.941
Number of samples	75	14,225	12,165	145	535	2,895	15,130	1,970	4,075	3,790	8,360	9,700	4,410	6,370	2,255	10,375

Note: ***P<0.01, **P<0.05, *P<0.10

Table A2(2) Estimation results (Mie, Specification 2 and A)

Industry category	Mining and quarrying of stone	Construc-tion	Manufac-turing	Electric-ity, gas, heat supply and water	Informa-tion and communications	Transport and postal services	Wholesale and retail trade	Finance and insurance	Real estate and goods rental and leasing	Scientific research, professional and technical services	Accommoda-tion, eating and drinking services	Living-related and personal services and amusement services	Education, learning support	Medical, health care and welfare	Compound services	Services
Constant term	—	1.270	1.977	1.880	3.872	0.797	3.688	2.081	1.217	0.944	2.220	2.018	4.436	2.850	1.192	1.927
dummy variable for inundation on 1st map	—	-0.326***	-0.351***	0.149	0.328*	0.104	-0.770***	-0.026	-0.038	0.036	-0.120	-0.289***	-0.078	-0.150**	-0.099	0.010
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	-0.163**	-0.240***	-0.238	-0.110	0.262**	-1.238***	-0.121	-0.229	0.082	-1.397***	-0.513***	0.128	0.294***	-0.133	-0.063
dummy variable for Inundation on 2nd map with inundation on 1st map	—	-0.089*	-0.102*	-0.362	-0.193	0.012	-0.771***	-0.228*	-0.003	0.063	-0.309*	-0.182***	0.073	-0.071	0.028	-0.040
Fixed effect																
time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
each grid square	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
t-values																
dummy variable for inundation on 1st map	—	-6.801	-6.518	0.674	1.659	1.326	-5.038	-0.197	-0.329	0.477	-0.738	-4.531	-0.909	-2.068	-1.609	0.194
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	-2.284	-2.726	-0.770	-0.452	2.117	-5.110	-0.645	-1.393	0.778	-5.139	-5.194	1.112	2.849	-1.418	-0.853
dummy variable for inundation on 2nd map with inundation on 1st map	—	-1.828	-1.863	-1.571	-0.876	0.143	-4.953	-1.675	-0.021	0.804	-1.851	-2.799	0.833	-0.959	0.441	-0.800
R-squared	—	0.868	0.900	0.613	0.917	0.825	0.946	0.954	0.934	0.951	0.973	0.946	0.881	0.909	0.611	0.941
Number of samples	—	14,225	12,165	145	535	2,895	15,130	1,970	4,075	3,790	8,360	9,700	4,410	6,370	2,255	10,375

Note: ***P<0.01, **P<0.05, *P<0.10

Table A3(1) Estimation results (Wakayama, Specification 1 and A)

Industry category	Mining and quarrying of stone	Construc-tion	Manufac-turing	Electric-ity, gas, heat supply and water	Informa-tion and communications	Transport and postal services	Wholesale and retail trade	Finance and insurance	Real estate and goods rental and leasing	Scientific research, professional and technical services	Accommoda-tion, eating and drinking services	Living-related and personal services and amusement services	Education, learning support	Medical, health care and welfare	Compound services	Services
Constant term	—	2.217	1.642	1.372	3.373	1.324	16.187	2.115	1.323	1.099	2.433	4.143	1.278	0.770	1.174	1.263
dummy variable for inundation on 1st map	—	-0.046**	-0.049*	0.047	-0.067	-0.051*	-0.321***	-0.029	-0.024	0.007	-0.076	-0.080***	-0.047	-0.007	-0.008	-0.032
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	-0.080**	0.025	-0.051	-0.086	-0.066	-0.225**	-0.014	-0.227***	-0.131*	-0.065	-0.047	-0.023	-0.017	-0.047	-0.030
dummy variable for Inundation on 2nd map with inundation on 1st map	—	-0.016*	0.027*	-0.023	0.049	-0.006	-0.089***	-0.037	-0.034	-0.018	-0.037	-0.023*	-0.027*	-0.018	-0.002	-0.022*
Fixed effect																
time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
each grid square	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
t-values																
dummy variable for inundation on 1st map	—	-2.381	-1.757	0.771	-0.491	-1.916	-5.702	-0.453	-0.511	0.146	-1.279	-3.108	-1.474	-0.219	-0.541	-1.237
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	-2.307	0.468	-0.609	-0.460	-1.515	-2.122	-0.137	-2.982	-1.757	-0.533	-0.944	-0.458	-0.354	-1.434	-0.645
dummy variable for inundation on 2nd map with inundation on 1st map	—	-1.717	1.880	-0.726	0.671	-0.444	-3.221	-1.023	-1.427	-0.774	-1.183	-1.805	-1.668	-1.183	-0.248	-1.695
R-squared	—	0.882	0.896	0.599	0.828	0.849	0.966	0.953	0.928	0.961	0.958	0.948	0.863	0.935	0.610	0.913
Number of samples	—	7,195	5,595	100	275	1,705	8,215	1,005	2,860	1,845	4,765	5,060	2,615	3,855	1,520	5,555

