Multidimensional Green Values: A Case of Green Condominiums with Longer Life Spans*

July 10, 2013

BY JIRO YOSHIDA† AND AYAKO SUGIURA‡

Abstract

This paper analyzes the transaction prices of green buildings when green factors are multidimensional. We develop a present value model that demonstrates that green buildings can have lower market values than similar non-green buildings depending on the green factors. In particular, if a green building has a higher life-cycle cost and a longer economic life, the initial green premium can be negative but becomes positive as the building ages. We empirically confirm this prediction using data on green condominiums in Tokyo, which are designed to have a longer economic life. We also find that some green factors are associated with price discounts. Although the long-life design is associated with a price premium, energy saving, water recycling, the use of eco-friendly materials, and renewable energy are associated with discounts.

(*JEL*: Q51, R21, R31).

Key words: sustainability, green buildings, hedonic pricing, property price, residential real estate, Japan

* We thank John Quigley, Piet Eichholtz, Nils Kok, Austin Jaffe, Brent Ambrose, Ed Coulson, Jenny Schuetz, Kerry Vandell, Patrick McAllister, Erin Mansur, James Conklin, Moussa Diop, Sun Young Park, and the participants of seminars at the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT), the AREUEA Denver conference, and the Berkeley-Maastricht Conference on Green Buildings for their comments. We also thank members of the Tokyo Association of Real Estate Appraisers for their valuable comments and support in configuring data. We gratefully acknowledge the MLIT grant that has supported this research.
† Corresponding Author. The Pennsylvania State University, 368 Business Building, University Park, PA 16802, USA. Phone: 814-865-0392, Fax: 814-865-6284, Email: jiro@psu.edu
‡ Tokyo Association of Real Estate Appraisers, 1-1 Ichigaya Motomura-Cho, Shinjuku, Tokyo 162-0845 Japan. sugiura@ogata-office.co.jp

I. Introduction

Green buildings are buildings with superior environmental performance. Because roughly 40 percent of total CO_2 emissions are generated by real estate in many countries, interest in energy-efficient buildings has increased in recent years.[1] However, green factors are not limited to energy efficiency. Major green labels define green buildings by various sustainability factors. For example, the Leadership in Energy and Environmental Design (LEED) in the United States and the Tokyo Green Building Program (TGBP) have constructed comprehensive measures of the environmental quality of real estate (see appendix A for the list of green factors in the TGBP).[2]

An important question concerning green buildings is whether and how their "greenness" is priced in the market. If green buildings, or at least some green factors, are associated with a large price premium, they serve as an economic incentive for the supply of green buildings in addition to incentives from corporate branding and social responsibility.

There are three potential sources of value premiums in green buildings. First, green technologies may reduce user costs. For example, better heat insulators and more energy-efficient equipment reduce operating costs for the property owner. The reduced user costs result in a high price if supply is not perfectly price elastic. Second, public policy programs can provide subsidies or tax incentives to reduce user costs. The building price reflects both current and expected future policies. Third, green buildings may provide higher utility or profits to the user. Tenants of commercial buildings may pay higher rents if the use of green buildings is an important part of their corporate social responsibility strategy. Homebuyers may also pay higher prices if they are more satisfied with green residential units.

Conversely, green technologies can result in a value discount. Although energy-efficient equipment reduces operating costs, if its replacement costs are high, the total

---

[1] For example, see Architectural Institute of Japan (2000).

[2] Comprehensive measures are also adopted by other major green labels such as the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in Japan and the BRE Environmental Assessment Method (BREEAM) in the UK.

life-cycle cost of the equipment for a potential owner can be higher. Similarly, other green technologies such as the use of recycled materials and water recycling can increase maintenance costs. If policy incentives and the pride of owning a green property are not strong enough, the potential owner would only be willing to pay a lower price for the property by subtracting the incremental life-cycle cost of the equipment. Even in this case, developers can still accept the price discount if the benefits derived from corporate branding are large.

In this study, we examine how different green factors are valued in real estate markets. We first construct a theoretical model to value green buildings and then empirically examine the transaction price of green condominiums in Tokyo. Our study is one of the first to present heterogeneous prices of various green factors. We find that the value of green buildings varies greatly depending on green factors.

In our model, we define the value of a building as the present value of net service flows. We allow green buildings to have different costs and benefits depending on their green factors. In particular, we show that a green building with a lower life-cycle cost for the owner is priced higher than a comparable non-green building throughout its life. In contrast, a green building with a higher life-cycle cost and a longer economic life can be initially priced lower but eventually priced higher than a comparable non-green building.

We empirically confirm this prediction. We employ hedonic regressions with fine controls for locational heterogeneity, a similar empirical strategy to that of Eichholtz, Kok, and Quigley (2010). The transaction price of a green condominium is initially lower than that of a non-green condominium after controlling for relevant characteristics. However, depreciation rates are lower for green buildings than for non-green buildings. As a result, after two years, the transaction price of a green condominium is higher than that of a comparable non-green building.

We further investigate whether green factors (see appendix A) affect property prices differently. Overall, long-life design[3], mitigation of the urban heat island

[3] The long-life design of a building is an architectural design that results in a longer economic life of the building through easier renovations and conversions. Commonly adopted technologies include a skeleton-infill separation, the use of modular units, double ceiling and floor, and high strength concrete.

phenomenon[4], planting, and the reduction of thermal loads are associated with positive price differences. In contrast, energy saving, water recycling, the use of eco-friendly materials, and the use of renewable energy are associated with negative price differences. However, while the majority of green buildings include long-life designs, they do not include anything special with respect to energy saving or the use of renewable energy. Japanese green buildings are characterized by long-life designs rather than energy efficiency.

Our explanation for the price difference is based on the capitalization of future user costs. A long-life design reduces an owner's life-cycle costs by facilitating maintenance, renovation, and conversion. According to an engineering study, the benefit of long-life design is as large as a 38 percent reduction in life-cycle costs in Japan, where the average life of a residential building is only 26 years.[5] In contrast, the use of eco-friendly materials, energy-efficient equipment, and water recycling will increase future maintenance expenses and capital expenditures. The high standards of Tokyo Green Building Program (TGBP) regarding these factors likely increase an owner's total life-cycle costs. For example, a water heater that meets a high energy-efficiency standard will cost more than twice as much as a standard heater. Eco-friendly materials such as mortar with recycled aggregate are significantly less durable. A water recycling system for a small building is four times more costly than public sewage services. These future benefits and costs are capitalized into the initial price of a condominium.

A price discount indicates that positive price factors such as policy incentives and homeowners' willingness-to-pay for greenness do not make up for the increased life-cycle cost. Nevertheless, developers may find it reasonable to build green condominiums for reasons of corporate branding and corporate social responsibility. Green corporate branding can help a developer win more businesses and achieve greater economies of

[4] The urban heat island is a phenomenon where the temperature is higher within a metropolitan area than in its surrounding areas. It is caused by the heat accumulated in concrete and the waste heat from human activities. It can be mitigated by covering roofs and walls with plants, water, or high-reflectivity coating and designing wind flows.

[5] The life-cycle cost estimate is provided by Komatsu (2010). The average life is provided by the National Infrastructure Council of Japan, January 2008.

scale. The developer can cross-subsidize the green development with overall gains. That major, well-known developers tend to supply green buildings supports this view.

Our finding does not contradict but rather complements the price premiums reported in previous studies. Our theoretical model predicts that a lower operating cost of a green building will result in a price premium, and a higher operating cost will result in a price discount. Because designated green factors are not uniform across countries, green value should depend on the specifics of green buildings. A Japanese green building has a longer economic life than a normal building, but it is costly to maintain. Green buildings in European countries and in the U.S. have normal life spans but likely have lower life-cycle costs. This study broadens our perspective on the value of green buildings by demonstrating that a result for a particular property type and country cannot be simply generalized.

This paper is organized as follows. Section II is the review of related literature. In Section III, we introduce our present value model of green buildings. In section IV, we summarize the data on transaction prices and green building factors used in the study. Section V presents the empirical analysis and a discussion of the results. Section VI concludes the study.

II. Literature

The majority of case studies and research reports on green buildings are non-academic in nature, often framed from an engineering perspective. These studies typically focus on cost issues rather than on values. For example, California's sustainable building task force (2003) presents case studies of 33 buildings on the technical aspects of green buildings. The Urban Land Institute has published a number of books on green buildings regarding their construction and operation costs.

Some industry studies address the values of and returns on green buildings (e.g., Smith, 2007; Nelson, 2007, 2008, 2009; Turner and Frankel, 2008). Although they report positive results on green building investments, the research methodologies are not necessarily satisfactory.

There are a growing number of academic studies on the economic value of green buildings. Laquatra (1986), Dian and Miranowski (1989), and Gilmer (1989) are early studies that report that energy efficiency leads to a higher residential price. More recently, Brounen and Kok (2011) report that an energy-saving label in the Netherlands is associated with an approximately 3 percent price premium after controlling for location and building quality. Price premiums for residential green buildings are also reported in the U.S. (Aroul and Hansz, 2012; Dastrup et al., 2012), Singapore (Deng et al., 2012), and China (Zheng et al., 2011, 2012). Regarding Japanese green buildings, Yoshida, Quigley, and Shimizu (2010) employ a different set of data and analyze how the asking prices of new condominiums are associated with itemized scores on the Tokyo Green Labeling System for Condominiums (TGLSC) and CASBEE. They find that developers add a 4.7 percent premium to the asking prices of newly constructed green condominiums. They also study transaction prices but the number of observed transactions is quite small.

Regarding commercial buildings, several studies report premiums for rents and property prices while others report no evidence of premiums. Eichholtz, Kok, and Quigley (2010) study US office markets using data from Energy-Star and LEED. They find an approximately 3 percent rent premium for 694 green office buildings after controlling for differences in quality and location. Miller et al. (2008) find no rent premium but a 6 to 10 percent premium on transaction prices. Pivo and Fisher (2010) and Fuerst and McAllister (2011a) also use the US data and report small rent premiums and relatively large price premiums. Although LEED is a comprehensive evaluation system for green buildings, these authors do not provide analysis of itemized effects. In contrast, Fuerst and McAllister (2011b) use UK commercial property data and find no evidence of premiums for rents or property values. Jaffee et al. (2011) use US commercial property data and report that Energy-Star label itself does not create a premium after controlling for the capitalization of energy-efficiency benefits.

III. Model

We construct a present value model of green buildings under certainty to motivate our empirical analysis of the price difference between green and non-green buildings. We consider housing as a leading example, but we could analogously consider commercial buildings. A residential unit provides a positive flow of housing services Sdt to the homeowner over a time interval dt. The constant service flow rate S in monetary terms can differ between green buildings ($S = S^G$) and otherwise identical non-green buildings ($S = S^N$). The user may be willing to pay a positive premium for green housing services ($S^G > S^N$) or no premium ($S^G = S^N$).

The homeowner must pay for cost flows Cdt to keep the house operational. The cost flows include utility costs and regular maintenance costs and a reserve for the periodic replacement of equipment. The lumpiness of actual replacement will not affect our analysis. The constant flow rate C can differ between green buildings ($C = C^G$) and non-green buildings ($C = C^N$). We assume that homeowners receive positive net service flows throughout the life of a house ($S^i - C^i > 0,\ i = \{G, N\}$). If green buildings yield sufficiently large savings in utility costs that outweigh the increase in the maintenance and replacement costs of green equipment, green buildings have a cost advantage ($C^G < C^N$). In contrast, if the increases in the maintenance and replacement costs exceed the savings in utility costs, green buildings have a cost disadvantage ($C^G > C^N$). The relationship critically depends on the choice of green factors, technological conditions, and government subsidies.

A house has an economic life span T^i. Green buildings can have a longer life span ($T^G > T^N$) if a long-life design is one of the green factors. A longer economic life for a building is a major green factor especially when the average life of a non-green residential building is short as in Japan. Therefore, $T^G > T^N$ is an important characteristic of Japanese green buildings. When we compare two buildings with different life spans, we assume that a short-lived building will be repeatedly rebuilt. Under the fair price assumption, the price for the new house equals the present value of the net service flows from the house. Because the net value of the rebuilt house (i.e., the present value minus building costs) is zero at the time of reconstruction, we assign zero value to rebuilt houses.

