


# Locational choice and the provision of safety services: the case of mega-natural disasters

Shinobu Ito<sup>1</sup> 

Received: 25 November 2016 / Accepted: 28 March 2017 / Published online: 12 April 2017  
© The Author(s) 2017. This article is an open access publication

**Abstract** This research aims to explain the roles of public sectors to protect cities from disasters within the framework of location theory. The paper introduces a new term ‘attained safety,’ that is, safety as a result of government investment. The following three types of attained safety can be said to exist: (i) invariant within a city, (ii) mono-centered in a city, and (iii) scattered throughout a city. The benefits of (i) are constant throughout a city, while (ii) and (iii) increase as households live closer to the facilities. There are two research questions. The first is how attained safety can be introduced into the location theory of urban economics, and the second is whether the model with attained safety performs as well as the general land use model of urban economics. The land use model with attained safety presents equilibria with each type of safety, and also meets the Samuelson condition for a spatial case, the first and second theorems of welfare economics.

**Keywords** Land use · Local government · Disaster prevention policy · Local community · Public safety services

**JEL Classification** D69 · H40 · R14

---

An earlier version of the article was presented at the 53rd Annual Meeting of Japan Section of the RSAI in Niigata University in October 2016.

---

✉ Shinobu Ito  
itoshi@meijo-u.ac.jp

<sup>1</sup> Faculty of Economics, Meijo University, 1-501 Shiogamaguchi, Tempaku, Nagoya 468-8502, Japan

## 1 Introduction

Whose problem is safety? On the website of NCAC (National Consumer Affairs Center of Japan), we can find that the aim is to obtain consumer safety and advance the quality of life. The Center helps their clients to solve problems and avoid consumer disputes, and shows us how to live safely. If a person discovers a problem with purchased goods or services, and if there is something unfair or fraudulent about a product, it is possible to visit or call the center, which has branches in all areas of Japan. It is also possible to file a case, which the Center will release as a warning to consumers. If necessary, they will send information about goods or services to the government and suggest regulations. NCAC acts as an intermediary between consumers, producers, traders, and the government. An important point is that there are four kinds of agents associated with safety problems: (i) consumers, (ii) producers, (iii) governments, and (iv) intermediaries. (To simplify matter, we call makers or retailers ‘producers.’) Literally speaking, combinations of these four kinds of agents have ‘safety allocation’ or ‘safety trading’ problems.

In this paper, we analyze a case involving two kinds of agents. We assume a case of consumers<sup>1</sup> and a government. The market clearing condition should show that both sides optimize their utilities and profits.

This research aims to explain the role of the public sector to protect cities from disasters. To place safety within our model, we apply urban economic theory. There is a local government that supplies public services pertaining to safety. These are, e.g., preparations for disasters, some regulations for commodities or trades, and water control to counter droughts or floods.

Safety appears to be a concept converted from risk. Should the level of risk aversion and probability be assumed for households? Further, should a distribution of probability be assigned to natural climate changes or disasters? In reply to the first question, in this paper, we assume that each household examines realized safety (attained safety) to choose locations. There is no uncertainty in the realization of public services. The public sector provides safety services under the city budget constraint. There are economic models for public services, of which discussion introduces into the regional sciences (Sakashita (1967) and Flatters et al. (1974)). This part of the framework in this paper refers to Arnott (1979) and Fujita (1989, Chapter 5), and Polinsky and Rubinfeld (1978), and Helpman and Pines (1980) for local public goods.

Since climate conditions and natural disasters are local-dependent events, a distribution of probability of natural climate changes, and disasters may affect the decision-making of both households and governments. Regarding the second question, in this paper, we take account with a mega-natural disaster like the Great Eastern Japan Disaster in 2011 or the Hurricane Katrina. The probability of those natural disasters is different between events, but that of damages is the same all over the city. There is no need to assume different probability depending on locations.

In preceding researches, benefits of public services are realized mainly in the form of externalities. In this paper, safety as public services is categorized by its spatial characteristics. Three types of safety and whose benefits are (i) invariant

---

<sup>1</sup> We apply the term households instead of consumers for our models in the following sections.

within a city, (ii) mono-centered in a city, and (iii) scattered throughout a city. Under severe natural disasters, a community plays significant roles for households to survive. This study highlights the community forming process, in which third type is a core public service. The discussion is extended to welfare economics and an allocation problem.

The remainder of this paper is structured as follows. Section 2 reviews the features of safety and how they can be introduced into the economic framework. Section 3 shows models. For analyzing safety in the economic model, we introduce the notion that the market is not perfectly competitive, and discuss the optimal choice and its allocation. Section 4 comprises concluding remarks.

## 2 Reviews

The global frequency of natural disasters has spawned theoretical and empirical studies in the field of regional science. These are studies on impacts of disasters, designs of resilient urban areas and safety policies preventing and avoiding risks of damage from disasters, and so on. Cavallo and Noy (2010) is a guidepost survey in this field. Hallegatte and Ghil (2008) and Hochrainer (2009) evaluate the macroeconomic impacts of natural disasters. Schnell and Weinstein (2012) analyzes especially the impacts of Japan's Earthquake of 2011. Kunreuther and Michel-Kerjan (2014) shows how to deal with catastrophes via insurance theory.

The method for estimating the resilience of communities (Cimellaro et al. 2010) and the impact of disasters on industries and lifelines (Martinellia et al. 2014) are researched from the viewpoint of the protection of residents' life and property from disasters and building resilient communities. The case in which residents who suffer high migration costs are unable to leave an at-risk city, or will lose property, is analyzed in Buntan and Kahn (2014). Local governments have policies to rebuild safer cities after disasters. Kates et al. (2006) interprets the reconstruction of New Orleans, its enormous losses and investments after Hurricane Katrina.

There are also preceding studies on location choice under uncertainty. These uncertainties are about transportation cost, market price, demand, and so on. In land use theory, both producers' and consumers' decision-making problems under uncertainty are analyzed in Mai (1981), Alperovich and Katz (1983), and Mathur (1983), in which the state preference approaches show the process by which an equilibrium is reached. As already mentioned, uncertainty assumption is not introduced into our model.