Note: ***P<0.01, **P<0.05, *P<0.10

Table A3(2) Estimation results (Wakayama, Specification 2 and A)

Industry category	Mining and quarrying of stone	Construc-tion	Manufac-turing	Electric-ity, gas, heat supply and water	Informa-tion and communications	Transport and postal services	Wholesale and retail trade	Finance and insurance	Real estate and goods rental and leasing	Scientific research, professional and technical services	Accommoda-tion, eating and drinking services	Living-related and personal services and amusement services	Education, learning support	Medical, health care and welfare	Compound services	Services
Constant term	—	2.197	1.807	1.350	3.179	1.219	16.477	1.987	1.397	1.121	2.604	4.173	1.231	0.625	1.174	1.129
dummy variable for inundation on 1st map	—	-0.219***	-0.460***	0.125	0.084	-0.080	-2.094***	-0.009	-0.271*	-0.001	-0.802***	-0.489***	-0.233**	0.176*	-0.048	0.034
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	-0.276***	-0.269*	-0.286	0.113	-0.210	-1.346***	0.111	-0.877***	-0.530**	-0.913***	-0.141	-0.113	0.136	-0.148*	-0.035
dummy variable for Inundation on 2nd map with inundation on 1st map	—	-0.179**	-0.106	-0.036	0.452	-0.079	-1.296***	0.027	-0.446***	-0.376**	-0.782***	-0.248**	-0.149	0.054	-0.030	-0.048
Fixed effect																
time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
each grid square	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
t-values																
dummy variable for inundation on 1st map	—	-3.069	-4.637	0.630	0.204	-0.869	-10.026	-0.042	-1.726	-0.009	-3.394	-5.017	-2.060	1.695	-0.873	0.376
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	-2.855	-1.820	-1.159	0.197	-1.585	-4.459	0.373	-4.090	-2.432	-2.620	-1.011	-0.782	1.007	-1.703	-0.277
dummy variable for inundation on 2nd map with inundation on 1st map	—	-2.445	-1.046	-0.160	0.936	-0.813	-6.056	0.113	-2.632	-2.297	-3.159	-2.434	-1.259	0.501	-0.528	-0.508
R-squared	—	0.882	0.896	0.605	0.828	0.849	0.967	0.953	0.928	0.961	0.958	0.948	0.863	0.935	0.611	0.913
Number of samples	—	7,195	5,595	100	275	1,705	8,215	1,005	2,860	1,845	4,765	5,060	2,615	3,855	1,520	5,555

Note: ***P<0.01, **P<0.05, *P<0.10

Table A4(1) Estimation results (Tokushima, Specification 1 and A)

Industry category	Mining and quarrying of stone	Construc-tion	Manufac-turing	Electric-ity, gas, heat supply and water	Informa-tion and communications	Transport and postal services	Wholesale and retail trade	Finance and insurance	Real estate and goods rental and leasing	Scientific research, professional and technical services	Accommoda-tion, eating and drinking services	Living-related and personal services and amusement services	Education, learning support	Medical, health care and welfare	Compound services	Services
Constant term	—	1.919	1.544	1.160	1.474	1.639	2.452	1.307	1.079	2.432	1.712	1.222	1.119	2.369	1.348	0.856
dummy variable for inundation on 1st map	—	-0.041	-0.082***	-0.369*	-0.006	-0.008	0.049	0.065	0.064	0.121	0.067	0.035	-0.078	-0.005	-0.052**	0.042
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	-0.070***	-0.052*	0.066	0.073	0.023	-0.481***	-0.212***	0.064	-0.085	-0.358**	-0.084**	0.022	-0.009	-0.058*	-0.011
dummy variable for Inundation on 2nd map with inundation on 1st map	—	-0.040***	-0.008	-0.008	-0.019	0.001	-0.103***	-0.057	-0.016	-0.009	-0.042	-0.043***	0.008	-0.015	-0.017*	-0.002
Fixed effect																
time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
each grid square	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
t-values																
dummy variable for inundation on 1st map	—	-1.570	-2.765	-1.753	-0.034	-0.265	0.593	0.624	0.820	1.645	0.512	0.967	-1.234	-0.102	-1.965	1.123
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	-2.879	-1.755	0.657	0.803	0.687	-5.306	-3.064	0.910	-1.578	-2.293	-2.365	0.462	-0.253	-1.918	-0.326
dummy variable for inundation on 2nd map with inundation on 1st map	—	-3.244	-0.618	-0.105	-0.266	0.101	-2.648	-1.209	-0.365	-0.275	-0.673	-2.588	0.269	-0.721	-1.712	-0.123
R-squared	—	0.838	0.870	0.578	0.907	0.906	0.949	0.946	0.955	0.960	0.978	0.956	0.878	0.928	0.631	0.945
Number of samples	—	6,540	4,720	60	285	1,530	7,270	955	1,895	1,530	3,530	4,515	1,800	3,250	970	4,035

