JAREFE
The Japanese Association of Real Estate Financial Engineering
日本不動産金融工学学会
URL http://www.jarefe.com

JAREFE Preprint

JP2020-01

DO LOW INTEREST RATES STIMULATE JAPANESE HOUSE PRICES?

著者 1　Hiroshi ISHIJIMA
Chuo University

著者 2　Akira MAEDA
University of Tokyo

著者 3　Tomohiro TSURUGA
Osaka University

Keywords: Generalized Hedonic Pricing Model, Interest Rates, House Prices

Received: October 20, 2020

DO LOW INTEREST RATES STIMULATE JAPANESE HOUSE PRICES?

Hiroshi ISHIJIMA
Chuo University Email: ishijima@tamacc.chuo-u.ac.jp

Akira MAEDA
University of Tokyo Email: akira-maeda@g.ecc.u-tokyo.ac.jp

Tomohiro TSURUGA
Osaka University Email: tomohiro.tsuruga@gmail.com

Abstract

We explore the issue of how low interest rates led by the Quantitative and Qualitative Monetary Easing (QQE) introduced by the Bank of Japan (BOJ) stimulate Japanese house prices. Since the introduction of QQE in the beginning of 2013, interest rates of Japanese Government Bonds (JGB) are being lowered than ever and have even entered into a negative range. We focus on the issue of whether or not QQE stimulates Japanese house prices that are the discounted sum of future rents which comprise the primary portion of the Japanese consumer price index (CPI). To conduct an empirical analysis on this issue, we develop a generalized hedonic pricing model that incorporates hedonic variables of real estate as well as interest rates in an affine form. By controlling hedonic variables carefully, we estimate the model to find evidence that low interest rates introduced by QQE have increased Japanese house prices.

To show reliable evidence, we first generalize the hedonic pricing model that can be regarded as a baseline to understand house prices. To this end, we begin our discussion with Ishijima and Maeda (2012, 2015) who developed a unified theoretical model that bridges the gap between the stochastic discounted cash flow model in the finance literature and the hedonic pricing model in the real estate economics literature.

Their unified pricing model comprises two procedures: (1) the real estate price is given by the expected sum of discounted rents that will stem in the future along the time horizon. This is a typical stochastic discounted cash flow model in use since the study by Merton (1969) and Lucas (1978) where the stochastic discount factor (SDF) is given by the intertemporal marginal rate of substitution (IMRS), also called the cash-flow pricing kernel. (2) The rent is represented as a linear combination of the attribute prices of real estate. The attributes, such as location, square footage, age of the property and so on, characterize each real estate property and provide some benefits to the residents, tenants, or other users. Hence, the rent is the source of the real estate price and is represented as a typical hedonic model used since the study by Lancaster (1966, 1971). They then showed that the real estate price is represented by a linear combination of attribute prices by imposing two technical assumptions.

Based on the unified pricing model of Ishijima and Maeda (2012, 2015), we develop a generalized hedonic pricing model that incorporates attribute variables of real estate as well as interest rates. To the best of our knowledge, this is the first real estate pricing model that theoretically incorporates interest rates in an affine form.

We then proceed to conduct an empirical analysis to show evidence that low interest rates under QQE stimulate Japanese house prices with hedonic variables appropriately controlled.

Keywords: Generalized Hedonic Pricing Model, Interest Rates, House Prices
JEL Classification: G12, R10, C58

DO LOW INTEREST RATES STIMULATE JAPANESE HOUSE PRICES?

1. Introduction

Real estate and financial asset markets are now merging and becoming significant driving forces of the global economy, as exemplified by the 2008 financial crisis, which was triggered by the boom and bust in the U.S. housing market. Considering this background, Ishijima and Maeda (2012, 2015) developed a unified theoretical model that bridges the gap between the stochastic discounted cash flow model in the finance literature and the hedonic pricing model in the real estate economics literature. Their approach was motivated by the classic dynamic portfolio choice models used since the study by Merton (1969) and the dynamic asset pricing models used since the study by Lucas (1978). They incorporated real estate into these standard pricing models of financial assets to develop a unified pricing model.

Their unified pricing model comprises two procedures: (1) the real estate price is the expected sum of discounted rent that will stem in the future along the time horizon. This is the typical stochastic discounted cash flow model in use since the study by Lucas (1978) where the stochastic discount factor (SDF) is given by the intertemporal marginal rate of substitution (IMRS), also called the cash-flow pricing kernel. (2) The rent is represented as a linear combination of the attribute prices of real estate. The attributes, such as location, square footage, age of the property and so on, characterize each real estate property and provide some benefits to the residents, tenants, or other users. Hence, the rent is the source of the real estate price and is represented as the typical hedonic model used since the study by Lancaster (1966, 1971). Theoretically, attribute prices are given as the marginal rate of substitution between the attributes of real estate and general consumption. According to Ishijima and Maeda (2012, 2015), however, it may not be so straightforward to simply represent the real estate price as a linear combination of attribute prices in the actual market. They demonstrated that two critical assumptions, which may or may not be realistic, are necessary to obtain the hedonic representation or linear pricing model. With these two assumptions, the real estate price is represented by the linear combination of attribute prices.

In this study, we develop a generalized hedonic pricing model that incorporates attribute variables of real estate as well as macroeconomic variables in an affine form. The model construction is based on the unified pricing model of Ishijima and Maeda (2012, 2015). Specifically, our model features the pricing kernel as the product of a hedonic pricing kernel and a cash-flow pricing kernel (stochastic discount factor) into which we introduce macroeconomic variables in an affine form. This feature enables us to derive a generalized hedonic pricing model in which macroeconomic variables as well as conventional hedonic attribute variables could be incorporated.

To the best of our knowledge, this is the first real estate pricing model that theoretically incorporates macroeconomic variables in an affine form.

Furthermore, we conduct an empirical analysis to understand Japanese housing prices. Our analysis reveals that macroeconomic variables serve as the major determinants of real estate prices with conventional hedonic variables appropriately controlled. We also show evidence that there exists a structural break after the introduction of QQE (Quantitative and Qualitative Monetary Easing) by the Bank of Japan. After 2013, interest rates has been negatively correlated with house prices.