The present value of a house $i, i = \{G, N\}$, at time t is

$$V^i(t) = \int_t^{T^i} e^{-r(u-t)} \left(S^i - C^i\right) du = \left(S^i - C^i\right) \frac{\left(1 - e^{-r(T^i - t)}\right)}{r}. \qquad (1)$$

where r is the instantaneous discount rate and the term $\left(1 - e^{-r(T^i-t)}\right)/r$ represents the annuity factor. The value $V^i(t)$ is well-defined up to $t < T^i$. The discount rate is common to both buildings under certainty. If uncertainty is introduced, the rate could differ across assets, especially when the green building technology is more risky. As is usual for any financial asset, the value represents the perfectly elastic demand for housing.

The depreciation rate δ is derived by taking a derivative of equation (1) with respect to t and dividing by $-V^i$:

$$\delta^i \equiv -\frac{dV^i}{dt}/V^i = r \frac{e^{-r(T^i-t)}}{1 - e^{-r(T^i-t)}}. \qquad (2)$$

The depreciation rate is increasing in the discount rate ($\partial \delta^i / \partial r > 0$) and decreasing in the life span ($\partial \delta^i / \partial T^i < 0$).[6] Thus, green buildings with long-life designs have a lower depreciation rate. A lower depreciation rate is associated with a higher property value after a certain period of time. For example, Knight and Sirmans (1996) and Wilhelmsson (2008) find that a building with an excellent maintenance condition has a lower depreciation rate and hence a significantly higher property value after years of depreciation than a comparable building with an inferior maintenance condition.

We compare green and non-green buildings by defining the price gap at time $t \in [0, \min(T^G, T^N)]$ as:

[6] In this model, the depreciation rate is increasing in time because the net service flow is constant. The depreciation rate becomes constant if the net service flow is proportional to the building value. The difference is not important in our analysis.

$$\Delta(t) \equiv V^G(t) - V^N(t) = (S^G - C^G)\frac{1 - e^{-r(T^G - t)}}{r} - (S^N - C^N)\frac{1 - e^{-r(T^N - t)}}{r}. \qquad (3)$$

See Appendix B for the derivation of equation (3). The first term of the equation is positive because $S^G - C^G > 0$, and the second term is negative because $-(S^N - C^N) < 0$. The sign of the price gap depends on the parameter values. In other words, the price of green buildings is lower than that of non-green buildings in some cases.

The comparative statics of the price difference are as follows.

$$\frac{\partial \Delta}{\partial S^G} > 0, \quad \frac{\partial \Delta}{\partial C^G} < 0, \quad \frac{\partial \Delta}{\partial S^N} < 0, \quad \frac{\partial \Delta}{\partial C^N} > 0,$$

$$\frac{\partial \Delta}{\partial T^G} = (S^G - C^G)e^{-r(T^G - t)} > 0, \quad \frac{\partial \Delta}{\partial T^N} = -(S^N - C^N)e^{-r(T^N - t)} < 0.$$

The results make intuitive sense. The price gap increases as green buildings provide greater services, require lower costs, and last longer, all else being held equal. The price gap also increases as non-green buildings provide fewer services, require higher costs, and last for a shorter period. The following proposition summarizes the condition that determines the sign of the price gap between green and non-green buildings.

Proposition 1: *The value of a green building is greater than or equal to the value of a comparable non-green building* ($i.e.,\ \Delta(t) \geq 0\ at\ \ t \in [0, \min(T^G, T^N)]$) *if the following condition is met:*

$$\frac{S^N - C^N}{S^G - C^G} \leq \frac{1 - e^{-r(T^G - t)}}{1 - e^{-r(T^N - t)}}.$$

Otherwise, the value of a green building is less than the value of a comparable non-green building.

Proof: In equation (3), by imposing $\Delta(t) \geq 0$, we readily obtain the condition.■

The left-hand side of the inequality is the disadvantage of a green building with respect to net service flows and the right-hand side is the advantage with respect to life spans. This condition is met if a green building has a sufficiently large advantage in either life spans or net-service flows. For example, if a green building has a cost advantage ($C^G < C^N$), it is traded at a premium even if it has no advantage in housing services or life spans. By contrast, a green building can be traded at a discount if it has a large cost disadvantage even if it has small advantages in housing services and life spans. A green building is not likely to have a discount for housing services ($S^G < S^N$) or a shorter life span ($T^G < T^N$), but possibly has a cost disadvantage ($C^G > C^N$). For example, a high green standard can result in a cost disadvantage due to high replacement and maintenance costs.

Next, we consider the dynamics of the price gap. If a green building has a longer life span than a comparable non-green building, as time approaches the end of the life of the non-green building, the price gap becomes positive. To see this, take the limit of $t \to T^N$ in equation (3):

$$\lim_{t \to T^N} \Delta(t) = \frac{1}{r}\left\{(S^G - C^G)\left(1 - e^{-r(T^G - t)}\right)\right\} > 0.$$

We analyze changes in Δ over time by taking the derivative of Δ with respect to t:

$$\frac{d\Delta}{dt} = -(S^G - C^G)e^{-r(T^G - t)} + (S^N - C^N)e^{-r(T^N - t)} \qquad (4).$$

The condition for changes in the price gap being positive is summarized in the following proposition.

Proposition 2: *Define the price gap as the value of a green building minus the value of a comparable non-green building at time* $t \in [0, \min(T^G, T^N)]$. *Changes in the price gap are positive (i.e., a negative price gap decreases and a positive price gap increases over time) if the following condition is met:*

$$\frac{S^N - C^N}{S^G - C^G} > \frac{e^{-r(T^G - t)}}{e^{-r(T^N - t)}}.$$

Otherwise, changes in the price gap are not positive.

Proof: In equation (4), by imposing $d\Delta/dt > 0$, we readily obtain the proposition. ■

The left-hand side of the inequality condition represents the disadvantage of a green building with respect to net service flows and the right-hand side represents relative depreciation costs for the green building. The condition is met if a green building is associated with a relatively low depreciation rate or small net service flows.

Proposition 2 determines the cross-sectional pattern of the average price gap in the market with respect to building ages. Suppose, at a given time t, there is a continuum of buildings with different ages. If we compare a set of newer buildings with a set of older buildings, the price gap between green and non-green buildings is larger in the set of older buildings. This is because at time t, older buildings have existed longer than newer buildings. Therefore, the model predicts that either 1) the negative price gaps become smaller for older buildings or 2) the positive price gaps become larger for older buildings.

Proposition 3: *Suppose there is a continuum of buildings with different ages in the market. When the condition in Proposition 2 holds, the price gap between green and non-green buildings is increasing in age (i.e., a smaller negative gap or a larger positive gap for older buildings).*

Proof: See above. ■

Figure 1 presents a numerical example of housing prices and age. Panel A is an example of a long life span and high running costs: $S^G = S^N = 100,\ C^G = 76,\ C^N = 70,$ $r = 0.05,\ T^G = 30,\ T^N = 20$. The price of green buildings is lower than that of non-green buildings at age zero. Because the depreciation rate is lower for long-lived green buildings, the negative price gap shrinks as age increases. The price gap eventually becomes positive after age 1.092. As will be demonstrated below, Japanese green buildings exhibit the same price gap pattern (figure 2).

Panel B is an example of the same life span and low running costs: $S^G = 105$, $S^N = 100$, $C^G = C^N = 70$, $r = 0.05$, $T^G = T^N = 20$. This type corresponds to energy efficient buildings with inexpensive technologies in a country where the life spans are identical. This case has been analyzed in previous studies. Green buildings maintain higher values than non-green buildings throughout their lives. Because the depreciation rate is the same for both green and non-green buildings, the premium ratio is constant over time.

[Figure 1 around here.]

IV. Data

A. Tokyo Green Building Program

The Tokyo Metropolitan Government launched the Basic Plan for Environmental Protection (BPEP) in 1997 and enacted the Tokyo Metropolitan Environmental Security Ordinance in 2000.[7] On the basis of the ordinance, the government launched the Tokyo Green Building Program (TGBP) in 2002, which covers all property types. The program was expanded in 2005, 2007, and 2009.[8] The 2005 amendment includes the creation of the Tokyo Green Labeling System for Condominiums (TGLSC), which requires the developers of large-scale condominium projects to announce their itemized green scores to potential buyers. TGLSC uses the evaluation criteria in the TGBP.

The goal of the TGBP is to encourage building owners to engage voluntarily in environmentally conscious efforts and create a more environmentally sound market

---

[7] Ordinance No. 215 is formally named "Tomin no Kenko to Anzen wo Kakuho Suru Kankyo ni Kansuru Jourei."
[8] The Tokyo Green Building Guidelines were published in Tokyo Metropolitan Notification No. 384 on March 28, 2002. For more information, see http://www2.kankyo.metro.tokyo.jp/sgw/English/Tokyo%20Green%20BUilding%20Program.pdf.

with high-quality buildings and structures. To achieve this goal, the Tokyo Metropolitan government requires large building owners to submit Tokyo Green Building Plans and subsequently releases the submitted plan and related materials on its website. There is no subsidy program or penalty that is explicitly linked to the TGBP.

The ordinance applies to both the private and public sectors and to all types of buildings. As of January 28, 2010, 1,154 buildings have been evaluated under the program. Although the evaluation is mandatory for new constructions or renovations exceeding 5,000 square meters in floor area, a large-scale project can be exempted from the evaluation if individual buildings in the project are below the threshold. Owners of smaller buildings can voluntarily participate in the program.

An advantage of the data set is that the Tokyo government publishes itemized scores on eight factors: (1) reduction of thermal loads, (2) use of renewable energy, (3) energy saving, (4) use of eco-friendly materials, (5) the long-life design of a building, (6) water recycling, (7) planting, and (8) mitigation of the urban heat island phenomenon. The list of evaluated green factors is shown in appendix A. A positive raw score (1, 2, 3, etc.) is awarded if a building satisfies the program's higher standards. Receiving zero points indicates that the building performs no better than an ordinary non-green building. The maximum points are different for each factor.

In our analysis, we first construct an indicator variable that identifies whether a building is evaluated under the TGBP:

$$I_{g,i} = \begin{cases} 1 & \text{if the building i is evaluated,} \\ 0 & \text{otherwise.} \end{cases}$$

Next, we construct a variable that represents a building's relative performance on each factor. We do not directly use the raw score because the maximum possible score varies by factor. The rescaled score relative to the maximum possible value is defined as $L_{m,i} \equiv S_{m,i}/\overline{S}_m$, where $S_{m,i}$ and $\overline{S}_m$ denote the raw score of building i and the maximum score for factor m, respectively. To capture potential nonlinear effects on prices, we use an indicator variable in the empirical analysis as follows:

$$I_{mn,i} = \begin{cases} 1 & \text{if } L_{m,i} \text{ takes the } n\text{-th lowest value for factor } m, \\ 0 & \text{otherwise,} \end{cases}$$

$$\text{for } m = 1, \ldots, 8;\ n = 1, \ldots,\ N_m.$$

B. Transaction Price Data

The transaction price data for condominium units in Tokyo are obtained from the Transaction Price Information Service (TPIS), which is jointly managed by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) and the Tokyo Association of Real Estate Appraisers (TAREA). The TPIS provides transaction price information and associated attributes such as location, size, zoning, and property use. The MLIT generates its data by combining three data sources: (1) the registry data obtained from the Ministry of Justice (MOJ) on transactions of raw land, built property, and condominiums; (2) survey results reported by property buyers; and (3) a field survey conducted by real estate appraisers.

A unique advantage of the TPIS data set is its quality. The data set contains rich property attributes. The data set is a combination of data from three distinct sources, which allows us to check the consistency and accuracy of the data.

