DOES THE AGENCY COST MODEL EXPLAIN BUSINESS FLUCTUATIONS IN JAPAN?: A BAYESIAN APPROACH TO ESTIMATE AGENCY COST FOR FIRMS CLASSIFIED BY SIZE

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We attempt to estimate a state space model of investment and borrowing in a Bayesian framework, and to extract the unobservable agency costs of Japanese firms, which we differentiate by firm size. Our estimates suggest that agency cost exhibited a declining trend in the late 1980s, which changed to an increasing trend in the 1990s. We pinned down the driving force of fluctuations in agency cost as the market value of land. Furthermore, we found that the investment and borrowing behavior of small firms was very much affected by their agency costs in the late 1980s and early 1990s. Our evidence suggests that imperfections in the capital market were important for small firms in Japan.

Key words and phrases: Agency cost, borrowing, collateral, Gibbs sampling, investment, Kalman filter, land, state space model.

1. Introduction

In the presence of asymmetric information between lenders and borrowers, financial arrangements arise to prevent borrowers from acting contrary to the interests of lenders. In addition, lenders may monitor the behavior of borrowers, to enforce such arrangements. The resulting agency cost caused by this inefficiency drives a wedge between the costs of internal and external funds and is known as the external finance premium. Agency cost, or the external finance premium, reflects the creditor’s cost of collecting information about the debtor and monitoring the debtor’s behavior, as well as the costs arising from any adverse selection or moral hazard problems. The premium for external funds influences the cost of external funds and thereby affects the investment decisions of the debtor.

It has frequently been asserted that the excessive fluctuations that occurred in the investment of Japanese firms during the late 1980s and early 1990s were mainly caused by changes in the external finance premium for the corresponding period. The argument generally proceeds as follows. As is well known, the external finance premium is inversely associated with a borrower’s collateralizable net worth.1 In particular, real estate played a collateral role in Japan, under the

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1 For example, see Hubbard (1995).
expectation that land prices would never fall. In fact, land prices soared in the late 1980s, when investment increased noticeably, and then, as land prices plummeted in the 1990s, investment activity became stagnant.

While this story may sound plausible, demonstration of its veracity in a rigorous manner is quite difficult. The main obstacle to conducting an empirical study along these lines is the unobservability of the agency cost facing borrowers. Therefore, in past studies relevant to this topic, some kind of proxy was used to represent the fluctuation of agency cost. One popular candidate was the market price of the land assets of the firms examined. A number of studies found a positive correlation between investment and land assets. However, it may be possible to interpret the land asset value of firms as their future profitability of investment, rather than as collateral used to reduce agency cost.

In this study, we provide more direct evidence for the role of agency cost in explaining the investment activities of Japanese firms in the late 1980s and early 1990s. We accomplish this by estimating the unobservable agency cost directly. We estimate a state space model by means of the Kalman filter in a Bayesian framework to extract the common factors from the observable variables closely related to agency cost. To the best of our knowledge, this constitutes the first attempt to estimate directly the agency costs faced by Japanese firms during the period of economic turmoil in the late 1980s and early 1990s.

In the course of conducting our research, we took into account the possibility that firms with different sizes may have faced agency costs of different magnitudes, because of the existence of an institutional device in Japan that helps to narrow the informational asymmetry between lenders and borrowers: industry groups known as keiretsu. Firms within a keiretsu are able to reduce agency cost for several reasons. First, they have close ties with affiliated banks, which hold both debt and equity in the group’s firms. This reduces conflicts among investors. Secondly, group firms enjoy long-term, stable relationships with their affiliated banks. Bank employees often hold management positions in the firms. This explains why agency costs were lower for firms within keiretsu groups, as compared to unaffiliated firms. Since large firms tend to be affiliated with banks, we can compare the magnitude of agency cost and its impact on investment activity across firms by using less aggregated data, in which firms are classified by size.

Let us preview our findings. First, we successfully extracted unobservable agency cost from observable interest spread. We found that agency cost decreased in the late 1980s, when land prices soared, while agency cost increased substantially in the 1990s, when land prices fell. This pattern of agency cost movement is observed irrespective of firm size and industry. Furthermore, the agency cost of small firms was significantly larger than the interest spread in the late 1990s, while the agency cost was almost identical with the interest rate spread for large

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2 For example, see Ogawa et al. (1996), Suzuki and Ogawa (1997), and Ogawa and Suzuki (1998, 2000).

3 Our idea for extracting agency cost stems from Stock and Watson (1991), where an unobservable composite index is extracted from the co-movement of economic variables.
firms. This hints that the agency cost of small firms has extra premium that is not well covered by the interest rate spread. Second, we find that investment and borrowing were closely associated with agency cost, which, in turn, was affected negatively by the land value of firms. The effect of agency cost on investment and borrowing was notably large for small firms in the 1990s. Our results are consistent with the theoretical predictions of the agency cost literature, which indicates that the investment activities of Japanese firms during the turbulent period of the late 1980s and early 1990s can be successfully explained by changing patterns in agency cost movement during that time.

