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The Effects of Macroeconomic Factors on Pricing Mortgage Insurance Contracts

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Abstract

Numerous empirical studies, including Abraham and Hendershott (1996), Muellbauer and Murphy (1997), Leung (2004), and Oikarinen (2009), have identified a significant relationship between housing prices and macroeconomic factors. Using a linear regression on the comovement of macroeconomic factors and housing prices, this article employs an option-pricing framework to price and hedge the fair premia of mortgage insurance (MI). Our model provides improved performance in terms of MI premium pricing, especially during periods that are characterized by high housing prices. Ignoring the impacts of macroeconomic factors on housing prices will lead to an underestimation of MI premia.

Introduction

The mortgage insurance (MI) system has long been the foundation of housing financial markets; thus, it is essential to properly price MI contracts. Many studies point out that changes in housing prices are a crucial factor in determining MI premia (Kau, Keenan, and Epperson, 1992, 1993, 1995; Chen et al., 2010). Meanwhile, numerous studies have identified a significant relationship between housing prices and macroeconomic factors; see Leung (2004) for a review of macroeconomics and housing. According to the relationship between housing prices and macroeconomic factors, MI premia probably depend on their covariance structure. To the best of our knowledge, the extent to which this covariance structure affects MI premia has not been studied. Therefore, the main objectives of this article are to fill this gap using linear regressions to model the relationship between housing prices and macroeconomic factors and to further examine the impacts of macroeconomic factors on MI premia.

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Almost all existing models for pricing MI premia assume that the housing price process follows geometric Brownian motion (Kau, Keenan, and Epperson, 1992, 1993, 1995; Kau and Keenan, 1995, 1996; Bardhan, Karapandža, and Urošević, 2006). However, this assumption only considers the randomness of housing prices themselves and ignores the comovement between housing prices and macroeconomic factors. Many studies empirically highlight the significant relationship between macroeconomic factors and real estate returns.[1] For example, McCue and Kling (1994) show that macroeconomic factors can explain almost 60 percent of the variation in real estate series. Green (2002) and Chen and Patel (2002) also demonstrate that stock return dynamics are a key determinant of housing price trends. In addition, from the perspective of housing supply, the cost of construction and land acquisition are the main components that determine the cost of houses. Jud and Winkler (2002) find that appreciation in real housing prices is strongly positively related to increases in construction costs. Grimes and Aitken (2010) indicate that land price dynamics influence the relationships among housing supply elasticity, land costs, and housing price dynamics. That is, an increase in land costs or construction costs reduces the supply of new housing, which in turn leads to an increase in housing prices. Consequently, in contrast to the existing literature, this article provides a MI pricing model by focusing on the linear cross-sectional regression relationship between housing prices and macroeconomic factors. Moreover, this article examines the extent to which the macroeconomic factors affect housing prices and MI premia.

This article provides some contributions to the current literature on pricing MI contracts. First, considering the comovement between housing prices and macroeconomic factors, we employ an option-pricing framework with a linear regression relationship to price and hedge MI contracts. Our model can be reduced to the model of Bardhan, Karapandža, and Urošević (2006) when neglecting the impact of macroeconomic factors on housing prices. Second, based on these empirical and numerical analyses, we demonstrate that the statistically significant determinants of housing price returns include the returns on land price, construction costs, the inflation rate, and the stock price index. Among these, the rate of change in land prices has the largest effect on MI premia. Finally, the MI premium in our model is higher than in Bardhan, Karapandža, and Urošević's model without macroeconomic factors, and our model provides improved performance in terms of pricing MI premia, especially during periods characterized by high housing prices. This implies that when determining fair MI premia, the insurer must consider the comovement between housing prices and macroeconomic factors; otherwise, MI premia are significantly underestimated.

This article is organized as follows. The "Model Setup of MI Contracts" section illustrates the structure of MI contracts. Housing price and macroeconomic dynamics are also discussed. The "Pricing MI Contracts" presents the closed-form formulas for

[1] Whitehead (1971), Mayes (1979), Meen (1990), Abraham and Hendershott (1996), and Muellbauer and Murphy (1997) analyze housing price dynamics and identify significant relationships between housing prices and macroeconomic factors based on linear regression models. In addition, the comovement of the housing market and macroeconomic factors is documented for several countries. For instance, see Baffoe (1998), Green (1997), and Yi (2001) for the United States, Bowen (1994) for the United Kingdom, Ito (1993) for Japan, Kim (2004) for Korea, and Chen and Patel (2002) for Taiwan.

MI premia together with a sensitivity analysis of MI contracts. The "Empirical and Numerical Analyses" section empirically tests housing price dynamics using a linear regression between housing prices and macroeconomic factors. A numerical analysis of MI premia is also provided. The "Conclusion" summarizes the article and presents the conclusions.

MODEL SETUP OF MI CONTRACTS

This section illustrates the structure of MI contracts and then provides a multiple linear regression model to describe the effect of macroeconomic factors on housing prices. The previous MI pricing models, such as Kau, Keenan, and Epperson (1992, 1993, 1995) and Kau and Keenan (1995, 1996), consider two state variables: the interest rate and the housing price. Defaults and prepayments can be determined endogenously within the model. However, a complex numerical procedure is required to implement the models, as no closed-form formulas exist. Furthermore, Hendershott and Van Order (1987) demonstrate that MI premia are seldom sensitive to interest rate volatility. Therefore, some studies, such as Schwartz and Torous (1992), Dennis et al. (1997), and Bardhan, Karapandža, and Urošević (2006), model the unconditional probability of default exogenously in an environment with a constant interest rate. However, as far as we know, no research addresses the impacts of macroeconomic factors on MI premia. As a result, following Bardhan, Karapandža, and Urošević's setup with a predetermined probability of default and a constant risk-free interest rate, we provide a multiple linear regression model to describe the relationship between housing prices and macroeconomic factors.

The Structure of MI Contracts

Consider that a lender issues a T-year mortgage loan in the amount of $L(0) = L_V H(0)$ to a borrower that originates at time 0 and is secured by the housing property, where L_V is the loan-to-value ratio. Therefore, with no default or prepayment prior to time t, the unpaid loan balance $L(t)$ at time t is

$$L(t) = \frac{x}{s}\left(1 - \frac{1}{(1+s)^{T-t}}\right),\ t \in [0, T],$$

where x represents an ordinary monthly annuity payment, and the discount rate is equal to the constant mortgage rate s. In addition, at the time of origin, the insurer writes a mortgage insurance contract that promises to compensate the lender should the borrower default. Therefore, based on Bardhan, Karapandža, and Urošević's (2006) model, if the borrower defaults at time t, the insurer must pay the lender the amount

$$LOSS(t) = \max\left[0, \min\left(L(t-) - H(t), L_R L(t-)\right)\right], \tag{1}$$

where L_R denotes the loss ratio. Equation (1) implies that if the house is sold at a price higher than the remaining loan balance, the lender sustains no loss; otherwise, the maximum payment for which the issuer will compensate the lender is equal to $L_R L(t-)$.

In terms of Equation (1), the insurer's loss depends on the remaining loan balance, the interest rate, and housing prices. Many studies have observed that changes in housing prices are a crucial factor in determining MI premia (Kau, Keenan, and Epperson, 1992, 1993, 1995; Chen et al., 2010). In previous models, the housing price process is typically modeled by geometric Brownian motion, where the variance of housing returns depends only on its own variance (Kau, Keenan, and Epperson, 1992, 1993, 1995; Kau and Keenan, 1995, 1999; Bardhan, Karapandža, and Urošević, 2006). However, this assumption overlooks the impact of macroeconomic factors on housing prices. Some empirical studies, such as Abraham and Hendershott (1996), Muellbauer and Murphy (1997), Leung (2004), and Oikarinen (2009), have documented a significant relationship between housing prices and macroeconomic factors. In the following, we employ a multiple linear regression model to incorporate macroeconomic factors into our model of housing prices.

The Effect of Macroeconomic Factors on Housing Prices Dynamics

The return on housing prices H, or the log-change in the housing price on a filtered probability space $(\Omega, F, P, (F_t)_{t=0}^{T})$, is governed by the following process:

$$\ln\left(\frac{H(t)}{H(t-1)}\right) = \mu_H + \sum_{i=1}^{n} c_i \ln\left(\frac{M_i(t)}{M_i(t-1)}\right) + \sigma_H(t)\,\varepsilon_H(t), \tag{2}$$

where P is the physical probability measure (i.e., real-world probability measure); F_t, $t \in [0, T]$, is the smallest sigma field such that $H(t)$ and $M_i(t)$ are known and measurable; $(F_t)_{t=0}^{T}$ is the right-continuous natural filtration, that is, $F_t \subset F_s$, $t \leq s$. Each macroeconomic factor M_i, $i = 1, \ldots, n$, follows a random walk model with drift:

$$\ln\left(\frac{M_i(t)}{M_i(t-1)}\right) = \mu_{M_i} + \sigma_{M_i}(t)\ \varepsilon_{M_i}(t),$$

where μ_H and μ_{M_i}, $i = 1, 2, \ldots, n$, are drift terms for the housing price and macroeconomic factors, respectively. c_i denotes the sensitivity parameter of the macroeconomic factor M_i on the housing price. The variances $\sigma_H^2(t)$ $(\sigma_{M_i}^2(t))$ denote the F_{t-1} conditional variance of the residual of the housing price (ith macroeconomic factor), and $\varepsilon_H(t)$ and $\varepsilon_{M_i}(t)$, which are conditional on F_{t-1}, are the normally distributed residuals for the housing price and macroeconomic factors, respectively. They satisfy

$$E(\varepsilon_H(t)\varepsilon_{M_i}(t)|F_{t-1}) = 0,\ E(\varepsilon_{M_i}(t)\varepsilon_{M_j}(t)|F_{t-1}) = \rho_{M_iM_j}(t), \quad i, j = 1, 2, \ldots, n. \tag{3}$$

Therefore, using a linear cross-sectional regression between housing prices and economic fundamentals, Equation (2) implies that the conditional variance of housing prices depends on the covariance structure between housing prices and macroeconomic factors. In light of numerous empirical studies, the potential macroeconomic factors M_i that affect the housing price include demand-side factors, such as the population (*PO*), household income (*Y*), the real interest rate (*RIR*), the inflation rate (*INF*), the stock price index (*SPI*), and the money supply (*MS*), and supply-side factors, such as land prices (*LP*) and construction costs (*CC*).

The economic implication is that the demand for goods is determined by the prices of these goods and the population. A greater number of people lead to a greater need for housing; therefore, an increase in the population leads to a shift in the demand curve to the right. With other things being equal, an increase in the population increases the demand for housing and thereby raises housing prices, which results in a positive relationship between the population (*PO*) and housing prices. However, Jud and Winkler (2002) and Miller and Peng (2006) argue that not all people who want to purchase a house have the ability to do so, and therefore, they suggest employing household income as a proxy for the effective demand for houses. In view of this permanent income hypothesis, an unanticipated increase in permanent household income should lead to a higher level of housing consumption, which suggests a positive relationship between changes in housing prices and changes in income.