The pioneering researches of amenity and public services are based on the concept of external economics (Chipman (1970) and Kanemoto (1980)). It seems that both amenities and safety are by-products of main economic activities. Amenity is 'ex post facto,' and safety is an objective in itself. Safety is also a location-dependent quality of the environment. Environment economics and urban economics analyze amenity as a kind of local public good. The neoclassical economic model for public goods with environmental resources, called urban open spaces, presents optimal conditions for land use in Yang and Fujita (1983). Natural endowments and amenities exist as location-specific characteristics, though it is

difficult to evaluate them. The hedonic method is applied in Cheshire and Sheppard (1995), treating amenities as location-specific characteristics and estimating the aggregate marginal value of amenities. Blomquist and Worley (1981) and Bartik (1988) analyze implicit prices of amenities in hedonic price models. Gyourko et al. (1999) shows the estimation method for implicit prices of environmental attributes. Kahn (2004) presents an improvement of the Hedonic method for various environments as local public goods. Hidano (2002) compiles studies of the environment and public policy, and shows various cases concerning Japan.

An amenity-embedded model of residential choice is established by Cho (2001), in which an ‘amenity charge’,  $G(r)$  is introduced, and equilibrium land use is examined in two cases: In one case, the level of amenities is assumed to increase toward the urban fringe. In the other case, the level of amenities decreases toward the urban fringe. Cho (2001) contributes by indicating equilibrium conditions, but fails to discuss cases in which amenities are centralized, invariant, and scattered, as in this paper.

What does the word safety cover? We prepare for disaster to maintain the stability of our lives in the face of various risks. We try: (i) to avoid risk, or (ii) to prevent it (to protect ourselves from it), or (iii) to adjust to it. Treating risks in these ways, we try to reduce the probability of damage caused by disasters. We call this gap of probability between the situation in which we have prepared for risks and that in which we have done nothing, *attained safety*. To accumulate attained safety, we incur costs. We assume this attained safety accumulates just like health does in field of health economics.

- (i) As an example for avoiding risks, we can cite the regulation of the purchase and use of guns in Japan. No one can keep a gun without permission that is strictly evaluated by a government agency. If you have a permit, your name is listed and monitored. Eliminating guns from homes helps us to feel safe from gun crimes. In the same way, to prohibit the use of some chemicals from food for preservatives or coloring purposes, and to stop the sale of no-brake (fixed-gear) bicycles also falls into this category.
- (ii) We cannot give up automobiles, even if we are afraid of car accidents. There are traffic rules and regulations for producing cars. These regulations lower the probability of accidents. To prevent accidents (and protect people), governments sometimes become paternalistic. Producer liability laws, age regulations for alcohol and smoking, vaccinations, and so on, all fall into this category.
- (iii) To adjust to risk may sound strange. We take precautions against earthquakes, but we can do nothing to stop natural disasters. We try to minimize damage and loss. We would also like to resume normal life as soon as possible in the aftermath of disasters. This process and treatment fall into the last category. Even under severe conditions, at the very least we have to pay attention to human security. This idea also belongs to the third category. Lindell and Perry (2000) and Torstar and Lindell (2012) use the term ‘adjustment’ to signify the response of households or society to earthquakes and floods.

The first two types of risks and policies may be applied to a whole country or city. The third one may vary over different areas. Imagine there is a city in which the local government issues a hazard map and supports people in making preparations for disasters. This kind of support system depends on areas and local governments. Your preparation may also be different from other citizens. For example, whether you have an evacuation route to a shelter, or how far the hilltop is from the floods, depend on the location where you live. Further, district communities' abilities and budget determine the availability of preparations for disasters. We assume that households' preferences are a projection of these attributes. There are alternatives for people to choose where to live and for local governments to choose the size of cities and public services.

This paper mainly focuses on the third type of risk and considers safety policies by a local government. We suspend the congestion problem and treat safety policies as pure public goods, though there is a capacity limit for shelters, e.g., sorting public goods out by juridical agency, there are national goods, city goods, and neighborhood goods.<sup>2</sup> It often happens that the benefits of local public goods vary over spaces. We call these kinds of public goods 'neighborhood services.' Underground reservoirs for controlling drains, as have been introduced in the case of Nagoya City<sup>3</sup> is an example of neighborhood goods. We discuss city goods and neighborhood goods in our research. To do so, we apply the urban economic land use theory. There is no uncertainty in the realization of public services. We do not assume uncertainty for the decision-making of households and local governments. Local governments and households have knowledge about past natural disasters at each location. Instead of uncertainty, we assume there is a given city safety plan, so that neither governments nor households need to be concerned about the probability of natural disasters.

### 3 Models

In this section, we attempt to apply the urban economic frameworks to the safety problem. We take the case of some familiar disaster-preparation policy by a local government. This has an effect on citizens' accommodation environment. When households move to a location to live, they maximize their utility function with respect to a composite good  $z$  and the size of accommodation (land)  $s$ . Firstly, we establish the household utility maximization problem and present the basic model that includes safety. Secondly, we examine a local government's profit maximizing model and choice of its city size, the population  $N$ , and the optimal safeguard policy  $K$ . Thirdly, we present communities' utility maximizing problem. We assume a certain number of people form a community and its safety services, e.g., evacuation networks or a manual for restarting daily life in the aftermath of a natural disaster. We find that the first and second theorems of welfare economics are applied in the community case.

---

<sup>2</sup> Fujita (1989).

<sup>3</sup> Nagoya City, the capital of Aichi Prefecture in Japan, has a population 2.3 million people. Drain control ponds and reservoirs can save 6,523,000 m<sup>3</sup> of water during 60 ml/h of rain.

For the purpose of constructing models, we sort safety policies into three types: public services (i) invariant within a city, (ii) mono-centered in a city, and (iii) scattered throughout a city.

Benefits from a policy of type (i) are constant within a city. For example, the city government uploads hazard maps, and maps of shelters and evacuation areas to its website. Anybody can access these by use of the Internet. This kind of information is the invariant type. We can evaluate the services by government expenditures by assuming that the cost of a public service represents the level of the service. We apply this type of public policy in Sect. 3.2.