The paper is organized as follows. Section 2 briefly reviews the agency cost model of investment and derives the fundamental equations to be estimated. Then, the model is cast into state space form. Section 3 explains the econometric procedure used to estimate unobservable agency cost. Section 4 describes the data set and presents descriptive statistics for some of the variables used in the subsequent analysis. In Section 5, we present estimated agency cost series and discuss the association of agency cost with investment, borrowing, and the land assets and interest rate premia of firms. Concluding remarks are given in Section 6.

2. The agency cost model of investment and borrowing

We construct a model of corporate investment and borrowing with agency cost, or an external finance premium, explicitly taken into consideration. Consider a firm that maximizes its value in the next period. The firm produces output by labor and capital stock. The firm can adjust its labor input without incurring any additional costs, while the firm has to pay extra adjustment cost in changing the level of fixed investment, which we assume to be a linear homogeneous function of investment and capital stock at the beginning of period \( t \). It is assumed that current investment contributes to the production next period and that the depreciation rate of capital stock is 100%. The firm finances investment expenditure by its current profit and/or borrowing. Then the budget constraint of the firm is written as follows:

\[
NB_t + p_t Y_t = w_t N_t + p_I^t I_t + p_I^t \phi(I_t, K_{t-1}),
\]

(2.1)

where \( \text{NB}_t \): net borrowing in period \( t \),
\( p_t \): output price in period \( t \),
\( Y_t \): output in period \( t \),
\( w_t \): wage rate in period \( t \),
\( N_t \): labor input in period \( t \),
\( p_I^t \): investment goods price in period \( t \),
\( I_t \): investment in period \( t \),
\( K_{t-1} = I_{t-1} \): capital stock at the beginning of period \( t \),
\( \phi(I_t, K_{t-1}) \): convex adjustment cost of investment,
\( \frac{\partial \phi}{\partial I_t} > 0, \quad \frac{\partial \phi}{\partial K_{t-1}} < 0, \quad \frac{\partial^2 \phi}{\partial I_t^2} > 0. \)
The production technology is given by the following production function with constant returns to scale technology:

\[
Y_t = F(K_{t-1}, N_t).
\]

The firm maximizes its value in the next period, which is written as

\[
p_{t+1}F(I_t, N_{t+1}) - w_{t+1}N_{t+1} - (1 + R)NB_t,
\]

where \(R\): interest rate.

The firm faces borrowing constraint where there is an upper limit on the amount of borrowing. It might be caused by asymmetric information between lenders and borrowers and the upper limit will depend on the collateralizable wealth of the firm. The borrowing constraint is given by

\[
NB_t \leq NB,
\]

where \(NB\): ceiling level of borrowing.

The firm maximizes equation (2.3) with respect to \(N_t, I_t, NB_t\) and \(N_{t+1}\) subject to equations (2.1), (2.2) and (2.4). The first order condition for investment is given by:

\[
1 + \frac{\partial \phi}{\partial I_t} = \frac{p_{t+1}I_t}{(1 + R + \lambda)p_t},
\]

where \(\lambda\): non-negative Lagrange multiplier associated with the borrowing constraint.

The left-hand-side of equation (2.5) is marginal cost of investment and the right-hand-side is marginal profitability of investment, known as marginal \(q\). It should be noted that the Lagrange multiplier (\(\lambda\)) associated with the borrowing constraint is added on to the discount rate. In other words, the Lagrange multiplier is interpreted as agency cost or external finance premium between the marker interest rate and the effective discount rate for the firm and it measures the severity of borrowing constraint, reflecting the asymmetry of information between lenders and borrowers. It is easy to show that investment rate \(\frac{I_t}{K_{t-1}}\) is an increasing function of the marginal \(q\) with the discount rate \((1 + R)\) and a decreasing function of the external finance premium.

As is well known, marginal \(q\) is a sufficient statistic for investment in a perfect capital market, when a firm incurs an additional convex cost in adjusting to investment.\(^4\) However, once we relax the assumption of a perfect capital market and incorporate asymmetric information between lenders and borrowers into the model, marginal \(q\) is no longer a sufficient statistic for investment. In addition,

\(^4\) See Hayashi (1982).
the degree of asymmetry, or the magnitude of agency cost, matters for the investment decision.\(^5\) Note that agency cost is generally unobservable. Therefore past studies incorporated those factors affecting agency cost as additional explanatory variables of the investment function. For example, cash flow and land used as collateral are popular alternative candidates to marginal \(q\) in the investment function. Then, the effects of agency cost on investment are measured by the magnitude of coefficient estimates of cash flow or land in investment function. Note that cash flow and land is only a proxy of unobservable agency cost and we are not sure what the best proxy for agency cost is.

Our approach differs from the past studies in that we directly extract the unobservable external finance premium from observable counterpart, or interest rate spread facing the firm. It has been asserted that the structure of agency cost depends on firm attributes. Therefore our exercise to estimate agency cost is conducted for different groups of firms classified by firm size. Once we obtain a series of agency cost by firm size, the estimated external finance premia for different groups are directly comparable. Moreover we can also incorporate the variables that affect agency cost in statistical formulation.