Chen and Patel (2002) demonstrate that the housing stock has the attributes of an investment asset. The housing investment decision is determined by the return on housing capital relative to the returns on other assets included in the portfolios of wealth holders. Therefore, the money supply (*MS*) and the relative stock price index (*SPI*) should be considered. Regarding money supply, because an expansion in the money supply leads to an increase in the general price level of goods, many studies (Darrat and Glascock, 1989; Kim, 1993; Chen et al., Forthcoming) indicate that housing prices are driven by rapid growth in the money supply. In addition, an increase in the money supply will enable households to invest in the housing market and allow banks to increase loans to households and developers, which in turn contributes to an increase in housing prices, as real assets are normally perceived as being relatively safe investments that offer a better inflation hedge than other financial assets (Chen and Patel, 2002).

For the effect of the stock price index, there is no consensus on the relationship between stock price returns and housing price returns. For example, Liu et al. (1990) contend that there is no immediate information flow between the real estate and stock markets because of legal restrictions and indirect barriers, which means that stock price returns are unrelated to housing prices. However, Gyourko and Keim (1992) present a compelling argument that real estate and stock markets should be expected to be positively correlated, as a large part (25 percent according to Zeckhauser and Silverman, 1983) of a company's value is tied up in real estate. Such a view is compatible with the life cycle hypothesis; when stock prices increase beyond expectations, investors' wealth suddenly increases, and their consumption levels increase as well (Green, 2002; Case et al., 2005; Calcagno, Fornero, and Rossi, 2009); as a result, real estate prices rise. In contrast, from the point of view of an individual's portfolio allocation, given a fixed amount of funds to invest, investing more money in the real estate market must decrease (or even stop) the cash flows of investments into the stock market. Therefore, an imminent rise in the stock market would drive demand for stocks and attract more cash inflows from other markets, resulting in less money being invested in the real estate market. Such an effect would bring about a negative relationship between stock prices and housing prices. In summary, the impact of stock price growth on housing prices remains unknown.

There is still no consensus on the relationship between real estate returns and interest rates or inflation. Hoesli, Lizieri, and MacGregor (2008) mention that the empirical

results on the relationship between inflation and real estate returns are mixed. While there is some evidence that directly owned private real estate provides a partial hedge against some components of inflation, securitized real estate is often shown to exhibit the same negative relationships found in stock market research, particularly with respect to unexpected inflation. Regarding interest rates, because an increase in interest rates leads to an upward movement in the housing supply curve but a downward movement in the housing demand curve, the net impact on housing prices depends on the relative shifts of the demand and supply curves. Therefore, the impact of interest rates on housing prices is unknown.

The supply side of the housing market is a crucial factor in shaping boom–bust housing cycles (Malpezzi and Wachter, 2005; Glaeser, Gyourko, and Saiz, 2008). The supply of housing is mainly determined by the price of housing. Specifically, in a new housing market, homebuilders decide to increase the supply of new houses based on their profit margins (i.e., price minus costs). Obviously, the costs of construction and land acquisition are the main components that determine the cost of houses. Therefore, land prices (*LP*) and construction costs (*CC*) are also responsible for the supply of houses (Potepan, 1996; Somerville, 1999; Jud and Winkler, 2002; Chen and Patel, 2002). Note that an increase in land prices and construction costs for builders usually causes a decrease in the housing supply, which in turn leads to higher housing prices. Therefore, the effects of land prices and construction costs on housing prices are expected to be positive.

PRICING MI CONTRACTS

We apply a linear regression model to price MI contracts in a risk-neutral world and then use sensitivity analysis to investigate the extent to which the macroeconomic factors affect the fair premia of MI contracts.

Housing Price and Macroeconomic Dynamics in a Risk-Neutral World

To price MI premia, housing prices and macroeconomic factors are determined under a risk-neutral assumption.[2] Using methods developed by Rubinstein (1976) and Brennan (1979) together with the valuation assumption of Duan (1995) and Duan and Pliska (2004) in a discrete-time model, the discount values of both the housing prices and the macroeconomic factors become martingales under a risk-neutral valuation relationship. Under the risk-neutral measure Q, the expected returns on the housing prices and the macroeconomic factors shift according to the risk-free interest rate, but the covariance structure is unchanged.[3] Through algebraic rearrangements, housing price and macroeconomic dynamics under the risk-neutral measure Q can

[2] Assuming that the agent is risk neutral, Bardhan, Karapandža, and Urošević (2006), represent the severity of loss on an MI contract as a portfolio of standard Black-Scholes put option prices. As argued by Bardhan, Karapandža, and Urošević, the valuation of the severity of loss can also be obtained if the assumption of risk neutrality of agents is relaxed and insurance contracts are assumed to be traded. Therefore, we can price MI contracts without assuming the risk neutrality of the agents by instead assuming that MI contracts are traded.

[3] In view of Equation (4), the housing price process is log-normally distributed. Therefore, as shown by Kijima (2006), using the multivariate Wang transform also transforms the log-normal distribution into another log-normal distribution with the same covariance matrix.

be obtained from the following expressions:

$$\ln\left(\frac{H(t)}{H(t-1)}\right) = r - \frac{1}{2}\sigma_H^2(t) - \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} c_i c_j \rho_{M_i M_j}(t)\sigma_{M_i}(t)\,\sigma_{M_j}(t)$$
$$+ \sigma_H(t)\,\varepsilon_H^Q(t) + \sum_{i=1}^{n} c_i\,\sigma_{M_i}(t)\,\varepsilon_{M_i}^Q(t), \tag{4}$$

$$\ln\left(\frac{M_i(t)}{M_i(t-1)}\right) = r - \frac{1}{2}\sigma_{M_i}^2(t) + \sigma_{M_i}(t)\,\varepsilon_{M_i}^Q(t), \quad i = 1, 2, \ldots, n. \tag{5}$$

The detailed proof is shown in Appendix A.

According to Equation (4), in addition to the volatilities σ_H and σ_{M_i}, the return on housing prices is related to the coefficient c_j, which gauges the impact of macroeconomic factor M_j on the housing price, and the covariance structure of the macroeconomic factors.

Closed-Form Formulas of the Fair Premia of Mortgage Insurance Contracts

According to Equation (1), the present value of the loss $DL(t)$ can be expressed as

$$DL(t) = e^{-rt}E^Q[LOSS(t)] = e^{-rt}E^Q[\max(K_1 - H(t), 0)]$$
$$- e^{-rt}E^Q[\max(K_2 - H(t), 0)], \tag{6}$$

where $K_1 = L(t-)$ and $K_2 = (1 - L_R)L(t-)$. When a borrower defaults at time t, Equation (6) shows that the present value of the severity of the loss $DL(t)$ can be duplicated by a long position in a European put option with a strike price K_1 and a short position in a European put option with a strike price K_2, both with the same time to maturity t. Solving Equation (6) with Equations (4) and (5) yields

$$DL(t) = [P_1(t) - P_2(t)], \tag{7}$$

where

$$P_i(t) = K_i e^{-rt}\Phi(-d_{2i}(t)) - H(0)\Phi(-d_{1i}(t)), \quad i = 1 \text{ or } 2,$$

$$d_{1i}(t) = \frac{\ln(H(0)/K_i) + rt + \frac{V(t)}{2}}{\sqrt{V(t)}},\ d_{2i}(t) = d_{1i}(t) - \sqrt{V(t)}$$

$$V(t) = \sum_{\tau=1}^{t}\left(C'\Sigma(\tau)C + \sigma_H^2(\tau)\right),\ C = [c_1, \ldots, c_n]',$$

$$\sigma_{M_i M_j}(t) = \rho_{M_i M_j}(t)\sigma_{M_i}(t)\sigma_{M_j}(t),\ \Sigma(t) = [\sigma_{M_i M_j}(t)]_{n\times n}, \quad i, j = 1, 2, \ldots, n.$$

The detailed proof is shown in Appendix B.

The total volatility of the housing price $V(t)$ required in Equation (7) includes two components: the covariance matrix of the macroeconomic factors $\Sigma(\tau)$ and the volatility of the housing price residual $\sigma_H^2(\tau)$. Therefore, the correlation structure between housing prices and macroeconomic factors is crucial to calculate the fair premia of MI contracts. Note that if $\boldsymbol{C}$ is a null vector, Equation (7) reduces to the closed-form formula of Bardhan, Karapandža, and Urošević (2006), as housing prices are irrelevant with respect to macroeconomic factors.

Following the exogenous-default-probability assumption of Bardhan, Karapandža, and Urošević (2006), the fair premium (FP) of a MI contract is given by

$$FP = \sum_{t=1}^{T} PD(t)\, DL(t), \tag{8}$$

where $PD(t) = 1 - \exp(-\lambda\, t)$ is the default probability at time t of the borrower, and λ is the default intensity of the borrower. Equation (8) implies that the fair premium (FP) is calculated by the sum of a series of the insurer's expected losses given the borrower's default multiplied by the default probability of the borrower.

Finally, across the life of the mortgage, insurers are expected to earn a profit margin q, even though they may lose money in some periods. Because the fair premium (FPA) is determined when the present value of the expected losses (plus a gross margin) is equal to that of the expected revenue, the equilibrium condition takes the form

$$FPA = (1 + q)FP. \tag{9}$$

Sensitivity Analysis of MI Contracts

To analyze the characteristics of MI contracts, together with their hedging strategies, in this section, we derive the delta and gamma of the MI contracts and their sensitivities to the macroeconomic factors as follows:

$$\frac{\partial\, FP}{\partial\, H(0)} = \sum_{t=1}^{T} PD(t)(\Phi(d_{11}(t)) - \Phi(d_{12}(t))) < 0, \tag{10}$$

$$\frac{\partial^2 FP}{\partial\, H(0)^2} = \sum_{t=1}^{T} PD(t) \frac{1}{H(t)\sqrt{2\pi V(t)}} \left\{ \exp\left(-\frac{d_{11}(t)^2}{2}\right) - \exp\left(-\frac{d_{12}(t)^2}{2}\right) \right\}, \tag{11}$$

$$\begin{aligned} \frac{\partial\, FP}{\partial\, c_i} = \sum_{t=1}^{T} \Bigg\{ & PD(t) \frac{H(0)}{\sqrt{2\pi V(t)}} \left(\sum_{\tau=1}^{t} \sum_{j=1}^{n} c_j \sigma_{M_i M_j}(\tau) \right) \\ & \times \left(\exp\left(-\frac{d_{11}(t)^2}{2}\right) - \exp\left(-\frac{d_{12}(t)^2}{2}\right) \right) \Bigg\}. \end{aligned} \tag{12}$$

The detailed proof is provided in Appendix C.