If the local government erects a central evacuation tower for tsunami, or a central hospital with a power generation facility in the middle of city, these are categorized as a monocentral type. A case in which only one big base supplies emergency provisions, we also call a monocentral type. We establish the model for this type and assume households consider safety environments in which to settle in Sect. 3.1. Turning to the scattered type, first-aid stations and flood drain reservoirs are allocated throughout the city. The 207 temporary water supply facilities and 44 drain control reservoirs in Nagoya, constructed according to drainage basins, are the scattered type. We assume that households consider safety environment when forming a community in Sect. 3.3. We regard public services as the core for a community, and assume housing location  $r$  is the distance from the service base (evacuation area or flood control reservoir, etc.).

The benefits of (i) are constant throughout a city, but (ii) and (iii) increase as households live closer. The monocentral type is analyzed in the households' utility maximizing model in Sect. 3.1. The invariant type fits into a local government profit maximizing model in Sect. 3.2, and the scattered type formation of a community is covered by a community utility maximizing model in Sect. 3.3. The discussion in this section relies on Fujita (1989, Chapters 5 and 6) and Duranton and Puga (2015).

### 3.1 Local public goods and households' optimal problem: mono-centered type

We need to distinguish a technical term, safety, from ordinary use. People see public policies for preventing disaster, and understand safe environments that are produced by governments. This safe environment is attained safety.

**Definition 1** (*attained safety*) If a government invests in a safeguard policy, we call this expenditure on reducing risks from the initial state, *attained safety*. Literally, we call an environmental gap between an initial state and invested state, *attained safety*.

Assume there is a local (city) government, and a number of households,  $N$ . The headquarters of the safety policy (the city government) is at the center of the city,  $O$ . The government and households rent land and pay rent  $R(r)$ , where  $r$  denotes a distance from the center  $O$  to their houses. Households can choose where to live, the location,  $r$ , and size of accommodation (land),  $s$  at  $r$ , and composite commodity

goods,  $z$ . Let us assume a safe environment at  $r$ ,  $E(r)$ , which presents a quantity level of safety at location  $r$ .  $E(r)$  may perform in alternative ways depending on various factors. Because of a trade-off between transport cost and accommodation size, generally, if net income rises, households will move farther from the center of a city,  $\partial E/\partial r > 0$ , where  $E(r)$  is the general environment. Affluent households enjoy the life of the suburbs.<sup>4</sup> Unlike these preceding studies, we assume  $\partial E/\partial r < 0$  and  $\partial^2 E/\partial r^2 < 0$ , where if  $r \rightarrow 0$ , then  $E \rightarrow \infty$ . For example, if there is only one large shelter in the inner city, and  $r$  represents the distance from it, then it is natural to set  $\partial E/\partial r < 0$ . This means the safety environment declines as the distance from the center increases.

Households have utility maximizing problems when choosing composite goods  $z$ , lot size of land at  $r$ ,  $s$ , and environment at  $r$ ,  $E(r)$ .

$$\begin{aligned} \max_{r,z,s} u &= U(z, s, E(r)) \\ \text{subject to } z + R(r)s &= Y^0 - G - T(r) \end{aligned} \quad (1)$$

where  $Y^0$  is pre-taxed income,  $G$  is an income tax for households assumed to be in the form of a lump sum tax, and  $T(r)$  is the transport cost at  $r$ . To have a well-behaved utility function, we assume the following conditions:

#### Assumption 1

$$\partial U(z, s, E(r))/\partial E(r) > 0. \quad (2)$$

**Assumption 2** (*well-behaved utility function*) This utility function is continuous and increasing at all  $z > 0$ ,  $s > 0$ ,  $E > 0$ , and satisfies the following conditions:

- (i) Under each fixed value of  $E > 0$ , all indifference curves in the  $s - z$  space are strictly convex and smooth, and they do not intersect axes.
- (ii) Given any  $z > 0$ ,  $s > 0$ ,

$$\lim_{E \rightarrow 0} U(z, s, E) = -\infty, \quad (3)$$

$$\lim_{E \rightarrow \infty} \partial Z(s, u, E)/\partial E = 0, \quad (4)$$

where  $Z(s, u, E)$  is the solution to  $u = U(z, s, E)$  for  $z$ , generally called the indirect utility function.

- (iii) This utility function is continuously differentiable in each variable as many times as desired.

Therefore, the marginal utility of each variable is positive,

$$\partial U(z, s, E)/\partial z > 0, \quad \partial U(z, s, E)/\partial s > 0, \quad \partial U(z, s, E)/\partial E > 0. \quad (5)$$

We also have the marginal substitution between each good.

<sup>4</sup> Cho (2001) gives different assumptions on amenity environments with distance from the center.

$$\partial Z(s, u, E)/\partial u > 0, \quad \partial Z(s, u, E)/\partial s < 0, \quad \partial Z(s, u, E)/\partial E < 0, \tag{6}$$

which indicates,

$$-\partial^2 Z(s, u, E)/\partial s^2 < 0, \quad -\partial^2 Z(s, u, E)/\partial E^2 < 0. \tag{7}$$

Note that the marginal utility of  $z$  and  $E$  is positive. The following condition holds.

$$\partial z(s, u, E)/\partial E < 0, \tag{8}$$

which means the better the safety environment, the smaller the amount of composite goods needed to achieve the same utility level.

**Assumption 3** (*increasing transport cost*)

$$T(r) = T(|r|). \tag{9}$$

$T(|r|)$  is increasing with  $|r|$ , where  $|r|$  represents the distance between  $O$  (the headquarters of the city government) and each location  $r$ .<sup>5</sup>

In addition,

$$0 \leq T(r) < Y^0, \tag{10}$$

where  $Y^0$  is pretax income. And  $T(\infty) = \infty$ .