In the model above we can also demonstrate that external finance premium affects net borrowing negatively, while a marginal \(q\) with the conventional discount rate \((1 + R)\) has a positive effect on net borrowing. Lastly we take account of the well-known proposition that the external finance premium is inversely associated with the collateralizable net worth of the firm. In particular, land assets have long played a collateral role in Japan under the expectation that land prices would never fall. However, the close association of borrowing with land assets made loans insolvent once land prices plummeted in the 1990s. Therefore, we regard land assets as a proxy for collateralizable net worth and assume that agency cost is affected negatively by the ratio of land assets to tangible assets (land assets plus the capital stock).

To sum up, our investment model consists of three equations: the investment equation, the borrowing equation, and the interest rate spread equation. We specify the investment equation as a function of marginal \(q\) and unobservable agency cost.

\[
\frac{I_t}{K_{t-1}} = \alpha_I + \beta_I q_t + \gamma_I AC_t + \varepsilon_{It}, \tag{2.6}
\]

where \(q_t\): marginal \(q\) in period \(t\),
\(AC_t\): agency cost in period \(t\),
\(\varepsilon_{It}\): error term in period \(t\).

In the borrowing equation we express the ratio of borrowing to capital stock, or the borrowing ratio, as a function of agency cost, as well as of marginal \(q\).

\[
\frac{\Delta B_t}{p_t K_{t-1}} = \alpha_B + \beta_B q_t + \gamma_B AC_t + \varepsilon_{Bt} \tag{2.7}
\]

where $\Delta B_t$: change in borrowing in period $t$,  
$p_t^L K_{t-1}$: capital stock at replacement cost at the end of period $t - 1$,  
$\varepsilon_{Bt}$: error term in period $t$.

The interest rate spread between the borrowing interest rate and the risk-free rate measures the magnitude of agency cost but has a degree of error. The error term might include measurement error as well as macro shocks that affect the supply and demand conditions of loans.

\[ \text{spread}_t = AC_t + \varepsilon_{St} \quad (2.8) \]

where $\text{spread}_t$: the interest rate spread between the borrowing interest rate and the risk-free rate in period $t$,  
$\varepsilon_{St}$: error term in period $t$.

In general the interest rate spread is specified as a linear function of agency cost. We impose the condition that the intercept is zero and the slope is unity in equation (2.8). This identification restriction enables us to extract and compare the external finance premia for different firm groups. Moreover we can compare the magnitude of measurement error across firm groups.

To close the model, we need an equation describing the movement of agency cost. We assume that agency cost is generated by the following error correction model.\(^6\)

\[
\Delta AC_t = \phi_1 \Delta AC_t + \phi_2 \Delta AC_{t-1} + \phi_3 \Delta AC_{t-2} \\
+ \theta_1 \Delta \left( \frac{p_t^L L_{t-1}}{p_t^L K_{t-1} + p_t^L L_{t-1}} \right) + \theta_2 \Delta \left( \frac{p_{t-1}^L L_{t-2}}{p_{t-1}^L K_{t-2} + p_{t-1}^L L_{t-2}} \right) \\
+ \theta_3 \Delta \left( \frac{p_{t-2}^L L_{t-3}}{p_{t-2}^L K_{t-3} + p_{t-2}^L L_{t-3}} \right) \\
+ \phi_1 \left( AC_{t-1} - \gamma_L \frac{p_{t-1}^L L_{t-2}}{p_{t-1}^L K_{t-2} + p_{t-1}^L L_{t-2}} - \alpha_L \right) + \varepsilon_{ACt}, \\
(2.9)
\]

where $p_t^L L_{t-1}$: land stock at market value at the end of period $t - 1$.  
$\varepsilon_{ACt}$: error term in period $t$.  
$\phi_1 < 0, \gamma_L < 0$

This state equation is assumed to be stationary.\(^7\)

We are now ready to cast our model in state space form. The state space model consists of observation equations and a state equation. A observation

\(^6\)The choice of lag length is partially motivated by the quarterly data set that we use.  
\(^7\)It is assumed that the roots of $\phi_1$, $\phi_2$ and $\phi_3$ lie outside the unit circle. The agency cost model represented by equations (2.9) and (2.10) was analyzed by Uchiyama (2006), who conducted the selection of the lag order and non-stationarity test (structural change test) for equation (2.9) by Bayes factor.
equation is defined as an equation in which an unobserved variable explains observed variables. In our model, observation equations correspond to equations (2.6) through (2.8). A given observation equation is summarized as follows:

\[
\begin{bmatrix}
\frac{I_t}{K_{t-1}} \\
\frac{\Delta B_t}{p_t^I K_{t-1}} \\
\text{spread}_t
\end{bmatrix} = \begin{bmatrix}
\alpha_I \\
\alpha_B \\
\alpha_S
\end{bmatrix} + \begin{bmatrix}
\gamma_I \\
\gamma_B \\
\gamma_S
\end{bmatrix} A C_t + \begin{bmatrix}
\beta_I \\
\beta_B \\
\beta_0
\end{bmatrix} q_t + \begin{bmatrix}
\varepsilon_{I_t} \\
\varepsilon_{B_t} \\
\varepsilon_{S_t}
\end{bmatrix},
\]

where \( \gamma_S = 1, \alpha_S = 0 \).