In view of Equation (10), because K_1 is larger than K_2, which in turn contributes to $d_{11}(t) \leq d_{12}(t)$, the delta of the MI contracts is negative: higher housing prices, *ceteris paribus*, lead to lower values of the MI contracts. Furthermore, to investigate the characteristics inherent in the gamma, the last term in Equation (11) is rewritten as:

$$\exp\left(-\frac{d_{11}(t)^2}{2}\right)\left[1-\exp\left(\frac{1}{2V(t)}\ln\left(\frac{1}{1-L_R}\right)\left(\ln\left(\frac{(1-L_R)\,L(t)^2}{H(0)^2}\right)-2rt-V(t)\right)\right)\right]. \tag{13}$$

A positive gamma is obtained when the housing price is far lower than the remaining loan balance, whereas a negative gamma is obtained when the housing price is larger than the remaining loan balance. Therefore, when the housing price moves downward, the increase in MI premia when the housing price is higher than the remaining loan balance is larger than when the housing price is far lower than the remaining loan balance, demonstrating an asymmetrical effect of the relative level of housing price on MI premia. Similarly, by virtue of Equations (12) and (13), sensitivity to the macroeconomic factors is associated with the level of housing price relative to the remaining loan balance, the covariance structure of macroeconomic factors, and the coefficients c_j gauging the impact of the macroeconomic factors on the housing price. For example, for a positive covariance structure and positive coefficient c_j, we conclude that $\partial FP/\partial c_i > 0$ when the housing price is higher than the remaining loan balance; thus, a higher coefficient c_j implying a larger impact of macroeconomic factor j on housing price leads to a higher MI premium.

EMPIRICAL AND NUMERICAL ANALYSES

In this section, we describe our data and then empirically test the linear regression model to determine the significant determinants of housing prices. To ensure that the log-change in the housing price follows a linear regression model, we also perform a strict test for endogeneity, multicollinearity, the normality and heteroskedasticity of regression residuals, and the time lags of the macroeconomic factors. Using the estimated parameters from the linear regression model, we further provide a numerical analysis to assess the impacts of macroeconomic factors on MI premia.

Data Description

To empirically test housing price dynamics, we employ the monthly observations of S&P/Case-Shiller Home Price Indices as a proxy for housing prices in the U.S. real estate market. In addition, each proxy for the determinants is selected as follows. First, the Construction Price Index (CPI), which is the proxy for construction costs, comes from U.S. Census Bureau statistics. The data on land prices are constructed based on the elegant work of Davis and Heathcote (2007). Other determinants,

TABLE 1
The Definitions of Variables

Variable	Definition	Proxy
P^H	Housing prices	S&P/Case-Shiller Home Price Indices composite-10 (CSXR-SA)
LP	Land prices	Aggregate U.S. land prices (FHFA-based price index)
CC	Construction cost	Price deflator (Fisher) index of new one-family houses under construction (2005 = 100)
PO	Population	Labor force (millions) (IFS-11167D.ZF. . .)
PI	Household permanent income	Household consumption expenditure (billions) (IFS-11196F.CZF. . .)
MS	Money supply	M2 seasonally adjusted (billions) (IFS-11159MBCZF. . .)
RIR	Real interest rate	Mortgage rate (percent) (IFS-11160PA.ZF. . .) minus the inflation rate
CPI	CPI	Consumer price index (IFS-11164.ZF. . .)
INF	Inflation rate	The change rate of CPI (percent)
SPI	Stock price index	S&P 500 Index

including population, household permanent income,[4] the money supply and interest rates, are available in the International Financial Statistics (IFS) database. The S&P 500 index is selected as the proxy for the stock price index. Except for population, all variables measured in nominal terms are deflated by the CPI, which is also available from the IFS database. The inflation rate is measured by the rate of change in the CPI. The real interest rate is directly calculated by deducting the inflation rate from the nominal rate of interest. To avoid the problem of scale, all variables are converted to natural logarithms, except for the inflation rate and the real interest rate. We summarize the proxies for the macroeconomic factors in Table 1. The sample period from January 1987 to December 2008 includes 264 monthly observations.

[4] The empirical proxy for permanent income is the subject of a long-standing debate that lasted nearly a half-century. Many sources in the literature suggest using the median or a weighted average of past actual levels of income as the proxy for permanent income, such as the gross domestic product (GDP). However, GDP represents current income rather than permanent income, although Meen (2002) indicates that this distinction is not of great importance. According to the permanent income hypothesis of Friedman (1957), consumption is proportional to a measure of permanent income. Using a bivariate framework, Cochrane (1994) finds that consumption is a good proxy for the permanent component of GDP because shocks to consumption have permanent effects on GDP, while shocks to GDP only have transitory effects on consumption. Therefore, follow-up studies, such as Peterson, Pratten, and Tatch (1997), also employ consumption as the proxy for permanent income. Therefore, we employ the household consumption expenditure as the proxy for household permanent income.

TABLE 2
Descriptive Statistics and Unit Root Tests

	Panel A: Descriptive Statistics							Panel B:	
Variables	Mean	Median	Max.	Min.	Std. Dev.	Skew	Kurt	ADF Test	
$\Delta \ln P^H$	0.0012	0.0014	0.0189	−0.0319	0.0083	−0.8940	4.6599	(0)	−3.689***
$\Delta \ln LP$	0.0026	0.0031	0.0172	−0.0190	0.0072	−0.5712	3.2795	(0)	−5.288***
$\Delta \ln CC$	0.0003	0.0001	0.0223	−0.0180	0.0053	0.2092	5.1399	(0)	−9.417***
$\Delta \ln PO$	0.0010	0.0011	0.0191	−0.0143	0.0059	0.3248	3.6028	(12)	−1.622*
$\Delta \ln PI$	0.0022	0.0023	0.0124	−0.0068	0.0030	−0.0527	3.7661	(0)	−7.929***
$\Delta \ln MS$	0.0017	0.0013	0.0329	−0.0086	0.0051	1.8565	10.8723	(0)	−5.835***
ΔRIR	−0.0085	−0.0125	1.3197	−1.6410	0.4147	0.0440	4.1498	(1)	−14.188***
INF	0.2443	0.2445	1.2211	−1.9153	0.3296	−1.4152	10.8933	(0)	−6.877***
$\Delta \ln SPI$	0.0021	0.0072	0.1051	−0.2480	0.0446	−1.2707	7.3111	(0)	−14.618***

Note: The numbers of lag length selected by the Schwartz information criterion are reported in parentheses.
*Statistical significance at the 10% level.
**Statistical significance at the 5% level.
***Statistical significance at the 1% level.

Calibrating the Model

Before fitting the regression, it is necessary to perform unit root tests on each data series to determine whether it is a stationary time series. The augmented Dickey–Fuller (ADF) unit root tests, together with the descriptive statistics, are reported in Table 2. We report the result of the ADF tests without the drift or trend because it is implausible to suspect that there is a quadratic trend or an upward/downward trend of the tested variables. The numbers of lag length selected by the Schwartz information criterion (SC) are 12 for population, 1 for the real interest rate, and 0 for the other variables. On the basis of the unit root tests, the null hypothesis of a unit root is rejected for each variable, which indicates that all of the variables in the regression are stationary.

Based on Equation (2), the full regression model includes eight macroeconomic factors. Because it is highly probable that the residuals from the housing price growth model will exhibit significant serial correlations, we use the Newey and West (1987)[5] procedure to correct the estimated standard errors as well as the test statistics. Table 3 shows that the significant determinants of housing returns are the inflation rate (INF), the log changes in land prices ($\Delta \ln LP$), the log changes in construction costs ($\Delta \ln CC$), and the log changes in the stock price index ($\Delta \ln SPI$). Ignoring the insignificant variables, we obtain a parsimonious model with the same significance level across four major macroeconomic factors but a higher adjusted $\bar{R}^2$ than that of the full regression model. The sensitivity parameters of the inflation rate, land prices, and construction costs are positive, in agreement with the empirical findings of Jud and Winkler (2002), Capozza, Hendershott, and Mack (2004), and Davis and Heathcote (2007). The coefficient of the first difference in the log stock price index

[5] In the Newey–West method, the selection of lag length is based on the built-in criterion of the EViews software, with $q = \text{floor}(4(T/100)^{2/9})$.

TABLE 3
Empirical Results: Dependent Variable ΔP^H

Variables	(1) Full Model	(2) Parsimonious Model
Constant	−0.0026 (0.0011)**	−0.0024 (0.0006)***
$\Delta \ln LP$	0.7779 (0.0867)***	0.7889 (0.0785)***
$\Delta \ln CC$	0.6632 (0.1173)***	0.6879 (0.1107)***
$\Delta \ln PO$	−0.0144 (0.0459)	
$\Delta \ln PI$	0.1510 (0.2569)	
$\Delta \ln MS$	−0.0620 (0.1249)	
ΔRIR	0.0003 (0.0007)	
INF	0.0058 (0.0026)**	0.0057 (0.0014)***
$\Delta \ln SPI$	−0.0132 (0.0061)**	−0.0123 (0.0056)**
$\overline{R}^2$	0.6896	0.6922
F-statistics	73.7559***	148.2734***

Note: The Newey–West standard errors are reported in parentheses.
*Statistical significance at the 10% level.
**Statistical significance at the 5% level.
***Statistical significance at the 1% level.

TABLE 4
Residuals Tests of Regressions

	Full Model	Parsimonious Model
Normality test		
H_0: Residuals are normally distributed		
Jarque–Bera statistic	3.757 (0.153)	4.524 (0.104)
Heteroskedasticity test		
H_0: No heteroskedasticity of residuals		
White	52.232 (0.185)	15.097 (0.371)
Breusch–Pagan–Godfrey	7.727 (0.460)	3.571 (0.467)
Harvey	5.563 (0.696)	3.021 (0.554)
Glejser	7.205 (0.515)	2.560 (0.634)

Note: The p-values are reported in parentheses.

($\Delta \ln SPI$) is significantly negative, which is consistent with the empirical work of Davidoff (2007).

Robustness Analysis

To ensure that housing prices process follows a linear regression model, we test robustly for endogeneity, multicollinearity, the normality and heteroskedasticity of residuals, and time lags in the macroeconomic factors. First, in Table 4, we test the normality and heteroskedasticity of the regression residuals. For the full and parsimonious models, neither test statistic rejects the hypothesis that the regression residuals are normally distributed or homoskedastic.