The data collection scheme is as follows. The MOJ, which administers the national real estate registration system, provides MLIT with updated information on ownership transfers. The MOJ's registry information includes location, plot number, land use type, area, dates of receipt and contract, and the name and address of the new owner. However, the registry does not record transaction prices. For each record in the registry, the MLIT sends questionnaires to each of the new owners and collects information on the transaction price, property size, and reason for the transaction. On the basis of the collected data, real estate appraisers conduct a field survey on each property to record the information necessary to perform an appraisal, such as building height, frontal road, distance from the nearest railway station, site shape, and land use. Finally, the information is compiled by MLIT.

The process typically takes three months. For example, registry data in April 2008 are obtained from the MOJ at the end of May 2008; next, questionnaires are mailed to buyers at the beginning of June 2008, which are then collected by the end of the same month. A small portion of the cases (approximately 3 percent of the total) is omitted after the merged data are checked. Cases are omitted if the field survey results are obviously different from the questionnaire results or if the property size is below 10 square meters.

For example, between July 2005 and December 2007, 6.3 million ownership transfers were registered for land, commercial and non-commercial properties, and condominiums, of which 1.34 million transfers were subject to the MLIT survey. Eventually, approximately 334,000 replies were collected (a 29.2 percent collection rate), and 220,000 records were published after excluding errors.

We use the sample of condominiums in Tokyo, which includes 41,560 transactions between 2002 and 2009. After removing incomplete observations, we obtain 34,862 observations. Table 1 lists the available variables. The dependent variable is the logarithm of price per square meter. The explanatory variables are classified into five categories: (1) room attributes, (2) transaction characteristics, (3) location, (4) building size, and (5) building quality.

[Table 1 around here.]

To control for unobserved heterogeneity in location, we include seven location variables, including indicator variables for jurisdictions and railway lines. The jurisdiction and railway lines are key determinants of property value because of income sorting, local public services, amenities, and local taxes. In particular, railway lines play an important role in Tokyo because of the extremely dense railway network. In our sample, the median distance between a property and the nearest railway station is only 530 meters (0.33 miles). These indicator variables and other location variables (the distance to the nearest railway station, the size of the station, and three zoning variables) suitably control for location heterogeneity.

Regarding physical characteristics, we include building size information and unit characteristics. The building size is represented by the lot area, the number of units, and the number of stories above and below ground. The unit characteristics consist of the log floor area, the floor number, and floor plan dummies.

We also control for transaction timing by quarter dummy variables. The market-wide trend of price changes is captured non-linearly by the quarter dummies. Finally, we control for building quality using the type of building structure, building age, and whether there is a superintendent.

Table 2 summarizes the descriptive statistics for samples of green and non-green buildings. The left column is for non-green condominiums and the right column is for green condominiums. It is clear that green condominiums are traded at significantly higher prices. The mean transaction price of green condominiums is 56 million yen, more than double that of non-green condominiums. However, green condominium units also have a larger average floor area. After computing unit prices per square meter of floor area, the price differential is reduced but persists.

Green condominiums are also newer (building age) and taller (stories above ground) and have larger lots (lot area) and more units (number of units). These differences in size and quality may be responsible for the price differential. Thus, it is important to carefully control for quality differences carefully to isolate the price differentials of green buildings.

[Table 2 around here.]

V. Empirical Analysis

A. Hedonic Model

We adopt a hedonic approach to the estimation of the green effect on transaction prices. The hedonic approach was theoretically formalized by Rosen (1974) and is widely used in the study of real estate valuation. The concept is to regard housing as a bundle of characteristics such as lot size, building size, and location. Under some conditions, housing prices in spatial equilibrium have been demonstrated to implicitly reveal a real-valued pricing function $p(\boldsymbol{z}) = p(z_1, \ldots, z_n)$, relating the property price and the n-vector of characteristics $\boldsymbol{z}$. Then, the implicit market price associated with characteristic z_i, holding all else constant, is given by $\partial p/\partial z_i$, assuming the continuity of z_i and differentiability of p. $\partial p/\partial z_i$ at a particular amount of z_i equals the slope of the bidding function of the buyer who chooses the amount of z_i. Given a continuum of buyers in the relevant domain of z_i, the envelope of buyers' bidding functions with respect to z_i forms the equilibrium price function $p(\boldsymbol{z})$, where the other characteristics are held constant. Similarly, the equilibrium price function is also the envelope of the sellers' offer functions. In other words, $\partial p/\partial z_i$ at a particular amount of z_i equals the slope of the offer function of the seller who selects the amount of z_i.

We investigate how green buildings are evaluated in the market in two ways. First, we estimate the effect of the evaluation of the TGBP on transaction prices. The indicator variable $I_{g,i}$, defined in section III, is used as the green building indicator. Second, we estimate the effects of itemized scores in the program by using indicator variables $I_{mn,i}$, which are also defined in section III.

B. Analysis by Green Building Indicator

In our first analysis using the green building indicator, we estimate eight variants of the following model by using different control variables:

$$ln\, P_{ijt} = b_0 + b_g I_{g,i} + \sum_{k=1}^{5} \sum_{f}^{F_k} b_{kf} X_{kf,ijt} + \varepsilon_{jt}. \qquad (1)$$

The logarithm of transaction price per square meter of room j in building i at time t ($\ln P_{ijt}$) is regressed on a constant, the indicator variable for green buildings $I_{g,i}$, and various hedonic characteristics $X_{kf,ijt}$. Category k ($k = 1, \ldots, 5$) contains F_k variables indexed by f. The hedonic characteristics X include the indicator variables for jurisdiction and railways to control for unobserved heterogeneity in location. The first variant does not include any hedonic characteristics to measure the mean difference between green and non-green buildings. We add other control variables sequentially to investigate interactions between hedonic characteristics and the green coefficient.

Table 3 presents the estimation results for the green building indicator. Column (1) reports the results without controlling for hedonic characteristics. The estimated green coefficient is 0.2477, which represents the simple mean difference between green and non-green condominiums. Based on this estimation, on average, the green condominiums are traded for prices that are 28.1 percent higher.[9] Even when all control variables except building quality are included (column 2), the green coefficient remains at the same level. Although a correlation between the green indicator and building size is a reasonable concern, the size variables ultimately have limited impacts on the green coefficient.

[Table 3 around here.]

However, when the variables for building quality are included, the result changes fundamentally (column 3). The green coefficient becomes negative (−0.0509), which is statistically significant at the 1 percent level. The adjusted R-squared increases to 0.61. This result suggests that the estimated green coefficient is significantly affected by correlations between the building quality variables and the green building indicator. The quality variables consist of the type of building structure, building age, and a dummy variable for superintendents. In particular, the building age is the most influential variable. Without controlling for building quality, the estimated coefficient for the green building indicator is subject to omitted-variable bias. Based on this estimation, green condominiums are traded at a 5.0 percent discount. The estimation by least absolute deviation (column 4) provides approximately the same result.[10] The

[9] In this paper, we report $\exp\left(b + \frac{1}{2}\sigma^2\right) - 1$ as the percentage difference when we interpret the coefficient b on the dummy variables with standard error σ. Van Garderen and Shah (2002) demonstrate the relevance of the statistic when degrees of freedom are large.

[10] The LAD estimator in our application is the solution to the problem

$$\min_{b_0, b_g, b_{kf}} \sum_j \sum_t \left| lnP_{jt} - b_0 - b_g I_{g,i} - \sum_{k=1}^{5} \sum_{f=1}^{F_k} b_{kf} X_{kf,ijt} \right|.$$

LAD estimator is also a median estimator and is less affected by the skewness or fat tails of the disturbance distribution. The outliers and distributional non-normality do not produce a negative effect. Rather, such non-normality slightly attenuates the estimate.

The signs of estimated coefficients for the other control variables, which are available on request, are generally as expected. For the results of the full model reported in column (3), the transaction price per square meter is higher if the unit is on a higher floor (0.0071 per floor), the unit is smaller (−0.0912 per log floor area), the unit is a studio, the condominium is closer to a railway station (−0.1246 per kilometer), the nearest station has more railway lines (0.0203 per line), zoning is residential, and there are superintendents (0.0405).

A potential concern is multi-collinearity among the control variables, particularly between log floor area and floor plan dummies, the number of stories and floor number, and the number of units and lot area. Appendix C demonstrates that the correlation coefficients among control variables are not particularly high. The variance inflation factor (VIF) is smaller than 10 for all variables except for a dummy variable that represents a minor railway line. In particular, VIF for the green label is smaller than 1.5. Thus, multi-collinearity does not affect the estimation result.

C. Modified Controls for Building Age

Given the importance of the building age, we further estimate equation (1) by modifying the building age variables. We first include the quadratic term of building age to capture some non-linearity. After confirming the statistical significance of the quadratic term, we introduce building age dummies. Furthermore, we allow for heterogeneous depreciation rates between green and non-green buildings because long-life design is a key feature of Japanese green buildings. We also examine a few smaller but better-matched samples by excluding old buildings and small buildings. Table 4 presents the results. A clear conclusion from this table is that the negative coefficient of the green building indicator is robust; the green-labeled new condominiums are traded at a discount.

[Table 4 around here.]

The first column presents the results after including the quadratic term for building age. The positive coefficient on the quadratic term indicates that the price function is convex in building age. With this age control, the green coefficient is −0.09278, or −8.9 percent.

The second column presents the results after including age dummy variables. Yearly age dummies are generated for buildings aged between one and ten years. For older buildings, we assign coarser dummy variables of 10-20, 20-30, 30-40, and 40 years or older. The green coefficient is almost unchanged (−0.09654). The age coefficients exhibit convexity.

The third column presents the results when we allow for heterogeneous depreciation rates between green and non-green buildings by including interaction terms of the green building indicator and the building age dummies. A different rate of depreciation may well arise because the long-life design of a building is a key component of the TGBP. We also restrict our sample to newer buildings by dropping observations that were built prior to 2002 because the TGBP began in 2002. We obtain a negative green coefficient (−0.07218)that is statistically significant at the 1 percent level. The implied green discount for newly built green buildings (i.e., at age zero) is 6.95 percent.

The negative coefficient on the green building indicator may seem puzzling at the first glance because previous studies have reported positive coefficients by using data from other countries. However, the negative coefficient for Japanese green buildings is not puzzling when we take heterogeneous depreciation into account. Model (3) has two columns of age coefficients, one for non-green buildings and the other for green buildings. The age coefficients for green buildings are obtained by summing the baseline coefficient for non-green buildings and the coefficient on the interaction term between the green building indicator and the age dummies. We find statistically significant heterogeneity in depreciation rates; green buildings depreciate much slower. For example, at ages 3-4 the coefficient for non-green buildings is −0.2212 and that for green buildings is only −0.07053. Green buildings are initially traded at lower prices but are traded at a premium after two years.

Figure 2 plots the estimated relative price against building age. The reference value (zero) is the value of non-green buildings at age zero. Non-green buildings exhibit a sharp decline in value a few years after completion. This is consistent with the common belief that Japanese housing values decline sharply immediately after completion and become negligible after 20 years. The average life of a housing unit is only 26 years according to government estimates. In sharp contrast, green buildings depreciate much slower. The value remains at 85 percent of the original value even after six years. The graphs in figure 2 closely match the theoretical predictions for a green building with longer life spans and higher operating costs depicted in panel A of figure 1. Green buildings are initially valued at a discount but shifts to being valued at a premium because of slow depreciation.

[Figure 2 around here.]

In the fourth column, we additionally limit our sample to larger buildings. We retain an observation if the number of units in the building exceeds the sample median (54 units). The size of a building with 54 units will be 5400 square meters if the average net unit size is 80 square meters and the common area is 20 percent of the total floor area. This building size roughly equals the minimum size of green buildings. The sample size is reduced to 5,325, but presumably the green and non-green samples are matched better. The estimation result is consistent with model (3). The green coefficient is −0.7087, and green buildings depreciate at a slower rate.

We conduct further robustness checks by imposing the common support restriction on the sample. The result is shown in appendix D. We first obtain the support (i.e., the minimum and the maximum) of the following variables in the green building sample: log floor area of the unit, floor number, distance to railway station, station size, maximum building coverage ratio, maximum floor-to-area ratio, number of units, stories above ground, stories below ground, and building age. Then, we exclude non-green building observations if they are outside of the support for any of these variables. The sample size is reduced by 23 percent. Using the new sample, we estimate the same models as in table 4. The estimation result is consistent with that in table 4; the green coefficient is significantly negative and green buildings depreciate at a slower rate.