Note that marginal \( q \) is exogenous to our model. The state equation describes the movement of the unobservable variable. Equation (2.9) is the state equation in our model. In the state space model, we estimate unobservable agency cost, as well as the other parameters and the error variances underlying the model. We now provide an explanation of our statistical tools.

3. Econometric procedure for estimation of the state space model

Agency cost is an unobserved variable in equations (2.6) to (2.9). The main feature of our paper is an estimation of this unobservable variable through the extraction of a common factor from the co-movement of the four observable variables: the investment rate, the borrowing ratio, the ratio of land to tangible assets, and the interest rate spread. This common factor is identified as the estimate of agency cost. To estimate the co-movement of these variables, we use the Kalman filter, which is an algorithm for estimating unobserved or state variables from a Gaussian linear state space model.\(^8\)

Since we deal with a relatively small sample in this study, and since we estimate a number of parameters and extract the unobservable series of agency cost from the state space model, using new Bayesian approach, such as the Markov Chain Monte Carlo (MCMC) simulation techniques, would be appropriate. This is because in a Bayesian framework the parameters and state variables of the agency cost model are all treated as unobservable random variables to be inferred from observable data and they are based on their posterior distributions as described in the next section, while the classical approach is based on asymptotic theory that requires large sample. In new Bayesian approach like MCMC, the estimation of such random variables is implemented by generating the sample from the posterior distributions by computers. Inference based on large number of samples drawn from the distribution would complement originally small sample of observations. We use the Gibbs sampler, one of the MCMC techniques, to obtain the posterior marginal distributions of the parameters and state variables, ultimate goal of our estimation, from posterior conditional distributions as explained in the next section.\(^9\)

\(^8\) See Hamilton (1994) for a detailed explanation of the algorithm of the Kalman filter.

\(^9\) See Casella and George (1992) for a comprehensive survey of the use of the Gibbs sampler.
Bayesian inference via the Gibbs sampler

In Bayesian inference, estimates of the means and standard deviations of parameters are derived from their marginal posterior distributions, which consist of their prior distributions and sample likelihoods as follows.

\[ p(\theta | Y) = \frac{p(\theta) L(Y | \theta)}{p(Y)} \]

where \( p(\theta | Y) \): posterior density of parameters \( \theta \),
\( Y \): sampled data,
\( p(\theta) \): prior density of \( \theta \),
\( L(Y | \theta) \): likelihood function,
\( p(Y) \): marginal density of \( Y \).

We execute the Gibbs sampler to find the marginal posterior distributions from the given conditional posterior distributions. The execution procedure for Gibbs sampler in a state space model with computational efficiency and faster convergence is the multi-move Gibbs sampler proposed by Carter and Kohn (1994). The multi-move Gibbs sampler draws all of state variables (or unobservable variables) corresponding to ACt in this study, with only one step. Following Carter and Kohn (1994) and Kim and Nelson (1999), the estimation procedure can be divided into five steps. In the following steps we denote the \( j \)-th iteration by superscript \( (j) \).

**Step 1.** Generate the unobservable variable \( AC_t^{(j)} \) for \( t = 1, 2, 3, \ldots, T \), using the state equation (2.9) in terms of level variables and the observation equation (2.10). This step is further divided into three parts (a), (b) and (c) as below.

(a) The observation equation (2.10) and the state equation (2.9) can be rewritten as equations (3.1) and (3.2), respectively.

\begin{align*}
(3.1) & 
   y_t = H z_t + Ax_t + \varepsilon_t \\
(3.2) & 
   z_t = F z_{t-1} + Gw_t + \nu_t
\end{align*}

where \( y_t = (I_t/K_t, \Delta B_t/p_L^t K_t', spread_t)' \), \( z_t = (AC_t, AC_{t-1}, AC_{t-2}, AC_{t-3})' \), \( x_t = (1, q_t)' \).

\[ w_t = \begin{bmatrix}
\Delta \left( \frac{p_L^t L_{t-1}}{p_L^t K_{t-1} + p_L^t L_{t-1}} \right), & \Delta \left( \frac{p_L^{t-1} L_{t-2}}{p_L^{t-1} K_{t-2} + p_L^{t-1} L_{t-2}} \right) \\
\Delta \left( \frac{p_L^{t-2} L_{t-3}}{p_L^{t-2} K_{t-3} + p_L^{t-2} L_{t-3}} \right), & \frac{p_L^{t-1} L_{t-2}}{p_L^{t-1} K_{t-2} + p_L^{t-1} L_{t-2}} - \alpha_L
\end{bmatrix}' \]

\[ H = \begin{bmatrix}
\gamma_I & 0 & 0 & 0 \\
\gamma_B & 0 & 0 & 0 \\
1 & 0 & 0 & 0
\end{bmatrix} \]
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\[
A = \begin{bmatrix}
\alpha_I & \beta_I \\
\alpha_B & \beta_B \\
0 & 0
\end{bmatrix},
\]

