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Abstract. Based on an inter-temporal general equilibrium model, we rigorously derive a measurement method using dynamic changes in cross-sectional hedonic prices to estimate the willingness to pay for urban esthetic projects. The method has advantages in common with a difference-in-differences approach. For example, fewer attributes are used as explanatory variables than with a cross-sectional hedonic approach because fixed effects can be ignored. It can therefore mitigate problems related to omitted variables and multicollinearity, which are prevalent in cross-sectional hedonic approaches. Nevertheless, either the measurement or one additional assumption of marginal utility of income is necessary for provision of correct measures. In addition, we consider the existence of condominiums, which has not been supposed in conventional hedonic approaches but must always be considered in practical situations. We apply the method to utility line undergrounding projects.

Keywords: *project evaluation, amenities, willingness to pay, dynamic hedonic approach, difference in differences*
JEL Classification: R11; R13; R14; R52

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1. Introduction

In many countries, a prerequisite of public projects is an economic evaluation of the project. One difficulty of conducting such an evaluation is measuring the value of non-market goods associated with land such as local environment and public facilities (e.g., local crime rates, school quality and transportation), which we call amenities hereafter. A typical methodology is a hedonic approach, which assumes perfect mobility of households across locations. Land prices reflect the residents' willingness to pay for such amenities because households move to areas offering high levels of amenities. This paper provides a rigorous derivation of a method measuring the willingness to pay for changes in amenities, using time-dimensional difference in cross-sectional differences in land prices, with an inter-temporal general equilibrium model, and applies the method to an aesthetic project.

Land prices reflect the land use and the residents' preferences. Therefore, they have been used for measuring difficult-to-observe factors. For land use, recently Brueckner et al. (2017) derived a novel approach of measuring the stringency of the floor area ratio regulation. For residents' preferences, the relation between cross-sectional hedonic prices and willingness to pay for amenities at a single time has been discussed at length in numerous papers (e.g., Rosen (1974), Polinsky and Shavell (1975, 1976); Polinsky and Rubinfeld (1977, 1978); and Harrison and Rubinfeld (1978)). Likewise, land rents differ in time-series data according to the time-series difference in amenities, which is explored by Starrett (1981), Case and Quigley (1991) and others. If we employ cross-sectional data at different times, we can observe time-dimensional difference in cross-sectional difference data.

While analyses discussed in most prior papers regarding cross-sectional hedonic approaches (e.g., Pines and Weiss (1976); Scotchmer (1985, 1986); Kanemoto (1988)) assume a common equilibrium utility level over locations at a certain time based on the free migration assumption, our approach based on the difference-in-differences supposes that the common 'equilibrium utility' changes equally over time in all locations. This supposition is novel in the hedonic approach literature. The inter-temporal common 'equilibrium utility' change in all locations involves the changes in land rents and the amenities. For that reason, their dynamic relation is obtainable; the willingness to pay for the improved amenities can be evaluated in a different manner from those using only cross-sectional differences at a single time.

Furthermore, while those previous papers mainly explore the relation between land rents and the social surplus, the current paper explores the relation between land rents and the resident's willingness to pay for amenities. From this difference, our discussion is different from the case of social surplus, which includes land revenue. Indeed, we can evaluate the project without assuming any economic conditions (e.g. small-open conditions) which are often assumed for measuring social surplus.

Surprisingly, most theoretical discussions on the hedonic approach have been confined to a static framework even though land prices are determined with a non-instant change in amenities and forward-looking households in a dynamic framework. Bishop and Murphy (2011), arguing that a drawback of traditional cross-sectional hedonic literature is the assumption of a myopic decision in a static framework, estimate the willingness to pay for reducing violent crime, using a dynamic model. They find a myopic model underestimates this willingness to pay because a dynamic approach involves forward-looking households.

To avoid this bias arising from ignoring a dynamic framework, we adopt an inter-temporal equilibrium model, and develop a hedonic model to explain how housing prices capitalize large environmental shocks. Without using an inter-temporal equilibrium, Kuminoff and Pope (2014) compare the pre- and post-shock price functions to obtain sufficient conditions of the price functions with which the parameters of the function can imply the marginal willingness to pay for an environmental factor. The sufficient conditions [1] they obtain for exact measurements with their method are (i) restrictions on preferences, income and technology to

[1] See Kuminoff and Pope (2014) for the exact description. These conditions are shown on page 1234 of their paper.

be constant over the duration of the study, (ii) restrictions on the shapes of supply and demand curves so that the marginal price of the environmental factor does not depend on the level of the factor, and (iii) further restrictions on supply and demand such that changes in the environmental factor do not affect the hedonic gradient. In short, if these three conditions hold, the difference between pre- and post-shock price functions is equal to the marginal willingness to pay for the environmental factor. So, clarification of these conditions is useful.

The current paper also derives a measurement method for the marginal willingness to pay, but it does this in a different way. First, our model is a dynamic model whereas Kuminoff and Pope (2014) use two static models at different points in time. Second, we use a difference-in-differences whereas Kuminoff and Pope (2014) use a difference in time–series between pre- and post-shock price functions. So, we obtain different sufficient conditions and a different measurement process from Kuminoff and Pope (2014). Actually, some conditions shown in Kuminoff and Pope (2014) might limit the situations in which their method can be applied. For example, their restrictions on income to be constant over the duration of the study and those on supply and demand curves are both unnecessary for our method in theory, although similar restrictions might make our empirical steps simpler in practice. But, instead, we need either the measurement or the assumption of marginal utility of income for provision of correct measures. With this difference, the Kuminoff and Pope method or the method of the current paper can be used when appropriate.

Our method has advantages in common with difference-in-differences approach. One advantage of our method is that fewer attributes are used as explanatory variables than when using the traditional cross-sectional approach. Correspondingly, the proposed approach tends to avoid multicolinearity problems in parameter estimation, which often arise in cross-sectional hedonic regressions. Using panel data to reduce the number of explanatory attributes is exploited also in the repeat-sales hedonic regression developed by Palmquist (1982). Such reduction is possible because characteristics that do not change over time can be omitted from the regression equation, whereas a cross-sectional hedonic approach should factor in all the geographically different amenities to explain the rent differences. Furthermore, recent papers such as those of Deschenes and Greenstone (2007) and Greenstone and Gallagher (2008) use panel data to incorporate location-specific fixed effects into the hedonic approach. Using panel data removes such fixed effects and estimates the impacts of the change in amenities. Thus, our proposed methods can also mitigate the problem of omitted variable bias.

However, unlike the current paper, these previous papers employing panel data confine the discussion to the relation between equilibrium land rents and amenities (i.e. hedonic regression only), and do not explore the relation between the equilibrium utility and amenities. Therefore, they cannot obtain any method to measure the willingness to pay for amenities. As demonstrated in Scotchmer (1985, 1986) and as discussed in the conclusion of Palmquist (1982), any hedonic rent including the repeat-sales hedonic approach measures neither the willingness to pay nor the social benefit for improved amenities unless the level of the residential utility is somehow unchanged by the improved amenities (e.g. by the assumption of a small–open city). We measure the resident's willingness to pay for amenities using the data on rents, and amenity levels without the small-open assumption.

To calculate the willingness to pay by households, we need lot sizes as the cross-sectional hedonic approach does. Actually, the traditional approaches have ignored the existence of condominiums for calculating the willingness to pay. However, in particular in urban areas, condominiums are common. So, we seek the measurement method useful for the existence of condominiums. In this case, we use the relationship between housing lot rents and land rents, which is also used in Brueckner et al. (2017).

We apply our proposed method to estimate the willingness to pay for utility line undergrounding pole removal. Overhead electric wires along roads are ugly and the poles block the flows of cars and pedestrians. Particularly in Japan, because electric and telephone wires are spread all over cities and most roads in residential areas are narrow, the problems with the effects of wires and poles are rather important. Accordingly, there are strong calls for undergrounding utility lines. We measure the willingness to pay for utility line undergrounding using the data of the Tokyo metropolitan areas. In addition, we compare our results and estimation procedures to those of a traditional cross-sectional hedonic approach. Simultaneously, we show advantages and disadvantages of our proposed method in comparison to the traditional cross-sectional approach.

Hedonic approaches are practical approaches, so the situations in which they are applied vary greatly. Accordingly, many papers take account of various practical aspects. For example, Kuminoff and Pope (2014) focus on the sorting processes which heterogeneous agents generate. However, the current paper only targets the homogeneous agent case mainly because this helps clarify the mechanism behind the method. This is limited, but this situation can be applied to many practical situations. For example, new development areas are usually composed of similar agents in the sense that they have similar incomes and similar life stages. Actually, to focus on the homogenous case, we can rigorously consider a spatial equilibrium and derive a novel measurement method.

Extension of our method to heterogenous residents is not difficult, and is discussed in the summary section. Likewise, as Parmeter and Pope (2012) note, endogeneity problems in estimation have been explored in hedonic papers. To avoid such problems, recent studies have begun to apply the hedonic approach to areas with data suited for quasi-experiments (e.g., Chay and Greenstone, 2005; Hallstrom and Smith, 2005; Linden and Rockoff, 2008; Pope, 2008). Specifically, Koster and Ommeren (2019) use discontinuity design to consider the heterogeneity in a spatial context. Actually, our proposed method can be straightforwardly applied to such quasi-experiments if target areas have panel data. Indeed, such quasi-experiment approaches often involve dynamic data (as in Koster and van Ommeren, 2019).

Section 2 develops a model and derives a relationship between the willingness to pay for amenities and the dynamics of land rent based on the dynamic model. Section 3, adding some reasonable assumptions, obtains a practical measurement method using only data at two points of time before and after the improvement in amenities. Section 4 compares the proposed approach with the traditional cross-sectional hedonic approach. Next, Section 5 applies our method to estimate the value of undergrounding utility lines empirically as an illustrative application example. Finally, we conclude the paper.