Second, Table 5 presents the correlation coefficients between the residuals and independent variables in the regression. As observed by Wooldridge (2002, p. 50), in

TABLE 5
Correlation Matrix of Regression Residuals and Explanatory Variables

Correlation Matrix

Panel A: Full Model

Variables	ε	$\Delta \ln LP$	$\Delta \ln CC$	$\Delta \ln PO$	$\Delta \ln PI$	$\Delta \ln MS$	ΔRIR	INF
$\Delta \ln LP$	−4.49E-10 (0.0619)	1 -						
$\Delta \ln CC$	−3.19E-10 (0.0618)	0.4045 (0.0566)	1 -					
$\Delta \ln PO$	−5.67E-10 (0.0619)	0.0277 (0.0619)	0.0243 (0.0619)	1 -				
$\Delta \ln PI$	−3.90E-10 (0.0619)	0.5235 (0.0527)	0.6756 (0.0456)	0.0121 (0.0619)	1 -			
$\Delta \ln MS$	−3.36E-10 (0.0620)	0.3274 (0.0585)	0.4014 (0.0567)	-0.0516 (0.0618)	0.5417 (0.0520)	1 -		
ΔRIR	−4.18E-10 (0.0619)	0.1989 (0.0607)	0.1769 (0.0609)	0.1181 (0.0615)	0.3964 (0.0568)	0.1419 (0.0613)	1 -	
INF	3.58E-10 (0.0618)	−0.3649 (0.0576)	−0.6417 (0.0475)	0.0194 (0.0619)	−0.8015 (0.0370)	−0.7631 (0.0400)	−0.3389 (0.0582)	1 -
$\Delta \ln SPI$	−1.02E-10 (0.0618)	0.1754 (0.0609)	0.1348 (0.0613)	0.0082 (0.0619)	0.1634 (0.0611)	−0.0114 (0.0619)	−0.0318 (0.0619)	−0.0712 (0.0617)

Panel B: Parsimonious Model

Variables	ε	$\Delta \ln LP$	$\Delta \ln CC$	INF
$\Delta \ln LP$	−9.20E-10 (0.0617)	1 -		
$\Delta \ln CC$	−5.70E-10 (0.0619)	0.4045 (0.0566)	1-	
INF	3.74E-10 (0.0619)	−0.3649 (0.0576)	−0.6417 (0.0475)	1 -
$\Delta \ln SPI$	4.58E-10 (0.0619)	0.1754 (0.0609)	0.1348 (0.0613)	−0.0712 (0.0617)

Note: The standard errors are reported in parentheses.

TABLE 6
The Hausman (1978) Test: Land Price and Household Consumption

Variables	Full Model With the Residual(s)			
Constant	−0.0026** (0.0011)	−0.0027*** (0.0009)	−0.0030** (0.0012)	−0.0028** (0.0013)
$\Delta \ln LP_t$	0.7779*** (0.0867)	0.8613*** (0.1686)	0.7723*** (0.0551)	0.8456*** (0.2157)
$\Delta \ln CC_t$	0.6632*** (0.1173)	0.6534*** (0.0853)	0.6574*** (0.0840)	0.6534*** (0.0854)
$\Delta \ln PO_t$	−0.0144 (0.0459)	−0.0154 (0.0487)	−0.0170 (0.0487)	−0.0159 (0.0490)
$\Delta \ln PI_t$	0.1510 (0.2569)	0.1373 (0.2125)	0.3408 (0.3838)	0.1898 (0.5294)
$\Delta \ln MS_t$	−0.0620 (0.1249)	−0.0769 (0.1146)	−0.0663 (0.1097)	−0.0758 (0.1146)
ΔRIR_t	0.0003 (0.0007)	0.0005 (0.0009)	0.0006 (0.0010)	0.0005 (0.0009)
INF_t	0.0058** (0.0026)	0.0056** (0.0023)	0.0060*** (0.0022)	0.0057** (0.0025)
$\Delta \ln SPI_t$	−0.0132** (0.0061)	−0.0133** (0.0063)	−0.0132** (0.0062)	−0.0133** (0.0063)
ε_t^{LP}		−0.0925 (0.1680)		−0.0765 (0.2226)
ε_t^{PI}			−0.2023 (0.3873)	−0.0541 (0.4908)
$\overline{R}^2$	0.6896	0.6885	0.6884	0.6873
F-statistic	73.7559***	65.1078***	65.0614***	58.3679***

Note: The Newey–West standard errors are reported in parentheses.
*Statistical significance at the 10% level.
**Statistical significance at the 5% level.
***Statistical significance at the 1% level.

applied econometrics, endogenous variable is a term used more broadly to describe any situation where an explanatory variable is correlated with the disturbance. If an explanatory variable is uncorrelated with the disturbance, then the explanatory variable is said to be exogenous. As shown in Table 5, the correlations between the residuals and independent variables are virtually equal to zero, which shows that endogeneity problems are not serious; this is in line with the fundamental assumptions of the linear regression in Equation (3).

We also use the Hausman (1978) test to determine whether the most suspicious variables, land price, and household consumption, are endogenous in the model. In the first stage, as suggested by Davidson and MacKinnon (1989), we ran auxiliary regressions in which the dependent variables were the suspect endogenous variables and in which the independent variables were the other exogenous explanatory variables in the full model. In the second stage, we reestimated the original regression (the full model) by including the residual of land price (ε_t^{LP}) and the residual of household consumption (ε_t^{PI}) from the above auxiliary regressions as additional regressors. The results are summarized in Table 6. Because all of the coefficients of residuals were not statistically significant, it can be concluded that on the basis of the results of Hausman test, the endogeneity problem does not exist in the regression model.

Third, we employ the variance inflation factor (VIF) as the criterion to detect the severity of multicollinearity. The highest VIF value in the parsimonious model is only 1.185, which is significantly lower than the cutoff value of 10. This indicates a lower likelihood of multicollinearity. Fourth, some studies claim that macroeconomic variables may affect the housing market with time lags (Leung, Leong, and Wong, 2006, 2007). Taking the parsimonious model as a benchmark, we further consider

TABLE 7
Base Parameter Values of MI Premiums

$H(0) = \$200,000$	Housing price
$L_R = 0.25$	Loss ratio
$r = 2\%$	Risk-free interest rate
$x = \$500$	Installments
$T = 360$ (30 year)	Time to maturity of mortgage contract
$s = 4\%$	Contract interest rate of mortgages
$q = 0.02$	Gross profit margin
$\lambda = 0.05$	Default intensity

different lags on macroeconomic variables to examine for robustness. The robustness analysis shows that there is no significant improvement in $\bar{R}^2$ values when lags on macroeconomic variables are considered. Therefore, for analytical tractability, we adopt the parsimonious model with a linear regression relationship between housing prices and macroeconomic factors to derive a pricing formula for MI premia and to demonstrate the impacts of economic fundamentals on MI premia.

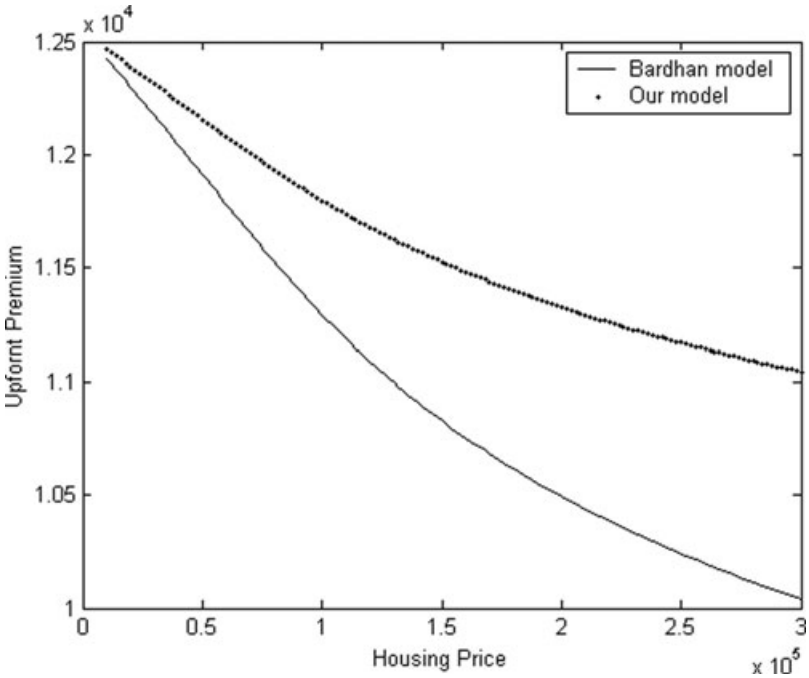
Numerical Analysis for MI Premia

Base Parameters and Fair MI Premia. Using the estimated parameters from the parsimonious model shown in Table 3 and Table 5, we provide a numerical analysis to assess the impacts of macroeconomic factors on MI premia. The relevant parameters for pricing MI premia are illustrated below. Consider a 30-year mortgage loan with a 4 percent mortgage rate and monthly payments of $500. The risk-free interest rate is 2 percent. The loss ratio L_R is 0.25. The initial housing price is $200,000. The borrower's default intensity is 0.05. The gross profit margin is 2 percent. We summarize the preceding parameters in Table 7. Using Equations (7), (8), and (9), the upfront MI premium based on the parameters is equal to $11,344.

Sensitivity Analysis of Macroeconomic Factors. Figure 1 depicts the relationship between the upfront MI premium and housing prices as compared to Bardhan, Karapandža, and Urošević's (2006) model in order to assess the impact of macroeconomic factors on the MI premia. Similar to the curve in Bardhan, Karapandža, and Urošević's model, the impact of macroeconomic factors on housing prices is depicted as a downward nonlinear curve. However, the MI premium in our model—with macroeconomic factors—is higher than that in Bardhan, Karapandža, and Urošević's model without macroeconomic factors, especially for higher housing prices.

We further compare the extended model and the original Bardhan, Karapandža, and Urošević (2006) model to provide more insight on how the macroeconomic variables affect MI premia under housing price changes. Let $H(t) = \hat{H}(t) + H^u(t)$, where $H(t)$ is the housing price, $\hat{H}(t)$ is the portion of the housing price explained by the macroeconomic variables, and $H^u(t)$ is the residual, which represents the portion of the housing price not explained by the macroeconomic variables. Hence, we compare the following three cases.

FIGURE 1
The Relationship Between the Upfront MI Premiums and the Housing Price by Different Models



Case 1. Putting $H(t)$ in the MI equation of the Bardhan model.

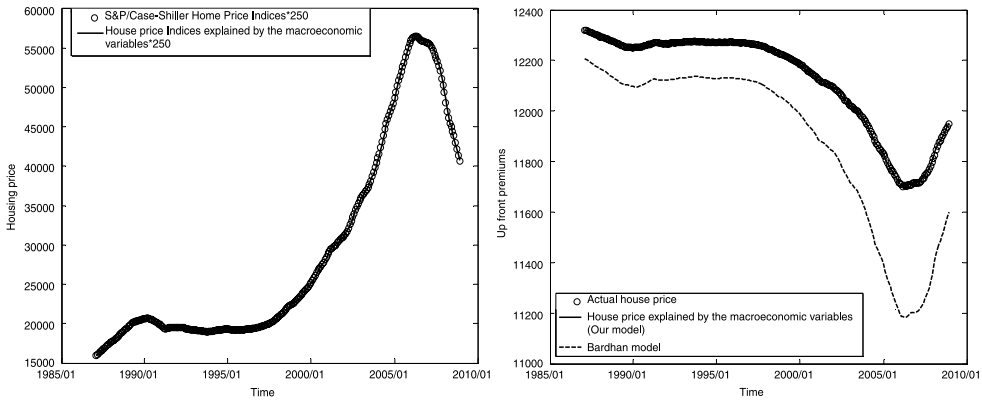
Case 2. Putting $\hat{H}(t)$ in the MI equation of our model.