\[
F = \begin{bmatrix}
1 + \phi_1 + \phi_2 - \phi_1 & \phi_3 - \phi_2 - \phi_3 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0
\end{bmatrix},
\]

\[
G = \begin{bmatrix}
\theta_1 & \theta_2 & \theta_3 & \varphi_1 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0
\end{bmatrix},
\]

\[
\varepsilon_t = (\varepsilon_{It}, \varepsilon_{Bt}, \varepsilon_{St})', \nu_t = (\varepsilon_{ACt}, 0, 0)', \varepsilon_t \sim iid N(0, R), \nu_t \sim iid N(0, Q),
\]

\[
R = \begin{bmatrix}
\sigma_I^2 & 0 & 0 \\
0 & \sigma_B^2 & 0 \\
0 & 0 & \sigma_S^2
\end{bmatrix},
\]

\[
Q = \begin{bmatrix}
\sigma_{AC}^2 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0
\end{bmatrix},
\]

where the error terms \(\varepsilon_{It}, \varepsilon_{Bt}, \varepsilon_{St}, \varepsilon_{ACt}\) represent the exogenous shocks that are assumed to be independent each other. Their variances are denoted by \(\sigma_I^2, \sigma_B^2, \sigma_S^2, \sigma_{AC}^2\), respectively.

(b) Using the state space model, (3.1) and (3.2), we run Kalman filter. To this end, we implement prediction and updating process from period 1 to period \(T\), iteratively. Prediction process is given by

\[
z_{t|t-1} = Fz_{t-1|t-1} + Gw_t, \quad P_{t|t-1} = FP_{t-1|t-1}F' + Q,
\]

\[
\eta_{t|t-1} = y_t - y_{t|t-1} = y_t - Hz_t - Ax_t, \quad f_{t|t-1} = HP_{t|t-1}H' + R.
\]

Updating process is given by

\[
z_{t|t} = z_{t|t-1} + K\eta_{t|t-1}, \quad P_{t|t} = P_{t|t-1} - K_tHP_{t|t-1},
\]

where subscript \((t \mid t - 1)\) of variable denotes the expected value of variables in period \(t\) conditional in period \(t - 1\),

\(P_t\): covariance matrix of \(z_t\),

\(\eta_t\): prediction error,

\(K_t = P_{t|t-1}H'f_{t|t-1}^{-1}\) is Kalman gain,

The initial values \(z_{0|0}\) and \(P_{0|0}\) are set zero.

(c) Sampling of the unobservable variables \(AC_t^{(j)}\) for \(t = 1, 2, 3, \ldots, T\).

Starting from the last period \(T\), we sample \(z_T\) using \(z_{T|T}\) and \(P_{T|T}\) that are obtained from Kalman filter in the previous part (b). Specifically we generate based on

\[
z_T \mid \Theta, y_T, x_T, w_T \sim N(z_{T|T}, P_{T|T}),
\]
where Θ: all parameters in the state space model (2.9) and (2.10), 
\( N(\cdot) \): the normal distribution.

Then we draw the sample \( z_t \) using the sample \( z_{t+1} \) for the period \( T - 1 \) to 1 in descending sequence. To do so, we calculate \( z_{t|t,z_{t+1}} \) and \( P_{t|t,P_{t+1}} \) in the following equations:

\[
\begin{align*}
  z_{t|t,z_{t+1}} &= z_t + P_t F'(FP_t F' + Q)^{-1}(z_{t+1} - F z_t - G w_t), \\
  P_{t|t,z_{t+1}} &= P_t + P_t F' (FP_t F' + Q)^{-1} F P_t.
\end{align*}
\]

Given two values \( z_{t|Z_{t+1}} \) and \( P_{t|P_{t+1}} \), we generate \( z_t \), based on

\[
  z_t \mid \Theta, y_t, x_t, w_t \sim N(z_{t|t,z_{t+1}}, P_{t|t,P_{t+1}}).
\]

**Step 2.** Generate the coefficients \( \alpha_n^{(j)}, \gamma_n^{(j)} \) and \( \beta_n^{(j)} \) for \( n = I, B, L \) of the observation equation (2.10) and the error correction term of the state equation (2.9).

From the error correction term of equation (2.9), we set the long-term relation as

\[
  AC_t = \alpha_L + \gamma_L \frac{p_L L_{t-1}}{p_L L_{t-1}} + \varepsilon_Lt.
\]

Notice that the error terms \( \varepsilon_{It}, \varepsilon_{Bt}, \varepsilon_{St}, \varepsilon_{Lt} \), are assumed to be independent each other so that the coefficients \( \alpha_n^{(j)}, \gamma_n^{(j)} \) and \( \beta_n^{(j)} \) for \( n = I, B, L \) can be estimated independently from equations (2.6), (2.7) and (3.3) but not from equation (2.10). Given the unobservable variables \( AC_1^{(j)}, \ldots, AC_T^{(j)} \), observed data \( Y(= (y_1, y_2, \ldots, y_T)) \), and the variances of their error terms \( \sigma_n^2 \) for \( n = I, B, S, L \), the coefficients, \( \alpha_n^{(j)}, \gamma_n^{(j)} \) and \( \beta_n^{(j)} \) for \( n = I, B, L \) are drawn based on a truncated normal distribution,