We also conduct the propensity score matching estimation as a robustness check. We take green buildings as the "treatment group" and non-green buildings as the "control group." For each building age group, we compare the log unit price for each green observation with a weighted average of log unit prices for non-green observations, and compute the average treatment effect for the treated (ATT). We assign a weight to each non-green observation using the propensity score of being a green building from a logit regression. Details are available upon request. The results of these matching estimations are largely consistent with the result in table 4. For ages 0-1, the estimated ATT is −0.251 and significant at the 1 percent level. For older buildings, the ATTs tend to be positive though they are not significant. The negative ATT indicates that green buildings are traded for lower prices than matched non-green buildings when they are new. After a few years, green buildings are traded at a premium.

D. Analysis by Itemized Green Scores

In this section, we report estimation results for itemized green scores. The main objective is to estimate heterogeneous effects across green factors. We estimate the coefficient on the indicator variable for each score for eight green factors in the TGBP, in addition to the baseline green building effect. The estimation equation is

$$ln\, P_{ijt} = b_0 + \left(b_g I_{g,i} + \sum_{m=1}^{8} \sum_{n=2}^{N_m} b_{mn} I_{mn,i} \right) + \sum_{k=1}^{5} \sum_{f}^{F_k} b_{kf} X_{kf,ijt} + \varepsilon_{jt}, \qquad (2)$$

where $I_{g,i}$ is the green building indicator and $I_{mn,i}$ is the indicator variable for each itemized score, as defined in section III. The green building indicator captures the baseline effect as a reference. The reference is the lowest score in each field. The coefficients on itemized scores capture deviations from the reference green building. We also exclude a score indicator if there are fewer than ten observations associated with the score.[11]

Table 5 presents the estimation results. We estimate equation (2) using the same four variants as in table 4. Model (1) includes the quadratic term of building age. Model (2) uses building age dummies. Model (3) allows for heterogeneous age coefficients in the restricted sample of new buildings. Model (4) further restricts the sample to new and large buildings. Figure 3 presents the estimated coefficients from model (3) with one-standard-error ranges.

[Table 5 around here.]

[Figure 3 around here.]

The coefficient on the green building indicator is negative (e.g., −0.098 in model 3). This coefficient represents the baseline difference between the reference green buildings and non-green buildings. The reference price is a hypothetical value for a green building that earns the lowest score on every factor. The price of a green building with higher scores can be estimated by adding coefficients for higher scores.

Among the eight factors, positive price differences are obtained for: 1. reduction of thermal loads, 5. long-life design, 7. planting, and 8. mitigation of the urban heat island phenomenon. While the reduction of thermal loads and planting make relatively small differences, the mitigation of the urban heat island and long-life design make large differences. For example, in model (3), the estimated coefficients are 0.08 for 1

[11] In particular, we do not use six observations that scored zero points in long-life design. As a result, the reference score for this factor is the second lowest score, 0.33.

point in thermal loads reduction and 0.04 for 1 point in planting, compared to 0.18 for 0.33 points of urban heat island mitigation and 0.17 for 1 point in long-life design.

However, the mitigation of the urban heat island phenomenon only affects a small fraction of the condominiums because only 102 units (7 percent of all green units) receive positive scores on this factor. In contrast, long-life design impacts most green buildings (99.6 percent of all green units). The six observations that scored zero points on this factor (0.4 percent of all units), which are excluded from our current regressions, have very low prices. As a result, if we include these zero-score observations, the baseline effect of the green label becomes lower at −0.455, and the coefficients on positive scores become higher at 0.358 (0.33 points), 0.348 (0.67 points), and 0.524 (1 point). Our current estimates on long-life design are relative to the second lowest score (0.33 points).

Negative price differences are obtained for: 2. the use of renewable energy, 3. energy saving, 4. the use of eco-friendly materials, and 6. water recycling. While the use of renewable energy and eco-friendly materials make relatively small differences, energy saving and water recycling make relatively large price differences. For example, in model (3), the estimated coefficients are −0.03 for 0.5 points in the use of renewable energy and −0.04 for 0.5 points in the use of eco-friendly materials, compared to −0.23 for 0.5 points in energy saving and −0.16 for 1 point in water recycling.

One question is whether the high correlations among the itemized green indicators create multi-collinearity. We compute cross correlations of the green indicators (appendix E). The correlation coefficients are quite low except for a few combinations (e.g., between 0.33 points on the mitigation of heat island and 0.5 points on energy saving). Our results are not driven by correlations among the green indicators.

To better understand each factor's contribution to the overall price difference, we focus on the median and maximum scores on each factor. Table 6 summarizes the selected coefficients. The median scores on the eight factors are 0.5 (reduction of thermal loads), 0 (renewable energy), 0 (energy saving), 0.5 (eco-friendly materials), 0.67 (long-life design), 0.5 (water recycling), 0.33 (planting), and 0 (mitigation of the heat island phenomenon). It is noteworthy that the majority of green buildings earn no points on the use of renewable energy, energy saving, and the mitigation of the urban heat island phenomenon. Therefore, the estimated coefficients on high scores in these factors are only relevant for a small number of high-performing green buildings. As we discuss below, TGBP's criteria for energy efficiency may be too aggressive to be satisfied at a reasonable cost. In contrast, the majority of green buildings earn high scores in long-life design. This confirms that long-life design is the most important factor for green buildings in Japan, where the average life span of non-green buildings is relatively short.

[Table 6 around here.]

For the median scores, the total difference is negative in all models. For example in model (3), the total difference is −0.0815, which is not substantially different from the baseline difference (−0.0983). The sum of the median score coefficients is very small (0.0168) after positive and negative factors cancel each other out. Positive differences for the reduction of thermal loads (0.0472), water recycling (0.0233), and planting (0.0016) are almost completely cancelled out by negative differences for the use of eco-friendly materials (−0.0447) and long-life design (−0.0105). Figure 4 graphically depicts the results of model (3) reported in table 6.

For the maximum scores, the total difference is positive in models (1) and (3) and negative in models (2) and (4). The magnitude of the total difference is relatively small. For example, in model (3), the total difference is only 0.0101. Again, large positive differences in some factors are cancelled by large negative differences in other factors. Long-life design (0.1659), mitigation of the urban heat island phenomenon (0.1112), reduction of thermal loads (0.0819), planting (0.0376), and the use of eco-friendly materials (0.0165) have positive impacts on price, but water recycling (−0.1599), energy saving (−0.1127), and the use of renewable energy (−0.0321) have negative impacts. Nevertheless, the sum of the itemized differences tends to be positive at the maximum scores and mitigates the negative baseline difference.

[Figure 4 around here.]

E. Discussion

Our empirical findings are summarized as follows. Overall, the transaction price of a green condominium is lower than that of a non-green counterpart at age zero. However, the depreciation rates are lower for green buildings than for non-green buildings. As a result, the transaction price of a green condominium two or more years after construction is higher than that of a comparable non-green building (figure 2). This is consistent with our theoretical model (figure 1). Different green factors and different scores affect price differently (figure 3). Generally, the mitigation of the urban heat island phenomenon, long-life design, planting, and the reduction of thermal loads are associated with positive price differences. In contrast, energy saving, water recycling, and the use of eco-friendly materials and renewable energy are associated with negative price differences. However, the price differences for renewable energy, energy saving, and the mitigation of the urban heat island phenomenon do not affect the majority of green buildings because the median scores on these factors are zero (figure 4).

Our primary explanation for the heterogeneous price differences is based on the capitalization of future maintenance costs. As our model shows, if a green factor of a condominium results in higher equipment maintenance and replacement costs, a potential owner rationally discounts the transaction price by subtracting the present value of future costs. In contrast, if a green factor leads to cost savings, the potential owner is willing to pay a higher price.

A building having a longer economic life is naturally associated with a higher price because the owners face lower life-cycle costs. Both the soft and hard aspects of long-life design (see appendix A) significantly reduce the life-cycle costs of the building by lowering maintenance, renovation, and redevelopment costs. A long-life design is especially effective in Japan, where residential structures have relatively short economic lives. Our estimation indicates that the price of a condominium is halved before it becomes 20 years old, and the common belief in Japan is that price becomes negligible after a building is twenty years old. Komatsu (2010), based on engineering simulations, reports that long-life design reduces the life-cycle costs of a residential building by 38 percent. On the demand side, a recent survey shows that people are willing to accept, on average, a 22 percent premium for a house with a long-life design.[12] From both the supply and demand sides, a significant premium on long-life design is rational.

In contrast, the use of eco-friendly materials is likely to increase an owner's maintenance costs. The strength and durability of eco-friendly materials are typically inferior to those of standard materials, and they are uncertain.[13] If buyers expect higher maintenance costs due to the frequent replacement of more costly eco-friendly materials, initial transaction prices may be discounted.

A water recycling system also incurs a higher life-cycle cost than standard water and sewage services because additional machines and pipes need to be cleaned, fixed, and replaced more frequently. The TGBP guidelines demonstrate that the use of water recycling is between 34 percent to 332 percent more costly than public sewage services, depending on the scale of the building.

The energy efficiency presents a seemingly puzzling result. Energy-saving equipment lowers the operating costs faced by condominium owners and thus is more likely to be associated with positive effects. However, the energy-saving criteria in the TGBP are likely to be too strict. For example, standard water heaters in Japan already exhibit very high energy efficiency, with output-input ratios in excess of 80 percent.[14,15] The TGBP requires a 90 percent ratio, which causes the cost of the equipment to more than double.[16] Because a condominium owner must replace costly equipment every few years, the life-cycle cost can be higher despite the operational energy efficiency.

[12] Japan Housing Finance Agency, 2009. A Survey on Attitudes Toward Housing. http://www.jhf.go.jp/files/100014048.pdf

[13] For example, Matsushita et al. (2006) report higher life-cycle costs and inferior strength and durability of recycled aggregate in concrete.

[14] 80 percent efficiency means that 80 percent of the energy in fuel is used to heat the water and 20percent is wasted.

[15] The ratio of CO_2 emissions to GDP in Japan is already low compared to other major economies. According to the International Energy Agency (Key World Energy Statistics 2010), CO_2 emissions to GDP in 2000 (kg/2000 US dollars) was 0.22 for Japan, compared to 0.48 for the US.

[16] For example, a high efficiency "Eco-Cute" system from Panasonic costs approximately 900 thousand yen, while standard heaters from the same manufacturer cost only 400 thousand yen (http://sumai.panasonic.jp/). Other manufacturers set similar prices.

Arguably, a high marginal cost of improving energy efficiency exceeds the marginal benefit. This explains why 87 percent of all green units receive zero points on this factor.

Interestingly, the median score is either zero or relatively low for the factors that are associated with particularly large discounts; e.g., zero points for renewable energy and energy saving and 0.5 points for water recycling. If the median scores were higher, the total discount would be much larger.[17] The median developer may have minimized price discounts by selecting less "damaging" green factors from the list for the TGBP. However, the developer would have received a higher price if he had included an additional factor in the mitigation of the urban heat island phenomenon because its effect is positive.

We have already addressed the concern of omitted-variable bias due to unobservable quality differences. A condominium may be developed as a green building to mitigate some negative factors regarding location or developer characteristics. For example, if the development site is a former industrial site surrounded by few green open spaces, the developer may choose to make the project green to mitigate the unattractiveness of the site. The effect of unobserved unattractiveness may appear as price discounts that are associated with green buildings. In our sample, a substantial amount of redevelopment of former industrial sites occurred along the newly opened Rinkai Line in the Koto ward. We have addressed this problem using jurisdiction and railway line fixed effects.

As another example, a less competitive or less creditworthy developer may choose to develop green condominiums to attract customers. Although we do not have developer information for all condominiums, we do have this information for green condominiums. On the basis of casual investigations into the names of the developers of green condominiums, we do not find a systematic tendency indicating that "low-quality" developers build green condominiums more frequently; instead, we frequently observe large and creditworthy developers. Therefore, better quality developers more likely attenuate our negative estimates of the green effect.