The rest of this paper is organized as follows. In the next section, we derive a generalized hedonic pricing model and its variants on the basis of the study by Ishijima and Maeda (2012, 2015). Then, we conduct an empirical analysis in the Japanese housing market to understand how interest rates and conventional hedonic variables could be the major determinants of real estate prices. We finally present the conclusion.

2. Model

In this section, we elaborate on a theory on which our generalized hedonic pricing models rely. Specifically, our pricing models are not heuristic but have a theoretical foundation. First, we briefly review a "theoretical hedonic pricing model" developed by Ishijima and Maeda (2012, 2015). This is an asset pricing model that can simultaneously price real estate and other financial assets. Thereafter, we extend the theoretical hedonic pricing model to incorporate macroeconomic variables in an affine form.

Proposition 1 (PHD Equations)

Let the occupancy rates $\mathbf{L}_t$ $(\forall t)$ *and dividends yielded by financial securities* $\boldsymbol{D}_t^P$ $(\forall t)$ *be exogenous. Then, financial security prices, real estate prices, and real estate rents are determined by the following equations:*

P: Financial asset equilibrium prices (P-equation)

$$\boldsymbol{P}_t = E_t\left[(\boldsymbol{D}_{t+1}^P + \boldsymbol{P}_{t+1})M_{t:t+1}^C\right] \tag{1}$$

H: Real estate equilibrium prices (H-equation)

$$\boldsymbol{H}_t = \boldsymbol{L}_t\boldsymbol{D}_t^H + E_t\left[\boldsymbol{H}_{t+1}M_{t:t+1}^C\right] = \boldsymbol{L}_t\boldsymbol{B}_t\boldsymbol{M}_{t:t}^z + E_t\left[\boldsymbol{H}_{t+1}M_{t:t+1}^C\right] \tag{2}$$

D: Real estate equilibrium rent (D-equation)

$$\boldsymbol{D}_t^H = \boldsymbol{B}_t\boldsymbol{M}_{t:t,}^z \tag{3}$$

where

$$M_{t:t+1}^C = \delta \cdot \frac{\partial u(C_{t+1}, \boldsymbol{Z}_{t+1})/\partial C_{t+1}}{\partial u(C_t, \boldsymbol{Z}_t)/\partial C_t} \tag{4}$$

$$\boldsymbol{M}^{Z}_{t:t} = \frac{\partial u(C_t, \boldsymbol{Z}_t)/\partial \boldsymbol{Z}_t}{\partial u(C_t, \boldsymbol{Z}_t)/\partial C_t} \tag{5}$$

$$C_t = \mathbf{1}'\boldsymbol{D}^{P}_t + Y_t \tag{6}$$

$$\boldsymbol{Z}_t = \boldsymbol{B}'_t \boldsymbol{L}_t \mathbf{1} \tag{7}$$

Remark that $M^{C}_{t:t+1}$ is the intertemporal marginal rate of substitution, u the time-additive utility function of the representative agent, δ the rate of time preference, C_t the general consumption, $\boldsymbol{Z}_t = (Z_{1,t} \cdots Z_{K,t})'$ the quantity of K attributes provided by entire real estate, $\boldsymbol{L}_t$ the occupancy rate (i.e. one minus vacancy rate), $\mathbf{B}_t = (\boldsymbol{b}_{i,t}) = ((b_{i1,t} \cdots b_{iK,t}))$ the quantity of K attributes given by real estate i, $\boldsymbol{M}^{Z}_{t:t}$ the marginal rate of substitution between K attributes and general consumption.

2.1. Modeling time series of real estate log prices

To model the time series of real estate log prices, we first consider the expected appreciation in real estate prices. Based on Proposition 1, we have

$$\begin{aligned} E_t[H_{i,t+1}] - H_{i,t} &= E_t[H_{i,t+1}] - (L_{i,t}D^{H}_{i,t} + E_t[H_{i,t+1}M^{C}_{t:t+1}]) \\ &= E_t[(1 - M^{C}_{t:t+1})H_{i,t+1}] - L_{i,t}D^{H}_{i,t} \\ &= E_t\left[(1 - M^{C}_{t:t+1})E_{t+1}\left[\sum_{\tau=0}^{\infty} L_{i,t+1+\tau}D^{H}_{i,t+1+\tau}M^{C}_{t+1:t+1+\tau}\right]\right] - L_{i,t}D^{H}_{i,t} \end{aligned} \tag{8}$$

We then have the expected rate of return on real estate i.

$$\frac{E_t[H_{i,t+1}] - H_{i,t}}{H_{i,t}} = E_t\left[(1 - M^{C}_{t:t+1})\sum_{\tau=0}^{\infty} E_{t+1}\left[\frac{L_{i,t+1+\tau}D^{H}_{i,t+1+\tau}M^{C}_{t+1:t+1+\tau}}{H_{i,t}}\right]\right] - \frac{L_{i,t}D^{H}_{i,t}}{H_{i,t}} \tag{9}$$

With the representation of rent $D^{H}_{i,t+1+\tau}$, we rewrite the present value of occupancy-adjusted rent that will stem at time $t + 1 + \tau$ as below:

$$\begin{aligned} L_{i,t+1+\tau}D^{H}_{i,t+1+\tau}M^{C}_{t+1:t+1+\tau} &= L_{i,t+1+\tau}(\boldsymbol{b}_{i,t+1+\tau}\boldsymbol{M}^{Z}_{t+1+\tau:t+1+\tau})M^{C}_{t+1:t+1+\tau} \\ &= L_{i,t+1+\tau}\boldsymbol{b}_i\boldsymbol{M}^{Z}_{t+1:t+1+\tau} \end{aligned} \tag{10}$$

where we assume $\boldsymbol{b}_{i,t+1+\tau} = \boldsymbol{b}_i$ is constant through time.