\[
  \{\alpha_n^{(j)}, \gamma_n^{(j)}, \beta_n^{(j)} \mid \sigma_n^2(j-1), Y, AC_1^{(j)} \ldots AC_T^{(j)} \} \sim N(\Gamma_n^{post(j)}, \Sigma_n^{post(j)})1[\{\alpha, \gamma, \beta\}],
\]

for \( n = I, B, L \),

where \( \Gamma_n^{post(j)} \) and \( \Sigma_n^{post(j)} \): the mean and variance of the posterior conditional distribution of the coefficients, \( \alpha_n^{(j)}, \gamma_n^{(j)} \) and \( \beta_n^{(j)} \) that are given by

\[
\begin{align*}
  \Gamma_n^{post(j)} &= (\Sigma_n^{prior-1} + \sigma_n^2(j-1)X_n'X_n)^{-1} \\
  &\quad \times (\Sigma_n^{prior-1})^{\Gamma_n^{prior}} + \sigma_n^2(j-1)X_n'y_n), \\
  \Sigma_n^{post(j)} &= (\Sigma_n^{prior-1} + \sigma_n^2(j-1)X_n'X_n)^{-1},
\end{align*}
\]
\( X_n \) and \( y_n \) for \( n = I, B, L \): the matrix of the explanatory variables and the vector of the dependent variable of the equations (2.6), (2.7) and (3.3), respectively.

\( \Gamma_n^{\text{prior}} \) and \( \Sigma_n^{\text{prior}} \): mean and variance of the prior distribution given by

\[
\{\alpha_n, \gamma_n, \beta_n\} \sim N(\Gamma_n^{\text{prior}}, \Sigma_n^{\text{prior}})1[s(\alpha, \gamma, \beta)].
\]

\( \sigma_n^{2(j-1)} \): the \((j-1)\)-th draw of the variance of the error term for \( n = I, B, L \).

\( 1[s(\alpha, \gamma, \beta)] \): the indicator function to accept a draw as the sample if the coefficient of autocorrelation of \( \varepsilon_{nt}, \rho_n \), is less than 0.9 for \( n = I, B, L \), otherwise reject a draw.\(^{10}\) This indicator function truncates the normal distribution.

**Step 3.** Generate the coefficients \( \phi_{1}^{(j)}, \phi_{2}^{(j)}, \phi_{3}^{(j)}, \theta_{1}^{(j)}, \theta_{2}^{(j)}, \theta_{3}^{(j)}, \varphi_{1}^{(j)} \) in the state equation (2.9).

Given the unobservable variables \( AC_1^{(j)}, \ldots, AC_T^{(j)} \), observed data \( Y \), and the other parameters \( \sigma_{AC_1}^{2(j-1)} \) and \( \alpha_n^{(j)}, \gamma_n^{(j)} \) and \( \beta_n^{(j)} \) for \( n = I, B, L, S \), the coefficients \( \phi_{1}^{(j)}, \phi_{2}^{(j)}, \phi_{3}^{(j)}, \theta_{1}^{(j)}, \theta_{2}^{(j)}, \theta_{3}^{(j)}, \varphi_{1}^{(j)} \) are drawn from a truncated normal distribution,

\[
\{\phi_{1}^{(j)}, \phi_{2}^{(j)}, \phi_{3}^{(j)}, \theta_{1}^{(j)}, \theta_{2}^{(j)}, \theta_{3}^{(j)}, \varphi_{1}^{(j)} \mid \sigma_{AC_1}^{2(j-1)}, \sigma_n^{2(j-1)}, \alpha_n^{(j)}, \gamma_n^{(j)}, \beta_n^{(j)}, Y, AC_1^{(j)} \cdots AC_T^{(j)}\}
\]

\[
\sim N(\Phi^{\text{post}(j)}, \Sigma_{AC_1}^{\text{post}(j)})1[s(\phi)].
\]

where \( \Phi^{\text{post}(j)} \) and \( \Sigma_{AC_1}^{\text{post}(j)} \): the mean and variance of the posterior conditional distribution of the coefficients, \( \phi_{1}^{(j)}, \phi_{2}^{(j)}, \phi_{3}^{(j)}, \theta_{1}^{(j)}, \theta_{2}^{(j)}, \theta_{3}^{(j)}, \varphi_{1}^{(j)} \) that are given by

\[
\Phi^{\text{post}(j)} = (\Sigma_{AC_1}^{-1} + \sigma_{AC_1}^{-2(j-1)}Z'Z)^{-1} \\
\times (\Sigma_{AC_1}^{\text{prior}}^{-1} \Phi^{\text{prior}} + \sigma_{AC_1}^{-2(j-1)}Z'z),
\]

\[
\Sigma_{AC_1}^{\text{post}(j)} = (\Sigma_{AC_1}^{-1} + \sigma_{AC_1}^{-2(j-1)}Z'Z)^{-1},
\]