Case 3. Putting $H(t)$ and other macro-variables in the MI equation of our model.

Using the monthly observations from the S&P/Case-Shiller Home Price Indices multiplied by 250[6] as a proxy for housing prices, we show the corresponding MI premia from January 1987 to December 2008 for the three cases in Figure 2. From Figure 2, we find that in each case, the MI premia in Case 2 is almost the same as in Case 3; the maximum difference is only about \$11. Because the selected macroeconomic variables explain housing prices quite well, the numerical results demonstrate that the MI premium is mainly determined by the portion of the housing price explained by the macroeconomic variables. In contrast, the differences in MI premia between Case 1 and Case 3 range from \$113 to \$521. A higher housing price leads to a greater difference in MI premia. Consequently, ignoring the impact of macroeconomic factors

[6] Each S&P/Case-Shiller Home Price Indices futures contract is valued at \$250 times the underlying index. Without loss of generality, we use \$250 times the index as the proxy for the housing price.

FIGURE 2
The Comparisons of Upfront MI Premiums by Different Model



on pricing MI contracts would severely underprice the MI premia, particularly for higher housing prices.

Table 8 reports the MI premia from adding (subtracting) two standard errors to (from) the sensitivity parameters of macroeconomic factors. Due to the positive correlation coefficient between $\Delta \ln LP$ and $\Delta \ln CC$, a higher level of sensitivity parameters of land prices and household construction costs contributes to a higher total volatility $V(t)$ as well as a higher MI premium. For instance, if the sensitivity parameter of land prices increases by two standard errors (from 0.7889 to 0.9459), *ceteris paribus*, the MI premium increases by 3.21 percent (from 10,113 to 10,448). In contrast, if the parameter decreases by two standard errors (from 0.7889 to 0.6319), *ceteris paribus*, it results in a 3.79 percent reduction in the MI premium.

However, a negative relationship is observed between the MI premia and the sensitivity parameters of the inflation rate. For example, when the sensitivity parameter of the inflation rate increases from 0.0057 to 0.0085, the MI premium decreases from \$10,113 to \$10,110. By Equation (12), sensitivity to the macroeconomic factors is associated with the level of the housing price relative to the remaining loan balance, the correlation structure of the macroeconomic factors and the sensitivity parameters of the macroeconomic factors. Therefore, one probable cause is the negative correlation structure between the inflation rate and the other two macroeconomic factors. Therefore, it is the correlational structure of the macroeconomic factors that plays an important role in pricing MI premia.

Note that the largest effect on MI premia is caused by a change in the sensitivity parameter of the land price. Our finding is compatible with the results of Grimes and Aitken's (2010) calibrated model, which identifies land price dynamics as an indispensable factor in considering the relationship between the housing supply and housing price dynamics. Epple, Gordon, and Sieg (2010) also point out that the variation in land prices induces variations in the relative factors used in housing production and thus induces variations in housing prices. Because housing prices play an essential role in MI premia (e.g., Kau, Keenan, and Epperson, 1992, 1993,

TABLE 8
The Relationship Between the Upfront Premium and the Parameters of Macroeconomic Factors

			$\ln SPI$		
$\ln LP$	$\ln CC$	INF	−0.0235	−0.0123	−0.0011
0.6319	0.4665	0.0029	9,659.9(−4.69%)	9,665.9(−4.63%)	9,672.9(−4.55%)
		0.0057	9,656.4(−4.73%)	9,662.4(−4.66%)	9,669.4(−4.59%)
		0.0085	9,652.9(−4.77%)	9,658.9(−4.70%)	9,665.9(−4.63%)
	0.6879	0.0029	9,741.0(−3.82%)	9,747.1(−3.75%)	9,754.1(−3.68%)
		0.0057	9,737.2(−3.86%)	9,743.4(−3.79%)	9,750.4(−3.72%)
		0.0085	9,733.5(−3.90%)	9,739.7(−3.83%)	9,746.7(−3.76%)
	0.9093	0.0029	9,828.3(−2.90%)	9,834.5(−2.83%)	9,841.5(−2.76%)
		0.0057	9,824.4(−2.94%)	9,830.6(−2.87%)	9,837.6(−2.80%)
		0.0085	9,820.6(−2.98%)	9,826.8(−2.91%)	9,833.8(−2.84%)
0.7889	0.4665	0.0029	10,039.0(−0.74%)	10,045.0(−0.68%)	10,052.0(−0.61%)
		0.0057	10,036.0(−0.77%)	10,042.0(−0.71%)	10,048.0(−0.65%)
		0.0085	10,033.0(−0.80%)	10,039.0(−0.74%)	10,045.0(−0.68%)
	0.6879	0.0029	10,111.0(−0.02%)	10,116.0(0.03%)	10,123.0(0.10%)
		0.0057	10,107.0(−0.06%)	10,113.0 (BV)	10,120.0(0.07%)
		0.0085	10,104.0(−0.09%)	10,110.0(−0.03%)	10,116.0(0.03%)
	0.9093	0.0029	10,186.0(0.72%)	10,192.0(0.78%)	10,198.0(0.83%)
		0.0057	10,183.0(0.69%)	10,188.0(0.74%)	10,195.0(0.80%)
		0.0085	10,179.0(0.65%)	10,185.0(0.71%)	10,192.0(0.78%)
0.9459	0.4665	0.0029	10,385.0(2.62%)	10,390.0(2.67%)	10,396.0(2.72%)
		0.0057	10,382.0(2.59%)	10,387.0(2.64%)	10,393.0(2.69%)
		0.0085	10,379.0(2.56%)	10,385.0(2.62%)	10,390.0(2.67%)
	0.6879	0.0029	10,446.0(3.19%)	10,451.0(3.23%)	10,456.0(3.28%)
		0.0057	10,443.0(3.16%)	10,448.0(3.21%)	10,454.0(3.26%)
		0.0085	10,440.0(3.13%)	10,445.0(3.18%)	10,451.0(3.23%)
	0.9093	0.0029	10,509.0(3.77%)	10,514.0(3.81%)	10,520.0(3.87%)
		0.0057	10,506.0(3.74%)	10,511.0(3.79%)	10,517.0(3.84%)
		0.0085	10,503.0(3.71%)	10,508.0(3.76%)	10,514.0(3.81%)

Notes: The values in parentheses denote the changing rate of the mortgage insurance premium when the parameters are plus or minus two standard errors. BV denotes the base value of the MI premium.

1995; Chen et al., 2010), similar inferences can be extended from housing prices to land prices; variations in land prices are crucial in determining MI premia.

In Table 9, we investigate the relationship between the upfront premium and the correlation coefficients of macroeconomic factors. Because the inflation rate has the smallest effect on MI premia, we focus on the correlational relationships between the other three macroeconomic factors. We denote $\Delta \ln LP$, $\Delta \ln CC$, and $\Delta \ln SPI$ by M_1, M_2, and M_3, respectively. As such, $\rho_{M_1M_2}$ is the correlation between the log-changes in land prices and construction costs; $\rho_{M_1M_3}$ and $\rho_{M_2M_3}$ are defined analogously. Table 9 reveals the relationship between the upfront premia and the correlation coefficients among the macroeconomic factors by adding (subtracting) two standard errors to (from) the correlation coefficients. Because the sensitivity parameters of land prices and household construction costs are positive but that of

TABLE 9
The Relationship Between the Upfront Premium and the Correlation Coefficients of Macroeconomic Factors

		$\rho_{M_1M_2}$		
$\rho_{M_2M_3}$	$\rho_{M_1M_3}$	0.2913	0.4045	0.5177
0.0122	0.0536	10,076 (−0.37%)	10,119 (0.06%)	10,159 (0.45%)
	0.1754	10,072 (−0.41%)	10,114 (0.01%)	10,155 (0.42%)
	0.2972	10,067 (−0.45%)	10,110 (−0.03%)	10,151 (0.38%)
0.1348	0.0536	10,075 (−0.38%)	10,118 (0.05%)	10,158 (0.44%)
	0.1754	10,071 (−0.42%)	10,113 (BV)	10,154 (0.41%)
	0.2972	10,066 (−0.46%)	10,109 (−0.04%)	10,150 (0.37%)
0.2574	0.0536	10,074 (−0.39%)	10,117 (0.04%)	10,157 (0.44%)
	0.1754	10,070 (−0.43%)	10,112 (−0.01%)	10,153 (0.40%)
	0.2972	10,065 (−0.47%)	10,108 (−0.05%)	10,149 (0.36%)

Note: Denote M_1, M_2, and M_3 by $\Delta \ln LP$, $\Delta \ln CC$, and $\Delta \ln SPI$, respectively. The values in parentheses denote the changing rate of the mortgage insurance premium when the parameters are plus or minus two standard errors. BV denotes the base value of the MI premium.

stock price index is negative, an increase in the correlation coefficient $\rho_{M_1M_2}$ and a decrease in the correlation coefficients $\rho_{M_1M_3}$ and $\rho_{M_2M_3}$ leads to an increase in both the total volatility and the MI premium.

CONCLUSIONS

In the previous models used to price MI contracts, the housing price process is assumed to follow geometric Brownian motion, and the variance of the housing price returns is assumed to depend only on its own variance. However, numerous empirical studies show a significant relationship between macroeconomic factors and housing prices. Consequently, this article derives a closed-form formula for MI premia when the housing price process behaves according to a linear regression model with macroeconomic factors as its regressors. It further examines the extent to which the macroeconomic factors affect MI premia.

Based on data sampled from January 1987 to December 2008, the empirical results significantly support the linear regression model with four regressors: log-changes in land price, inflation rate, log-changes in construction costs, and log-changes in the stock price index. According to numerical analysis, MI premia would be severely underestimated without considering the comovement between housing prices and macroeconomic factors, especially for higher levels of housing prices. In addition, the correlational structure among the macroeconomic factors also plays an important role in determining the level of MI premia. In most cases, when the correlation coefficient is positive, MI premia are positively related to the levels of the sensitivity parameters of the macroeconomic factors. When the correlation coefficient is negative, however, MI premia may be negatively related to the sensitivity parameters. Finally, among the macroeconomic factors, the change in the sensitivity parameter of land prices has the greatest impact on the MI premium, which implies that the insurer should consider the impact of land prices when determining fair MI premia.

There are several potential improvements to and possible extensions of this model. First, many studies suggest modeling potential structural changes in housing prices by employing threshold regressions, smooth threshold autoregressive (STAR) models, and Markov-switching models, among others. Therefore, the structured change in U.S. housing prices is also an important issue in pricing mortgage insurance contracts. Next, the jump effect and volatility clustering phenomena encountered in housing price dynamics may also be considered in the MI pricing model. Finally, due to the subprime crisis, the issue of counterparty default risk is also an important topic for further examination.