---

[17] If the median scores were 0.5, 0.5, and 1 for renewable energy, energy saving, and water recycling, respectively, the total price difference would become -0.5301 in model (3).

VI. Conclusion

We study multidimensional green factors in green buildings and find that green factors have heterogeneous effects on property prices. We also find that the average price difference is negative for a new green condominium in Tokyo. However, the difference becomes positive after two years because of the slower depreciation rate of green condominiums. In fact, Japanese green condominiums are characterized by long-life designs rather than energy efficiency. The majority of green buildings adopt long-life designs, which eventually lead to a price premium, even though they do not include anything special in terms of energy savings or the use of renewable energy, which are associated with price discounts. Potentially, the marginal cost of improving energy efficiency is high in Japan. This study broadens our perspective by revealing the heterogeneous green values of properties. To better understand green effects, additional empirical studies on different property types in different countries are needed.

References

Architectural Institute of Japan. 2000. Architectural Charter for a Global Environment. Tokyo, Japan.

Aroul, Ramya Rajajagadeesan and J. Andrew Hansz. 2012. The Value of "Green": Evidence from the First Mandatory Residential Green Building Program, Journal of Real Estate Research 34(1): 27-50.

Brounen, Dirk and Nils Kok. 2011. On the economics of energy labels in the housing market. Journal of Environmental Economics and Management 62(2): 166-179.

California's Sustainable Building Task Force. 2003. The Costs and Financial Benefits of Green Buildings. Sacramento, California.

Dastrup, S.R., J.G.Zivin, D.L.Costa, M.E.Kahn. 2012. Understanding the Solar Home price premium: Electricity generation and "Green" social status. European Economic Review 56(5): 961-973.

Deng, Y., Z. Li, and J.M. Quigley. 2012. Economic returns to energy-efficient investments in the housing market: evidence from Singapore. Regional Science and Urban Economics 42: 506–515.

Eichholtz, Piet, Nils Kok, and John M. Quigley. 2010. Doing Well by Doing Good? Green Office Buildings. American Economic Review, 100(5): 2492–2509.

Fuerst, Franz and Patrick McAllister. 2011a. Green Noise or Green Value? Measuring the Effects of Environmental Certification on Office Values. Real Estate Economics, 39(1): 45–69.

Fuerst, Franz and Patrick McAllister. 2011b. The impact of Energy Performance Certificates on the rental and capital values of commercial property assets. Energy Policy 39(10): 6608-6614.Gilmer, Robert W. 1989. Energy labels and economic search. Energy economics 11 (3): 213.

Jaffee, Dwight, Richard Stanton, and Nancy Wallace. 2011. Energy Factors, Leasing Structure and the Market Price of Office Buildings in the U.S. Working paper.

Knight, John R, and C.F. Sirmans. 1996. Depreciation, Maintenance, and Housing Prices. Journal of Housing Economics 5: 369-389.

Komatsu, Yukio. 2010. The Life-Span of Buildings. Presentation material for Committee on PRE Strategy, Ministry of Finance, Japan.

Laquatra, Joseph. 1986. Housing market capitalization of thermal integrity. Energy Economics 8(3): 134-138.

Matsushita, Hiromichi, Yasutaka Sagawa, and Yuichiro Kawabata. 2006. The Effect of Microstructure on Strength and Durability of Mortar Incorporating Recycled Fine Aggregate. Journal of the Japan Society of Civil Engineers, 62(1): 230-242.

Miller, N., Spivey, J. & Florance, A. 2008. Does Green Pay Off? Unpublished Manuscript.

Nelson, Andrew J. 2007. The Greening of U.S. Investment Real Estate – Market Fundamentals, Prospects and Opportunities. RREEF Research, No. 57.

Nelson, Andrew J. 2008. Globalization and Global Greening Trends in Green Real Estate Investment. RREEF Research, No. 64.

Nelson, Andrew J. 2009. How Green a Recession? – Sustainability Prospects in the US Real Estate Industry. RREEF Research, No. 70.

Pivo, Gary and Jeffrey D. Fisher. 2010. Income, Value and Returns in Socially Responsible Office Properties. Journal of Real Estate Research 32(3): 243-270.

Rosen, Sherwin. 1974. Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition, Journal of Political Economy, Vol.82, pp34-55.

Smith, Allen. 2007. To Be Green or Not to Be Green? Why that is Not the Question? Pramerica Real Estate Investors Research Report.

Turner, Cathy and Frankel, Mark. 2008. Energy Performance of LEED for New Construction Buildings, U.S. Green Building Council, Washington, DC., USA.

van Garderen, Kees Jan and Chandra Shah. 2002. Exact interpretation of dummy variables in semilogarithmic equations. Econometrics Journal 5: 149-159.

Wilhelmsson, Mats. 2008. House price depreciation rates and level of maintenance, Journal of Housing Economics 17(1):88-101.

Yoshida, Jiro, John M. Quigley, and Chihiro Shimizu. 2010. The Effect of Green Building Label on Real Estate Prices: The Case of New Condominiums in Japan. Unpublished manuscript.

Zheng, S., R.Wang, M.E. Kahn, and E.L. Glaeser. 2011. The greenness of China: household carbon dioxide emissions and urban development. Journal of Economic Geography 11: 761–792.

Zheng, S., J.Wu, M.E.Kahn, and Y.Deng. 2012. The nascent market for “green” real estate in Beijing. European Economic Review 56: 974-984.

Appendix A: Green Factors in the Tokyo Green Building Program

(1) Reduction of thermal loads

Sun shaded windows and the insulation of walls, roofs, floors, and windows.

(2) Use of renewable energy

Using natural light, photovoltaic power generation, wind power generation, solar heating systems, and other renewable energy.

(3) Energy saving

Using energy efficient equipment for water heating, floor heating, ventilation, and air conditioning (e.g., a condensing gas water heater).

(4) Use of eco-friendly materials

Using recycled aggregates in concrete, blended cement (e.g., blast-furnace slag coarse cement), recycled steel, and other recycled building materials.

(5) Long-life design of the building

Flexible structure enabling easy maintenance, renovation, and conversion (e.g., skeleton-infill separation, modular configuration of plumbing, beams, floor height, etc.) and physical durability (e.g., quality of cement, the thickness of reinforced concrete, and exterior material)

(6) Water recycling

Recycling rain and wastewater through on-site sewage treatment; using rainfall infiltration.

(7) Planting

A larger area of planting; planting on the wall and roof of the building; optimal mix of shrubs and trees; coordination with surrounding green areas; attention to the local eco-system.

(8) Mitigation of the urban heat island phenomenon

Covering the ground with plants, water, or materials with water retention capability; covering building walls and roofs with plants, water, materials with water retention capability, or high-reflectivity coating; manipulating the shape and configuration of buildings to improve wind flows.

Appendix B:

Derivation of equation (3).

We plug equation (1) into equation (2) and define the price difference as:

$$
\begin{aligned}
\Delta(t; S^G, C^G, S^N, C^N, T^G, T^N, r) &\equiv V^G(t) - V^N(t) \\
&= \int_t^{T^G} e^{-r(u-t)}(S^G - C^G)du - \int_t^{T^N} e^{-r(u-t)}(S^N - C^N)du \\
&= (S^G - C^G)\frac{1 - e^{-r(T^G - t)}}{r} - (S^N - C^N)\frac{1 - e^{-r(T^N - t)}}{r}. \qquad (3)
\end{aligned}
$$

Appendix C: Cross Correlations of Control Variables

	Green building indicator	Log floor area	Floor number	Floor Plan: 1K	Floor Plan: 1DK	Floor Plan: 2DK	Floor Plan: 1LDK	Floor Plan: 2LDK	Floor Plan: 3LDK	Floor Plan: 4LDK	Floor Plan: Other Type	Lot area	The number of units	The number of stories above ground	The number of stories below ground
Green building indicator	1.00														
Log floor area	0.19	1.00													
Floor number	0.26	0.19	1.00												
Floor Plan: 1K	-0.03	-0.17	-0.02	1.00											
Floor Plan: 1DK	-0.03	0.03	-0.01	-0.06	1.00										
Floor Plan: 2DK	0.06	0.03	0.06	-0.07	-0.06	1.00									
Floor Plan: 1LDK	0.07	0.28	0.11	-0.11	-0.10	-0.11	1.00								
Floor Plan: 2LDK	0.06	0.55	0.04	-0.15	-0.14	-0.16	-0.27	1.00							
Floor Plan: 3LDK	0.10	0.23	0.02	-0.05	-0.04	-0.05	-0.08	-0.11	1.00						
Floor Plan: 4LDK	-0.02	0.03	-0.04	-0.02	-0.02	-0.02	-0.04	-0.06	-0.02	1.00					
Floor Plan: Other Type	-0.05	-0.07	-0.05	-0.07	-0.06	-0.07	-0.12	-0.17	-0.05	-0.02	1.00				
Lot area	0.31	0.63	0.26	-0.13	0.01	-0.02	0.15	0.39	0.21	-0.03	-0.02	1.00			
The number of units	0.37	0.24	0.47	-0.04	0.01	0.02	0.06	0.12	0.08	0.00	-0.01	0.70	1.00		
The number of stories above ground	0.38	0.24	0.73	-0.02	-0.02	0.09	0.13	0.04	0.01	0.00	-0.06	0.37	0.66	1.00	
The number of stories below ground	0.24	0.16	0.26	-0.01	-0.02	0.08	0.09	0.01	0.00	0.05	-0.02	0.20	0.29	0.40	1.00

Appendix D: Robustness Checks with the Common Support Restriction

(dependent variable: logarithm of price per square meter)

	(1)	(2)	(3)		(4)	
	Quadratic Age	Age Dummies	Heterogeneous age coefficients, built after 2002		Heterogeneous age coefficients, built after 2002, large buildings	
			Non-Green	Green	Non-Green	Green
$\widehat{b_g}$ (Green Building)	-0.09605***	-0.09953***	-	-0.1011***	-	-0.08037***
	(0.009141)	(0.009668)		(0.02119)		(0.02557)
Controls						
Bldg. Age	-0.04628***	-	-		-	
	(0.0008078)					
[Bldg. Age]^2	0.0006140***	-	-		-	
	(0.00002546)					
Age1_2	-	-0.07274***	-0.04373***	-0.01068	-0.01805	-0.001847
		(0.007919)	(0.008420)	(0.02263)	(0.01570)	(0.02531)
Age2_3	-	-0.2343***	-0.1744***	-0.008248	-0.1577***	-0.004897
		(0.01190)	(0.01508)	(0.02507)	(0.02385)	(0.02672)
Age3_4	-	-0.3030***	-0.2233***	-0.07260***	-0.1781***	-0.09233***
		(0.01024)	(0.01400)	(0.02301)	(0.02206)	(0.025995)
Age4_5	-	-0.3500***	-0.2652***	-0.07462***	-0.2477***	-0.1194***
		(0.009524)	(0.01161)	(0.02233)	(0.01836)	(0.02578)
Age5_6	-	-0.3725***	-0.2625***	-0.08029***	-0.2555***	-0.1359***
		(0.01054)	(0.01627)	(0.03124)	(0.02054)	(0.03440)
Age6_7	-	-0.3953***	-0.2908***	0.01517	-0.2859***	-0.1793***
		(0.01069)	(0.02826)	(0.07239)	(0.03853)	(0.05721)
Dummies for age7 or older	-	Yes	-		-	
Log floor area	-0.1178***	-0.1032***	-0.1595***		-0.04171	
	(0.01462)	(0.01558)	(0.02206)		(0.02756)	
Floor number	0.007207***	0.006883***	0.006913***		0.006390***	
	(0.0005233)	(0.0005317)	(0.0006181)		(0.0006575)	
Floor Plan	Yes	Yes	Yes		Yes	
Transaction qtr.	Yes	Yes	Yes		Yes	
Jurisdiction	Yes	Yes	Yes		Yes	
Station Size	0.02671***	0.02666***	0.03288***		0.03221***	
	(0.002879)	(0.002867)	(0.004170)		(0.006937)	
Railway Line	Yes	Yes	Yes		Yes	
Distance to Station	-0.1553***	-0.1602***	-0.1210***		-0.1560***	
	(0.005610)	(0.005620)	(0.008832)		(0.01296)	
Zoning	Yes	Yes	Yes		Yes	
Max. Building Coverage Ratio	0.1297*	0.1194	0.04777		0.1939	
	(0.07830)	(0.07839)	(0.09479)		(0.1460)	
Max. Floor-to-Area Ratio	-0.005982	-0.003392	-0.01687***		-0.007774	
	(0.003642)	(0.003651)	(0.005287)		(0.008157)	
Log Lot Area [a]	0.06178***	0.02797***	-0.01664**		-0.02752**	
	(0.007092)	(0.004392)	(0.008260)		(0.01131)	
Log Number of Units [a]	-0.1076***	-0.01425***	0.02606***		0.02410*	
	(0.02132)	(0.005531)	(0.009477)		(0.01296)	
Stories Above Ground [a]	0.002771**	-0.001727***	-0.001662**		-0.001341	
	(0.001257)	(5.518e-04)	(0.0007731)		(0.0009077)	
Stories Below Ground [a]	0.02923***	0.01108***	0.01452**		0.005864	
	(0.006068)	(0.004177)	(0.005821)		(0.007097)	
Bldg. Structure	Yes	Yes	Yes		Yes	
Superintendent	0.01719**	0.01642**	0.002599		-0.02511	
	(0.008311)	(0.008276)	(0.008463)		(0.01906)	
Constant	13.359***	13.532***	13.525***		13.439***	
	(0.06911)	(0.07074)	(0.08689)		(0.1379)	
Adjusted R^2	0.6735	0.6741	0.6127		0.6383	
Explanatory Variables	167	174	168		164	
N	26955	26955	9704		4687	