\( Z \) and \( z \): the matrix of the explanatory variables,

\[
\Delta AC_{t-1}, \Delta AC_{t-2}, \Delta AC_{t-3}, \Delta \left(\frac{p_{L-1}^{L_{t-1}} - p_{L-2}^{L_{t-2}}}{p_{L-1}^{L_{t-1}} + p_{L-2}^{L_{t-2}}} \right), \\
\Delta \left(\frac{p_{L-1}^{L_{t-1}} L_{t-2}}{p_{L-1}^{L_{t-1}} + p_{L-2}^{L_{t-2}}} \right), \Delta \left(\frac{p_{L-1}^{L_{t-1}} L_{t-2}}{p_{L-1}^{L_{t-1}} + p_{L-2}^{L_{t-2}}} \right),
\]

including \( \varepsilon_{Lt} (= AC_t - \alpha_L - \gamma_L \frac{p_{L-1}^{L_{t-1}}}{p_{L-1}^{L_{t-1}} + p_{L-2}^{L_{t-2}}} ) \) derived from

Step 2, and the vector of the dependent variable, \( \Delta AC_t \), of the state equation (2.9), respectively.

\(^{10}\) Here, we introduce parameters \( \rho_n \) for \( n = I, B, L \) which are the coefficients of AR(1) representation of the error terms, \( \varepsilon_{nt} = \rho_n \varepsilon_{nt-1} + u_{nt} \) in order to guarantee the stationarity of the error terms and the stability of long-term relationship of equations (2.6), (2.7), and (3.3).
Prior and Prior: the mean and variance of the prior distribution given by
\[
\{\phi_1, \phi_2, \phi_3, \theta_1, \theta_2, \theta_3, \varphi_1\} \sim N(\Phi_{prior}, \Sigma_{AC}^{prior})1[s(\phi)].
\]
\[\sigma_{AC}^{2(j-1)}: \text{the } (j - 1)-\text{th draw of the variance of the error term } \varepsilon_{ACt}.
\]
\[1[s(\phi)]: \text{the indicator function to accept a draw as the sample if the roots of } \phi(L) = 0 \text{ lie outside the unit circle, otherwise reject a draw.}^{11

Step 4. Generate the variances of the error terms, \(\sigma_n^{2(j)}\) for \(n = I, B, S\) in the observation equation (2.10).

The variances \(\sigma_n^{2(j)}\) for \(n = I, B, S\) are assumed to be independent each other so that they can be separately estimated. The variances, \(\sigma_n^{2(j)}\) for \(n = I, B, S\) of the observation equation (2.10) are drawn from the inverted gamma distribution conditional on \(AC_1^{(j)}, \ldots, AC_T^{(j)}\), observed data \(Y\) and the other parameters \(\alpha_n^{(j)}, \gamma_n^{(j)}, \beta_n^{(j)}\), i.e.,
\[
\{\sigma_n^{2(j)} \mid \alpha_n^{(j)}, \gamma_n^{(j)}, \beta_n^{(j)}, Y, AC_1^{(j)}, \ldots, AC_T^{(j)}\} \sim IG\left(\frac{1}{2}\nu_n^{post}, \frac{1}{2}\sigma_n^{post}\right),
\]
for \(n = I, B, S\)

where \(\nu_n^{post}\) and \(\sigma_n^{post}\): the posterior degree of freedom and the posterior variance of the inverted gamma distribution \(IG(\ )\) that are given by
\[
\nu_n^{post} = \nu_n^{prior} + N, \\
\sigma_n^{post} = \sigma_n^{prior} + (y_n - X_n\Gamma_n^{(j)})'(y_n - X_n\Gamma_n^{(j)}),
\]
\(N\): the number of observation.
\(X_n\) and \(y_n\) for \(n = I, B, S\): the matrix of the explanatory variables and the vector of the dependent variable of the equations (2.6), (2.7) and (2.8), respectively.
\(\Gamma_n^{(j)}\): the \(j\)-th draw of vector of coefficients \(\alpha_n^{(j)}, \gamma_n^{(j)}, \beta_n^{(j)}\).
\(\nu_n^{prior}\) and \(\sigma_n^{prior}\): the prior degree of freedom and the prior variance of the inverted gamma distribution given by
\[
\{\sigma_n^2\} \sim IG\left(\frac{1}{2}\nu_n^{prior}, \frac{1}{2}\sigma_n^{prior}\right), \text{ for } n = I, B, S.
\]

11 The indicator function is adopted to guarantee the stationarity of the state equation.
**Step 5.** Generate the variance of the error term, $\sigma_{AC}^2(j)$ in the state equation (2.9).