APPENDIX A

This appendix illustrates the detailed proof of change measure from the physical measure P to the risk-neutral measure Q.

Under the risk-neutral measure Q, the one-period cumulated change rate of macroeconomic factors is given by

$$\begin{aligned} E^Q_{t-1}\left[\frac{M_i(t)}{M_i(t-1)}\right] &= E^Q_{t-1}\left[\exp\left(\ln\left[\frac{M_i(t)}{M_i(t-1)}\right]\right)\right] = E^Q_{t-1}\left[e^{\mu_{M_i}+\sigma_{M_i}(t)\varepsilon_{M_i}(t)}\right] \\ &= e^{\mu_{M_i}} E^Q_{t-1}\left[e^{\sigma_{M_i}(t)\varepsilon_{M_i}(t)}\right], \qquad i = 1, 2, \ldots, n, \end{aligned} \tag{A1}$$

where $E^Q_{t-1}(.)$ is the expectation given the time $t-1$ information F_{t-1}. Let $\varepsilon^Q_{M_i}(t) = \varepsilon_{M_i}(t) + \lambda^Q_{M_i}(t)\sigma_{M_i}(t)$. Under the risk-neutral measure Q, the expected returns of both housing price and the macroeconomic factors shift to the risk-free interest rate but the covariance structure is unchanged. Therefore, we have

$$\begin{aligned} E^Q_{t-1}\left[\frac{M_i(t)}{M_i(t-1)}\right] &= e^{\mu_{M_i}-\lambda^Q_{M_i}(t)\sigma_{M_i^2}(t)} E^Q_{t-1}\left[e^{\sigma_{M_i}(t)\varepsilon^Q_{M_i}(t)}\right] \\ &= e^{\mu_{M_i}-\lambda^Q_{M_i}(t)\sigma_{M_i}(t)+\frac{1}{2}\sigma^2_{M_i}(t)} = e^r, \end{aligned} \tag{A2}$$

which implies

$$\mu_{M_i} = r + \lambda^Q_{M_i}(t)\sigma^2_{M_i}(t) - \frac{\sigma^2_{M_i}(t)}{2}, \qquad i = 1, 2, \ldots, n. \tag{A3}$$

As a result, under the risk-neutral measure Q, the processes of macroeconomic factors can be rewritten as follows:

$$\begin{aligned} \ln\left(\frac{M_i(t)}{M_i(t-1)}\right) &= \mu_{M_i} + \sigma_{M_i}(t)\ \varepsilon_{M_i}(t) = \mu_{M_i} - \lambda^Q_{M_i}(t)\sigma^2_{M_i}(t) + \sigma_{M_i}(t)\,\varepsilon^Q_{M_i}(t) \\ &= r - \frac{\sigma^2_{M_i}(t)}{2} + \sigma_{M_i}(t)\,\varepsilon^Q_{M_i}(t). \end{aligned} \tag{A4}$$

Similarly, given $\varepsilon_H^Q(t) = \varepsilon_H(t) + \lambda_H^Q(t)\sigma_H(t)$, the one-period cumulated change rate of housing price can be rewritten as

$$\begin{aligned}
&E_{t-1}^Q\left[\frac{H(t)}{H(t-1)}\right] \\
&= E_{t-1}^Q\left[e^{\mu_H - \lambda_H^Q(t)\sigma_H^2(t) + \sum_{i=1}^n c_i \ln\left[\frac{M_i(t)}{M_i(t-1)}\right] + \sigma_H(t)\varepsilon_H^Q(t)}\right] \\
&= E_{t-1}^Q\left[e^{\mu_H - \lambda_H^Q(t)\sigma_H^2(t) + \sum_{i=1}^n c_i (r - \frac{1}{2}\sigma_{M_i}^2(t) + \sigma_{M_i}(t)\varepsilon_{M_i}^Q(t)) + \sigma_H(t)\varepsilon_H^Q(t)}\right] \\
&= e^{\mu_H - \lambda_H^Q(t)\sigma_H^2(t) + \sum_{i=1}^n c_i (r - \frac{1}{2}\sigma_{M_i}^2(t))} E_{t-1}^Q\left[e^{\sum_{i=1}^n c_i (\sigma_{M_i}(t)\varepsilon_{M_i}^Q(t)) + \sigma_H(t)\varepsilon_H^Q(t)}\right].
\end{aligned} \tag{A5}$$

Since $\varepsilon_H(t)$ and $\varepsilon_{M_i}(t)$, conditional on F_{t-1}, are correspondingly the normally distributed residuals for the housing price and macroeconomic factors and satisfy Equation (5), the expectation part in Equation (A5) takes the following expression:

$$E_{t-1}^Q\left[e^{\sum_{i=1}^n c_i (\sigma_{M_i}(t)\varepsilon_{M_i}^Q(t)) + \sigma_H(t)\varepsilon_H^Q(t)}\right] = e^{\frac{1}{2}\sum_{i=1}^n \sum_{j=1}^n c_i c_j \rho_{M_i M_j}(t)\sigma_{M_i}(t)\sigma_{M_j}(t) + \frac{1}{2}\sigma_H^2(t)}. \tag{A6}$$

Substituting Equation (A6) into Equation (A5), we obtain

$$\begin{aligned}
&E_{t-1}^Q\left[\frac{H(t)}{H(t-1)}\right] \\
&= e^{\mu_H - \lambda_H^Q(t)\sigma_H^2(t) + \sum_{i=1}^n c_i (r - \frac{1}{2}\sigma_{M_i}^2(t)) + \frac{1}{2}\sum_{i=1}^n \sum_{j=1}^n c_i c_j \rho_{M_i M_j}(t)\sigma_{M_i}(t)\sigma_{M_j}(t) + \frac{1}{2}\sigma_H^2(t)} = e^r,
\end{aligned} \tag{A7}$$

which implies

$$\begin{aligned}
\mu_H = r + \lambda_H^Q(t)\sigma_H^2(t) - \sum_{i=1}^n c_i \left(r - \frac{1}{2}\sigma_{M_i}^2(t)\right) \\
-\frac{1}{2}\sum_{i=1}^n \sum_{j=1}^n c_i c_j \rho_{M_i M_j}(t)\sigma_{M_i}(t)\sigma_{M_j}(t) - \frac{1}{2}\sigma_H^2(t).
\end{aligned} \tag{A8}$$

Substituting Equation (A5) and Equation (A8) into Equation (4) yields Equation (6). This completes the proof of Appendix A.

APPENDIX B

In this appendix, we derive the closed-form formula of mortgage insurance contracts under the risk-neutral measure Q.

In virtue of Equation (9), under the risk-neutral measure Q, the present value of the severity of loss $DL(t)$, can be given by the following expression:

$$DL(t) = e^{-rt} E^{Q}[\max(K_1 - H(t), 0)] - e^{-rt} E^{Q}[\max(K_2 - H(t), 0)], \tag{B1}$$

where $K_1 = L(t-)$, $K_2 = (1 - L_R)L(t-)$.

First, the first term in the right-hand side of Equation (B1) is rewritten as follows:

$$e^{-rt} E^{Q}[\max(K_1 - H(t), 0)] = K_1 e^{-rt} E^{Q}(1_D) - e^{-rt} E^{Q}(H(t)\, 1_D), \tag{B2}$$

where $1_{\{\cdot\}}$ denotes the indicator function and $D \equiv \{H(t) \leq K_1\}$. Using Equation (4), we have

$$\begin{aligned} \ln\left(\frac{H(t)}{H(0)}\right) = \sum_{\tau=1}^{t} \ln\left(\frac{H(\tau)}{H(\tau-1)}\right) = \sum_{\tau=1}^{t} \Bigg(r - \frac{1}{2}\left(\sigma_H^2(\tau) + C'\,\Sigma(\tau)\,C\right) \\ + \sigma_H(\tau)\,\varepsilon_H^{Q}(\tau) + \sum_{i=1}^{n} c_i\,\sigma_{M_i}(\tau)\,\varepsilon_{M_i}^{Q}(\tau) \Bigg). \end{aligned} \tag{B3}$$

Plugging Equation (B3) into Equation (B2) yields

$$\begin{aligned} & K_1 e^{-rt} E^{Q}(1_D) \\ & = K_1 e^{-rt} \mathrm{Prob}^{Q}\Bigg(\ln H(0) + rt - \frac{1}{2}\sum_{\tau=1}^{t}\left(\sigma_H^2(\tau) + C'\,\Sigma(\tau)\,C\right) \\ & \quad + \sum_{\tau=1}^{t}\left(\sigma_H(\tau)\,\varepsilon_H^{Q}(\tau) + \sum_{i=1}^{n} c_i\,\sigma_{M_i}(\tau)\,\varepsilon_{M_i}^{Q}(\tau)\right) \leq \ln K_1 \Bigg) \\ & = K_1 e^{-rt} \mathrm{Prob}^{Q}\Bigg(\frac{\sum_{\tau=1}^{t}\left(\sigma_H(\tau)\,\varepsilon_H^{Q}(\tau) + \sum_{i=1}^{n} c_i\,\sigma_{M_i}(\tau)\,\varepsilon_{M_i}^{Q}(\tau)\right)}{\sqrt{V(t)}} \\ & \quad \leq -\frac{\ln(H(0)/K_1) + r\,t - \frac{V(t)}{2}}{\sqrt{V(t)}} \Bigg) = K_1 e^{-rt}\,\Phi\left(-d_{21}(t)\right). \end{aligned} \tag{B4}$$