2. Model and willingness to pay for amenities

We derive the willingness to pay for amenities by using the relationship between the dynamic change in utility, rents and amenities in a dynamic model. Our target is to obtain the formula for measuring the willingness to pay for amenities with observable economic variables (e.g., rents, housing lot sizes, and amenity levels). We suppose multiple amenities. Some amenities change dynamically and other amenities do not change. The dynamic change in amenities are often caused by public projects (e.g., subway construction). Projects often have so-called announcement effects, meaning that planning the project affects the economy somehow when it is announced publicly. Accordingly, the effect of a project will begin before the project actually starts. In addition, in most projects, amenities improve slowly over many years (e.g. construction of parks, development of stations, etc.).

To simplify the discussion, we suppose that amenities are improved by projects, and we evaluate the willingness to pay for the project. This supposition does not lose the generality at all. If some amenities change due to natural change in the environment, we just suppose that the change is caused by 'natural projects'. Amenities are expressed by $\mathbf{A}^i$, which is a set of amenities at location *i* over time points, $\mathbf{A}^i = (A^i(0),\cdots,A^i(t),\cdots A^i(\infty))$, where $\{0,\cdots,t,\cdots,\infty\}$ is a set of time indices. Furthermore, $A^i(t)$ is a set of amenities of various types, i.e., $A^i(t) = (a^i(t), b^i(t),...,e^i(t))$ (e.g. $a^i(t)$ is the existence of overhead wires, $b^i(t)$ is distance to the station, $c^i(t)$ is quality of parks, and so on), which expresses the levels of amenities at location *i* at time *t*. We assume five kinds of amenities without loss of generality. The following theory does not depend on the number of amenities. The amenities include any location-related utility-enhancing and utility-worsening factors without prices.

For individuals, amenities $\mathbf{A}^i$ are exogenous variables. A project increases the level of each component of amenities. Figure 1 shows a project of improving amenity $a^i(t) \in A^i(t)$ for example. Subscript 0 or 1 implies before or after a project. Multiple projects are implemented in the real world, so amenities change from $\mathbf{A}_0^i$ to $\mathbf{A}_1^i$. In order to take account of the announcement effect and the project duration, we suppose that the project starts at time $T^c - n$ and finishes at time T^c, as shown in Figure 1, and the announcement effect occurs at time T^a, which is before $T^c - n$. To avoid measurement biases due to the announcement effect, the benefit measurement method uses the data of time *T*-*m*, which is before T^a, and time *T*, which is after the completion of the project. It is assumed that any future change in amenities is not expected before the announcement of the project.

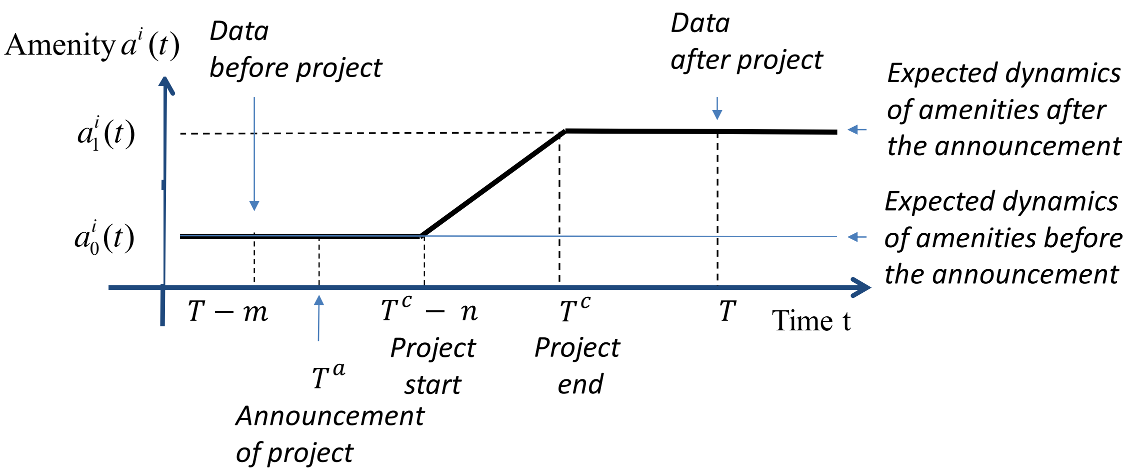

Figure 1 Change in amenity $a^i(t) \in A^i(t)$ and data collection timing

2.1 Household Behavior

We use a dynamic model to derive a benefit measurement formula for amenities. The model assumes that the target area comprises homogeneous individuals, who have homogeneous utility functions and equal income. The target area has *I* zones, each of which is labeled

$i \in \{1,...,I\}$. This homogeneity assumption might sound unrealistic. However, we do not have to target all residential areas affected by projects. We can choose areas with relatively homogenous residents (e.g., with Regression Discontinuity Design). This point is also discussed in the conclusion.

At time *t*, individuals living in zone *i* consume the composite good $x^i(t)$ at price 1, setting the good as the numeraire good, housing lot size at time *t*, $h^i(t)$ at the housing lot rent $r^i(t)$. [2] In Section 2, we assume only houses, not condominiums. In Section 3, we first derive a benefit measurement method based on this model in Subsection 3.1, and then we extend the model to include the case of condominiums in Subsection 3.2.

The willingness to pay for amenities is definable simply using the indirect lifetime utility function. Individual behavior is expressed as the maximization of the lifetime utility at a given income. The individual maximizes his lifetime indirect utility at any time $z \in \{0,\cdots,\infty\}$. The lifetime is set up to infinity as the dynasty model sets. This can be justified if their descendants' utilities are supposed to be considered with a discount rate. If the dynamics of amenities is given as $\mathbf{A}^i = (A^i(0),\cdots,A^i(t),\cdots A^i(\infty))$, the behavior of an individual living in zone *i* from time *z* to ∞ is expressed as

$$V^i(z) = \max_{x(t),h(t),s^i(t+1)} \sum_{t=z}^{\infty} u\left(x^i(t),h^i(t),A^i(t)\right)\rho^{-t} \tag{1}$$

$$s.t. \quad w^i(t) + \rho s^i(t) - x^i(t) - r^i(t)h^i(t) - s^i(t+1) = 0,\ t = z, z+1,...,\infty \tag{2a}$$

$$s^i(z) \text{ is exogenously given.} \tag{2b}$$

$$\lim_{t\to\infty} \rho^{-t} s^i(t) = 0\ , \tag{2c}$$

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[2] In real cities, land consumption is fixed for some time because cost is required for adjusting the size. However, for simple exposition, the current paper assumes free adjustment cost so that land consumption (i.e. lot size) at time *t*, $h^i(t)$ is variable with time. Actually, even if the adjustment costs are considered, the conclusions do not change.

where $V^i(z)$ is the lifetime utility function for an individual living in zone i from time z to time ∞, and $u\left(x^i(t), h^i(t), A^i(t)\right)$ is the per-time utility function for an individual living in zone i at time t. $\rho(>1)$ is a gross (not net) discount factor. $w^i(t)$ is the given income level of an individual living in zone i.

The housing lot is owned by absentee landowners so that the land revenue is not returned to the residents. The current paper assumes that amenities do not affect $w^i(t)$ for simplicity[3], although we can take account of this effect easily by assuming a wage function $w^i(t, \mathbf{A})$. That is, the current paper targets amenities affecting residents. In addition, people at time z might plan to migrate in the future, while eq. (1) supposes no migration. However, if free migration is assumed, as described later, the lifetime utility at any time is constant across locations. So, the current model is valid even in the existence of migration.

We can sum up eq. (2) over time z to ∞ for an individual living in zone i.

$$s^i(z)\rho - s^i(\infty)\rho^{-\infty} = \sum_{t=z}^{\infty} x^i(t)\rho^{-t} + \sum_{t=z}^{\infty} r^i(t)h^i(t)\rho^{-t} - \sum_{t=z}^{\infty} w^i(t)\rho^{-t} \ , \qquad (3)$$

where $s^i(z)$ is the initial given endowments at z. $-s^i(\infty)\rho^{-\infty}$ should be 0 from a non-Ponzi condition. Therefore, we can rewrite eq. (2a) as

$$W^i(z) = \sum_{t=z}^{\infty} x^i(t)\rho^{-t} + \sum_{t=z}^{\infty} r^i(t)h^i(t)\rho^{-t} \ , \qquad (4)$$

where $W^i(z) \equiv \sum_{t=z}^{\infty} w^i(t)\rho^{-t} + s^i(z)\rho$ is the present value of income.

The indirect utility function is obtained as follows. $V^i(z) \equiv \sum_{t=z}^{\infty} u(x^{i*}(t), h^{i*}(t), A^i(t))\rho^{-t}$, where optimal demand $x^{i*}(t)$ and $h^{i*}(t)$ are obtained as the functions of

[3] The version of taking account of changes in wages associated with amenities can be obtained from the authors.

$[W^i(z), r^i(z), ..., r^i(\infty), A^i(z), ..., A^i(\infty)]$, which are exogenous for residents. Substituting these optimal demand functions into the utility function, we obtain

$$V^i(z) \equiv V^i(z)[W^i(z), r^i(z), ..., r^i(\infty), A^i(z), ..., A^i(\infty)], \qquad (5)$$

which implies the indirect utility function is the function of $[W^i(z), r^i(z), ..., r^i(\infty), A^i(z), ..., A^i(\infty)]$.