To simplify the model, we assume the rent and transport functions.

$$R(r) = \gamma r, \quad \gamma < 0, \tag{11}$$

$$T(r) = \tau r, \quad 0 < \tau < 1. \tag{12}$$

We define the Lagrangean function of the problem (1):

$$L(z, s, E(r)) = U(z, s, E(r)) - \lambda(z + R(r)s - Y^0 + G + T(r)), \tag{13}$$

where  $\lambda$  is the Lagrangean coefficient.

The first-order conditions become:

$$\partial L(z, s, E(r))/\partial z = \partial U(z, s, E(r))/\partial z - \lambda = 0, \tag{14}$$

$$\partial L(z, s, E(r))/\partial s = \partial U(z, s, E(r))/\partial s - \lambda R(r) = 0, \tag{15}$$

$$\partial L(z, s, E(r))/\partial r = [\partial U(z, s, E(r))/\partial E](dE/dr) - \lambda(R(r)/\partial r + T(r)/\partial r) = 0, \tag{16}$$

$$\partial L(z, s, E(r))/\partial \lambda = z + R(r)s - Y^0 + G + T(r) = 0. \tag{17}$$

We have equations as follows:

$$[\partial U(z, s, E(r))/\partial z]/[\partial U(z, s, E(r))/\partial s] = 1/R(r) = (\gamma r)^{-1}, \tag{18}$$

<sup>5</sup>  $O$  can be any place, though it is usually assumed to be the center of the business area.



$$[\partial U(z, s, E(r))/\partial E](dE/dr) = \lambda(\gamma + \tau). \quad (19)$$

**Assumption 4** (*normality of land*) Under each fixed value of  $E > 0$ , the income effect on the Marshallian demand for land is positive.

Let  $I = Y^0 - G - T(r)$  be net income, which gives,

$$\begin{aligned} \max_{z,s} u &= U(z, s, E), \\ \text{subject to } z + Rs &= I. \end{aligned} \quad (20)$$

Here, we employ a definition for bid rent and optimal lot size.

**Definition 2** (*bid rent and bid-max lot size*) The bid rent  $P(I, u, E)$  is the maximum rent per unit of land that the household can pay for renting at the distance  $r$  while enjoying a fixed utility level  $u$ . The bid-max lot size  $S(I, u, E)$  is the optimal lot size of land that we obtain when households maximize the problem (1).

The following equations are obtained by the definitions.

$$P(I, u, E) = P(Y^0 - G - T(r), u, E(r)) \quad (21)$$

$$S(I, u, E) = S(Y^0 - G - T(r), u, E(r)). \quad (22)$$

As net income changes, optimal lot size for the utility maximizing problem of (20) changes, and we obtain the bid-max lot size function, which presents lot sizes that households choose under a given utility level  $u$ . These are kinds of expenditure and demand functions.

$$P(I, u, E) = \max\{I - Z(s, u, E)\}/s \quad (23)$$

is the maximum rent (per unit of land) that households can pay under the constant level  $E$ , while they enjoy a given utility level  $u$ . In other words, we can call  $P$  the reservation price of land, up to which households can pay.

The optimal land size  $s = S(I, u, E)$ , obtained from the solution, is known as the bid-max lot size function. It is easy to understand that the bid rent is the slope of the budget line that is tangent to the indifference curve  $u = U(z, s, E)$  between  $z$  and  $s$  at the maximum point. The tangency point on the  $s$ -axis is the bid-max lot size,  $s = S(I, u, E)$ . These definitions will be useful when we discuss the local government's maximizing problem in the following section.

For the following discussion, another assumption is required, as follows,

**Assumption 5** (*substitutability between land and environment*) The bid-max lot size  $S(I, u, E)$  decreases with  $E$ :

$$\partial S(I, u, E)/\partial E < 0.$$

Under the same utility level, if a safe environment is better, then households choose lower composite goods  $z$  and lot size  $s$ .

$R(r)$  is assumed to be convex downward. We then have a proposition as follows:

**Proposition 1** (household equilibrium) *Given the market rent  $R(r)$ ,  $u^*$  is the equilibrium utility of the household and  $r^*$  is the optimal location to live, if, and only if;*

$$R(r) = P(I, u, E), \text{ and} \\ R(r) > P(I, u, E).$$

We have learned that transport cost and the rent affect households' choices through net income changes. If commuting cost rises, then normally households will try to maintain their net income level and their living standard. Following this path, they may decide to move inward. Since  $\partial E/\partial r < 0$ ,  $\partial U(z, s, E)/\partial E > 0$ , and marginal substitutions, households' new decisions for accommodation contracts utility levels through safety environments. Our model shows a path whereby safe environments affect the size of a city through households' decisions. This gives us a new point of view for discussing a compact city hypothesis.

To conclude this section, let us refer to the case of the 10-m-high tsunami barrier in Tarou Town in Iwate Prefecture, Japan. This town was famous for its especially large-scale tsunami barrier,<sup>6</sup> and people used to live close to the barrier to seek safety. This behavior showed that households deliberately choose environments they believe are safe. The approach above is well known as a land use problem where accessibility is the key concept. We applied this to the optimal choice of safety policy.

### 3.2 A local government optimal problem: invariant type

If we assume that  $K$  represents a cost (i.e., the quantity) of public goods, and if there is no congestion, then for any  $K$ ,  $E(K)$  becomes constant and equal throughout a city. A local government budget for the preparation policy, free information about preparation against disasters, and construction of earthquake-resistant type water facilities are examples of this type. In this case, the public services are constant regardless of location.

Let  $K$  be the fixed cost of a public services or facilities. For example,  $K$  presents the cost of preparation for disaster or shelter systems. We replace the location index  $r$  by  $K$  for safety environment,  $E(K)$ , and assume that

$$dE(K)/dK > 0.$$

This means when a new public facility is supplied, the safety environment for household life improves. If a local government replaced its water pipes with earthquake-resistant type pipes, then the environment would be safer throughout the whole city. There is no congestion and  $E(K)$  does not depend on location.  $K$  is assumed to be indispensable.

<sup>6</sup> The barrier was 2600 m long and 10 m high.