For the second part in the right-hand side of Equation (B2), we have

$$
\begin{aligned}
& e^{-rt} E^{Q}(H(t)\,1_D) \\
& = H(0) E^{Q}\left(\exp\left(-\frac{1}{2}\sum_{\tau=1}^{t}\left(\sigma_H^2(\tau) + C' \sum^{*}(\tau)\, C\right) + \sum_{\tau=1}^{t}\left(\sigma_H(\tau)\,\varepsilon_H^{Q}(\tau)\right.\right.\right. \\
& \quad \left.\left.\left. + \sum_{i=1}^{n} c_i\, \sigma_{M_i}(\tau)\,\varepsilon_{M_i}^{Q}(\tau)\right)\right) 1_D\right) = H(0) E^{Q} \exp\left(-\frac{1}{2}\sum_{\tau=1}^{t}\left(\sigma_H^2(\tau)\right.\right. \\
& \quad \left.\left. + C' \sum{}^{*}(\tau)\Omega(\tau)\Sigma^{*}(\tau)C) + \sum_{\tau=1}^{t}\left(\sigma_H(\tau)\,\varepsilon_H^{Q}(\tau) + C'\Sigma^{*}(\tau)\,\varepsilon_{\mathrm{M}}^{Q}(\tau)\right)\right) 1_D\right), \qquad \text{(B5)}
\end{aligned}
$$

where $\varepsilon_M^{Q}(\tau) = [\varepsilon_{M_1}^{Q}(\tau), \varepsilon_{M_2}^{Q}(\tau), \ldots ;, \varepsilon_{M_n}^{Q}(\tau)]'$ is a multivariate normal distribution with null mean vector and variance–covariance matrix $\Omega(\tau) = [\rho_{M_i M_j}]_{n\times n}$; $\Sigma^{*}(\tau)$ is a diagonal matrix satisfying $\Sigma^{*}(\tau) = diag(\sigma_{M_1}, \ldots, \sigma_{M_n})$. As $\varepsilon_{M_i}^{Q}(\tau)$ is independent of $\varepsilon_H^{Q}(\tau)$, Equation (B5) can be rewritten as follows:

$$
\begin{aligned}
& e^{-rt} E^{Q}(H(t)\,1_D) \\
& = H(0) \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} \exp\left(-\frac{1}{2}\sum_{\tau=1}^{t}\left(\sigma_H^2(\tau) + C'\Sigma^{*}(\tau)\Omega(\tau)\Sigma^{*}(\tau)C\right)\right. \\
& \quad \left. + \sum_{\tau=1}^{t}\left(\sigma_H(\tau)\, e_H^{Q}(\tau) + C'\Sigma^{*}(\tau)\; e_M^{Q}(\tau)\right)\right) \\
& \quad \times \frac{\prod_{\tau=1}^{t} \left|\,\Omega(\tau)\right|^{-\frac{1}{2}}}{(2\pi)^{\frac{nt}{2}}} \exp\left(-\frac{1}{2}\sum_{\tau=1}^{t}[e_M^{Q}(\tau)'\Omega^{-1} e_M^{Q}(\tau)]\right) \times \frac{1}{(2\pi)^{\frac{t}{2}}} \exp\left(-\frac{1}{2}\sum_{\tau=1}^{t}(e_H^{Q}(\tau))^2\right) \\
& \quad \times 1_D\, de_{M_1}^{Q}(1) \cdots de_{M_1}^{Q}(t) \cdots de_{M_n}^{Q}(t)\, de_H^{Q}(1) \cdots de_H^{Q}(t). \\
& = H(0) \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} \frac{\prod_{\tau=1}^{t} \left|\,\Omega(\tau)\right|^{-\frac{1}{2}}}{(2\pi)^{\frac{nt}{2}}} \exp\left(-\frac{1}{2}\sum_{\tau=1}^{t}\left(\left(e_M^{Q}(\tau) - \Omega(\tau)\Sigma^{*}(\tau)C\right)'\right.\right. \\
& \quad \left.\left. \times \Omega^{-1}\left(e_M^{Q}(\tau) - \Omega(\tau)\Sigma^{*}(\tau)C\right)\right)\right) \times \left(\frac{1}{\sqrt{2\pi}}\right)^{t} \exp\left(-\frac{1}{2}\sum_{\tau=1}^{t}(e_H^{Q}(\tau) - \sigma_H(\tau))^2\right) \\
& \quad \times 1_D de_{M_1}^{Q}(1) \cdots de_{M_1}^{Q}(t) \cdots de_{M_n}^{Q}(t)\, de_H^{Q}(1) \cdots de_H^{Q}(t). \qquad \text{(B6)}
\end{aligned}
$$

In view of Equation (B6), we define a new auxiliary probability measure R, under which $\varepsilon_M^{R}(\tau)$ and $\varepsilon_H^{R}(\tau)$ are given by

$$
\varepsilon_M^{R}(\tau) = \varepsilon_M^{Q}(\tau) - \Omega(\tau)\Sigma^{*}(\tau)\, C, \qquad \text{(B7)}
$$

$$\varepsilon_H^R(\tau) = \varepsilon_H^Q(\tau) - \sigma_{M_i}(\tau). \tag{B8}$$

Therefore, the housing price under probability measure R can be expressed as

$$\ln\left(\frac{H(t)}{H(0)}\right) = rt + \frac{1}{2}\sum_{\tau=1}^{t}\left(C\,\Sigma\,(\tau)C' + \sigma_H^2(\tau)\right) + \sum_{\tau=1}^{t}\sum_{i=1}^{n} c_i\left(\sigma_{M_i}(\tau)\varepsilon_{M_i}^R(\tau)\right) + \sum_{\tau=1}^{t}\sigma_H(\tau)\,\varepsilon_H^R(\tau). \tag{B9}$$

Using Equations (B7), (B8), and (B9), we have

$$\begin{aligned} e^{-rt}E^Q(H(t)\,1_D) &= H(0)\mathrm{Prob}^R(\ln H(t) \geq \ln K_1|\mathcal{F}_t) \\ &= H(0)\mathrm{Prob}^R\left(\frac{\sum_{\tau=1}^{t}\sum_{i=1}^{n} c_i(\sigma_{M_i}(\tau)\varepsilon_{M_i}^R(\tau)) + \sigma_H(\tau)\,\varepsilon_H^R(\tau)}{\sqrt{\sum_{\tau=1}^{t}(C\,\Sigma\,(\tau)C' + \sigma_H^2(\tau))}}\right. \\ &\left.\leq -\frac{\ln(H(0)/K_1) + r\,t + \frac{V(t)}{2}}{\sqrt{V(t)}}\right) = H(0)\Phi(-d_{1,1}(t)). \end{aligned} \tag{B10}$$

Thus, the proof of the first term of Equation (B1) is completed. Following the similar procedure, we can also derive the second term of Equation (B1). This completes the proof of Appendix B.

APPENDIX C

In this appendix, the delta and gamma of mortgage insurance contracts, together with their sensitivity to the macroeconomic factors, are derived. To derive the Delta and Gamma of mortgage insurance contracts, applying the chain rule of differentiation to Equation (8), we obtain

$$\frac{\partial\ FP}{\partial\ H(0)} = \sum_{t=1}^{T} PD(t)\frac{\partial\ DL(t)}{\partial\ H(0)} = \sum_{t=1}^{T} PD(t)\left(\frac{\partial\ P_1(t)}{\partial\ H(0)} - \frac{\partial\ P_2(t)}{\partial\ H(0)}\right),$$

where

$$\frac{\partial\ P_i(t)}{\partial\ H(0)} = \Phi\left(d_{1i}(t)\right) - 1 + H(0)\frac{\partial\ \Phi\left(d_{1\,i}(t)\right)}{\partial\ H(0)} - K_i\,e^{-r\,t}\frac{\partial\ \Phi\left(d_{2i}(t)\right)}{\partial\ H(0)}.$$

Since

$$H(0)\frac{\partial\,\Phi\,(d_{1i}(t))}{\partial\,H(0)} = \frac{1}{H(t)\sqrt{2\,\pi\,V(t)}}\exp\left(\frac{-(d_{2i}(t)+\sqrt{V(t)})^2}{2}\right)$$
$$= K_i\,e^{-r\,t}\frac{1}{H(t)\sqrt{2\,\pi\,V(t)}}\exp\left(\frac{-d_{2i}(t)^2}{2}\right) = K_i\,e^{-r\,t}\frac{\partial\,\Phi\,(d_{2i}(t))}{\partial\,H(0)},$$

we obtain the delta of a mortgage insurance contract as follows:

$$\frac{\partial\,FP}{\partial\,H(0)} = \sum_{t=1}^{T} PD(t)\left(\Phi\,(d_{11}(t)) - \Phi\,(d_{12}(t))\right).$$

Similarly, the gamma of a mortgage insurance contract is of the form:

$$\frac{\partial^2 F\,P}{\partial\,H(0)^2} = \sum_{t=1}^{T} P\,D(t)\frac{\partial^2 DL(t)}{\partial\,H(0)^2} = \sum_{t=1}^{T} P\,D(t)\frac{1}{H(t)\sqrt{2\,\pi\,V(t)}}\left(\exp\left(-\frac{d_{11}(t)^2}{2}\right)\right.$$
$$\left. - \exp\left(-\frac{d_{12}(t)^2}{2}\right)\right).$$

Following the analogical derivation, we obtain the sensitivity of a mortgage insurance contract to the macroeconomic factors as follows:

$$\frac{\partial\,F\,P}{\partial\,c_i} = \sum_{t=1}^{T} P\,D(t)\frac{\partial\,DL(t)}{\partial\,c_i} = \sum_{t=1}^{T} P\,D(t)\left(\frac{\partial\,P_1(t)}{\partial\,c_i} - \frac{\partial\,P_2(t)}{\partial\,c_i}\right), \tag{C1}$$

where

$$\begin{aligned}\frac{\partial\,P_i(t)}{\partial\,c_i} &= H(0)\frac{\partial\,\Phi\,(d_{1i}(t))}{\partial\,c_i} - K_i\,e^{-rt}\frac{\partial\,\Phi\,(d_{2i}(t))}{\partial\,c_i}\\ &= H(0)\frac{\partial\,\Phi\,(d_{1i}(t))}{\partial\,d_{1i}(t)}\frac{\partial\,d_{1i}(t)}{\partial\,c_i} - K_i\,e^{-rt}\frac{\partial\,\Phi\,(d_{2i}(t))}{\partial\,d_{2i}(t)}\frac{\partial\,d_{2i}(t)}{\partial\,c_i}\\ &= H(0)\frac{\partial\,\Phi\,(d_{1i}(t))}{\partial\,d_{1i}(t)}\left(\frac{\partial\,d_{1i}(t)}{\partial\,V(t)} - \frac{\partial\,d_{2i}(t)}{\partial V(t)}\right)\frac{\partial\,V(t)}{\partial c_i}\\ &= \frac{H(0)}{2\sqrt{2\,\pi\,V(t)}}\exp\left(-\frac{d_{1i}(t)^2}{2}\right)\frac{\partial\,V(t)}{\partial c_i}.\end{aligned} \tag{C2}$$

Due to the fact that

$$\frac{\partial\ V(t)}{\partial c_i} = \frac{\partial \sum_{\tau=1}^{t} \left(C\ \Sigma(\tau)\, C' + \sigma_H^2(\tau)\right)}{\partial c_i} = 2 \sum_{\tau=1}^{t} \sum_{j=1}^{n} c_j \sigma_{M_i M_j}(\tau),$$

Equation (C2) can be rewritten as

$$\frac{\partial\ P_i(t)}{\partial\ c_i} = \frac{H(0)}{\sqrt{2\pi V(t)}} \left(\sum_{\tau=1}^{t} \sum_{j=1}^{n} c_j \sigma_{M_i M_j}(\tau) \right) \exp\left(-\frac{d_{1i}(t)^2}{2} \right). \tag{C3}$$

Incorporating Equation (C3) into Equation (C1), we obtain

$$\frac{\partial FP}{\partial\ c_i} = \sum_{t=1}^{T} PD(t) \frac{H(0)}{\sqrt{2\pi V(t)}} \left(\sum_{\tau=1}^{t} \sum_{j=1}^{n} c_j \sigma_{M_i M_j}(\tau) \right) \left(\exp\left(-\frac{d_{11}(t)^2}{2} \right) - \exp\left(-\frac{d_{12}(t)^2}{2} \right) \right).$$

This completes the proof of Appendix C.