We remark that the current occupancy-adjusted rent at time t is $L_{i,t}D^{H}_{i,t} = L_{i,t}\boldsymbol{b}_i\boldsymbol{M}^{Z}_{t:t}$. Plugging in to Eq. (9), we have the expression for the expected rate of return on real estate i.

$$\frac{E_t[H_{i,t+1}] - H_{i,t}}{H_{i,t}} = \frac{\boldsymbol{b}_i}{H_{i,t}} \cdot E_t[\boldsymbol{\kappa}_{i,t+1}] = \boldsymbol{b}^{*}_{i,t} \cdot E_t[\boldsymbol{\kappa}_{i,t+1}], \tag{11}$$

where $\boldsymbol{b}^{*}_{i,t} \coloneqq \boldsymbol{b}_i/H_{i,t}$ and

$$\boldsymbol{\kappa}_{i,t+1} \coloneqq \sum_{\tau=0}^{\infty}(1 - M^{C}_{t:t+1})L_{i,t+1+\tau}\boldsymbol{M}^{Z}_{t+1:t+1+\tau} - L_{i,t}\boldsymbol{M}^{Z}_{t:t}\,. \tag{12}$$

Then, the rate of return on real estate i, denoted by $R_{i,t+1} \coloneqq (H_{i,t+1} - H_{i,t})/H_{i,t}$, has an expression of

$$R_{i,t+1} = \boldsymbol{b}_{i,t}^{*} \cdot \boldsymbol{\kappa}_{i,t+1} + \varepsilon_{i,t+1}\ , \tag{13}$$

where $\varepsilon_{i,t+1}$ has a zero conditional mean. Additionally, we impose the conditional normality:

Assumption 1 (Conditionally Normal Return)

The return of real estate is conditionally normal, that is $\varepsilon_{i,t+1} \sim \mathcal{N}\left(0, \sigma_{i,t}^{2}\right)$.

By the first-order approximation, the log return $r_{i,t+1}^{H} \coloneqq \log\left(H_{i,t+1}/H_{i,t}\right) \approx R_{i,t+1}$ is given by

$$r_{i,t+1}^{H} = \boldsymbol{b}_{i,t}^{*} \cdot \boldsymbol{\kappa}_{i,t+1} + \varepsilon_{i,t+1}, \tag{14}$$

or the log price of real estate i, denoted by $h_{i,t+1}$, is now represented as

$$h_{i,t+1} = h_{i,t} + \boldsymbol{b}_{i,t}^{*} \cdot \boldsymbol{\kappa}_{i,t+1} + \varepsilon_{i,t+1}, \tag{15}$$

This is our theoretical time series modeling of real estate log prices.

2.2. Generalized hedonic pricing model

Our next motivation is to develop a generalized hedonic pricing model that is ready to implement empirical analyses in the real estate market. Closely examining the theoretical log pricing model of Eq. (15), $\boldsymbol{k}_{i,t+1}$, defined as Eq. (12), can be regarded as a pseudo pricing kernel, which has the following expansion.

$$\boldsymbol{k}_{i,t+1} = \sum_{\tau=0}^{\infty} L_{i,t+1+\tau} M_{t+1:t+1+\tau}^{C} \boldsymbol{M}_{t+1+\tau:t+1+\tau}^{Z} - \sum_{\tau=0}^{\infty} L_{i,t+1+\tau} M_{t:t+1+\tau}^{C} \boldsymbol{M}_{t+1+\tau:t+1+\tau}^{Z} - L_{i,t} \boldsymbol{M}_{t:t}^{Z} \tag{16}$$

As is specific in the real estate market, the liquidity is poor, asymmetric information exists among market participants, and transaction costs are high. Hence, it would be natural to let a pseudo pricing kernel $\boldsymbol{k}_{i,t+1}$ fluctuate among each piece of real estate when we develop a statistical log pricing model. To make a hedonic pricing model more general, we impose the following assumption on the theoretical log pricing model of Eq. (15) and its pseudo pricing kernel Eq. (16).

Assumption 2 (Generalized Hedonic Pricing Kernel Incorporating Macroeconomic Variables in an Affine Form)

We assume that the cash-flow pricing kernel $M_{t+1:t+1+\tau}^{C}$ *has the form of* $\rho^{\tau}(a_0 + \boldsymbol{\gamma}'\boldsymbol{z})$, *where* $|\rho| < 1$, a_0 *and* $\boldsymbol{\gamma} \in \mathbb{R}^{K_z}$ *are constant.* $\boldsymbol{z} \in \mathbb{R}^{K_z}$ *is a vector of macroeconomic variables that might affect the SDF through the time horizon.* ρ^{τ} *is the time discount from* $t+1$ *to* $t+1+\tau$. *Moreover, we assume that the occupancy-rate-adjusted hedonic pricing kernel* $L_{i,t+1+\tau}\boldsymbol{M}_{t+1+\tau:t+1+\tau}^{Z}$ *is a time-invariant random vector, which enables us to rewrite it as* $\boldsymbol{M}_{i}^{Z} \in \mathbb{R}^{K}$. *Furthermore, we assume that* $L_{i,t}\boldsymbol{M}_{t:t}^{Z}$, *which is a realized random vector of* $\boldsymbol{M}_{i}^{Z}$, *has the form of* $\boldsymbol{m}_{i}^{Z} \in \mathbb{R}^{K}$.

This assumption of representing the cash-flow pricing kernel by an affine function of macroeconomic variables is frequently imposed in the macro-finance literature (Ang and Piazzesi, 2003). In conjunction with Assumption 2, Eq. (16) reduces to

$$\boldsymbol{k}_{i,t+1} = (a_0 + \boldsymbol{\gamma}'\boldsymbol{z})\boldsymbol{M}_i^Z - \boldsymbol{m}_i^Z \tag{17}$$

In theory, $\boldsymbol{M}_i^{\mathrm{Z}}$ must be homogeneous to any real estate i if it serves as a genuine hedonic pricing kernel. In the actual market, however, real estate has some specific features. Every real estate property is unique in the market. Thus, the market price might reflect strong heterogeneity. Furthermore, the transaction is illiquid, information is asymmetric, and large transaction costs are incurred. The above insight leads us to assume that $\boldsymbol{M}_i^{\mathrm{Z}}$ would randomly fluctuate around its expected value that is homogeneous to every real estate. We then identify the hedonic pricing kernel as $\boldsymbol{M}_i^Z = \boldsymbol{\beta} + \boldsymbol{\nu}_i$, where $\boldsymbol{\beta} \in \mathbb{R}^K$ is the expected value of $\boldsymbol{M}_i^{\mathrm{Z}}$ and $\boldsymbol{\nu}_i \in \mathbb{R}^K$ is a random vector with a zero mean. We also assume that $\boldsymbol{m}_i^Z$, which is a realization of $\boldsymbol{M}_i^{\mathrm{Z}}$, takes the same $\boldsymbol{\beta}$. Thus, we have the representation of $\boldsymbol{k}_{i,t+1}$ as follows:

$$\boldsymbol{k}_{i,t+1} = (a + \boldsymbol{\gamma}'\boldsymbol{z})\boldsymbol{\beta} + (a_0 + \boldsymbol{\gamma}'\boldsymbol{z})\boldsymbol{\nu}_i \tag{18}$$

where $a \coloneqq a_0 - 1$. Inserting Eq. (18) into Eq. (15), which is theoretical time series modeling of real estate log prices, we have

$$h_{i,t+1} = h_{i,t} + \boldsymbol{b}_{i,t}^{*}\{(a + \boldsymbol{\gamma}'\boldsymbol{z})\boldsymbol{\beta} + (a_0 + \boldsymbol{\gamma}'\boldsymbol{z})\boldsymbol{\nu}_i\} + \varepsilon_{i,t+1} \tag{19}$$

This is a generalized version of our hedonic pricing model, which we call "generalized hedonic pricing model."

On the basis of a generalized hedonic pricing model of Eq. (19), we proceed to propose a simple version that is ready to be applied for in the Japanese housing market. Here, we address a question of how to define real estate i. The difficulty is that we cannot frequently observe the price and attributes for each individual property. Thus, we categorize properties into plausible sets to identify real estate i. To this end, we introduce a stratum $i \in \mathcal{I}$ in our analysis. For example, if we take a set $\mathcal{I}$ as prefectures in Japan, a stratum i could be Tokyo. Then, we can drop off the subscript of time and rewrite the variables as follows:

$$\begin{array}{lll} h_{i,t+1} & \rightarrow & y_i \\ h_{i,t} & \rightarrow & \bar{y}_i \\ \boldsymbol{b}_{i,t}^{*} & \rightarrow & \boldsymbol{x}_i = \left(x_i^{(0)} \quad x_i^{(1)} \quad \cdots \quad x_i^{(K)}\right) \\ a + \boldsymbol{\gamma}'\boldsymbol{z} & \rightarrow & \boldsymbol{\gamma}'\boldsymbol{z} \\ \boldsymbol{\beta} & \rightarrow & \boldsymbol{\beta} = \left(\beta^{(0)} \quad \beta^{(1)} \quad \cdots \quad \beta^{(K)}\right)' \\ a_0 + \boldsymbol{\gamma}'\boldsymbol{z} & \rightarrow & \boldsymbol{\gamma}'\boldsymbol{z} \\ \boldsymbol{\nu}_i & \rightarrow & \boldsymbol{\nu}_i = \left(\nu_i^{(0)} \quad x_i^{(1)} \quad \cdots \quad x_i^{(K)}\right)' \end{array} \tag{20}$$

where we let constants of a, a_0 equal zeros. Then, we have

$$
\begin{aligned}
y_i &= \bar{y}_i + \sum_{k=0}^{K} x_i^{(k)} \boldsymbol{\gamma}' \boldsymbol{z} \left(\beta^{(k)} + \nu_i^{(k)}\right) + \varepsilon_i \\
&= \bar{y}_i + \left(\beta^{(0)} + \nu_i^{(0)}\right) \sum_{j=1}^{K_z} \gamma^{(j)} z^{(j)} + \sum_{k=1}^{K} x_i^{(k)} \left(\beta^{(k)} + \nu_i^{(k)}\right) + \varepsilon_i,
\end{aligned} \tag{21}
$$

where in the last equation, we further impose the following assumption:

$$
\begin{aligned}
&x_i^{(0)} = 1 \\
&x_i^{(k)} \boldsymbol{\gamma}' \boldsymbol{z} = x_i^{(k)} \ (k = 1, \cdots, K),
\end{aligned} \tag{22}
$$

We would like to remark that this version of our generalized hedonic pricing model, Eq. (21), can be regarded as a typical mixed effects model, if we assume that $\nu_i^{(\cdot)}$ is normal. The mixed effects model has been well-developed in statistics literature (Fitzmaurice et al. 2004 and McCulloch et al. 2008). Thus, we can easily estimate our generalized hedonic pricing model of Eq. (21) by the MIXED procedure in SAS (Littell et al. 2006).

To have a simple version of the generalized hedonic pricing model of Eq. (21), we let $\nu_i^{(k)} = 0 \ (k = 0, \cdots, K)$ and $\beta^{(0)} \cdot \gamma^{(j)} =: \tilde{\gamma}^{(j)}$. For real estate m categorized into stratum i, we regress the log price $y_{i,m}$ on the attribute variables $x_{i,m}^{(k)}$ and macroeconomic variables $z^{(j)}$.

(Generalized Hedonic Pricing Model)

$$
y_{i,m} = \bar{y}_i + \sum_{k=1}^{K} \beta^{(k)} x_{i,m}^{(k)} + \sum_{j=1}^{K_z} \tilde{\gamma}^{(j)} z^{(j)} + \varepsilon_{i,m} \tag{23}
$$

If we omit the macroeconomic variables $z^{(j)}$, the above model reduces to the conventional hedonic regression.

(Conventional Hedonic Pricing Model)

$$
y_{i,m} = \bar{y}_i + \sum_{k=1}^{K} \beta^{(k)} x_{i,m}^{(k)} + \varepsilon_{i,m} \tag{24}
$$

3. An Empirical Analysis of the Japanese Housing Market

With a generalized hedonic pricing model developed in the previous section, we conduct an empirical analysis to show evidence that there was a structural break at which the BOJ has started the Quantitative and Qualitative Monetary Easing (QQE) and after that long term interest rates have been negatively correlated with house prices.

To this end, our empirical analysis comprises two regressions:

First Stage Regression: For a paired data set of house prices and 46 hedonic variables across all areas of Japan, we employ a conventional hedonic regression model to select the primary five hedonic variables that contribute beyond 90% in R-squares for all the area. Then, by clustering the paired data set into each of 47 prefectures in Japan, we regress house prices on five hedonic variables year-on-year. We then reveal the existence of a time-varying intercept that seems to be correlated with the interest rate behavior.

Second Stage Regression: We regress the residuals of log prices in the first stage regression on JGB interest rates with different maturities. We show evidence that low interest rates under the BOJ monetary policy increase Japanese house prices.