Note: ***P<0.01, **P<0.05, *P<0.10

Table A4(2) Estimation results (Tokushima, Specification 2 and A)

Industry category	Mining and quarrying of stone	Construc-tion	Manufac-turing	Electric-ity, gas, heat supply and water	Informa-tion and communications	Transport and postal services	Wholesale and retail trade	Finance and insurance	Real estate and goods rental and leasing	Scientific research, professional and technical services	Accommoda-tion, eating and drinking services	Living-related and personal services and amusement services	Education, learning support	Medical, health care and welfare	Compound services	Services
Constant term	—	1.906	1.511	1.067	1.470	1.631	2.359	1.334	1.033	2.374	1.610	1.204	1.109	2.400	1.326	0.854
dummy variable for inundation on 1st map	—	-0.160**	-0.273***	-0.444	-0.055	-0.029	-0.365	0.161	-0.014	-0.019	-0.104	-0.017	-0.184	0.096	-0.217**	0.085
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	-0.197***	-0.266***	0.250	0.117	0.016	-1.033***	-0.477**	0.104	-0.199	-1.212**	-0.211*	0.020	0.056	-0.168	-0.034
dummy variable for Inundation on 2nd map with inundation on 1st map	—	-0.197***	-0.178**	0.528	-0.176	-0.031	-0.580**	-0.188	-0.063	-0.027	-0.608	-0.220**	0.088	0.013	-0.205**	-0.059
Fixed effect																
time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
each grid square	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
t-values																
dummy variable for inundation on 1st map	—	-2.279	-3.357	-0.895	-0.183	-0.331	-1.520	0.726	-0.071	-0.126	-0.250	-0.178	-1.292	0.861	-2.529	0.869
dummy variable for inundation on 2nd map with no-inundation on 1st map	—	-2.659	-2.928	0.490	0.337	0.134	-3.725	-2.035	0.448	-1.156	-2.489	-1.943	0.130	0.472	-1.638	-0.341
dummy variable for inundation on 2nd map with inundation on 1st map	—	-2.693	-2.065	1.005	-0.503	-0.328	-2.312	-0.751	-0.278	-0.165	-1.366	-2.138	0.567	0.108	-2.300	-0.581
R-squared	—	0.838	0.871	0.553	0.907	0.906	0.949	0.945	0.955	0.960	0.978	0.955	0.878	0.928	0.634	0.945
Number of samples	—	6,540	4,720	60	285	1,530	7,270	955	1,895	1,530	3,530	4,515	1,800	3,250	970	4,035

Note: ***P<0.01, **P<0.05, *P<0.10

Table A5(1) Estimation results (Kochi, Specification 1 and A)