The table summarizes the estimation results with modified age controls. The control variables are listed in table 1. The White heteroscedasticity-consistent standard errors are in parentheses. Significance at the 0.10, 0.05, and 0.01 levels is indicated by *, **, and ***, respectively. Location controls include indicator variables for jurisdictions and railway lines. The timing of transactions is controlled for using quarter-year dummies as a transaction control.

a. In model (1), variables are not in natural log. Instead, we include quadratic terms.

Appendix E: Cross Correlations of Green Factors

Green Factor	Score	1	1	2	2	3	3	4	4	5	5	5	6	7	7	7	7	7	8
		0.5	1	0.33	0.5	0.5	1	0.33	0.5	0.33	0.67	1	1	0.25	0.33	0.67	0.75	1	0.33
1. Reduction	0.5	1.00																	
of thermal loads	1	-0.59	1.00																
2. Renewable	0.33	-0.02	0.07	1.00															
energy	0.5	-0.25	0.02	-0.05	1.00														
3. Energy saving	0.5	0.13	-0.07	0.11	-0.13	1.00													
	1	-0.27	0.50	0.24	-0.12	-0.07	1.00												
4. Eco-friendly	0.33	0.09	0.00	-0.04	-0.04	-0.10	-0.09	1.00											
materials	0.5	-0.09	-0.11	-0.01	0.05	0.11	-0.21	-0.37	1.00										
5. Long-life design	0.33	-0.07	0.14	0.01	0.06	0.21	0.34	-0.15	-0.23	1.00									
of the building	0.67	0.10	-0.22	0.00	-0.13	-0.17	-0.30	0.18	0.16	-0.89	1.00								
	1	-0.09	0.21	-0.02	0.17	-0.06	-0.05	-0.08	0.16	-0.12	-0.32	1.00							
6. Water recycling	1	0.11	0.01	0.04	0.19	-0.11	-0.07	-0.07	-0.05	0.11	-0.25	0.34	1.00						
7. Planting	0.25	0.06	-0.04	-0.01	-0.06	0.43	-0.03	-0.05	0.03	0.21	-0.19	-0.02	-0.05	1.00					
	0.33	0.06	-0.11	-0.06	-0.12	-0.17	-0.15	0.31	-0.02	-0.16	0.12	0.09	-0.07	-0.07	1.00				
	0.67	0.12	-0.05	-0.03	0.29	-0.08	-0.07	-0.07	-0.21	0.29	-0.28	0.01	0.24	-0.04	-0.19	1.00			
	0.75	-0.25	0.48	0.26	-0.12	0.27	0.65	-0.10	-0.09	0.36	-0.32	-0.05	-0.07	-0.03	-0.16	-0.08	1.00		
	1	-0.16	-0.11	0.03	0.27	-0.07	-0.09	-0.09	0.16	-0.06	0.06	-0.01	0.03	-0.04	-0.22	-0.11	-0.09	1.00	
8. Mitigation of heat island	0.33	0.09	-0.03	0.26	-0.11	0.68	0.11	-0.09	0.03	0.12	-0.09	-0.05	-0.06	0.52	-0.14	-0.07	0.15	-0.08	1.00

Tables and Figures

Table 1: List of Explanatory Variables

Variable	Unit/Classification
1) Room Attributes	
Log Floor Area	ln (m^2)
Floor Number	
Floor Plan	Indicators for studio, 1K, 1DK, 2DK, 1LDK, 2LDK, 3LDK, & 4-LDK
2) Transaction	
Transaction Quarter	Indicators for quarter-year of transaction
3) Location	
Jurisdiction	Indicators for 23 wards and cities
Station Size	Number of railway lines coming to the nearest station
Railway Line	Indicators for railway lines
Distance to Station	Road distance to the nearest station in kilometers
Zoning	Indicators for twelve zoning types (e.g., commercial, industrial, low-rise residential)
Maximum Building Coverage Ratio	Percentage, as defined by zoning regulation
Maximum Floor-to-Area Ratio	Percentage, as defined by zoning regulation
4) Building Size	
Lot Area	Square meters
Number of Units	Number of units in the building
Stories Above Ground	Number of stories above ground
Stories Below Ground	Number of stories below ground
5) Building Quality	
Building Structure	Indicators for steel-reinforced concrete, reinforced concrete, steel, wood, and blocks
Building Age	Years after completion of the building
Superintendent	Indicator for having superintendents

Note: For Floor Plan, numeric values show the number of rooms, K stands for kitchen, D stands for dining room, and L stands for living room.

Table 2: Descriptive Statistics

	Non-Green Condominiums			Green Condominiums		
	Number of observations: 33,379			Number of observations: 1,470		
Variables	mean	standard deviation	median	mean	standard deviation	median
Transaction Price (yen)	2.72E+07	3.04E+07	2.27E+07	5.58E+07	5.52E+07	4.50E+07
Price (yen) per sq. m.	6.46E+05	4.82E+05	5.59E+05	7.73E+05	5.51E+05	7.12E+05
ln (Price per sq. m.)	13.22	0.58	13.23	13.47	0.38	13.48
Floor area (sq. m.)	0.46	0.31	0.48	0.73	0.41	0.72
ln (Floor area)	-0.94	0.60	-0.74	-0.37	0.29	-0.33
Floor number	5.47	4.69	4.00	12.18	10.04	9.00
Station size (number of lines)	1.53	1.16	1.00	1.81	1.37	1.00
Distance to station (km)	0.62	0.48	0.52	0.69	0.47	0.63
Max. building coverage ratio	0.70	0.22	0.60	0.65	0.10	0.60
Max. floor to area ratio	3.54	1.57	3.00	3.41	1.43	3.00
Lot area	0.32	0.90	0.08	1.25	1.19	0.85
Number of units	0.10	0.19	0.05	0.42	0.32	0.34
Stories above ground	9.76	6.39	9.00	23.72	12.57	20.00
Stories below ground	0.25	0.55	0.00	0.95	0.96	1.00
Building age	12.84	11.09	10.00	1.81	2.17	1.00
Superintendent	0.89	0.31	1.00	1.00	0.06	1.00

Table 3: Regression Results with the Green Building Indicator
(dependent variable: logarithm of price per square meter)

	(1)	(2)	(3)	(4)
	OLS	OLS	OLS	LAD
$\hat{b}_g$ (Green Building)	0.2477***	0.2298***	-0.05090***	-0.05566***
	(0.01051)	(0.009688)	(0.008097)	(0.007264)
Controls				
Log floor area	-	0.01996	-0.09117***	-0.05952***
		(0.01667)	(0.01475)	(0.004671)
Floor number	-	0.007783***	0.007061***	0.007293***
		(0.0006059)	(0.0004964)	(0.0003405)
Floor Plan	-	Yes	Yes	Yes
Transaction qtr.	-	Yes	Yes	Yes
Jurisdiction	-	Yes	Yes	Yes
Station Size	-	0.01007***	0.02031***	0.02258***
		(0.003272)	(0.002830)	(0.001536)
Railway Line	-	Yes	Yes	Yes
Distance to	-	-0.09243***	-0.1246***	-0.1446***
Station		(0.009800)	(0.01108)	(0.003114)
Zoning	-	Yes	Yes	Yes
Max. Building	-	0.02689***	0.01136*	0.01334**
Coverage Ratio		(0.008232)	(0.005870)	(0.006372)
Max. Floor-to-	-	-0.02010***	0.001783	-6.574e-04
Area Ratio		(0.004762)	(0.002861)	(0.001829)
Log Lot Area	-	-0.03742***	0.02901***	0.02559***
		(0.003113)	(0.002806)	(0.001777)
Log Number of	-	-0.3231***	-0.1011***	-0.05846***
Units		(0.02048)	(0.01372)	(0.01002)
Stories	-	0.01231***	-0.0002801	-0.001540***
Above Ground		(7.145e-04)	(0.0005360)	(0.0003611)
Stories	-	0.007256	0.01001**	0.01638***
Below Ground		(0.004614)	(0.003974)	(0.002378)
Bldg. Structure	-	-	Yes	Yes
Building Age	-	-	-0.02749***	-0.02698***
			(2.435e-04)	(1.379e-04)
Superintendent	-	-	0.04046***	0.02570***
			(0.007911)	(0.004141)
Constant	13.221***	13.600***	13.744***	13.851***
	(0.003160)	(0.04487)	(0.03708)	(0.01955)
Adjusted R^2	0.007534	0.4000	0.6088	0.5000
Explanatory Variables	1	158	164	164
N	34,849	34,849	34,849	34,849

The table summarizes the estimation results of six variants of equation (1) for different control variables. The control variables are listed in table 1. The White heteroscedasticity-consistent standard errors are in parentheses. Significance at the 0.10, 0.05, and 0.01 levels is indicated by *, **, and ***, respectively. Location controls include indicator variables for jurisdictions and railway lines. The timing of transactions is controlled for using quarter-year dummies as a transaction control. R^2 for model (4) is pseudo R^2.