The supply of land[4] is fixed in each zone,

$$N^i(t)h^i(t) = \bar{H}^i \qquad (6)$$

where $N^i(t)$ is the population of zone *I*, and $\bar{H}^i$ is the fixed area of zone *i*.

Individuals can migrate to seek a higher utility level. Regarding migration, we assume Assumption 1, as in the traditional hedonic approach.

Assumption 1. The utility level is equal among locations at any time.

Assumption 1 holds when people migrate freely. In the real world, migration cost is not zero; however, the cost can be negligible from the long-term viewpoint. Due to Assumption 1, in equilibrium at any time *z*, the utility levels of individuals are equal among zones in which the number of individuals is positive. That is, we have

$$V^i(z) = V(z) \text{ if } N^i(z) > 0 \text{ for } i \in \{1, ..., I\}, \text{ and} \qquad (7a)$$

$$V^j(z) < V(z) \text{ if } N^j(z) = 0 \text{ for } j \in \{1, ..., I\}, \qquad (7b)$$

where $V(z)$ expresses the equilibrium utility of an individual at time *t*. For our purpose, the city can be either open or closed. Accordingly, the equilibrium utility $V(z)$ can be determined either exogenously (in open city cases) or endogenously (in closed city cases).

[4] Actually, in hedonic approaches, rents after the projects are observed or forecasted. So, formulating the supply side of land is not necessary. The current paper, assuming a general equilibrium framework, provides a rigorous derivation of a benefit measurement formula from it.

The equilibrium solution of the above general equilibrium model is ascertained as follows. We can obtain the equilibrium rent as $r^i(t)[\mathbf{A}(z),...,\mathbf{A}(\infty)]$ because $[\mathbf{A}(z),...,\mathbf{A}(\infty)]$ are exogenous policy variables for the general equilibrium model, where $\mathbf{A}(t)=(A^1(t),\cdots,A^i(t),\cdots A^I(t))$. That implies that the equilibrium housing lot rent depends on $[\mathbf{A}(z),...,\mathbf{A}(\infty)]$. Substituting this into eq. (5), we derive the equilibrium lifetime indirect utility function as

$$V^i(z,\mathbf{A})=V^i\left(W^i(z),r^i(z)[\mathbf{A}(z),...,\mathbf{A}(\infty)],...,r^i(\infty)[\mathbf{A}(z),...,\mathbf{A}(\infty)]\right),A^i(z),...,A^i(\infty)\Big) . \tag{8}$$

2.2 Relationship between willingness to pay for amenities and land rents

The willingness to pay for a change in an amenity can be defined using the monetary-measured change in the indirect utility associated with a change in the amenity. Because the indirect utility depends on when it is defined, the willingness to pay depends on the year at which the utility is measured. Although our model can measure it at any time, the current paper measures the willingness to pay at time *T*, which is the time of data collection after the project's end.

The change in the lifetime indirect utility function at *T* from the original amenity level $\mathbf{A}_0$ to the improved level $\mathbf{A}_1$ is expressed as

$$\begin{aligned}
&V^i\left(T,\mathbf{A}_1\right)-V^i\left(T,\mathbf{A}_0\right)\\
&=V^i\left(W^i(z),r^i(z)[\mathbf{A}_1(z),...,\mathbf{A}_1(\infty)],...,r^i(\infty)[\mathbf{A}_1(z),...,\mathbf{A}_1(\infty)]\right),A_1^i(z),...,A_1^i(\infty)\Big)\\
&-V^i\left(W^i(z),r^i(z)[\mathbf{A}_0(z),...,\mathbf{A}_0(\infty)],...,r^i(\infty)[\mathbf{A}_0(z),...,\mathbf{A}_0(\infty)]\right),A_0^i(z),...,A_0^i(\infty)\Big) \quad (9)\\
&=\sum_{t=T}^{\infty}\int_{\mathbf{A}_0^i}^{\mathbf{A}_1^i}\frac{\partial V^i}{\partial r^i(t)}\frac{\partial r^i(t)}{\partial \mathbf{A}(t)}\bullet d\mathbf{A}(t)+\int_{\mathbf{A}_0^i}^{\mathbf{A}_1^i}\frac{\partial V^i(T)}{\partial \mathbf{A}^i}\bullet d\mathbf{A}^i \quad \text{for } i\in\{i:N^i(t)>0\}
\end{aligned}$$

where $\partial r^i(t)/\partial\mathbf{A}(t)$ is the vector of the derivative of $r^i(z,\mathbf{A}(z))$ with respect to each component of the vector $\mathbf{A}(z)$. $d\mathbf{A}(t)$ is the vector of the differential of each component of the vector $\mathbf{A}(z)$. The mathematical symbol '$\bullet$' is an inner product between the vectors. The same expression is used in the second term and thereafter. The last line is obtained from rewriting the second line using the integral of the derivatives of function V^i. Note that we have already supposed that the wage $W^i(T)$ is independent of amenities $\mathbf{A}^i$.

The first term on the last line in eq. (9) includes $\partial V^i(T)/\partial r^i(t)$, which is marginal lifetime indirect utility with respect to housing lot rent, and $(\partial r^i(t)/\partial \mathbf{A}(t))d\mathbf{A}(t)$ is the change in land rent associated with a change in amenities. The second term, $\int_{\mathbf{A}_0^i}^{\mathbf{A}_1^i}(\partial V^i(T)/\partial \mathbf{A}^i)d\mathbf{A}^i$, is a marginal indirect utility of the individual for amenities. We want to estimate the value of this term in terms of money. Among the terms of the first line and last lines of eq. (9), $V^i(T,\mathbf{A}_1)-V^i(T,\mathbf{A}_0)$ on the first line and $\partial V^i(T)/\partial r^i(t)$ and $\partial V^i(T)/\partial \mathbf{A}^i$ on the last line are unobservable because these are related to utility, which is inherently unobservable.

To measure the willingness to pay for amenities using observable terms, we must eliminate the unobservable terms from Eq. (9). Here we can use Assumption 1. As Appendix 1 shows, if Assumption 1 holds, we can derive Eq. (10) from Eq. (9), using the dynamic difference in cross-sectional differences of residential utility, i.e., $V^i(z,\mathbf{A}_1)-V^i(z,\mathbf{A}_0)=$ $V^I(z,\mathbf{A}_1)-V^I(z,\mathbf{A}_0)$, where location I is selected by presuming $N^I>0$ without loss of generality.

$$\frac{\partial V^i(T)}{\partial W^i}\left(\sum_{t=T}^{\infty}\int_{\mathbf{A}_0}^{\mathbf{A}_1}\rho^{-t}h^i(t)\frac{\partial r^i(t)}{\partial \mathbf{A}(t)}\bullet d\mathbf{A}(t)+\int_{\mathbf{A}_0^i}^{\mathbf{A}_1^i}\frac{\partial V^i(T)}{\partial \mathbf{A}^i}\Bigg/\frac{\partial V^i(T)}{\partial W^i}\bullet d\mathbf{A}^i\right)$$
$$=\frac{\partial V^I(T)}{\partial W^I}\left(\sum_{t=T}^{\infty}\int_{\mathbf{A}_0}^{\mathbf{A}_1}\rho^{-t}h^I(t)\frac{\partial r^I(t)}{\partial \mathbf{A}(t)}\bullet d\mathbf{A}(t)+\int_{\mathbf{A}_0^I}^{\mathbf{A}_1^I}\frac{\partial V^I(T)}{\partial \mathbf{A}^I}\Bigg/\frac{\partial V^I(T)}{\partial W^I}\bullet d\mathbf{A}^I\right), \tag{10}$$

for locations $i\in\{i=1,2,...,I-1:N^i(t)>0\}$.

The term, $(\partial V^i(T)/\partial \mathbf{A}^i)/(\partial V^i(T)/\partial W^i)$, in Eq. (10) represents the willingness to pay for the amenity in terms of income. We want to measure this value. Besides this term, Eq. (10)

has only one unobserved term $\partial V^i(T)/\partial W^i$. So, to measure the willingness to pay for the amenities, we have to know $\dfrac{\partial V^i(T)/\partial W^i}{\partial V^I(T)/\partial W^I}$ in Eq. (10). We can approach this term in two ways: Approach 1) assuming $\partial V^i(T)/\partial W^i = \partial V^I(T)/\partial W^I$, and Approach 2) measuring $\dfrac{\partial V^i(T)/\partial W^i}{\partial V^I(T)/\partial W^I}$. We will explain them individually.

Approach 1). The first approach is simple. Actually, this term vanishes from Eq. (10) if $\partial V^i(T)/\partial W^i = \partial V^I(T)/\partial W^I$ holds. We denote this equality as Assumption 2.

Assumption 2 (Equal marginal utility of income among locations)

$\dfrac{\partial V^i(T)}{\partial W^i} = \dfrac{\partial V^I(T)}{\partial W^I}$ for any location $i \in \{i = 1,2,...,I-1 : N^i(t) > 0\}$.

Two examples in which Assumption 2 holds are as follows. First, if the utility function is a quasi-linear utility function (e.g. $u^i(x^i, h^i, \mathbf{A}^i) = g(h^i, \mathbf{A}^i) + x^i$), then the marginal utility with respect to income is constant in all locations at any time *t*. In this case, $\partial V^i(T)/\partial W^i = 1$ for any location *i*. Accordingly, Assumption 2 holds. Another example is when the distribution of income is always adjusted to be optimal. At optimal, the marginal utility with respect to income should be identical in all locations. That implies that the relation $\partial V^i/\partial W^i = \partial V^I/\partial W^I$ $i \in \{i = 1,2,...,I-1 : N^i(t) > 0\}$ holds.