Households commute to the business center, where commodity goods are produced, and earn the income  $\delta$ , the marginal production of labor. A transportation cost,  $T(r)$ , is incurred. We assume households live in the suburbs of the city, denoted  $r^f$ , the distance to the fringe from the center,  $r \leq r^f$ . Newcomers from outside the city note the public policies and freely make the decision to settle in the city. We call this a case of free migration to an open-city case. Thus, households maximize the utility function with respect to  $r$ ,  $z$ , and  $s$ , locations, composite goods, and accommodation size (lot size), respectively. Given this household utility,  $u^*$ , the local government maximizes its surplus from the city. The local government rents land and pays a market rent. Land is developed and subleased to the households.

Here, we assume a fixed cost production function.  $f(N)$  is defined as a production function which increases with  $N$ . We assume it is possible to aggregate  $f(N)$  and obtain a city production function,  $F(N)$ .

$$F(N) = f(N)N = \delta N, \quad (24)$$

where  $\delta$  is the marginal product of labor.

Rewriting the maximizing problem (1) gives the following:

$$\begin{aligned} \max_{r, z, s} u &= U(z, s, E(K)), \\ \text{subject to } z + R(r)s &= Y^0 - G - T(r) \end{aligned} \quad (25)$$

To balance the city account, we multiply individual budget constraints by the population:

$$\begin{aligned} Y^0 &= Z(s(r), u, E(K)) + T(r) + R(r)s + G \quad \text{for any } r \leq r^f \\ Y^0 n(r) &= [Z(s(r), u, E(K)) + T(r) + R(r)s + G]n(r) \\ &= \frac{[Z(s(r), u, E(K)) + T(r)]n(r)}{\text{Total residential cost}} + \frac{R(r)sn(r)}{\text{Total rent}} + \frac{Gn(r)}{\text{Total income tax}} \end{aligned} \quad (26)$$

where  $R(r)$  is rent for land of lot size  $s$  at  $r$ , and  $n(r)$  is the number of households living at  $r$ . Gross income  $Y^0 n(r)$  is divided into three expenditures, the total residential cost, the total rent, and the total income tax. Let us define the population cost function  $C(u, N, K)$  with fixed cost  $K$ .

**Definition 3** (the population cost function)

$$\begin{aligned} C(u, N, K) &= \min_{r, z, s} \int_0^{r^f} [T(r) + Z(s(r), u, E(K)) + R(r)s(r)]n(r)dr, \\ &\text{subject to } s(r)n(r) \leq L(r) \quad \text{for any } r \leq r^f, \\ &\int_0^{r^f} n(r)dr = N, \end{aligned}$$

where  $L(r)$  is the land available. Under a given  $K$ , the population cost represents the minimum residential cost for achieving the common utility level  $u^*$  for all  $N$  households. The maximum surplus from the city is then,

**Definition 4** (surplus from city)

$$S(\delta, u, N, K) = \delta N - C(u, N, K).$$

We have a city government profit maximizing problem. The local government chooses its cost of public services, i.e., a safeguard policy and size of the city.

$$\max_{N \geq 0, K \geq 0} \Pi = \mathcal{S}(\delta, u, N, K) - K. \tag{27}$$

Let us solve this problem in two steps. First, the problem is solved under  $K = K^*$ , a fixed value  $K$ . Once the local government chooses the size of city,  $N$ , we can then move to a choice for  $K$ .

$$\max_{N \geq 0} \mathcal{S}(\delta, u, N, K^*) = \delta N - C(u, N, K^*). \tag{28}$$

The first-order conditions of (28) are:

$$\partial \mathcal{S}(\delta, u, N, K^*) / \partial N = 0 = \delta - \partial C(u, N, K^*) / \partial N, \delta = \partial C(u, N, K^*) / \partial N. \tag{29}$$

This means that the surplus from the city is maximized when the marginal product of labor equals the marginal population cost for the city. We call  $N^*$  the equilibrium population when (29) is satisfied.

**Proposition 2** *Given any  $(\delta, u)$ , such that  $\delta > 0$ , surplus from a city is maximized when  $N$  is equal to the equilibrium population  $N^*$ .*

**Proposition 3** *When the land market is in equilibrium, the gross surplus equals the total rent.*

$$\mathcal{S}(\delta, u, N, K) = \int_0^{r^f} (R(r)L(r)n(r)dr.$$

We have an optimal surplus of the city government and the equilibrium population  $N$  above. As a second step, we need to attain the optimal level of public service  $K$ . Substituting population function  $N(\delta, u, N, K)$  into the surplus, we have,

$$\max_{K \geq 0} P = \mathcal{S}(\delta, u, N(\delta, u, K), K) - K. \tag{30}$$

Differentiating with respect to  $K$ , we obtain the first-order condition:

$$d\mathcal{S}(\delta, u, N(\delta, u, K), K) / dK - 1 = 0 \text{ at } K = K(u^*). \tag{31}$$

Equation (31) shows that the marginal cost of public goods (= 1) equals the marginal surplus of public goods. This is the Samuelson condition for a local government and open-city case. We can rewrite (31) as Proposition 4.

**Proposition 4** (the Samuelson condition for a local government and an open-city)

$$\int_0^{r^f} -\{\partial Z(s(r), u, E(K)) / \partial K\} n(r) dr = 1.$$

*The sum of the marginal benefits (measured by the rate of substitution)  $-\partial Z(s(r), u, E(K)) / \partial K$  must equal the marginal cost of the public good.*

Note that in this model, people are free to choose the locations they wish to live in, and rents are competitively determined in the market.

### 3.3 The community's optimal problem: scattered type

In the aftermath of a disaster, your community may play a critical role in your survival. In the Great Kobe Earthquake of 1995, the author's grandmother was trapped in a room and was helped by the owner of a grocery store she used to go to for years. Her neighbor carried a heavy water tank to supply her with water every day until the utilities restarted. Communities are a very important factor for surviving disasters. There used to be good communities in Japan that had regional festivals at harvest times. Shrines or other religious sites were centers of communities. However, things have changed.

On postdisaster difficulties, Sheller (2016) discusses disaster logistics and human mobilizations. This article focuses on disaster prevention public goods and communities. What, then, is the role public safety policy can play to form communities in preparation for disasters?