Table 4
Regression Results with Modified Age Controls
(dependent variable: logarithm of price per square meter)

	(1)	(2)	(3)		(4)	
	Quadratic Age	Age Dummies	Heterogeneous age coefficients, built after 2002		Heterogeneous age coefficients, built after 2002, large buildings	
			Non-Green	Green	Non-Green	Green
$\hat{b}_g$ (Green Building)	-0.09278***	-0.09654***	-	-0.07218***	-	-0.07087***
	(0.008219)	(0.009223)		(0.01881)		(0.02368)
Controls						
Bldg. Age	-0.05209***	-	-		-	
	(0.0007065)					
$[\text{Bldg. Age}]^2$	0.0007371***	-	-		-	
	(0.0002066)					
Age1_2	-	-0.07060***	-0.04082***	-0.009592	-0.009020	0.003844
		(0.007351)	(0.007573)	(0.02205)	(0.01468)	(0.02516)
Age2_3	-	-0.2579***	-0.1751***	-0.006500	-0.1579***	-0.0004915
		(0.01135)	(0.01428)	(0.02475)	(0.02275)	(0.02703)
Age3_4	-	-0.3255***	-0.2212***	-0.07053***	-0.1779***	-0.07922***
		(0.009735)	(0.01323)	(0.02251)	(0.02120)	(0.02574)
Age4_5	-	-0.3753***	-0.2572***	-0.08192***	-0.2409***	-0.1135***
		(0.009507)	(0.01218)	(0.02168)	(0.02021)	(0.02523)
Age5_6	-	-0.3996***	-0.2570***	-0.07871***	-0.2522***	-0.1324***
		(0.01029)	(0.01632)	(0.02988)	(0.02013)	(0.03255)
Age6_7	-	-0.4241***	-0.2969***	-0.01171	-0.2833***	-0.1049*
		(0.01028)	(0.02699)	(0.05039)	(0.03724)	(0.06215)
Dummies for age7 or older	-	Yes	-		-	
Log floor area	-0.1078***	-0.1043***	-0.2311***		-0.09349***	
	(0.01433)	(0.01582)	(0.02366)		(0.02675)	
Floor number	0.006723***	0.006221***	0.007352***		0.007136***	
	(0.0004930)	(0.0005061)	(0.0005889)		(0.0006176)	
Floor Plan	Yes	Yes	Yes		Yes	
Transaction qtr.	Yes	Yes	Yes		Yes	
Jurisdiction	Yes	Yes	Yes		Yes	
Station Size	0.01943***	0.01908***	0.02615***		0.02231***	
	(0.002751)	(0.002729)	(0.003818)		(0.006645)	
Railway Line	Yes	Yes	Yes		Yes	
Distance to Station	-0.1234***	-0.1275***	-0.08867***		-0.1355***	
	(0.01073)	(0.01116)	(0.02007)		(0.01271)	
Zoning	Yes	Yes	Yes		Yes	
Max. Building Coverage Ratio	0.008367	0.009594*	0.004032		0.03618***	
	(0.005781)	(0.005772)	(0.007046)		(0.009389)	
Max. Floor-to-Area Ratio	-0.004744*	-0.002676	-0.009911***		-0.01227	
	(0.002744)	(0.002833)	(0.003572)		(0.007880)	
Log Lot Area [a]	0.01538***	0.02652***	-0.005138		-0.02381**	
	(0.002865)	(0.004555)	(0.007579)		(0.01112)	
Log Number of Units [a]	-0.1056***	-0.01156**	0.006822		0.02136*	
	(0.01358)	(0.005441)	(0.008775)		(0.01264)	
Stories Above Ground [a]	-0.001699***	-0.004702***	-0.003859***		-0.003829***	
	(0.0005286)	(0.0005154)	(0.0006780)		(0.0007816)	
Stories Below Ground [a]	0.02078***	0.01906***	0.03354***		0.02145***	
	(0.003977)	(0.004031)	(0.005636)		(0.006661)	
Bldg. Structure	Yes	Yes	Yes		Yes	
Superintendent	0.02484***	0.02072***	-0.01109		-0.01712	
	(0.007594)	(0.007693)	(0.007509)		(0.01803)	
Constant	13.862***	13.994***	13.787***		13.971***	
	(0.03569)	(0.04068)	(0.05919)		(0.07821)	
Adjusted R^2	0.6285	0.6278	0.5908		0.6195	
Explanatory Variables	165	176	168		164	
N	34849	34849	11696		5325	

The table summarizes the estimation results with modified age controls in equation (1). The control variables are listed in table 1. Age coefficients for green buildings are the sum of coefficients on age dummies and the interaction terms. The White heteroscedasticity-consistent standard errors are in parentheses. Significance at the 0.10, 0.05, and 0.01 levels is indicated by *, **, and ***, respectively. Location controls include indicator variables for jurisdictions and railway lines. The timing of transactions is controlled for by quarter-year dummies as a transaction control.

a. In model (1), variables are not in natural log. Instead, we include quadratic terms.

Table 5: Regression Results on Itemized Green Scores
(dependent variable: logarithm of price per square meter)

	Score	(1) Quadratic Age	(2) Age Dummies	(3) Heterogeneous age coefficients, built after 2002	(4) Heterogeneous age coefficients, built after 2002, large buildings
$_g$ (Green Building)		-0.04777*	-0.02862	-0.09831***	-0.09452**
. Reduction of	0.5	0.0005887	0.02676	0.04720	-0.02078
iermal loads	1	0.03210	0.06422	0.08187*	0.02370
. Renewable energy	0.33	-0.05017	0.004465	0.01529	-0.06104
	0.5	-0.04805**	-0.05038**	-0.03206	-0.05046**
. Energy saving	0.5	-0.1695***	-0.2283***	-0.2334***	-0.2127***
	1	-0.09068	-0.1980***	-0.1127**	-0.04730
. Eco-friendly	0.33	-0.06096***	-0.08949***	-0.01570	-0.002345
iaterials	0.5	-0.009510	-0.01758	-0.04474**	-0.008144
	0.67	-0.06460	-0.04730	-0.08646	-0.06822
	1	0.03538	0.02657	0.01647	0.03837
. Long-life design	0.67	-0.01949	-0.01918	-0.01048	0.01561
	1	0.09000	0.07672	0.1659***	0.09019
. Water recycling	0.5	-0.002185	-0.02162	0.02327	0.03473*
	1	-0.1366***	-0.1641***	-0.1599***	-0.1276***
. Planting	0.25	-0.2247***	-0.3031***	0.04714	0.1705*
	0.33	-0.003645	-0.005492	0.001593	0.006008
	0.5	0.07940	0.03869	0.07564*	0.09977*
	0.67	0.08947**	0.07819*	0.06972	0.08703*
	0.75	-0.1346**	-0.2045***	0.06917	0.08500
	1	0.001169	-0.01333	0.03763	0.02960
. Mitigation of	0.33	0.2756***	0.2688***	0.1802***	0.09014
rban heat island	0.67	0.2089***	0.2185***	0.1112	0.1080
'ontrols					
Bldg. age		Yes	Yes	Yes	Yes
Bldg. age × Green Bldg.		-	Yes	Yes	Yes
Bldg. structure		Yes	Yes	Yes	Yes
Superintendent		Yes	Yes	Yes	Yes
Room, transaction & location		Yes	Yes	Yes	Yes
Bldg. size		Yes	Yes	Yes	Yes
'onstant		13.863***	14.006***	13.769***	13.948***
djusted R^2		0.6288	0.6284	0.5916	0.6194
'xplanatory Variables		187	198	190	186
I		34840	34840	11687	5316

The table summarizes the estimation results of equation (2). The control variables are listed in table 1. Significance at the 0.10, 0.05, and 0.01 levels are indicated by *, **, and ***, respectively. The White heteroscedasticity-consistent standard errors are used. Location controls include indicator variables for jurisdictions and railway lines. The timing of transactions is controlled for using quarter-year dummies as a transaction control.

Table 6: Decomposition of Overall Price Differences for Buildings with Median and Maximum Green Scores.

Panel A: Median green scores

	Median Score	(1) Quadratic Age	(2) Age Dummies	(3) Heterogeneous age coefficients, built after 2002	(4) Heterogeneou age coefficien built after 20(large buildin
1. Reduction of thermal loads	0.5	0.0006	0.0268	0.0472	-0.0208
2. Renewable energy	0	-	-	-	-
3. Energy saving	0	-	-	-	-
4. Eco-friendly materials	0.5	-0.0095	-0.0176	-0.0447	-0.0081
5. Long-life design	0.67	-0.0195	-0.0192	-0.0105	0.0156
6. Water recycling	0.5	-0.0022	-0.0216	0.0233	0.0347
7. Planting	0.33	-0.0036	-0.0055	0.0016	0.0060
8. Mitigation of urban heat island	0	-	-	-	-
(A) Sum of itemized scores		-0.0342	-0.0371	0.0168	0.0274
(B) Baseline Difference		-0.0478	-0.0286	-0.0983	-0.0945
Total Difference (A+B)		-0.0820	-0.0657	-0.0815	-0.0671

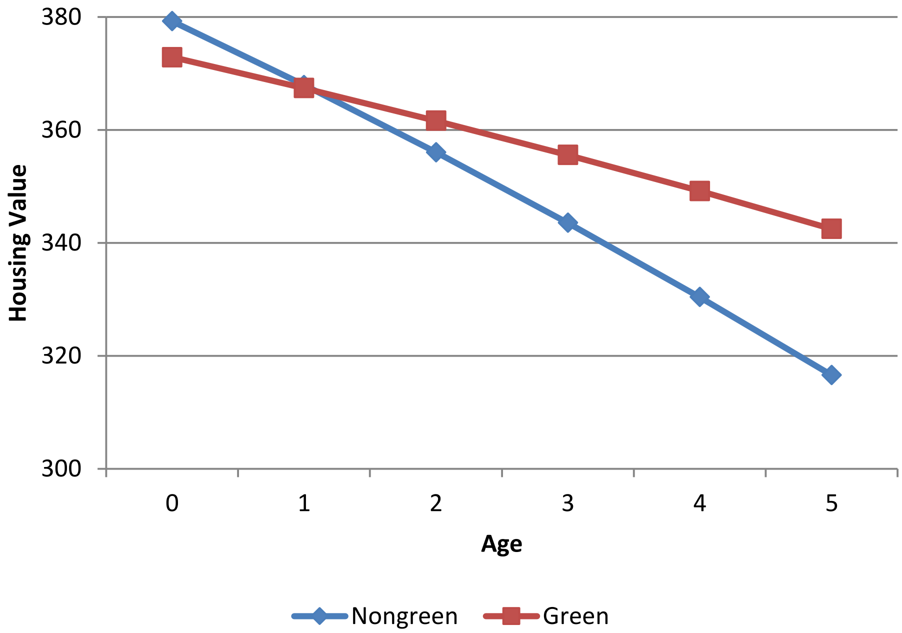
Panel B: Maximum green scores

	Maximum Score	(1) Quadratic Age	(2) Age Dummies	(3) Heterogeneous age coefficients, built after 2002	(4) Heterogeneou age coefficien built after 20(large buildin
1. Reduction of thermal loads	1	0.0321	0.0642	0.0819	0.0237
2. Renewable energy	0.5	-0.0480	-0.0504	-0.0321	-0.0505
3. Energy saving	1	-0.0907	-0.1980	-0.1127	-0.0473
4. Eco-friendly materials	1	0.0354	0.0266	0.0165	0.0384
5. Long-life design	1	0.0900	0.0767	0.1659	0.0902
6. Water recycling	1	-0.1366	-0.1641	-0.1599	-0.1276
7. Planting	1	0.0012	-0.0133	0.0376	0.0296
8. Mitigation of urban heat island	0.67	0.2089	0.2185	0.1112	0.1080
(A) Sum of itemized scores		0.0922	-0.0397	0.1084	0.0645
(B) Baseline Difference		-0.0478	-0.0286	-0.0983	-0.0945
Total Difference (A+B)		0.0445	-0.0684	0.0101	-0.0300

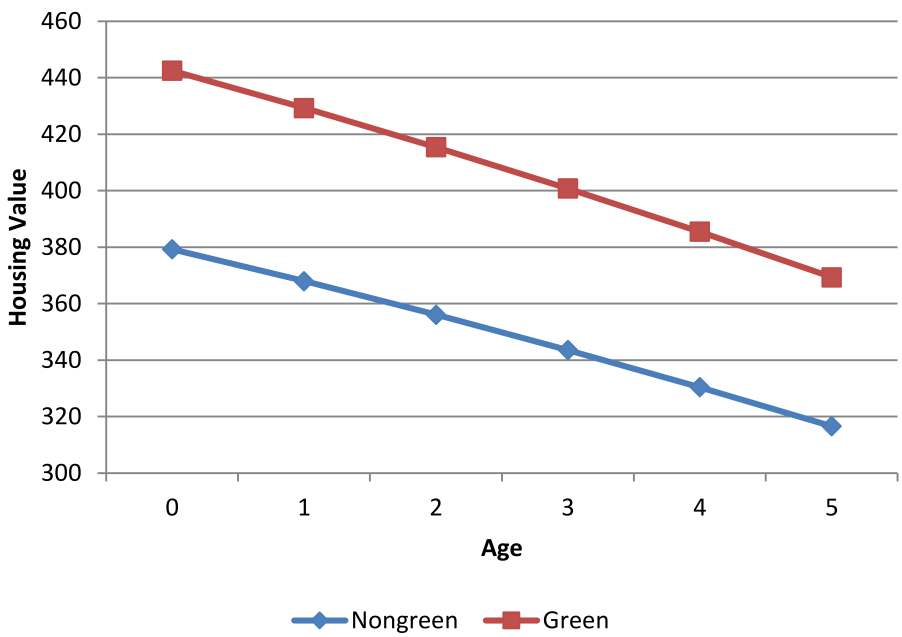
Note: This table shows each factor’s contribution to the overall price difference between green and non-green buildings. The numbers are estimated coefficients for median and maximum green scores. In panel A, the coefficients are not shown for renewable energy, energy saving, and the mitigation of urban heal-island phenomenon because the median score is zero.