REFERENCES

Abraham, J. M., and P. H. Hendershott, 1996, Bubbles in Metropolitan Housing Markets, *Journal of Housing Research*, 7: 191-208.

Baffoe, B. J., 1998, The Dynamic Impact of Macroeconomic Aggregates on Housing Prices and Stock of Houses: A National and Regional Analysis, *Journal of Real Estate Finance and Economics*, 17: 179-197.

Bardhan, A., R. Karapandža, and B. Urošević, 2006, Valuing Mortgage Insurance Contracts in Emerging Market Economies, *Journal of Real Estate Finance and Economics*, 32: 9-20.

Bowen, A., 1994, Housing and the Macroeconomy in the United Kingdom, *Housing Policy Debate*, 5: 241-251.

Brennan, M. J., 1979, The Pricing of Contingent Claims in Discrete-Time Model, *Journal of Finance*, 34: 53-68.

Calcagno, R., E. Fornero, and M. Rossi, 2009, The Effect of House Prices on Household Consumption in Italy, *Journal of Real Estate Finance and Economics*, 39: 284-300.

Capozza, D. R, P. H., Hendershott, and C. Mack, 2004, An Anatomy of Price Dynamics in Illiquid Markets: Analysis and Evidence From Local Housing Markets, *Real Estate Economics*, 32: 1-32.

Case, K. E., J. M. Quigley, and R. J. Shiller, 2005, Comparing Wealth Effects: The Stock Market Versus the Housing Market, *Advances in Macroeconomics*, 5: 1-32.

Chen, M. C., C. C. Chang, S. K. Lin, and D. Shyu, 2010, Estimation of Housing Price Jump Risks and Their Impact on the Valuation of Mortgage Insurance Contracts, *The Journal of Risk and Insurance*, 77: 399-422.

Chen, M. C., C. O. Chang, C. Y. Yang, and B. M. Hsieh, Forthcoming, Investment Demand and Housing Prices in an Emerging Economy, *Journal of Real Estate Research*.

Chen, M. C., and K. Patel, 2002, An Empirical Analysis of Determination of House Prices in the Taipei Area, *Taiwan Economic Review*, 30: 563-595.

Cochrane, J. H., 1994, Permanent and Transitory Components of GNP and Stock Prices, *Quarterly Journal of Economics*, 109: 241-265.

Darrat, A. F., and J. L. Glascock, 1989, Real Estate Returns, Money and Fiscal Deficits: Is the Real Estate Market Efficient? *Journal of Real Estate Finance and Economics*, 2: 197-208.

Davidoff, T., 2007, Stock Prices, Housing Prices, Housing Stock Prices, and Fundamentals, Working paper, University of California, Berkley.

Davis, M., and J. Heathcote, 2007, The Price and Quantity of Residential Land in the United States, *Journal of Monetary Economics*, 54: 2595-2620.

Davidson, R. and J. G. MacKinnon, 1989, Testing for Consistency Using Artificial Regressions, *Econometric Theory*, 5: 363-384.

Dennis, B., C. Kuo, and T. T. Yang, 1997, Rationales of Mortgage Insurance Premium Structures, *Journal of Real Estate Research*, 14: 359-378.

Duan, J. C., 1995, The GARCH Option Pricing Model, *Mathematical Finance*, 5: 13-32.

Duan, J. C., and S. R. Pliska, 2004, Option Valuation with Co-integrated Asset Prices, *Journal of Economic Dynamics and Control*, 28: 727-754.

Epple, D., B. Gordon, and H. Sieg, 2010, A New Approach to Estimating the Production Function for Housing, *American Economic Review*, 100: 905-924.

Friedman, M., 1957, *A Theory of the Consumption Function*. (Princeton, NJ: Princeton University Press).

Geltner, D., 1990, Return Risk and Cash Flow With Long Term Riskless Leases in Commercial Real Estate, *Journal of the American Real Estate and Urban Economics Association*, 18: 377-402.

Glaeser, E. L., J. Gyourko, and A. Saiz, 2008, Housing Supply and Housing Bubbles, *Journal of Urban Economics*, 64: 198-217.

Green, R., 1997, Follow the Leader: How Changes in Residential and Non-Residential Investment Predict Changes in GDP, *Real Estate Economics*, 25: 253-270.

Green, R., 2002, Stock Prices and House Prices in California: A New Evidence of a Wealth Effect? *Regional Science and Urban Economics*, 32: 775-783.

Grimes, A., and A. Aitken, 2010, Housing Supply, Land Costs and Price Adjustment, *Real Estate Economics*, 38: 325-353.

Gyourko, J., and D. Keim, 1992, What Does the Stock Market Tell Us About Real Returns, *Journal of the American Real Estate Finance and Urban Economics Association*, 20: 457-486.

Hausman, J. A., 1978, Specification Tests in Econometrics, *Econometrica*, 46: 1251-1272.

Hendershott, P., and R. Van Order, 1987, Pricing Mortgages: Interpretation of the Models and Results, *Journal of Financial Services Research*, 1: 19-55.

Hoesli, M., C. Lizieri, and B. MacGregor, 2008, The Inflation Hedging Characteristics of US and UK Investments: A Multi-Factor Error Correction Approach, *Journal of Real Estate Finance and Economics*, 36: 183-206.

Ito, T., 1993, The Land/Housing Problem in Japan: A Macroeconomic Approach, *Journal of the Japanese and International Economies*, 7: 1-31.

Jud, D., and D. Winkler, 2002, The Dynamics of Metropolitan Housing Prices, *Journal of Real Estate Research*, 23: 29-45.

Kau, J. B., and D. C. Keenan, 1995, An Overview of the Option-Theoretic Pricing of Mortgages, *Journal of Housing Research*, 6: 217-244.

Kau, J. B., and D. C. Keenan, 1996, An Option-Theoretic Model of Catastrophes Applied to Mortgage Insurance, *Journal of Risk and Insurance*, 63: 639-656.

Kau, J. B., D. Keenan, and J. E. Epperson, 1992, A Generalized Valuation Model for Fixed-Rate Residential Mortgages, *Journal of Money, Credit and Banking*, 24: 280-299.

Kau, J. B., D. Keenan, and W. J. Muller, 1993, An Option-Based Pricing Model of Private Mortgage Insurance, *Journal of Risk and Insurance*, 60: 288-299.

Kau, J. B., D. Keenan, W. J. Muller, and J. E. Epperson, 1995, The Valuation at Origination of Fixed-Rate Mortgages with Default and Prepayment, *The Journal of Real Estate Finance and Economics*, 11: 3-36.

Kim, K. H., 1993, Housing Prices, Affordability, and Government Policy in Korea, *Journal of Real Estate Finance and Economics*, 6: 55-71.

Kim, K. H., 2004, Housing and the Korean Economy, *Journal of Housing Economics*, 13: 321-341.

Leung, C., 2004, Macroeconomics and Housing: A Review of the Literature, *Journal of Housing Economics*, 13: 249-267.

Leung, C. K., Y. Y. Leong, and S. K. Wong, 2006, Housing Price Dispersion: An Empirical Investigation, *Journal of Real Estate Finance and Economics*, 32: 357-385.

Leung, C. K. Y., K. S. K. Wong, and P. W. Y. Cheung, 2007, On the Stability of the Implicit Prices of Housing Attributes: A Dynamic Theory and Some Evidence, *International Real Estate Review*, 10: 66-93.

Ling, D. C., and A. Naranjo, 1999, The Integration of Commercial Real Estate Markets and Stock Markets, *Real Estate Economics*, 27: 1-28.

Liu, C., and J. Mei, 1992, The Predictability of Returns on Equity REIT's and Their Co-movements With Other Assets, *Journal of Real Estate Finance and Economics*, 5: 401-418.

Liu, C., D. Hartzell, D. W. Greig, and T. V. Grissom, 1990, The Integration of The Real Estate Market and The Stock Market: Some Preliminary Evidence, *Journal of Real Estate Finance and Economics*, 3: 261-282.

Malpezzi, S., and S. M. Wachter, 2005, The Role of Speculation in Real Estate Cycles, *Journal of Real Estate Literature*, 13: 143-164.

Mayes, D., 1979, *The Property Boom* (Oxford: Martin Robertson).

McCue, T. E., and J. L. Kling, 1994, Real Estate Returns and the Macroeconomy: Some Empirical Evidence From Real Estate Investment Trust Data, 1972–1991, *Journal of Real Estate Research*, 9: 277-288.

Meen, G. P., 1990, The Removal of Mortgage Market Constraints and the Implications for Econometric Modelling of UK House Prices, *Oxford Bulletin Economics and Statistics*, 52: 1-23.

Meen, G. P., 2002, The Time-Series Behavior of House Prices: A Transatlantic Divide? *Journal of Housing Economics*, 11: 1-23.

Miller, N. G., and L. Peng, 2006, Exploring Metropolitan Housing Price Volatility, *Journal of Real Estate Finance and Economics*, 33: 5-18.

Muellbauer, J., and A. Murphy, 1997, Booms and Busts in the UK Housing Market, *Economic Journal*, 107: 1701-1727.

Newey, W., and K. West, 1987, A Simple Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix, *Econometrica*, 55: 703-708

Oikarinen, E., 2009, Interaction Between Housing Prices and Household Borrowing: The Finnish Case, *Journal of Banking and Finance*, 33: 747-756.

Peterson, W., C. Pratten, and J. Tatch, 1997, *An Economic Model of the Demand and Need for Social Housing* (London: Department of the Environment, Transport and the Regions).

Potepan, M., 1996, Explaining Intennetropolitan Variation in Housing Prices, Rents, and Land Prices, *Real Estate Economics*, 24: 219-246.

Rubinstein, M., 1976, The Valuation of Uncertain Income Streams and the Pricing of Options, *Bell Journal of Economics*, 7: 407-425.

Schwartz, E. S., and W. N. Torous, 1992, Prepayment, Default, and the Valuation of Mortgage Pass-Through Securities, *Journal of Business*, 65: 221-239.

Somerville, C. T., 1999, Residential Construction Costs and the Supply of New Housing: Endogenity and Bias in Construction Cost Indexes, *Journal of Real Estate Finance and Economics*, 18: 43-62.

Whitehead, C., 1971, A Model of the UK Housing Market, *Oxford Bulletin of Economics and Statistics*, 33: 245-266.

Wooldridge, J. M., 2002, *Econometric Analysis of Cross Section and Panel Data* (Cambridge, MA: MIT Press).

Yi, W., 2001, Residential Investment and Economic Growth, *Annals of Economics and Finance*, 2: 437-444.

Zeckhauser, S., and R. Silverman, 1983, Rediscover Your Company's Real Estate, *Harvard Business Review*, 61: 111-117.