Natural disaster prevention and reduction is a main concern of modern Japanese society. Since the Great Eastern Japan Disaster of 2011, the Japanese government has encouraged local governments to formulate policies for citizens to take care of themselves and each other. This is because public services were not able to cover and help everyone in their jurisdictions who were facing severe problems. People have to help each other and prepare for disaster beforehand.

The community you live in is crucial to your survival at the time of a crisis. In the aftermath of natural disasters, quick and appropriate support depends on the community you belong to. In Nagoya, emergency water supply systems and temporary facilities are allocated to each elementary school. Under an evacuation order, households are obliged to move to public schools or community centers as shelters. Emergency provisions are always maintained in reserve in these locations. Thus, school districts play important roles in preparing policy for disasters. This is the best example of the kind of community that is discussed here. We consider that underground reservoirs are also a good example of a core facility of a community. Unlike school districts, underground reservoirs are neighborhood goods and have an effect on other communities. For simplicity, we assume all these core public services are limited to the community.

A community is identified by its public services,  $K_j$ ,  $j = 1, 2, 3, \dots, m$ . There are  $m$  number of communities in the city. The population of the whole city,  $N$ , is fixed, where  $\sum_{j=1}^m N_j = N$ . Households consider safety environments and move to form communities inside the city. Households choose the location in which to live. Once they form the community, the community itself maximizes the common highest utility. Other assumptions are as above.

As discussed in the previous section, households also look at the whole city to judge the quality of the safety environment and maximize their common utility. To do so, let us assume that a certain number of households forms a community that rents land to pay  $R_j(r)$  the developers (some households) to develop a region in a city. Households enjoy the common highest level of utility; we can rewrite the maximizing problem (25) as:

$$\begin{aligned} \max_{r,z,s} u &= U(z, s, E(K_j)), \\ \text{subject to } z + R_j(r)s &= (1 - g_j)Y^0, \end{aligned} \tag{32}$$

where the community number  $j = 1, 2, 3, \dots, m$ ,  $g_j Y^0$  represents tax.

We assume  $K_j$  is invariant within a community and different from other communities. The location  $r$  is the distance between accommodations and the closest safeguard policy base, e.g., evacuation areas. Intuitively,  $R_j(r)$  then implies the price of real estate in the area. We assume  $N_j > 0$ , for all  $j = 1, 2, 3, \dots, m$ . As the community account, we have:

$$\begin{aligned} Y^0 n(r) &= [Z(s(r), u, E(K_j)) + R(r)s + g_j Y^0] n(r) \\ &= \frac{[Z(s(r), u, E(K_j))]n(r)}{\text{Total residential cost}} + \frac{R(r)sn(r)}{\text{Total rent}} + \frac{g_j Y^0 n(r)}{\text{Total income tax}} \end{aligned} \tag{33}$$

As we have shown,  $N_j$  households agree to form the community; that means they maximize their utility according to the safety environment. Once a community is formed, it maximizes the common utility level, where  $N(\delta, u)$  is the population supply function. We assume that households earn wages  $\delta$  as income and pay an income tax  $g_j Y^0$ .

Here, we establish the community’s maximizing problem and solve it in two steps, as before. The budget constraint of the  $j$ th community is:

$$\mathcal{S}(\delta, u, N, K_j) = \delta N - C(u, N, K_j) \geq K_j. \tag{34}$$

The community’s problem is as follows;

$$\begin{aligned} \max_{N > 0, K \geq 0} u \\ \text{subject to } \mathcal{S}(\delta, u, N, K_j) &\geq K_j \end{aligned} \tag{35}$$

Suppose we obtain a solution of this problem,  $(u', N', K')$ ,  $N'$  must equal the equilibrium population  $N(\delta, u', K')$ .

$$N' = N(\delta, u', K'), \tag{36}$$

where we have this relation, Eq. (37) holds.

$$\partial N(\delta, u'(K')) / \partial K > 0. \tag{37}$$

With any  $K > 0$  and any combination of  $(u', N')$ , the surplus function  $\mathcal{S}(\delta, u, N, K)$  achieves the maximum when the budget constraint holds.

Under each combination of  $(u, K)$ , the surplus maximizing problem is:

$$\begin{aligned} \max_{N \geq 0} \mathcal{S}(\delta, u, N, K_j) &= \delta N - C(u, N, K). \\ \text{subject to } u &= u^* \end{aligned} \tag{38}$$

Solving (38) will enable us to obtain optimal  $N^*$  and combination of  $(\delta, u, K)$ . We then move to the next problem for  $K_j$ , the public service level.

$$\begin{aligned} & \max_{K \geq 0} u \\ & \text{subject to } S(\delta, u, N^*(\delta, u, K_j), K_j) \geq K_j. \end{aligned} \quad (39)$$

While achieving the highest utility,  $\mathbf{N} = N(\delta, u, K)$ , the community can choose the public service level,  $K$ .

The surplus curve is depicted in Fig. 1. Under the budget constraint, it must pass the region above the public-good cost line,  $K$ . Maximum utility is obtained at the tangency point  $K(u^*)$ . If the utility level increases, then the higher population cost brings a lower surplus level. To meet the budget constraint, we find the optimal utility point A in Fig. 1 and attain the equilibrium population  $N^*$ . At the equilibrium, no households can achieve a higher level than  $u^*$ . The equilibrium is Pareto-optimal.

Let us extend the discussion above to the framework for welfare economics. The discussion here relies on Varian (1992).