Approach 2). The second approach uses the Arrow–Pratt measure of absolute risk aversion to obtain the relation between $\partial V^i(T)/\partial W^i$ and $\partial V^I(T)/\partial W^I$. The lifetime utility function is expressed as $V^i\left(W^i(z), r^i(z,\mathbf{A}) \cdots r^i(\infty,\mathbf{A}), \mathbf{A}^i\right)$. If the function is strongly separable into the wage and other variables, $\dfrac{\partial V^i\left(W^i(z)\right)}{\partial W^i} = \dfrac{\partial V^I\left(W^I(z)\right)}{\partial W^I} + \dfrac{\partial^2 V^I\left(W^I(z)\right)}{\partial W^{I2}}(W^i(z) - W^I(z))$, using a first-order expansion to the lifetime utility function with respect to the wage. This can be arranged into $\dfrac{\partial V^i\left(W^i(z)\right)}{\partial W^i} \Big/ \dfrac{\partial V^I\left(W^I(z)\right)}{\partial W^I} = 1 + \kappa[W^i(z) - W^I(z)]$, where $\kappa \equiv \dfrac{\partial^2 V^I\left(W^1(z)\right)}{\partial W^{I2}} \Big/ \dfrac{\partial V^I\left(W^I(z)\right)}{\partial W^I}$ is an Arrow–Pratt measure of absolute risk aversion on the wage. For example, if the lifetime utility function takes $V^i = g(r^i(z,\mathbf{A}) \cdots r^i(\infty,\mathbf{A}), \mathbf{A}^i) - \kappa^{-1}\exp(-\kappa W^i(z))$), then the Arrow–Pratt measure of absolute risk aversion is constant in all locations. Using this equation, $\dfrac{\partial V^i}{\partial W^i} \Big/ \dfrac{\partial V^I}{\partial W^I}$ can be measured with observable variables if the Arrow–Pratt measure is measured (e.g., Becker et al. (1964) and Levy and Levy (2001)). We can apply $\varphi^i \equiv \frac{\partial V^i}{\partial W^i} \Big/ \frac{\partial V^I}{\partial W^I}$ to Eq. (10).

Summing what we have obtained, we have Lemma 1.

Lemma 1 (relationship between land rent and willingness to pay for amenities). *If Assumption 1 holds, using Eq. (10), the resident's willingness to pay for the marginal change in the amenities at location i, that is (* $\partial V^i(T)/\partial A^i \Big/ \partial V^i(T)/\partial W^i$ *), can be obtained from the dynamic change in land rents, land consumption and the amenities, irrespective of whether the city is open or closed.*

Note that Assumption 1, which is necessary for Lemma 1, is different from the so-called small-open assumption. The small-open implies that the project is so small that it does not affect the equilibrium utility level. However, under Assumption 1, the equilibrium utility level can change dynamically with a change in amenities or other factors. In other words, Assumption 1 holds more widely than the small-open assumption.

3. Derivation of a measurement formula

3.1 Cases in which amenities change instantly

This section derives a formula to estimate the willingness to pay for amenities using only data at two points: before and after the amenities change, using Lemma 1. To simplify notation, we define the present value of the expenditure for housing lot consumption as

$$H^i(z, \mathbf{A}) \equiv \sum_{t=z}^{\infty} h^i r^i(t, \mathbf{A}) \big/ \rho^t \quad . \qquad (11)$$

We apply Eq. (11) to Eq. (10) and assume that each element of the vector $\frac{\partial V^i(T)}{\partial \mathbf{A}^i}$ is constant for the respective amenity change to obtain

$$
-\left[\left(\left(H^i(T,\mathbf{A}_1)-H^i(T,\mathbf{A}_0)\right)-\left(H^I(T,\mathbf{A}_1)-H^I(T,\mathbf{A}_0)\right)\right)\right]
$$

$$
+\left[\frac{\partial V^i(T)}{\partial \mathbf{A}^i}\Bigg/\frac{\partial V^i(T)}{\partial W^i}\bullet\left(\mathbf{A}_1^i-\mathbf{A}_0^i\right)\right]-\left[\frac{\partial V^I(T)}{\partial \mathbf{A}^I}\Bigg/\frac{\partial V^I(T)}{\partial W^I}\bullet\left(\mathbf{A}_1^I-\mathbf{A}_0^I\right)\right]=0, \qquad (12)
$$

where $\mathbf{A}_1^i-\mathbf{A}_0^i$ is a vector of the change in each element from 0 to 1. Note that $\frac{\partial V^i(T)}{\partial \mathbf{A}^i}\equiv[\frac{\partial V^i(T)}{\partial a^i(T)} \quad \frac{\partial V^i(T)}{\partial b^i(T)} \quad \cdots \quad \frac{\partial V^i(T)}{\partial e^i(T)} \quad \frac{\partial V^i(T)}{\partial a^i(T+1)} \quad \frac{\partial V^i(T)}{\partial b^i(T+1)} \quad \cdots \quad \frac{\partial V^i(T)}{\partial e^i(T+1)}\ldots]$.

$H^i(T,\mathbf{A}_1)-H^i(T,\mathbf{A}_0)$ is the increase in the present value of expenditure for housing lot consumption in location *i* from pre-project amenity $\mathbf{A}_0$ to post-project amenity $\mathbf{A}_1$. The first bracket [ ] implies the difference of that term between location *i* and location *I*. If amenities $\mathbf{A}$ changes at once at time T, i.e., $T=T^c=T^c-n=T^A$, we can observe the amount in the bracket. The second bracket, which expresses the marginal value of a dynamic change in the amenities, can be alternatively expressed as

$$
\left[\frac{\partial V^i(T)}{\partial \mathbf{A}^i}\Bigg/\frac{\partial V^i(T)}{\partial W^i}\bullet\left(\mathbf{A}_1^i-\mathbf{A}_0^i\right)\right]\equiv
$$

$$
\sum_{t=T}^{\infty}\frac{\partial V^i(T)}{\partial a^i(t)}\Bigg/\frac{\partial V^i(T)}{\partial W^i}\times(a_1^i(t)-a_0^i(t))+\ldots+\sum_{t=T}^{\infty}\frac{\partial V^i(T)}{\partial e^i(t)}\Bigg/\frac{\partial V^i(T)}{\partial W^i}\times(e_1^i(t)-e_0^i(t)), \qquad (13)
$$

where $\sum_{t=T}^{\infty}\frac{\partial V^i(T)}{\partial a^i(t)}\Big/\frac{\partial V^i(T)}{\partial W^i}$ is the present value of the willingness to pay for an increase in amenity $a^i(t)$. The last bracket is that for location *I*. Accordingly, we can estimate the willingness to pay for amenities by using Eq. (12). For example, if the announcement effect is the total effect in a project, Eq. (12) can measure the willingness to pay for the amenities.

3.2 Cases in which amenities change slowly

In most projects, amenities change slowly. In this case, Eq. (12) cannot estimate the willingness to pay for amenities with observable variables because we cannot obtain the first bracket [ ], which is composed of the expenditure for the housing lot consumption before and after the amenities change when the total effect of the project is supposed to occur at time *T*.

To cope with this, we rewrite Eq. (12) as follows. We can express $H^i\left(T,\mathbf{A}_0\right)$ as

$$H^i\left(T,\mathbf{A}_0\right)=[H^i\left(T,\mathbf{A}_0\right)-H^i\left(T-m,\mathbf{A}_0\right)]+H^i\left(T-m,\mathbf{A}_0\right). \tag{14}$$

We apply Eq. (14) to Eq. (12) to obtain

$$\begin{aligned}
&-\left(H^i\left(T,\mathbf{A}_1\right)-\left([H^i\left(T,\mathbf{A}_0\right)-H^i\left(T-m,\mathbf{A}_0\right)]+H^i\left(T-m,\mathbf{A}_0\right)\right)\right)\\
&+\left(H^I\left(T,\mathbf{A}_1\right)-\left([H^I\left(T,\mathbf{A}_0\right)-H^I\left(T-m,\mathbf{A}_0\right)]+H^I\left(T-m,\mathbf{A}_0\right)\right)\right)\\
&+\left[\left(\frac{\partial V^i\left(T\right)}{\partial \mathbf{A}^i}\Big/\frac{\partial V^i\left(T\right)}{\partial W^i}\bullet\left(\mathbf{A}_1^i-\mathbf{A}_0^i\right)\right)-\left(\frac{\partial V^I\left(T\right)}{\partial \mathbf{A}^I}\Big/\frac{\partial V^I\left(T\right)}{\partial W^I}\bullet\left(\mathbf{A}_1^I-\mathbf{A}_0^I\right)\right)\right]=0.
\end{aligned} \tag{15a}$$

The measurement formula, Eq. (15a) requires the data of $H^i\left(T,\mathbf{A}_0\right)$, which are the expenditure on housing lot consumption with $\mathbf{A}_0$. This is, however, not observable because amenity level $\mathbf{A}_1$ is achieved sometime from $t=T^c-n$ to t=T, implying that $\mathbf{A}_0$ is not present at *T*. So $H^i\left(T,\mathbf{A}_0\right)$ should be estimated.