In this section, we first outline the dataset and the models. We then present the result for each of two regressions, followed by the interpretations.

3.1. Data

Data for preliminary and first stage regressions

To estimate the conventional hedonic pricing model, we use a paired data set that comprises transaction log prices of the property and its hedonic attributes. While the former serves as the dependent variable, the latter the independent variables. The paired data used in our empirical analyses are obtained from the Japanese Ministry of Land, Infrastructure, Transport and Tourism. This database compiles and discloses the transaction prices and attributes for each of residential properties that were traded in each quarter. Residential properties are categorized into two types: single family homes and apartments. We conduct analyses on the latter, the apartment market, as apartments are much more liquid than single family homes in Japan. Categories of hedonic attributes employed by the Japanese Ministry of Land, Infrastructure, Transport and Tourism are as follows: total floor area (m^2), age (year), nearest station in distance (min.), maximus building coverage ratio (%), maximus floor-area ratio (%), layout, building structure, building use, purpose of use in the future, and city planning. From these categories, we incorporate as many different types of attributes as possible, such as layout, maximum floor-area ratio and so on, that are available in our dataset. These are regarded as hedonic variables in our analyses.

Data for second stage regression

To estimate the generalized hedonic pricing models, we also employ exogenous interest rates; that is, yields to maturity of Japanese government bonds (JGB) with different types of maturities. These are obtained from Bloomberg as shown in the right panel of Table 2.

Data summary

The dataset in our study is defined as transaction log prices, hedonic variables and exogenous interest rates. Our dataset spreads over the periods on a quarterly basis from the first quarter of 2006 to the third quarter of 2015, which is 39 quarters in total. The data used in our analysis comes from 395,787 apartments.

3.2. First Stage Regression: Identify the primary five hedonic variables

We first regress log prices of Japanese apartments on hedonic variables alone. On the basis of a conventional hedonic pricing model of Eq. (24), we introduce some plausible sets which the real estate stratum i belongs to. The first one is a set of 39 quarterly points in time $\mathcal{T} \coloneqq \{1\text{Q}2006, \cdots, 3\text{Q}2015\}$. The second is a set of prefectures, $\mathcal{L} \coloneqq \{\text{Hokkaido}, \cdots, \text{Tokyo}, \cdots \text{Okinawa}\}$ that identifies the location of each property. We then define the product set $\mathcal{J} \coloneqq \mathcal{T} \times \mathcal{L}$. Either set $\mathcal{T}$ or $\mathcal{J}$ will be a candidate for defining the real estate stratum; that is, we estimate the model for each stratum $t \in \mathcal{T}$ and $j \in \mathcal{J}$. With these definitions, we estimated two models in the Japanese apartment market as follows:

(1) Conventional Hedonic Pricing Model with Time-Varying Intercept

$$y = \bar{y}_t + \sum_{k=1}^{K} \beta^{(k)} x^{(k)} + \varepsilon \tag{25}$$

Where the real estate stratum t belongs to the set of quarterly points in time $t \in \mathcal{T}$ and the second,

(2) Conventional Hedonic Pricing Models with Time × Location-Varying Intercept

$$y = \bar{y}_j + \sum_{k=1}^{K} \beta^{(k)} x^{(k)} + \varepsilon \tag{26}$$

where the real estate stratum j belongs to the product set of quarterly points in time and prefectures, i.e., $j \in \mathcal{J}$.

We conduct preliminary analyses from two aspects: the dynamics of log price level and the regional clusters in log price level. We elaborate on each result to provide the direction of further analyses.

Dynamics of log price level

We used the entire dataset to estimate the conventional hedonic pricing model with time-varying intercepts of Eq. (25). The time-varying intercept of the model can be interpreted as the log price level that will fluctuate over time. In Figure 1, we show log price levels in solid lines. For comparison, dashed lines show the yield to maturity of Japanese Government 10-year bonds (JGB 10-year yield).

Figure 1 gives us some insights on log price levels. Since 2006, the log price level has been descending with a large drop in 2008 due to the financial crisis. Since then, the market shows a cyclical pattern until the first quarter of 2011. After the Great East Japan Earthquake in March 2011, the market has started to decrease again. When Abenomics started in December 2012, the market quickly recovered. Basically, the repeatedly implemented QQE conducted by the Bank of Japan, as shown in the downtrend of the JGB 10-year yield, has been successful in raising the log price level of real estate.

The above discussion leads us to the possibility that the information about macroeconomic variables, such as the JGB 10-year yield, might still remain in the time-varying intercept. Hence, this finding motivates us to incorporate macroeconomic variables such as interest rates with hedonic variables appropriately controlled.

Regional clusters in log price levels

In Figure 2, we show log price levels for some selected prefectures. We ranked prefectures according to the log price level in the apartment market. We then charted the top three prefectures of Tokyo, Kanagawa, and Kyoto and the bottom three of Yamaguchi, Hokkaido, and Kagawa. The top three prefectures are located in the capital of Japan or they are popular tourist areas.

Furthermore, the log price level remains stable along time horizon for these prefectures. On the flip side, the bottom three prefectures are located in the rural areas of Japan. The log price level seems to be volatile for these prefectures. In sum, the adequately modeled random intercepts enable us to clarify the regional clusters in the log price level.

The above insight leads us to the estimation that it would be better off to estimate our models on the plausible region basis. Hence, in conjunction with the findings so far, we can estimate the generalized hedonic pricing model that incorporates macroeconomic variables, such as interest rate, for each of the plausible regions in Japan.

Identify the Primary Five Hedonic Variables

We estimate the conventional hedonic pricing model by employing the entire dataset.

$$y = \alpha + \sum_{k=1}^{K} \beta^{(k)} x^{(k)} + \varepsilon \tag{27}$$

This is the model of Eq. (24) in which we replace the random intercept $\bar{y}_i$ with a fixed intercept α. The purpose is to select the primary determinants of Japanese apartment prices. Out of 64 hedonic variables available in our data set, we first identified the top 40 that are chosen by stepwise regressions by using the entire data set.