Suppose that the initial state is the time when the  $j$ th community is formed. Household  $\mathbf{i}$  holds an initial endowment  $\mathbf{W}_i$  that is a bundle containing commodity goods and land. Under the assumption of strict convexity for preferences (Assumption 2), each household's demand function is homogeneous of degree zero in prices, so that the excess demand function is also homogeneous of degree zero in prices. In the  $j$ th community, we can define the aggregate excess demand function by:

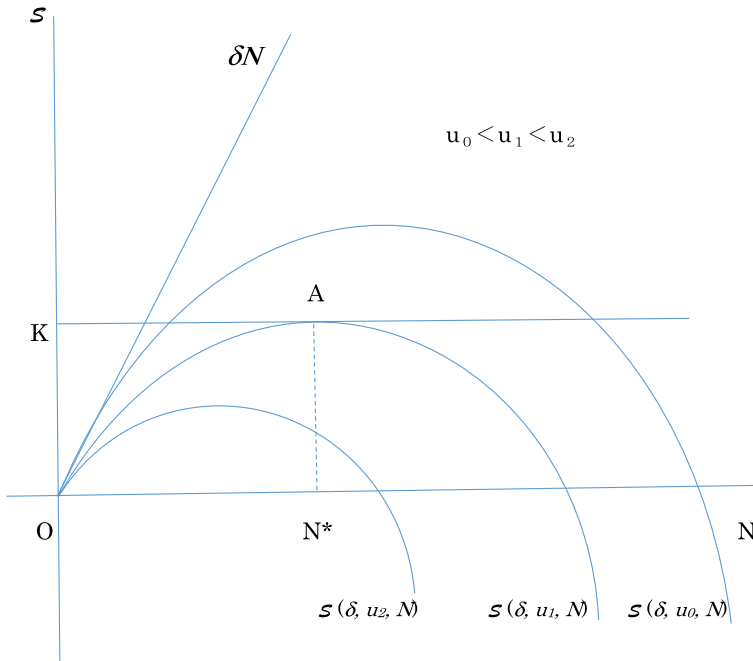
$$Ex(\mathbf{p}) = \Sigma \mathbf{p} \cdot z_{ij} + \Sigma \mathbf{p} \cdot s_{ij} + \Sigma g_{ij} \mathbf{p} \cdot k - \Sigma \mathbf{p} \cdot W_{ij}, \quad (40)$$

where  $\mathbf{p}^*$  is some vector of prices,  $\Sigma_{ij} g_{ij} = 1$ ,  $\Sigma g_{ij} \mathbf{p}_i \cdot k = K_j$ ,  $x = F(N) = \delta N$  for household  $i = 1, 2, 3, \dots, N_j$ . There will then be some  $\mathbf{p}^*$  that causes the market to clear where each household enjoys its bundle containing commodities and accommodations. This is a Walrasian equilibrium. In this form, land is also exchanged among households like other commodity goods. What  $g_{ij}$  represents is a community fee. It usually, for example, around ¥2000 per year in the eastern suburbs of Nagoya.<sup>7</sup> We can regard this fee as a kind of tax, and a subsidy if it is negative. We then reach the theorems of welfare economics for the community having safe public services.

**Proposition 5** (*the first theorem of welfare economics in the provision of safety policy*) There are assumed to be  $m$  number of public services and  $N$  households in a city limit.  $\sum_{j=1}^m N_j = N$ . If  $N_j$  households agree to form a community of the  $j$ th public service, and if Assumptions 1–5 and the community account budget constraint are satisfied, then the competitive equilibrium for the community is Pareto-efficient allocation.

**Proposition 6** (*the second theorem of welfare economics in the provision of safety policy*) Any efficient allocation under the equal utility constraint of the community can be achieved by appropriate income taxes or subsidies.

<sup>7</sup> The local community is a voluntary group to which households may sign up and contribute.



**Fig. 1** The highest utility level

### 4 Concluding remarks

Safety is the opposite idea of risk. The existence of an underground reservoir indicates low ground that is at high risk of flood. Some people question why we need to analyze safety problems instead of risk. As referred to above, there are some useful engineering approaches for controlling and reducing risks, and economists have evolved risk analysis theoretically and empirically. Why do we need to focus on safety, and not risk, in building a model for our research? This is because we observe allocations from the standpoint of safety. Our model of community formation shows how local governments allocate their safety public services among communities inside a city limit. This point is a unique view from the field of economics.

In this paper, we applied urban economic theory to analyze the safety policies of public agencies. It is impossible to quantify a safe environment or present numerical qualities of safety. To overcome this difficulty, we presumed that household’s location choice presents revealed preference for public safety policies. We approached the safe environments problem using general public safeguard policies to factor into the economic model. We categorized these policies into three types: (i) invariant within a city, (ii) mono-centered in a city, and (iii) scattered throughout a city. We built economic models and developed local government and community utility maximizing models and confirmed the existence of equilibria. There are three main remarks that result from the movement of households: (i) changes in city size



with net income changes, (ii) the Samuelson condition for a local government case, (iii) the first and second theorems of welfare economics for a community case.

Intuitively, if households choose the fringe of the city, then the benefit from the greater shelter of the inner city would become lower than at the center. The fringe may even expand outward. On the contrary, if households chose to live in the center of the city, then they could enjoy greater benefit from the policies. Although we assume there are no problems arising from the congestion of public goods, safety benefits vary over households depending on location choice. This is the point where we emphasize that  $K$  is a fixed cost of public services and benefits might differ between households.

To consider the city size, we examine some effects of changes in variables such as  $I$ ,  $T(r)$ , and  $R(r)$ . If household disposable income,  $I$ , increases, naturally the city fringe will expand outward, causing land demand to rise, bringing about an increase in equilibrium utility. To attain this higher utility, households consume more of  $(z, s, E)$ . The change in each element depends on marginal substitutions. An increase in  $T(r)$  means household disposable income decreases, causing the city fringe to contract inward, and equilibrium utility to fall. Bid rent will be lower, accommodations will be relocated relatively nearer to the center, and higher utility will be achieved. This movement implies a greater consumption of  $(z, s, E)$  and, again, the change in each element depends on marginal substitutions, i.e., preferences. If the market land rent  $R(r)$  rises (falls), then the city fringe will move outward (inward), and remaining process follow the same path as above. Our model supplies points of view for discussing a compact city problem which emerges as one of the most important issues in aging societies such as that of Japan.

The remaining problem is congestion of public goods  $K$ . We ignored, for example, the capacity of shelters in this paper. According to real policies for preparing for disasters, however, we need to assume congestions and rebuild the model to allow for this. To answer this problem, we may apply the density of population and services to our models. These are subjects for further research.