One usual estimation method is to use time-fixed effects which are constant across locations. Indeed, these time-fixed effects are often used in difference-in-differences approaches. For example, if log functional forms are assumed, the growth rate of the expenditure on housing lot consumption, $H^i\left(T,\mathbf{A}_j\right)/H^i\left(T-m,\mathbf{A}_j\right)$ (j= 0 or 1) is constant across locations. In the case of linear functions, the growth amount, $H^i\left(T,\mathbf{A}_j\right)-H^i\left(T-m,\mathbf{A}_j\right)$ is identical across locations. These are estimated as time-fixed effects in the difference-in-differences. When applying the time-fixed effect of a linear function to Eq. (12) yields Eq. (15b), because $H^i\left(T,\mathbf{A}_0\right)-H^i\left(T-m,\mathbf{A}_0\right)=H^I\left(T,\mathbf{A}_0\right)-H^I\left(T-m,\mathbf{A}_0\right)$.

$$-\left(H^i\left(T,\mathbf{A}_1\right)-H^i\left(T-m,\mathbf{A}_0\right)\right)+\left(H^I\left(T,\mathbf{A}_1\right)-H^I\left(T-m,\mathbf{A}_0\right)\right)$$

$$+\left[\left(\frac{\partial V^i(T)}{\partial \mathbf{A}^i}\Big/\frac{\partial V^i(T)}{\partial W^i}\bullet\left(\mathbf{A}_1^i-\mathbf{A}_0^i\right)\right)-\left(\frac{\partial V^I(T)}{\partial \mathbf{A}^I}\Big/\frac{\partial V^I(T)}{\partial W^I}\bullet\left(\mathbf{A}_1^I-\mathbf{A}_0^I\right)\right)\right]=0. \quad (15b)$$

Eq. (15b) is very easily applied because all variables except for the willingness to pay for the amenities are easily observable. Note that this is simply an example in the case of constant time-fixed effects in a linear function. We can use a more flexible form to estimate $H^i\left(T,\mathbf{A}_0\right)$ (e.g., the combination of time-fixed effects and local fixed effects). We can summarize what we have obtained as Proposition 1.

Proposition 1 (proposed approach). *We can estimate the willingness to pay for amenities using a measurement formula, Eq. (12) when the amenities change instantly, or Eq. (15a) otherwise. If we use constant time-effects in a linear regression form in a difference-in-differences approach, Eq. (15a) can be expressed as Eq.(15b).*

Proposition 1 implies that the resident's willingness to pay for the marginal change in the amenities in location *i*, that is ($\partial V^i(T)/\partial A^i \Big/ \partial V^i(T)/\partial W^i$), can be obtained with housing lot prices and housing lot consumption using data at two time points, irrespective of whether the city is open or closed, using the data at two points of time: before and after the amenity change.

3.3 Taking account of condominiums

Land is occupied by not only houses but also condominiums. The willingness to pay by a household is reflected in floor space rent directly but it is not reflected in land rent in a simple way because a number of households share the land in the case of condominiums. Surprisingly, in the context of hedonic approach, condominiums have not been explicitly taken into account.

Since a floor rent reflects household's willingness to pay, the following discussion explores the relationship between floor rent and land rent. First, we suppose developers' behavior as Brueckner et al. (2017) and others have assumed. Developers construct condominiums using capital (i.e., housing materials) and land. The number of developers is large, so the market is perfectly competitive. The cost function of supplying floor area is given as $F(S)$, where S is capital/land ratio, which implies building height. Setting the inverse function of $F(S)$ as $S(F)$, $S(F)$ implies the capital necessary for constructing floor area F. The profit of a perfect competitive developer in zone i is defined as

$$\Pi^i = F^i r^i - S(F^i) - P^i, \tag{16}$$

where Π is the profit, r is floor rent, and P is land rent. The price of capital is normalized at one. Note that, up to this section, we did not consider condominiums. Since housing lots are placed directly on land, housing lot rents were equal to land rents. In this section, we can replace housing lot rents with floor rent when the households reside in condominiums. Floor area rents are determined by bid-rent function as housing lot rents. So, we use the same notation. But, to clarify the difference between land rents and floor rents in condominiums, we use P as land rent in this case.

The profit of the developer is maximized but is zero because of perfect competition. That is, $\Pi^i = 0$. Landowners rent their land to highest bidders. So, developers maximize the land rent as follows.

$$\max_{F^i} \quad P^i = F^i r^i - S(F^i). \tag{17}$$

The first order condition is $r(i) - \partial S/\partial F = 0$. This first order condition implies that F^i and $S(F^i)$ are functions of r^i. Accordingly, substituting them into Eq. (17), we have

$$P^i = F(r^i) r^i - S(r^i). \tag{18}$$

To see the change in land prices with respect to amenities, we differentiate Eq. (18) with respect to amenities A.

$$\frac{dP^i}{dA} = F(r^i)\frac{\partial r^i}{\partial A} \tag{19}$$

Equation (19) is obtained by assuming that F^i is variable. However, floor area ratio regulation is common in urban areas. In this situation, F^i is fixed at a regulated level[5] if the regulation is binding. Even in this situation, the same equation can be obtained directly from Eq. (17). Indeed, Eq. (6) in Brueckner et al. (2017), which can be expressed as $dP^i / dA = \bar{F} \partial r^i / \partial A$ in our notation, expresses this binding case. Multiplying both sides with h^i, dividing them by *F*, and finally exchanging the right-hand side with the left-hand side, yields

$$h^i \frac{\partial r^i}{\partial A} = \frac{h_i}{F(r^i)} \frac{\partial P^i}{\partial A} = \frac{1}{n^i} \frac{\partial P^i}{\partial A} , \tag{20}$$

where n^i is household density. Using Eq. (20) and Eq. (15b), we have

$$\left[\left(\left(\frac{1}{n_i} P_i(T) - \frac{1}{n_i} P_i(T-m)\right) - \left(\frac{1}{n_I} P_I(T) - \frac{1}{n_I} P_I(T-m)\right)\right)\right]$$
$$= \left[\frac{\partial V_I(T)}{\partial \mathbf{A}_I} \Bigg/ \frac{\partial V_I(T)}{\partial W_I} \bullet \left(\mathbf{A}_{i,1} - \mathbf{A}_{i,0}\right) \right] - \left[\frac{\partial V_I(T)}{\partial \mathbf{A}_I} \Bigg/ \frac{\partial V_I(T)}{\partial W_I} \bullet \left(\mathbf{A}_{I,1} - \mathbf{A}_{I,0}\right) \right] . \tag{21}$$

We can summarize what we have obtained as Proposition 2.

Proposition 2 (proposed approach with the existence of condominiums). *We can estimate the willingness to pay for amenities using a measurement formula, Eq. (21).*

The measurement method shown in Proposition 2 can be used in the existence of condominiums. In central cities, there are many condominiums. In this case, Eq. (21) should be used. This measurement formula is intuitively interpreted as follows. In the case of condominiums, multiple households residing in a condominium share the land. Accordingly, when some local amenities increase, the increase in the land price is related to the multiple households' WTPs for the increase in the amenities. This is why household density is used in the case of condominiums, instead of lot size in the case of detached houses. But note that

[5] Regarding optimal setting of floor area ratios, see Kono and Joshi (2019).

this formula can be applied to detached houses as it is, simply because the building is occupied by only one household.

4. Difference from the cross-sectional hedonic approach

The proposed approach, as derived in the preceding section, uses the relation between the level of utility, the level of amenities, and land rents. In this respect, the proposed approach resembles those of Pines and Weiss (1976) and Scotchmer (1985, 1986), which explore the relation between cross-sectional land rents and the willingness to pay for amenities using the static general equilibrium model. This section explains the differences and similarities between their static cross-sectional hedonic approach and the proposed dynamic approach.

4.1 Relation between the cross-sectional approach and the proposed approach

First, we review a discussion by Pines and Weiss (1976), which explore a method to estimate the willingness to pay for amenities using cross-section analysis. Although many papers analyze the relationship between rent and willingness to pay for amenities, the basic theoretical structure used is completely identical to Pines and Weiss. Pines and Weiss (1976) presume that there are many locations and that the continuum function of a single amenity factor a can be formed using the cross-section data. Because the utility level $U(x,h,a)$, where x is composite good consumption and h is lot size consumption, is common among the locations under the free migration assumption, the following relation holds:

$$\frac{dU(x,h,a)}{da}=0\,. \tag{22}$$

That is, if people migrate to another location with a different level of the amenity factor a, then the same utility level is attained, thereby maintaining the utility level. Total differentiation of Eq. (22), with $\partial U/\partial h \big/ \partial U/\partial x = r$ and slight rearrangement, yields

$$\frac{\partial U/\partial a}{\partial U/\partial a}d\alpha+\frac{\partial x}{\partial a}da+r\frac{\partial h}{\partial a}da=0\,, \tag{23}$$

where r is the land rent and the price of composite good x is 1.

The budget constraint is represented as $w = x + rh$, where w signifies income. Using this equation, differentiating the budget constraint with respect to *a* gives

$$\frac{\partial w}{\partial a}da = \frac{\partial x}{\partial a}da + r\frac{\partial h}{\partial a}da + h\frac{\partial r}{\partial a}da = 0, \tag{24}$$

where we assume that $\frac{\partial w}{\partial a} = 0$, whereas the original Pines and Weiss paper does not assume this. Combining Eq. (23) and Eq. (24) yields

$$0 = h\frac{\partial r}{\partial a}da - \frac{\partial U / \partial a}{\partial U / \partial x}da. \tag{25}$$

Pines and Weiss (1976) state that Eq. (25) is used for measuring the willingness to pay for amenities[6], $\partial U/\partial a \big/ \partial U/\partial x$. We summarize this result as the Pines and Weiss proposition.

Pines and Weiss (1976)'s Proposition (the cross-sectional approach). *If people migrate freely among locations, then the change in land rents, and the willingness to pay for the marginal change in the amenities are as shown in Eq. (25). Consequently, if one obtains data on the land consumption and land rents, then the willingness to pay for amenities is calculable based on Eq. (25).*

The first term of the right-hand side of Eq. (25) is the lot size multiplied by the change in land rent; the second term is the willingness to pay for the marginal change in amenity. The composition is the same as Eq. (15a) and (15b) derived in our dynamic case.