Industry category	Mining and quarrying of stone	Construc-tion	Manufac-turing	Electric-ity, gas, heat supply and water	Informa-tion and communications	Transport and postal services	Wholesale and retail trade	Finance and insurance	Real estate and goods rental and leasing	Scientific research, professional and technical services	Accommoda-tion, eating and drinking services	Living-related and personal services and amusement services	Education, learning support	Medical, health care and welfare	Compound services	Services
Constant term	0.983	1.169	3.460	1.219	2.907	1.037	4.639	2.184	3.082	4.085	2.397	2.773	3.089	0.441	2.025	1.178
dummy variable for inundation on 1st map	-0.068	-0.090***	-0.057**	-0.025	0.206**	-0.053*	-0.257***	0.013	0.064	0.035	-0.058	-0.054	-0.064*	-0.029	-0.009	-0.043*
dummy variable for inundation on 2nd map with no-inundation on 1st map	1.163	0.031	0.042*	0.021	0.795	0.076**	0.054	0.007	0.142*	-0.134*	0.034	-0.009	-0.030	-0.070	0.004	-0.002
dummy variable for Inundation on 2nd map with inundation on 1st map	0.023	-0.010*	0.016**	0.007	-0.026	-0.006	-0.014	0.009	-0.018	-0.003	0.029	0.006	-0.004	-0.012	0.003	-0.003
Fixed effect																
time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
each grid square	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
t-values																
dummy variable for inundation on 1st map	-0.964	-4.703	-2.388	-0.573	2.034	-1.816	-3.939	0.211	0.996	0.590	-0.358	-1.639	-1.751	-0.851	-0.708	-1.851
dummy variable for inundation on 2nd map with no-inundation on 1st map	0.616	1.563	1.838	0.496	1.626	1.967	0.808	0.098	1.713	-1.659	0.220	-0.262	-0.654	-1.559	0.364	-0.086
dummy variable for inundation on 2nd map with inundation on 1st map	1.063	-1.711	2.288	0.649	-0.670	-0.633	-0.744	0.413	-0.699	-0.123	0.629	0.661	-0.296	-1.123	0.806	-0.462
R-squared	0.405	0.904	0.878	0.815	0.897	0.820	0.960	0.962	0.943	0.964	0.938	0.965	0.897	0.945	0.701	0.964
Number of samples	65	5,515	3,600	105	295	1,445	6,845	810	1,465	1,170	3,805	3,670	1,575	2,655	1,505	3,215

Note: ***P<0.01, **P<0.05, *P<0.10

Table A5(2) Estimation results (Kochi, Specification 2 and A)

Industry category	Mining and quarrying of stone	Construc-tion	Manufac-turing	Electric-ity, gas, heat supply and water	Informa-tion and communications	Transport and postal services	Wholesale and retail trade	Finance and insurance	Real estate and goods rental and leasing	Scientific research, professional and technical services	Accommoda-tion, eating and drinking services	Living-related and personal services and amusement services	Education, learning support	Medical, health care and welfare	Compound services	Services
Constant term	1.000	1.143	3.777	1.240	3.084	0.967	4.862	2.442	3.378	4.319	3.431	2.828	2.961	0.491	2.033	1.105
dummy variable for inundation on 1st map	-0.250	-0.415***	-0.310***	-0.136	-0.574	-0.403***	-1.756***	-0.366	-0.331	-0.354*	-2.224***	-0.416***	-0.248*	-0.134	-0.041	-0.149
dummy variable for inundation on 2nd map with no-inundation on 1st map	0.167	0.127	0.121	0.150	1.567	0.287	0.036	-0.237	0.399	-0.648**	-0.110	-0.031	-0.144	-0.071	-0.023	0.040
dummy variable for Inundation on 2nd map with inundation on 1st map	0.000	-0.211***	0.083	0.095	0.110	0.054	-0.767***	-0.351*	-0.291	-0.057	-0.479	-0.010	0.108	0.249**	-0.033	0.011
Fixed effect																
time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
each grid square	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
t-values																
dummy variable for inundation on 1st map	-0.755	-5.707	-3.247	-0.831	-1.311	-3.491	-6.699	-1.499	-1.388	-1.675	-3.329	-3.138	-1.815	-1.017	-0.744	-1.640
dummy variable for inundation on 2nd map with no-inundation on 1st map	0.348	1.423	0.905	0.511	1.477	1.440	0.105	-0.604	1.200	-1.988	-0.113	-0.172	-0.786	-0.407	-0.295	0.334
dummy variable for inundation on 2nd map with inundation on 1st map	0.000	-3.448	1.030	0.699	0.309	0.556	-3.465	-1.701	-1.442	-0.322	-0.852	-0.093	0.928	2.229	-0.716	0.148
R-squared	0.394	0.905	0.878	0.816	0.896	0.821	0.960	0.962	0.943	0.964	0.938	0.965	0.897	0.945	0.701	0.964
Number of samples	65	5,515	3,600	105	295	1,445	6,845	810	1,465	1,170	3,805	3,670	1,575	2,655	1,505	3,215

Note: ***P<0.01, **P<0.05, *P<0.10