By employing a conventional hedonic pricing model with time-varying intercept of Eq. (25) for each area in Japan, we then conducted regressions with the chosen 40 variables to verify each of P-values and contributions in R-squares. We finally selected the top five hedonic variables that contributed beyond 90% in R-squares for all the area. Table 1 indicates the top five variables in terms of the R-square contribution for each prefecture in Japan. We verify that these five hedonic variables contribute 73.8% in average to explain Japanese apartment prices. We summarize the identified primary hedonic variables in Table 2.

In the following analysis, we will focus on the Tokyo apartment market which is the top prefecture in log price levels. We regress Tokyo house prices on the primary five hedonic variables year-on-year. Table 3 shows the estimation result. We verify that all five hedonic variables are significant every year. On the other hand, we reveal the existence of a time-varying intercept that seems to be correlated with the interest rate behavior. Hence we proceed to explore its determinants in the next subsection.

3.3. Second State Regression: Effect of Low Interest Rates

We regress the residual of log prices on the JGB interest rates with different maturities. The residual is defined as the difference in log prices between observation and estimation. The latter log prices are estimated in the first stage regression. Table 4 shows the estimation results for both periods prior and posterior to QQE introduced in the early 2013.

As shown in Table 4, our findings are two folds: As for the coefficients of JGB interest rates with different maturities, while they are positive before QQE, they turns to be negative afterwards. The result asserts that the lower interest rates BOJ leads the JGB to, the higher the Japanese house price becomes. Moreover, the result is robust to the different kinds of maturities from the short to the long, and also to the difference in long and short maturities.

To show clear evidence, we conduct the Chow test to verify that there was a structural break when QQE was introduced in the early 2013. We show the result in the right most column of Table 4 to verify that the structural break have occurred at the introduction of QQE.

4. Conclusion

In this study, we developed a generalized hedonic pricing model that incorporates hedonic variables of real estate as well as interest rates in an affine form. We then conducted an empirical analysis to show evidence that after the introduction of QQE in the early 2013, long-term interest rates have been negatively correlated with house prices.

Figure 1: Time-varying Log Price Level of Japanese Apartments and JGB 10-year Interest Rates

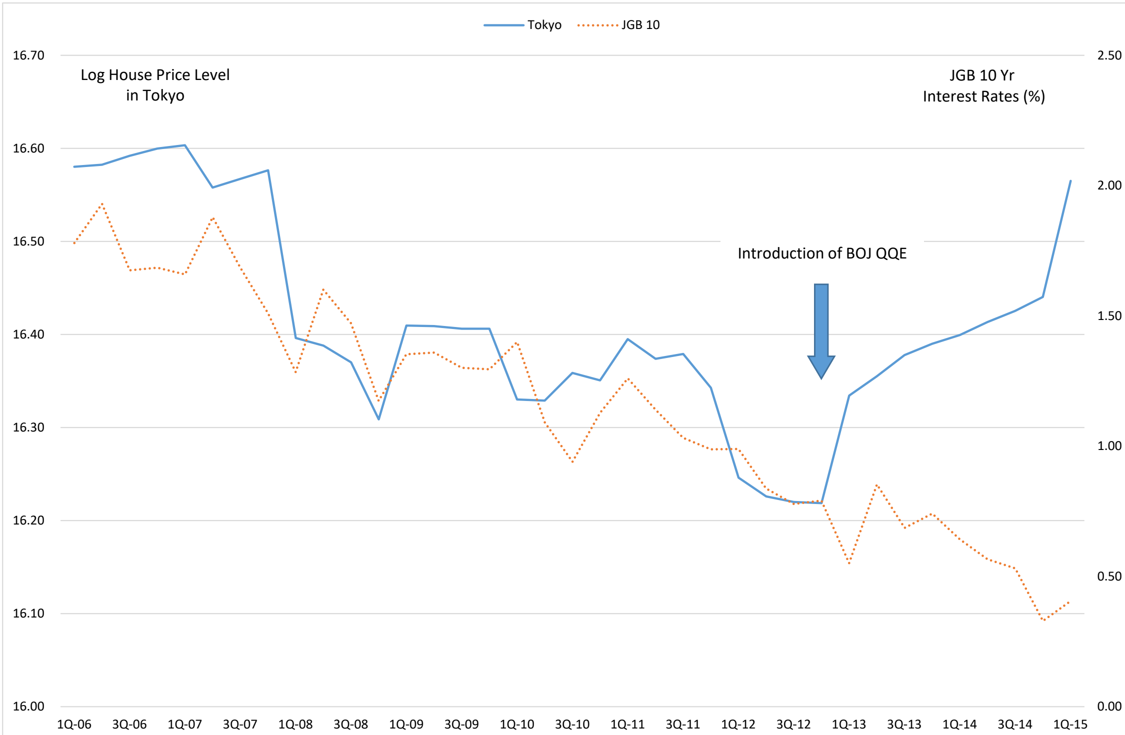

Figure 2: Estimated Apartment Log Price Level for the Top and Bottom Three Prefectures