Pines and Weiss (1977) assume that there is only one amenity, but the rent cannot be explained by only one amenity in a real city. So, extending to many amenities, we obtain

$$0 = h\frac{\partial r}{\partial \mathbf{A}} \bullet d\mathbf{A} - \frac{\partial U / \partial \mathbf{A}}{\partial U / \partial x} \bullet d\mathbf{A}, \tag{25'}$$

[6] This equation corresponds to the equation above eq. (21) on page 10 in Pines and Weiss. Actually, their main target is not to obtain this equation. Their target is to obtain the social benefit function, which is expressed by eq. (20) in their paper.

where • expresses inner product, and the variables before and after • are in a vector.

Eq. (25') is based on the cross-sectional changes. For the time-series changes, the level of the utility can change, whereas the cross-sectional hedonic approach presumes a common utility level across locations. Figure 2 expresses the relation between a cross-sectional change, a time-series change, and a difference in differences. In a cross-sectional change, because of free migration at time *t*, the level of the utility does not change even if people migrate to another location (i.e., location *i* to *j*). This implies that the increase in a utility-enhancing amenity increases the land rent to maintain the constant utility. In a time-series change, the utility can change for various reasons, including a change in amenity. In a difference-in-differences case, the increase in the level of the equilibrium utility from time *t* to time *t'* (i.e., $V(t')$-$V(t)$) is constant over different amenities because of free migration (i.e. Assumption 1).

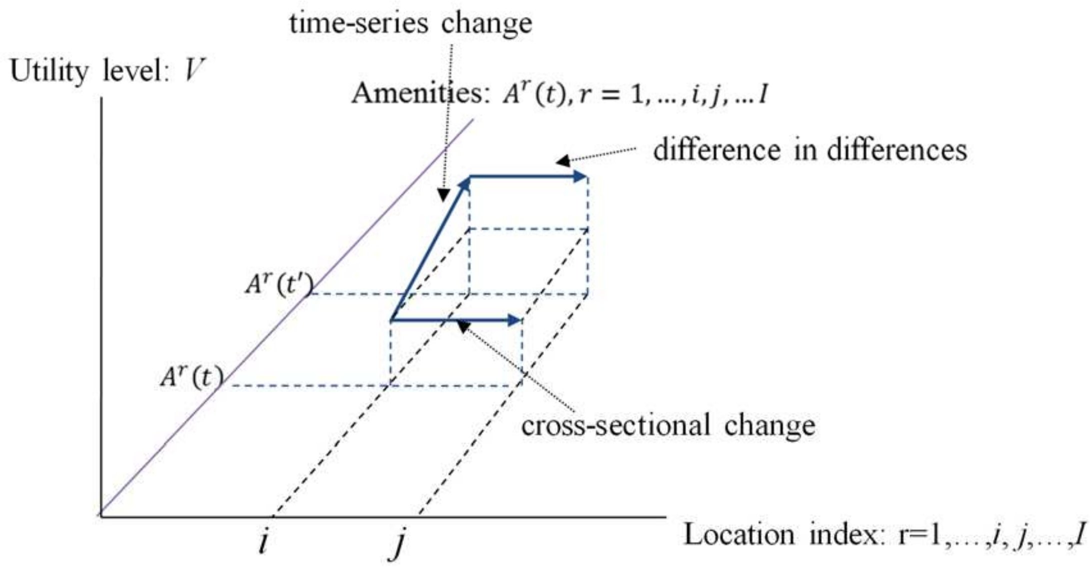

Figure 2 Traditional cross-sectional approach and our proposed approach

4.2 Advantages and disadvantages of the proposed approach

The cross-sectional approach demands the use of data for all local amenities, such as landscape characteristics and geographical characteristics (e.g., the existence of a nearby train station or parks) because cross-sectional differences in land rent are explained using cross-sectional differences in all local amenities. Our proposed approach requires no data that do not change in a time-series because such unchanging amenities contribute nothing to any utility change that occurs in a time series. Many local amenities such as landscape characteristics (existence of nearby rivers), the existence of nearby train stations, and positioning in relation to roads do not change during a certain time. Since the proposed approach need not consider such amenities, it might require less data than the cross-sectional hedonic approach.

This difference in the required data from the cross-sectional approach generates two advantages: 1) data on amenities that have not changed need not be collected, and 2) in estimation of parameters, fewer amenities are used as explanatory variables in the proposed approach than in the cross-sectional approach.

Advantage 1) is important when an analyst cannot obtain detailed data on the target areas. This lack of data often occurs because the number of attributes of each location is essentially vast. Indeed, some local environmental factors (e.g. atmosphere) cannot be collected as quantitative data, or the analyst may unintentionally ignore the difference in such local factors if they check only documented data. Actually, it is hard for analysts to visit all the points they use as data. Accordingly, it is normal to estimate hedonic price functions, ignoring some undocumented amenities. In that case, our approach, requiring only time-series-changing amenity data, has an advantage because such factors may be constant over some time interval.

Advantage 2) can be explained as follows. Cross-sectional hedonic regressions often exhibit a multicollinearity problem in the estimation of the land rent function because it uses all amenities, such as the landscape character, as explanatory variables. In contrast, the proposed approach requires no data that do not change in a time series. Accordingly, this parsimony of explanatory variables often prevents multicollinearity problems, which is a great benefit. On the other hand, the proposed approach cannot measure the value of amenities that are dropped from the cross-sectional approach. However, this point presents no problem because a cost–benefit analysis need not measure unchanging amenities.

The proposed approach, however, has a restriction: it necessitates either the measurement of the marginal utility of income or the assumption of equal marginal utility of income among locations (e.g. quasi-linear utility function or maximization of the social welfare over the whole city through some policies.)

Although many time-series-unchanged amenities exist, amenities that change similarly over the whole area can also be found. Examples of such amenities are the effects of global warming and changes in interest rates. If the time-series change in such global amenities similarly affects the utility of individuals over the whole area, then we need not consider them because their effects are distributed equally. This advantage is shared with other difference-in-differences approaches. Consequently, the proposed approach requires fewer data than the cross-sectional hedonic approach does.

As described above, the proposed approach presents advantages and disadvantages. Agents conducting a cost–benefit analysis should choose the method from among established methods (e.g., contingent valuation method, travel cost method…) while comparing the advantages and disadvantages for their given situation. The proposed approach can be considered as an additional option or as a supplement to other methods.

5. An illustrative application of the proposed approach

This section presents the application of the proposed method to an esthetic project as an illustration to demonstrate its procedures concretely. We apply the approach to empirically estimate the willingness to pay for utility line undergrounding in residential areas, which is a neighborhood amenity, in the Tokyo metropolitan area. Undergrounding projects are proceeding worldwide, although there are many regions (e.g., European capital cities) without utility lines on roads. In particular, Japanese cities' undergrounding rates are very low[7].

[7] For example, the rate in the 23 special wards of Tokyo is 7%, and that in the municipality of Osaka is 5%. Undergrounding rates are still low in developed as well as developing countries. While large cities have high undergrounding rates in Europe, some countries as a whole have low rates (e.g., 83% in the UK, 39%

The purpose of this empirical research is to show the analysis procedure and to highlight the advantages and the disadvantages of the method. For that purpose, we compare the conventional method and our method in terms of estimation process and estimation results. Note that our main purpose is not to measure accurate value of the willingness to pay for utility line undergrounding, although the estimates we obtain are statistically significant. Indeed, there are some limitations of this empirical research as follows.

First, the land prices we used[8] are prices assessed by governments, although these prices are used very widely, including in many hedonic studies (e.g., Kanemoto and Nakamura, 1986; Kanemoto et al., 1996; Nakagawa et al., 2009; Tabuchi, 1996). As Nakagawa et al. (2009) explain, the land price data is assessed by the certified real estate appraisers. The real estate appraisers usually pay attention to market prices quoted in the neighborhood in assessing these land prices; in this sense, the market assessment of environmental factors may be reflected in the Koji-Chika data. Ideally, we need actual land price data. Secondly, undergrounding lines involves associated amenity changes such as road and sidewalk widening and tree planting. We do not obtain information about which associated-amenities changed and how, because they are not described in government reports. Lastly, we need lot sizes to calculate WTP as shown in eqs. (25) and (26). But there are no available data on lot sizes. So, we use building areas instead of lot sizes. The lot size includes areas other than the building area, such as a garden, which would increase the value of WTP. However, the real WTP and our calculated WTP are roughly correlated because the building coverage ratio does not differ much across buildings. Note that these limitations are not critical problems for our purpose.

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in France and 33% in Italy based on the length of a distribution circuit of 1kv, according to Eurelectric., 2013).

[8] We use the data of ‘road rating (valuation for inheritance tax)’, not ‘road rating (valuation for fixed asset tax)’. These are assessed by the national tax agency and by municipal governments, respectively, using the same method. There is a possibility that land appraisal for fixed asset tax might be biased because the municipal government has an incentive for over-or-under estimation for various reasons. The sample size of road rating for inheritance tax is enough for our analysis.

5.1 Estimation target

Utility line undergrounding is a public project for the purpose of providing safe and comfortable pedestrian space, improvement of urban landscape, improvement of disaster prevention capability[9] and smooth traffic. Wires have been buried by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT, hereafter) under projects starting in 1986 all over Japan. However, the rate of undergrounding utility lines in Japanese cities is still low. The rate of undergrounded utility lines on roads is 10% in Sapporo, 30% in the Tokyo metropolitan area, and 14% in Kyoto[10] according to the MLIT (2014).

5.2 Data

We use the data of land prices, R^i from the data of 'road rating (valuation for inheritance tax)' which are obtained from the Research Center for Property Assessment System. This data defines a 'road' as a road between two intersections, and it is appraised at almost every road in urban areas so that most undergrounded points can be used for estimation. Since 1994, the assessors have been mandated to produce the values which are 80% of the values of the land market value publication. Thus, we need to divide the WTP estimated by 0.8 to adjust the scale and derive the market value.