There are two questions. One concerns individual behavior, and the other is the randomness of natural events. In reply to these questions in this paper, we assume that each household examines realized safety (attained safety) when choosing locations. There is no uncertainty in the realization of public services. We do not assume uncertainty in the decision-making of households and local governments. The public sector provides safety services simply under the city budget constraint. This is a convenient notion to focus on when discussing safety in terms of public services and community formation. Further, researchers would need to expand the model and analyze it empirically, although in this paper, we take account with a mega-natural disaster to avoid assuming probability of natural events. This model has a superior aspect that we can avoid uncertainty discussion.

However, not assuming uncertainty does not mean there is no uncertainty. The model needs to be expanded with stochastic assumptions. This should be studied in future research.

**Acknowledgements** The author would like to thank Professors Masatsugu Tsuji and Sakae Mitsui, Dr. Hiroaki Shiroyanagi, two anonymous referees for their useful comments and suggestions.

**Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

## References

- Alperovich G, Katz E (1983) Transportation rate uncertainty and optimal location of the firm. *Journal of Regional Science* 23:389–396
- Arnott R (1979) Optimal city size in a spatial economy. *J Urban Econ* 6:65–89
- Bartik TJ (1988) Measuring the benefits of amenity improvements in hedonic price models. *Land Econ* 64:172–183
- Blomquist GC, Worley L (1981) Hedonic prices, demand for urban housing amenities, and benefit estimates. *J Urban Econ* 9:212–221
- Bunten D, Kahn ME (2014) The impact of emerging climate risk on urban real estate price dynamics. NBER Working paper #20018
- Cavallo EA, Noy I (2010) The economics of natural disasters: a survey. IDB Working Paper Series, No. IDB-WP-124
- Cheshire P, Sheppard S (1995) On the price of land and value of amenities. *Economica* 62(246):247–267
- Chipman JS (1970) External economies of scale and competitive equilibrium. *Q J Econ* 84(3):347–385
- Cho CJ (2001) Amenities and urban residential structure: an amenity-embedded model of residential choice. *Pap Reg Sci* 80:483–498
- Cimellaro GP, Reinhorn AM, Bruneau M (2010) Framework for analytical quantification of disaster resilience. *Eng Struct* 32(11):3639–3649
- Duranton G, Puga D (2015) Urban land use. In: Duranton G, Henderson JV, Strange W (eds) *Hand books in economics, regional, urban economics*, vol 5A. North-Holland, Amsterdam, pp 467–560
- Flatters F, Henderson JV, Mieszkowski P (1974) Public goods, efficiency and regional fiscal equalization. *J Public Econ* 3:99–112
- Fujita M (1989) *Urban economic theory: land use and city size*. Cambridge University Press, Cambridge
- Gyourko J, Kahn M, Tracy J (1999) Quality of life and environmental comparisons. *Handbook of regional and urban economics*. Volume 3. Applied urban economics, handbooks in economics, vol 7. Amsterdam/New York/Oxford, Elsevier Science/North-Holland/Amsterdam, pp 1413–1454
- Hallegatte S, Ghil M (2008) Natural disasters impacting a macroeconomic model with endogenous dynamics. *Ecol Econ* 68:582–592
- Helpman E, Pines D (1980) Optimal public investment and dispersion policy in system of open cities. *Am Econ Rev* 70:177–197
- Hidano N (2002) The economic valuation of the environment and public policy: a hedonic approach. Edward Elgar, Cheltenham
- Hochrainer S (2009) Assessing the macroeconomic impacts of natural disasters: are there any? Policy Research Working Paper Series, 4968, The World Bank
- Kahn ME (2004) Environmental valuation using cross-city Hedonic Methods. Available at SSRN: <https://ssrn.com/abstract=556739>
- Kanemoto Y (1980) *Theories of urban externalities*. North-Holland, Amsterdam
- Kates RW, Colten CE, Laska S, Leatherman SP (2006) Reconstruction of new orleans after hurricane katrina: a research perspective. *PNAS* 103(40):14653–14660
- Kunreuther H, Michel-Kerjan E (2014) Economics of natural catastrophe risk insurance. In: Machina MJ, Viscusi WK, Mark J (eds) *Handbook of the economics of risk and uncertainty*. Elsevier, Amsterdam, pp 651–699
- Lindell MK, Perry RW (2000) Household adjustment to earthquake hazard: a review of research. *Environ Behav* 32(4):461–501
- Mai CC (1981) Optimal Location and the theory of the firm under demand uncertainty. *Reg Sci Urban Econ* 11:549–557
- Martinellia D, Cimellaro GP, Terzic V, Mahinb S (2014) Analysis of economic resiliency of communities affected by natural disasters: the bay area case study. *Proc Econ Finance* 18:959–968

- Mathur VK (1983) Location theory under price uncertainty. *Reg Sci Urban Econ* 13:411–428
- Polinsky AM, Rubinfeld DL (1978) The long-run effects of a residential property tax and local public services. *J Urban Econ* 5:241–262
- Sakashita N (1967) Regional allocation of public investment. *Pap Reg Sci* 19(1):161–182
- Schnell MK, Weinstein DE (2012) Evaluating the economic response to Japan's Earthquake. RIETI Policy Discussion Paper 12-p-003
- Sheller M (2016) Connected mobility in a disconnected world: contested infrastructure in postdisaster contexts. *Ann Am Assoc Geogr* 106:330–339
- Torstar T, Lindell MK (2012) Citizens' perceptions of flood hazard adjustments: an application of the protective action decision model. *Environ Behav* 45(8):993–1018
- Varian HR (1992) *Microeconomic analysis*. W. W. Norton & Company Inc., New York
- Yang CH, Fujita M (1983) Urban spatial structure with open space. *Environ Plan* 15:67–84

## URL

- Nagoya Waterworks & Sewerage Bureau. <http://www.water.city.nagoya.jp/> Accessed 30 Oct 2016
- National Consumer Affairs Center of Japan. [http://www.kokusen.go.jp/ncac\\_index\\_e.html](http://www.kokusen.go.jp/ncac_index_e.html) Accessed 24 Nov 2016