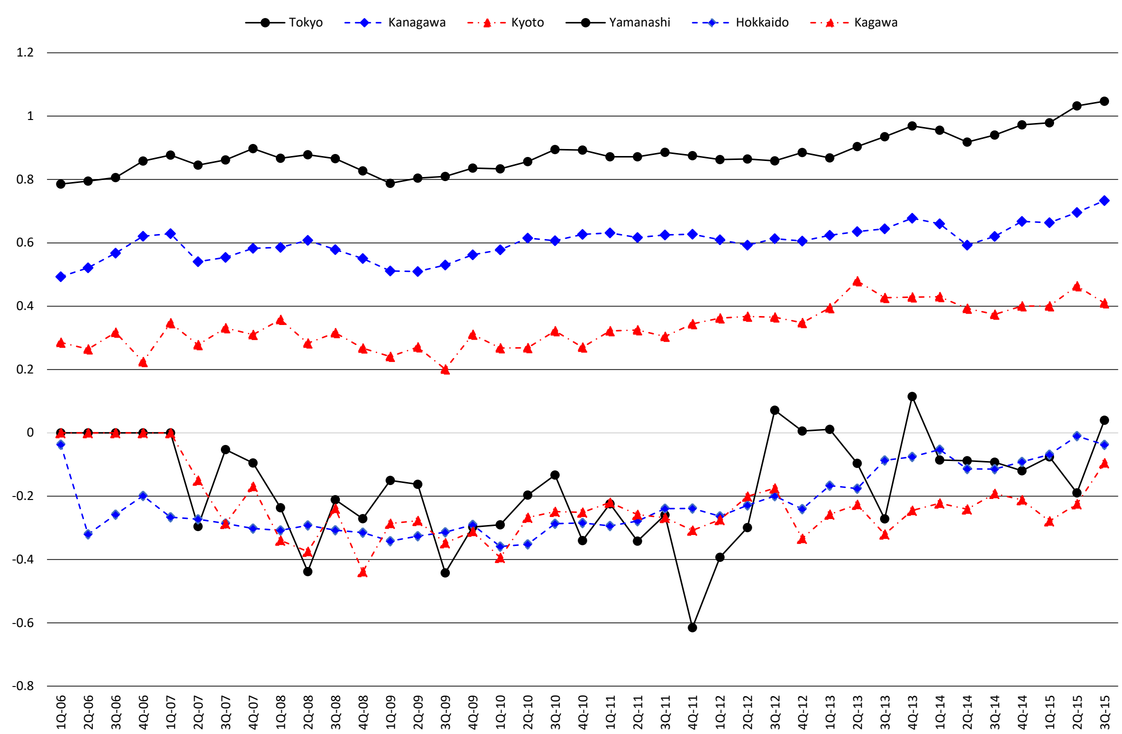

Table 1: Primary Five Hedonic Variables and Cumulative Contribution in R^2

			Contribution in R^2					
	AIC	R^2	Age (Year)	Floor Area (m^2)	Distance from Station (min.)	Layout	Maximus Floor-area Ratio (%)	Total
All	599,797	52.4%	53.2%	25.6%	7.8%	3.2%	2.3%	92.1%
Hokkaido	12,893	76.5%	71.7%	19.8%	3.2%	2.1%	1.1%	97.8%
Aomori	311	83.6%	71.7%	19.8%	3.2%	2.1%	1.1%	97.8%
Iwate	885	73.8%	56.1%	28.0%	4.6%	3.5%	3.0%	95.1%
Miyagi	6,401	67.6%	56.8%	22.3%	8.1%	4.1%	4.6%	95.9%
Akita	348	88.3%	81.9%	10.5%	4.1%	1.3%	0.7%	98.5%
Yamagata	471	56.7%	56.1%	26.3%				82.4%
Fukushima	1,312	75.2%	63.7%	26.2%	5.1%	1.1%	1.2%	97.3%
Ibaraki	2,362	72.9%	78.0%	10.8%	4.3%	1.7%	1.5%	96.4%
Tochigi	1,204	83.2%	74.5%	21.4%	0.8%	0.6%	0.7%	97.9%
Gunma	984	81.5%	72.5%	12.9%	5.5%	6.9%	0.6%	98.4%
Saitama	29,165	61.2%	64.8%	20.7%	5.2%	3.7%	1.1%	95.5%
Chiba	26,131	60.7%	68.7%	18.1%	6.0%	1.7%	1.7%	96.3%
Tokyo	118,792	64.5%	58.9%	25.2%	4.6%	5.3%	1.2%	95.2%
Kanagawa	61,440	66.7%	54.7%	31.9%	4.9%	4.3%	1.6%	97.3%
Niigata	2,520	70.9%	67.5%	28.5%	0.9%	1.0%	0.8%	98.8%
Toyama	454	83.2%	67.7%	29.6%	0.8%			98.1%
Ishikawa	974	85.7%	76.4%	15.3%	4.0%	1.7%	0.7%	98.2%
Fukui	396	86.2%	78.0%	17.9%	1.9%	0.7%		98.5%
Yamanashi	388	89.5%	88.3%	5.8%	2.0%	1.2%	0.4%	97.6%
Nagano	1,051	64.7%	67.5%	13.5%	4.9%	2.5%	2.2%	90.5%
Gifu	548	75.5%	57.0%	29.1%	4.6%	4.4%	1.5%	96.7%
Shizuoka	4,557	74.6%	65.9%	19.4%	6.8%	2.8%	1.5%	96.5%
Aichi	17,889	69.4%	59.5%	28.7%	3.7%	2.1%	1.5%	95.6%
Mie	1,236	61.2%	80.7%	8.9%	2.7%	2.4%	1.6%	96.2%
Shiga	1,574	61.5%	54.6%	20.1%	8.2%	9.4%	2.8%	95.1%
Kyoto	9,674	66.5%	45.7%	40.6%	4.8%	3.9%	1.4%	96.5%
Osaka	46,094	61.6%	53.6%	35.0%	3.0%	2.1%	2.4%	96.2%
Hyogo	31,772	55.8%	61.9%	25.3%	4.3%	4.4%	1.1%	96.9%
Nara	2,764	62.6%	78.9%	6.5%	3.4%	3.1%	2.2%	94.2%
Wakayama	319	80.7%	78.1%	14.8%	2.5%	1.7%	0.5%	97.6%
Tottori	274	87.7%	83.8%	11.5%	1.0%	0.6%	0.6%	97.5%
Shimane	106	59.6%	62.7%	18.6%	7.2%	2.5%	2.2%	93.2%
Okayama	1,340	79.7%	74.6%	14.6%	4.7%	1.9%	1.4%	97.2%
Hiroshima	3,057	75.0%	67.8%	23.5%	3.8%	1.9%	1.3%	98.3%
Yamaguchi	1,032	73.1%	59.4%	29.6%	5.2%	0.9%	1.0%	96.1%
Tokushima	458	76.1%	69.6%	16.5%	6.4%	1.4%	1.3%	95.3%
Kagawa	875	83.3%	67.7%	26.6%	1.8%	1.5%	0.9%	98.4%
Ehime	779	87.0%	72.6%	21.9%	1.5%	1.4%	0.9%	98.4%
Kochi	290	78.8%	76.6%	15.0%	2.2%	2.6%	1.4%	97.8%
Fukuoka	21,590	68.6%	56.5%	34.5%	2.2%	2.2%	1.8%	97.3%
Saga	374	70.2%	61.6%	17.7%	9.7%	2.8%	2.1%	93.9%
Nagasaki	611	66.6%	62.6%	9.6%	10.0%	5.6%	2.1%	89.9%
Kumamoto	1,200	83.4%	77.3%	10.1%	5.4%	2.2%	1.0%	96.0%
Oita	1,740	76.8%	77.8%	12.4%	3.2%	3.3%	0.8%	97.4%
Miyazaki	654	82.8%	89.0%	5.2%	3.5%	0.3%		98.1%
Kagoshima	829	81.6%	70.9%	15.8%	9.6%	1.1%	1.1%	98.5%
Okinawa	453	76.9%	71.9%	21.6%	3.1%	1.8%		98.3%