We use the data of land prices r^i and land consumption h^i in 2015, 2009, and 2003. We converted the nominal land prices into real prices (2015 prices) using the GDP deflator by dividing the 2009 data and the 2003 data by deflator 1.0088 and 1.0642. For our method, we use all the data, and for the traditional cross-sectional analysis, we use only 2015 data.

Our target is the residential areas in the Tokyo metropolitan area. Considering the

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[9] When a big earthquake occurs, electric wires and poles fall down on to roads. This prevents the area from quickly recovering from the disaster.

[10] Compared to these Japanese rates, cities in other countries have much higher rates. For example, Hong Kong has 100 %, Seoul has 46%, Paris and London have 100%, and New York has 83%, according to the documents issued by the MLIT (2014).

locations of undergrounded lines, we target Tokyo, Kanagawa, Saitama and Chiba prefectures. In addition, we only use the data of cities or wards which have implemented undergrounding projects. The target cities and wards are Chiyoda, Chuo, Minato, Shinjuku, Bunkyo, Koto, Shinagawa, Meguro, Nakano, and Toshima wards in Tokyo; Tsurumi, Kanagawa, Naka, Isogo, Kanazawa, Totsuka, Aoba, Nakahara, Takatsu wards in Kanagawa; Chuo, Hanamigawa, Inage, Wakaba, Mihama wards and Ichikawa city in Chiba; Kita, Chuo, and Minami wards, Kawagoe, Kawaguchi, Tokorozawa, Kasukabe, and Sakato cities in Saitama.

The number of lines undergrounded during the target period (2003-2015) in the target area is 53. The number of lines undergrounded from 2003 to 2009 is 11, and the number from 2009 to 2015 is 42. Furthermore, in order to eliminate the effects of outliers, we exclude the top 5% and the bottom 5% of land prices. We show the number of roads with undergrounded utility lines (abbreviated as UGUL in the Tables) and that in the neighborhood in Table 1. It shows the descriptive statistics on land price for analysis 1 and analysis 2 (1000 JPY). The average increase in the land prices in the areas with undergrounded lines is about 30,000 JPY per square meter from 2003 to 2015, whereas that in the areas without undergrounding projects is about 15, 000 JPY per square meter. So, the undergrounding projects increase the land prices on average.

Undergrounding utility lines may have spatial spillover effects. The effects are composed of esthetic benefits, improved traffic flow, and increased safety in disaster situations. From the esthetic viewpoint, residents walk in their neighborhood so might enjoy the roads with undergrounded lines. From the viewpoints of traffic flow as well as safety in disaster situations, residents use the roads with undergrounded lines.

To capture such neighborhood benefit, we define ‘the roads in the neighborhood not facing roads with undergrounded lines’ as the roads which at least partly lie within 50 m of the roads with undergrounded lines. Note that these neighboring roads do not include the road with undergrounded lines. We call this area ‘the neighborhood’.

Our approach does not have to consider amenities that do not change, (e.g. river). We chose newly opened train stations (within 1 km) and highway interchanges (within 5 km) as dynamically changeable amenities. But the parameters of the train stations and highway interchanges are not statistically significant.

Table 1 Data Summary

(Unit: 1000 JPY excluding sample sizes)

Group or Variable	Statistics	Year		
		2003	2009	2015
Undergrounded utility lines (UGUL) undergrounded from 2003 to 2015	Mean	209	241	239
	Median	155	173	170
	Standard deviation	93	122	123
	Sample size (lines)	53	53	53
Neighborhood of UGUL	Mean	157	169	164
	Median	146	154	150
	Standard deviation	45	60	60
	Sample size (lines)	170	171	171
Control (without UGUL)	Mean	189	211	204
	Median	164	173	170
	Standard deviation	73	103	100
	Sample size (lines)	32132	32401	32409

For the traditional cross-sectional hedonic approach, we use data on the nearest station, elementary school, clinic, hospital, and park, and whether a road is narrow, medium, or wide, and other factors. Furthermore, we set the area dummy as location-specific fixed effects of each area. All the explanatory variables are shown in Table A1 in Appendix 2.

5.3 Estimation

Under the assumptions described above, Eq. (21) is the measurement formula. We specify Eq. (21) in the following two manners. Specification 1 specifies the effect of undergrounding utility lines and nearby undergrounding lines as constant values. Specification 1 considers both time-fixed effects and local-fixed effect, which are adopted often in a standard difference-in-differences approach. However, as shown in Table 1, the number of undergrounded points is small. So, the undergrounded points may not have been randomly chosen[11]. To reflect this, dividing all the sample data into 10 quantiles according to the 2009 land prices, we consider a different time-fixed effect for each decile[12]. This is Specification II.

Our model

Specification I:

$$\frac{1}{n^i} P^i(T) = B_i + \left(\alpha_{2015} + \alpha_{2009}\right) + \sum_k \beta_k \cdot (\delta^i_{k2003-2009} + \delta^i_{k2009-2015}) + \varepsilon^{it} \qquad (26a)$$

Specification II:

$$\frac{1}{n^i} P^i(T) = B_i + \sum_{q=1}^{10} \left(\alpha_{2015,q} + \alpha_{2009,q}\right) + \sum_k \beta_k \cdot (\delta^i_{k2003-2009} + \delta^i_{k2009-2015}) + \varepsilon^{it} \qquad (26b)$$

where B_i is the fixed effect term, α_t in Specification I represents the fixed-time effect term for year *t*, $\alpha_{t,q}$ in Specification II represents the fixed-time effect term for year *t* and decile *q*, β_k are parameters for amenity *k* which dynamically change. $\delta^i_{k t_a - t_b}$ is a dummy variable expressing a change in amenity *k* from t_a to t_b, including whether nearby utility poles are removed or not. In particular, ε^{it} is an *i.i.d.* error term.

The two specifications reflect the situation of the current target. Note that original measurement Eq. (21) can be more flexible. In the above two specifications, we assume a common β_k across the two time intervals. The willingness to pay for amenities can change over time. If we assume different values of β_k in different time intervals, we can identify the

[11] The Tokyo Olympic is determined in September of 2013. After this, Tokyo promotes undergrounding projects. Our latest data is 2015. We use the date of the completion of undergrounding projects. Because it takes time to complete the projects, our data is not affected by the determination of the Tokyo Olympic.

[12] In difference-in-differences approaches, parallel trends are often verified in data. However, in our cases, it is impossible to check this because data earlier than 2009 cannot be obtained in text which can be identified by computers. So, instead of this parallel trend verification, we used the time-fixed effects for each quantile. If undergrounding points are chosen according to land rents, this can avoid a relevant bias in the estimation.

change in the willingness to pay. However, we did not set different β_k this time because the number of undergrounding cases is not large. So, estimated β_k can be interpreted as average willingness to pay for amenities over time. In addition, although Eq. (21) can allow explanatory variables to be continuous variables, the explanatory variables in the current case are only dummy variables (i.e., 1 or 0).

To compare our approach with the conventional cross-sectional hedonic approach, we measure the benefit of undergrounding utility poles, using the cross-sectional approach. The conventional cross-sectional approach is set as

$$r^i\left(T, \mathbf{A}_1\right) = \gamma_0 + \sum_k \gamma_k b_k^i + \varepsilon_C^i \quad (27)$$

where γ_0 is a constant, and γ_k is the parameter for amenity *k*. b_k represents the level of amenity *k*, and ε_C^i represents an *i.i.d.* error term.

We estimate parameters in Eq. (26) and Eq. (27) by application of ordinary least-squares regression analysis. But the parameters of Eq. (26) are estimated after the within transformation.

5.4 Results

Estimates using our method are shown in Table 2. The estimated parameters of Eq. (26) are statistically significant (undergrounded areas parameter, p=0.1%; neighboring areas parameter, p= 1.0).

Table 2a. Estimation of Eq. (26) in Specification I

	Coefficient	Standard Error	t-value	Pr(>|t|)	Significant level
Undergrounded areas	1049955	176005	5.97	2.45E-09	***
Neighboring areas of undergrounded lines	289255	97759	2.96	3.09E-03	**
Individual fixed effects				Yes	
Economic trend (Pref. Year dummies)				Yes	
Adjusted R-squared (full)			0.9923		

Note: +, *, **, *** indicate significance at the 10%, 5%, 1%, and 0.1% levels, respectively.

Table 2b. Estimation of Eq. (26) in Specification II

	Coefficient	Standard Error	t-value	Pr(>|t|)	Significant level
Undergrounded areas	962456	165407	5.82	5.96E-09	***
Neighboring areas of undergrounded lines	270640	92050	2.94	3.28E-03	**
Individual fixed effects				Yes	
Economic trend (Pref. Year dummies)				Yes	
Heterogeneous time trend (Price quantile * Year dummies)				Yes	
Adjusted R-squared (full)			0.9931		

Note: +, *, **, *** indicate significance at the 10%, 5%, 1%, and 0.1% levels, respectively.

The willingness to pay can be represented basically by the parameter of the target amenity in the proposed method. In our case, dividing the estimated parameters by 0.8, which is the conversion rate of the real prices and the data prices, we can estimate the willingness to pay for utility line undergrounding, as shown in our theoretical section The willingness to pay for undergrounding the utility lines in the front of the home is approximately 1.32 million JPY[13]. That in the neighborhood of undergrounded lines is approximately 0.37 million JPY. These are stock values. Using the discount rate 0.25%, which is the geometric average value of the 10-year Japanese national bond yields from 1990 to 2014, we can calculate the willingness to pay per month. Those values are shown in the lower line in Table 3.