Figure 1. The Value of Green and Non-Green Buildings Over Time.

Panel A. A Long Life Span and High Running Costs.

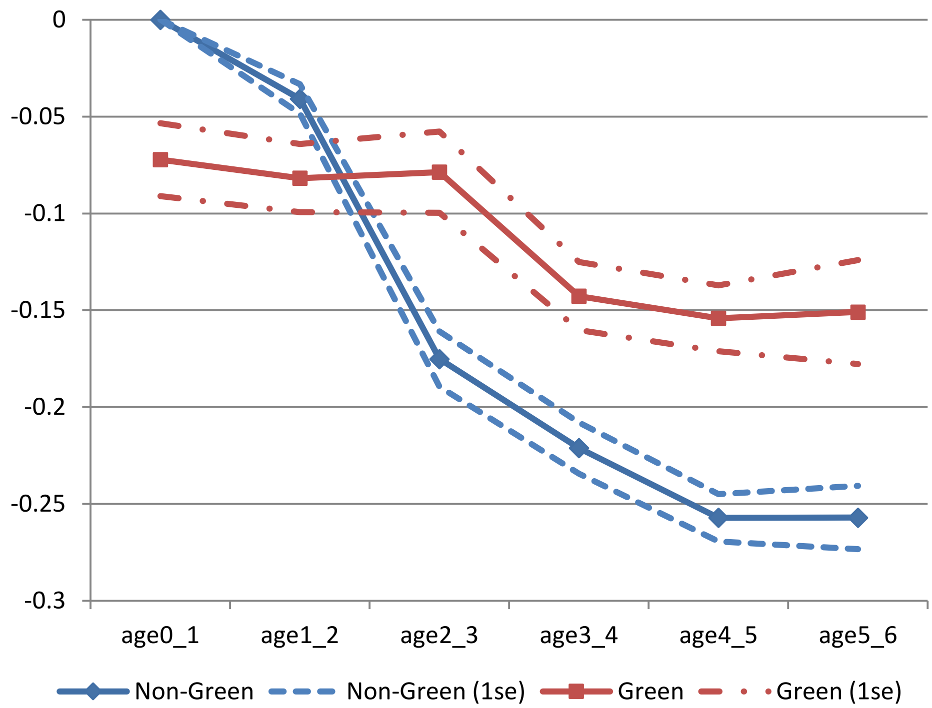


Panel B. The Same Life Span and Low Running Costs.



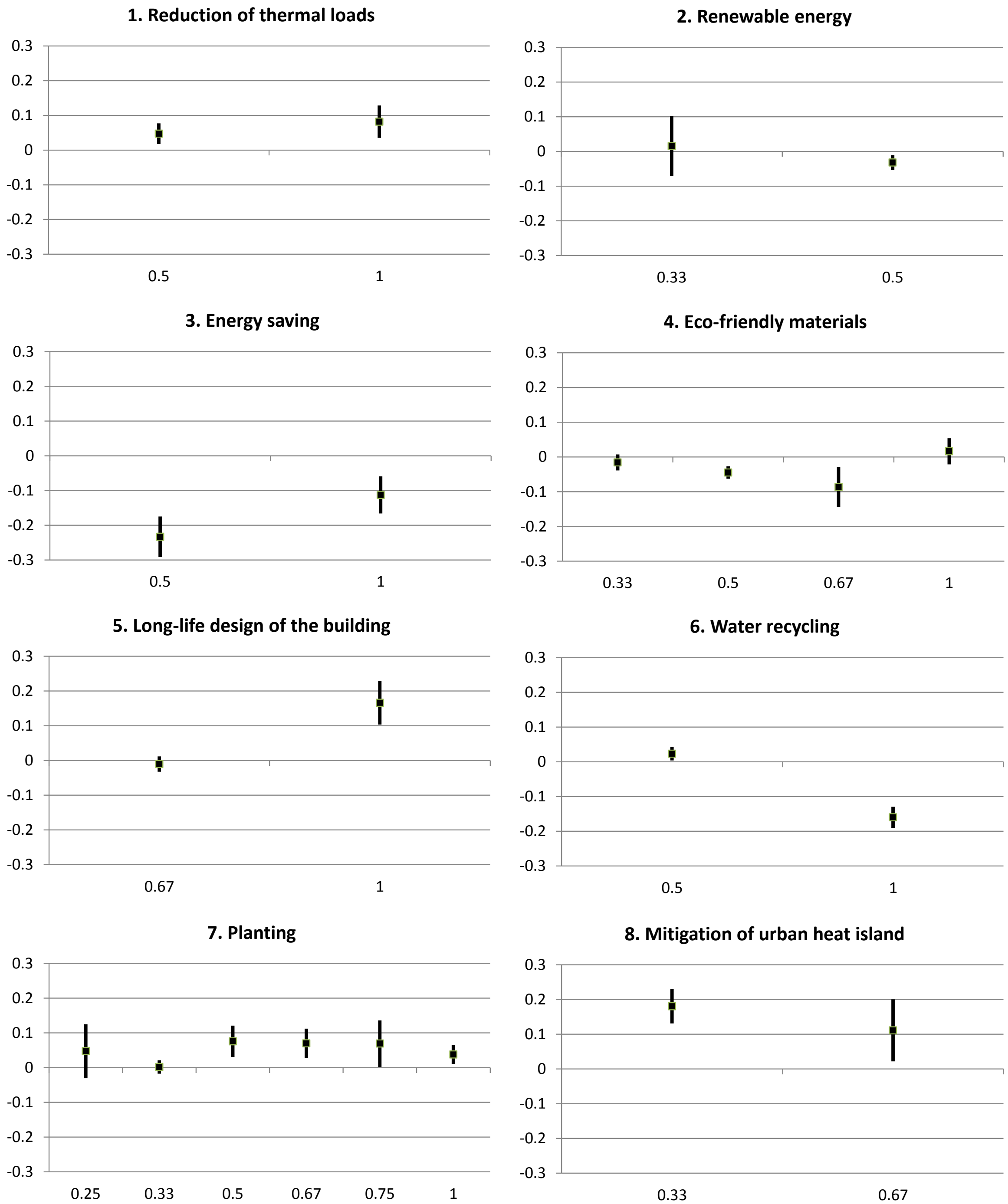
Notes: This figure is a numerical example of the values of green and non-green buildings based on equation (1). Panel A: $S^G = S^N = 100,\ C^G = 76,\ C^N = 70,\ r = 0.05,\ T^G = 30,\ T^N = 20$. Panel B: $S^G = S^N = 100,\ C^G = 65,\ C^N = 70,\ r = 0.05,\ T^G = T^N = 20$.

Figure 2. Price Gap by Building Age.



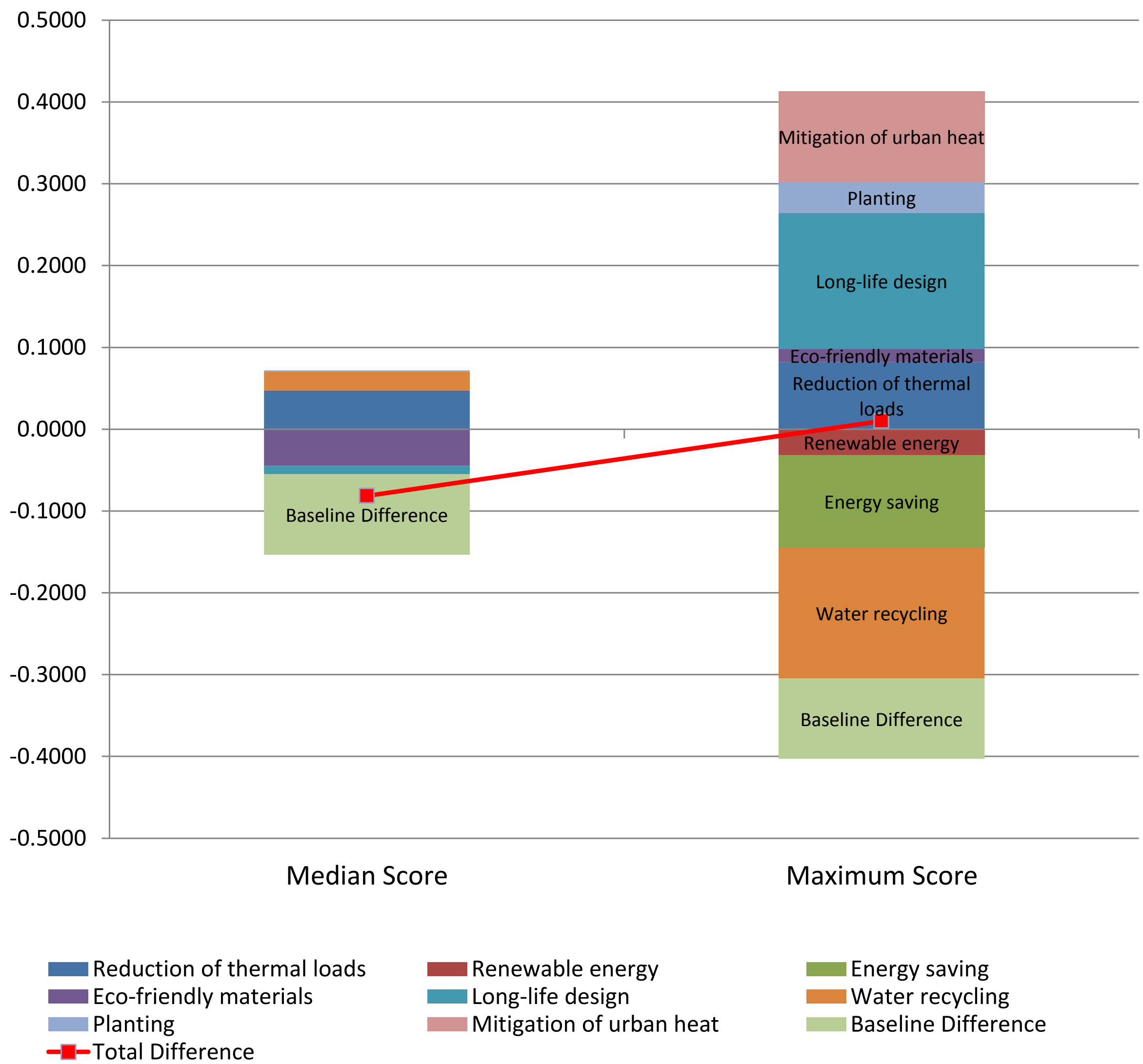
Notes: This figure plots the estimated coefficients on age dummies based on model (3) in table 4. The log-price of non-green buildings for age0_1 is used as a reference (zero). The value for green buildings is the sum of the coefficients of age, the green building indicator, and the interaction of age and the green indicator.

Figure 3. Coefficients on Green Factors.



Notes: This figure plots the estimated coefficients on green factors based on model (3) in table 5. The coefficient represents the difference in log prices associated with each green score. The reference value (zero) is a benchmark green building with minimal scores. Squares depict the point estimates, and the vertical bars depict one-standard-error bands.

Figure 4. Decomposition of Overall Price Differences for Buildings with Median and Maximum Green Scores.



Notes: This figure plots the result of model (3) reported in table 6. The bar graphs aggregate both positive and negative coefficients for the median scores (left) and the maximum scores (right). The line graph shows the total difference in logarithms from the non-green building price.