Table 2: Selected Hedonic and Exogenous Interest Rates

	Primary Five Hedonic Variables	Exogenous Interest Rates
Independent Variables	1) Age (Year)	Japan Govt. Bond 1 Year Yield
	2) Total floor area (m^2)	Japan Govt. Bond 5 Year Yield
	3) Nearest station: Distance (min.)	Japan Govt. Bond 10 Year Yield
	4) Layout	Japan Govt. Bond 30 Year Yield
	5) Maximus Floor-area Ratio (%)	Difference of 10 and 1 Year Yields

Table 3: First Stage Regression: Estimated Results of the Conventional Hedonic Model

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Intercept	16.5999***	16.5764***	16.3088***	16.4063***	16.3508***	16.3428***	16.2187***	16.3901***	16.4404***	16.5797***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
1Q	-0.0196	0.0270*	0.0874***	0.0034	-0.0206*	0.0522***	0.0274***	-0.0558***	-0.0411***	-0.0145
	(0.3086)	(0.0745)	(0.0001)	(0.7826)	(0.0722)	(0.0001)	(0.0077)	(0.0001)	(0.0001)	(0.2398)
2Q	-0.0175	-0.0185	0.0792***	0.0026	-0.0218*	0.0311**	0.0073	-0.0350***	-0.0271***	-0.0024
	(0.3878)	(0.1401)	(0.0001)	(0.8283)	(0.0554)	(0.0126)	(0.4834)	(0.0005)	(0.0073)	(0.8331)
3Q	-0.0078	-0.0091	0.0613***	-0.0002	0.0079	0.0363***	0.0012	-0.0122	-0.0149	0
	(0.6961)	(0.4724)	(0.0001)	(0.9898)	(0.4828)	(0.0030)	(0.9088)	(0.2303)	(0.1377)	
4Q	0	0	0	0	0	0	0	0	0	0
Age (Year)	-0.0267***	-0.0270***	-0.0259***	-0.0268***	-0.0252***	-0.0264***	-0.0246***	-0.0254***	-0.0236***	-0.0235***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Total floor area	0.0114***	0.0098***	0.0116***	0.0124***	0.0151***	0.0108***	0.0165***	0.0145***	0.0161***	0.0132***
(m2)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Nearest station	-0.0188***	-0.0162***	-0.0137***	-0.0179***	-0.0204***	-0.0134***	-0.0168***	-0.0175***	-0.0198***	-0.0183***
Distance (min.)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Layout	0.2914***	0.4139***	0.4094***	0.3831***	0.3353***	0.5010***	0.2747***	0.3263***	0.2517***	0.3375***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Maximus Floor-	0.0002***	0.0003***	0.0006***	0.0004***	0.0004***	0.0005***	0.0005***	0.0005***	0.0005***	0.0005***
area Ratio (%)	(0.0007)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
R2	59.2%	56.5%	59.1%	59.6%	60.9%	61.1%	67.6%	66.7%	66.5%	61.7%
AIC	4,378.7	10,591.2	13,377.2	14,957.8	17,984.7	15,677.8	12,999.0	15,552.9	13,861.3	9,777.3

Table 4: Second Stage Regression: Structural Breaks in the Effect of JGB Interest Rates on House Price Residuals

	'10 - '12		'13 - '15		Chow Test
	Int.	JGB	Int.	JGB	Stat.
JGB 1	-0.1158***	0.6343***	0.1126***	-0.9564***	118.4600***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
JGB 5	-0.0610***	0.0646***	0.1185***	-0.3757***	223.3700***
	(0.0001)	(0.0018)	(0.0001)	(0.0001)	(0.0001)
JGB 10	-0.0801***	0.0402***	0.1955***	-0.2458***	150.7000***
	(0.0001)	(0.0020)	(0.0001)	(0.0001)	(0.0001)
JGB 30	-0.0855**	0.0238	0.3100***	-0.1626***	89.2400***
	(0.0140)	(0.1751)	(0.0001)	(0.0001)	(0.0001)
JGB 30 - 1	-0.0656*	0.0146	0.3392***	-0.1887***	96.3600***
	(0.0553)	(0.4257)	(0.0001)	(0.0001)	(0.0001)

References

Ang A. and M. Piazzesi. 2003. A No-Arbitrage Vector Autoregression of Term Structure Dynamics with Macroeconomic and Latent Variables, Journal of Monetary Economics 50(4), 745–787.

Fitzmaurice, G.M., N.M. Laird and J.H. Ware. 2004. *Applied Longitudinal Analysis*. Hoboken, New Jersey: John Wiley & Sons.

Ishijima, H. and A. Maeda. 2012. Real Estate Price Modeling and Empirical Analysis. *International Journal of Economic Policy Studies* 7: 31–51.

Ishijima, H. and A. Maeda. 2015. Real Estate Pricing Models: Theory, Evidence, and Implementation. *Asia-Pacific Financial Markets* 22(4), 369–396.

Lancaster, K. 1966. A New Approach to Consumer Theory. *Journal of Political Economy* 74(2), 132–157.

Lancaster, K. 1971. *Consumer Demand: A New Approach*. New York and London: Columbia University Press.

Littell, R.C., G.A. Milliken, W.W. Stroup, R.D. Wolfinger and O.Schabenberber. 2006. *SAS for Mixed Models: Second Edition*. Cary, North Carolina: SAS Instituite.

Lucas, R. E. Jr. 1978. Asset Prices in an Exchange Economy. *Econometrica* 46(6), 1429–45.

Merton, R.C. 1969. Lifetime Portfolio Selection under Uncertainty: The Continuous-Time Case. *Review of Economics and Statistics* 51(3), 247–257.

McCulloch, C.E., S.R. Searle and J.M. Neuhaus. 2008. *Generalized, Linear, and Mixed Models: Second Edition*. Hoboken, New Jersey: John Wiley & Sons.