Table 3. Willingness to pay for utility line undergrounding based on Eq. (26)

	Undergrounded areas	Neighboring areas of undergrounded areas
Specification I		
WTP per household (million yen)	1.31	0.36
WTP per household per month (yen)	2734	753
Specification II		
WTP per household (million yen)	1.20	0.34
WTP per household per month (yen)	2506	705

Note: 1$ ≈ 100 yen.

[13] As we have already explained, when calculating WTP in our paper, the lot size is replaced by the building area dues to data constraint. So, the exact WTP is larger than those in Table 3.

Estimates of the parameters based on the conventional cross-sectional hedonic approach are presented in Table 4. Adjusted R-squared is reasonably high, and most of the explanatory variables are statistically significant at a level of 1%. Using the measurement function Eq. (25), we can calculate the willingness to pay in the case of the cross-sectional analyses. The lot size is required to calculate this[14]. In our case, the median value is used.[15]

Table 4. parameter estimation - cross-sectional approach

	Coefficient	Standard Error	t-value	Pr(>|t|)	Significant level
Undergrounded areas	26975	3830	7.04	1.91E-12	***
Neighboring areas of undergrounded lines	7270	2358	3.08	2.05E-03	**
Other explanatory variables		(See the Appendix for the values)			
Adjusted R-squared			0.908		
WTP per household one time (million yen)			1.35		

Note: *, **, *** indicate significance at the 5%, 1%, and 0.1% levels, respectively. Estimated parameters of the other explanatory variables are shown in Appendix 2 with the statistics.

The estimate in the cross-sectional hedonic approach is 1.35 million yen (=26,975(yen/m^2)×median per-household building area 49.95(m^2)) per household in terms of stock value. The estimates with the proposed method (1.31 million in Specification I, and 1.20 million in Specification II) is very close to this (1.35 million). In other words, the conventional hedonic approach and our difference-in-differences approach yield similar results.

As we have already shown in the theoretical section, the number of explanatory variables in our proposed method is smaller than that in the conventional cross-sectional hedonic approach. This implies that the possibility of multicollinearity can be reduced in the proposed

[14] As we have already explained, when calculating WTP, the data of building area is used instead of lot sizes due to data constraint. So, the exact WTP is larger than those in Table 4.

[15] We can use the average value. However, an economic value usually includes excess values, so the average value usually is greater than the median. In the case of lot sizes, some rich people have very large lot sizes. This value does not necessarily reflect the normal condition. So we use the median. However, the average lot size in this area is . So, the result will not change much.

method.

We compare the levels of estimates of our method with those in a previous paper. McNair and Abelson (2010) estimate the willingness to pay for undergrounding nearby utility lines[16] using the conventional hedonic approach, using the data of Canberra. Their estimates per household in terms of stock values is \$12,350 (=1.30 million yen with the 2014 average exchange rate of 106 yen/\$). Our estimates in the three methods are about 1.31, 1.20 and 1.35 million yen. These values are very similar to McNair and Abelson's estimation. But, to calculate our willingness to pay, we use building sizes instead of lot sizes. The lot size is larger than the building area. So, if we used the lot size to calculate the WTP, our estimates would be larger. This difference arises first from the differences between road conditions in Japan and Australia. For example, the visual impact of electric wires in Japan is greater than in Australia because roads in Australia are wider than roads in Japan, and the percentage of the field of view occupied by electric wires in Australia is far less than in Japan. In addition, projects of undergrounding utility lines involve refurbishing roads and sidewalks and often involves widening sidewalks and planting street trees.

6 Conclusion

This paper presents a theoretical method to estimate the value of amenities. Using the spatial economy's property of common dynamic changes in the utility across locations, we derive a formula to estimate the willingness to pay for amenities using panel data. The advantages of the proposed approach over the conventional cross-sectional approach are savings related to data collection and the increased possibility of avoiding multicollinearity problems arising from parameter estimation. Although a cross-sectional hedonic approach should factor in all the geographically different amenities to explain the rent differences, some local

[16] McNair and Abelson (2010) do not define the affected area of undergrounding utilities in terms of distance from residential houses. However, judging from their maps in the paper, the affected areas are defined as blocks in the immediate vicinity of the residents' homes.

environmental factors (e.g. atmosphere) cannot be collected as quantitative data. Our approach, requiring only time-series-changing amenity data, has an advantage if such local factors are constant over time. However, a key restriction is that either the measurement or the assumption of marginal utility of income is necessary for provision of correct measures.

Every cost–benefit analysis method (e.g. contingent valuation method (CVM), travel cost method) has advantages and disadvantages. The method should be chosen depending on the situation. The proposed method presents one such option. Alternatively, a combination of this method with another method (e.g. CVM) might be useful.

This paper presents one illustrative application of the proposed method. The method is applicable to the measurement of values of any amenity associated with the land: environmental factors such as natural environment and landscape, and public infrastructure such as parks. Additional applications are necessary in future to ascertain more broad applicability of the proposed method.

Appendix 1

We first arrange Eq. (9) to eliminate an unobservable term, $V^i\left(T,\mathbf{A}_1\right)-V^i\left(T,\mathbf{A}_0\right)$. Among locations i that have a positive population, i.e. $N^i>0$, we select one location. Without loss of generality, assuming that location I is selected by presuming that for $N^I>0$, we have

$$V^i\left(z,\mathbf{A}_1\right)-V^i\left(z,\mathbf{A}_0\right)=V^I\left(z,\mathbf{A}_1\right)-V^I\left(z,\mathbf{A}_0\right) \text{ for any } i\in\{1,2,...,I-1\}, \quad \text{(A1)}$$

if Assumption 1 holds. This expresses that the increase in the level of the utility associated with a change in amenities from $\mathbf{A}_0$ to $\mathbf{A}_1$ is equal among locations $i\in\{1,...,I\}$ whether the area, which comprises all locations $i\in\{1,...,I\}$, is open or closed (i.e., whether or not free migration can occur between the target area and other areas).

Under Assumption 1, we can eliminate the unobservable term, $V^i\left(T,\mathbf{A}_1\right)-V^i\left(T,\mathbf{A}_0\right)$, by calculating the difference in this term between location i and location I as

$$V^i\left(T,\mathbf{A}_1\right)-V^i\left(T,\mathbf{A}_0\right)-V^I\left(T,\mathbf{A}_1\right)+V^I\left(T,\mathbf{A}_0\right)=0$$

$$=\sum_{t=T}^{\infty}\int_{\mathbf{A}_0}^{\mathbf{A}_1}\rho^{-t}\frac{\partial V^i\left(T\right)}{\partial r^i\left(t\right)}\frac{\partial r^i\left(t\right)}{\partial \mathbf{A}\left(t\right)}\bullet dA^i\left(t\right)+\int_{\mathbf{A}_0^i}^{\mathbf{A}_1^i}\frac{\partial V^i\left(T\right)}{\partial \mathbf{A}^i}\bullet d\mathbf{A}^i \tag{A2}$$

$$-\left(\sum_{t=T}^{\infty}\int_{\mathbf{A}_0}^{\mathbf{A}_1}\rho^{-t}\frac{\partial V^I\left(T\right)}{\partial r^I\left(t\right)}\frac{\partial r^I\left(t\right)}{\partial \mathbf{A}}\bullet dA^i+\int_{\mathbf{A}_0^I}^{\mathbf{A}_1^I}\frac{\partial V^I\left(T\right)}{\partial \mathbf{A}^I}\bullet d\mathbf{A}^I\right)$$

for any location $i\in\{i=1,2,...,I-1:N^i\left(t\right)>0\}$.

Second, we arrange Eq. (A2) to eliminate another unobservable term, $\frac{\partial V^i}{\partial r^i\left(t\right)}$, using Roy's identity. To use Roy's identity $h^i\left(t\right)\equiv\frac{\partial V^i\left(T\right)}{\partial r^i\left(t\right)}\Big/\frac{\partial V^i\left(T\right)}{\partial W^i}$, we arrange Eq. (A2) using $\frac{\partial V^i\left(T\right)}{\partial W^i}$ and $\frac{\partial V^I\left(T\right)}{\partial W^I}$ to yield Eq. (10).

Appendix 2.

Table A1 shows a detailed version of the parameter estimation shown in Table 4.

Table A1. Parameter estimation for the cross-sectional approach

Variables		Coef.	Std. Error	t-value	Pr(>|t|)
Undergrounded areas		26974.7	3829.667	7.04	1.91E-12
Neighboring areas of undergrounded lines		7269.65	2357.767	3.08	0.002049
(Intercept)		180562	2878.117	62.74	0
Distance to	the main station	-2.5763	0.121	-21.34	2.2E-100
	the nearest station	-27.013	0.437	-61.79	0
	the nearest bus stop	13.498	1.534	8.80	1.42E-18
	the nearest elementary school	-5.7649	0.913	-6.31	2.76E-10
	the nearest junior high school	-12.565	0.587	-21.40	6.4E-101
	the nearest clinic	-31.156	1.405	-22.18	3.5E-108
	the nearest hospital	-3.8691	0.440	-8.80	1.49E-18
	the nearest post office	-17.257	0.899	-19.20	1.14E-81
the existence of a nearby park		24389	2482.283	9.83	9.43E-23
New towns developed after 1976		306.95	979.395	0.31	0.753973
New towns developed before 1976		707.383	693.599	1.02	0.307797
Landscape planning area		8838.29	723.252	12.22	2.88E-34
Narrow road		-	-	-	-
Medium road		7293.38	443.8948	16.4304	2.03E-60

Wide road	15632.8	2356.939	6.63266	3.35E-11
Local fixed effects	omitted			
Sample size	32633			
Adjusted R-squared	0.908			

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