The variance ($\sigma_{AC}^2(j)$) of the state equation (2.9) is drawn from the inverted gamma distribution conditional on $AC_{1}^{(j)}, \ldots, AC_{T}^{(j)}$, observed data $Y$ and other parameters, i.e.,

$$\{\sigma_{AC}^2(j) | \alpha_n, \gamma_n, \beta_n, \phi_1^{(j)}, \phi_2^{(j)}, \phi_3^{(j)}, \theta_1^{(j)}, \theta_2^{(j)}, \theta_3^{(j)}, \varphi_1^{(j)}, Y, AC_{1}^{(j)}, \ldots, AC_{T}^{(j)} \}$$

$$\sim IG \left( \frac{1}{2} \nu_{AC}^{post}, \frac{1}{2} \sigma_{AC}^{post} \right).$$

where $\nu_{AC}^{post}$ and $\sigma_{AC}^{post}$: the posterior degree of freedom and the posterior variance of the inverted gamma distribution $IG(\ )$ that are given by

$$\nu_{AC}^{post} = \nu_{AC}^{prior} + N,$$

$$\sigma_{AC}^{post} = \sigma_{AC}^{prior} + (z - Z\Phi^{(j)})' (z - Z\Phi^{(j)}),$$

$N$: the number of observation.
$Z$ and $z$: the matrix of the explanatory variables
$\Delta AC_{t-1}, \Delta AC_{t-2}, \Delta AC_{t-3}, \Delta \left( \frac{p_{L}^{t}L_{t-1}}{p_{L}^{t}K_{t-1}+p_{L}^{t}L_{t-1}} \right),$ $\Delta \left( \frac{p_{L}^{t-1}L_{t-2}}{p_{L}^{t-1}K_{t-2}+p_{L}^{t-1}L_{t-2}} \right), \Delta \left( \frac{p_{L}^{t-2}L_{t-3}}{p_{L}^{t-2}K_{t-3}+p_{L}^{t-2}L_{t-3}} \right),$ including $\varepsilon_{LT}(= AC_{t} - \alpha L - \gamma L \frac{p_{L}^{t}L_{t-1}}{p_{L}^{t}K_{t-1}+p_{L}^{t}L_{t-1}})$ derived from Step 2 and the vector of the dependent variable, $\Delta AC_{t}$, of the state equation (2.9), respectively.

$\Phi^{(j)}$: the $j$-th draw of the vector of coefficients, $\phi_1^{(j)}, \phi_2^{(j)}, \phi_3^{(j)}, \theta_1^{(j)}, \theta_2^{(j)}, \theta_3^{(j)}, \varphi_1^{(j)}$.

$\nu_{AC}^{prior}$ and $\sigma_{AC}^{prior}$: the prior degree of freedom and the prior variance of the inverted gamma distribution given by

$$\{\sigma_{AC}^2 \} \sim IG \left( \frac{1}{2} \nu_{AC}^{prior}, \frac{1}{2} \sigma_{AC}^{prior} \right).$$

As a result of the iteration of these five steps, the conditional distribution of each parameter converges to the invariant marginal distribution, which is independent of the other parameters. The sample extracted from converged distribution shapes the posterior marginal distribution, and the parameter estimators are obtained from this sample. We use natural conjugate priors for all parameters. In this study, the first 1000 iterations of Gibbs sampler are discarded, to allow for convergence, and the next 5000 iterations are taken as our sample. A sequence of iterative steps converged after 1000 iterations, as indicated by a diagnostic proposed by Geweke (1992). Then we derive the means, standard deviations, medians and the 95% posterior probability bands (2.5%-th and 97.5%-th values of the sample) from the sample.
4. Data construction and descriptive analysis

We use quarterly data reported in the Quarterly Report of Financial Statements of Incorporated Business (QRFS), of the Ministry of Finance. The QRFS produces quarterly reports for manufacturing and non-manufacturing firms on major items in their balance sheets, and profit and loss statements, disaggregated by firm size. The virtue of this data source is in its decomposition of tangible fixed assets into components; as a result, we can construct a time-series for land stocks, which play an important role in our analysis. Our sample period begins in the first quarter of 1975 and continues through the first quarter of 1998, covering both the long booms and the severe recessions that occurred in the 1980s and 1990s.

We categorize firm size with respect to capital. Firms are partitioned into three groups according to their levels of equity capital: small, medium, and large firms. Small firms have less than 100 million yen in capital; medium firms have between 100 and 1,000 million yen in capital; and large firms have over 1,000 million yen in capital.

Data construction

The discontinuity of the time-series is one major problem with the QRFS. This arises from the complete renewal of the corporations in the sample that occurs every April, after which the sample is fixed for one year. It is necessary to adjust for this discontinuity in a consistent manner. Fortunately, the survey contains the values of main balance sheet items for the beginning and end of each period covered in the sample. This implies that we can compute the time-series of flow variables in a consistent way. Once the flow-series is computed, the perpetual inventory method can be applied to the construction of the stock series. See Ogawa (2000b) for a detailed description of the procedure that we use to construct a consistent data series.\(^\text{12}\)

Descriptive analysis of the major variables in firm balance sheets

Let us first describe the characteristics of the major variables used in our analysis. Tables 1 to 4 present the sample means of the investment rate, the rate of change in total borrowing, the rate of change in land stocks at market prices, and marginal \(q\), respectively, for the whole sample period, as well as for three subperiods. These subperiods include the period from the second quarter of 1975 to the fourth quarter of 1986, the period from the first quarter of 1987 to the first quarter of 1991, and the period from the second quarter of 1991 to the first quarter of 1998. The second subperiod corresponds to the occurrence of the long booms (Heisei Keiki) in the late 1980s, when land prices exhibited an upward trend. During the third subperiod, land prices plummeted, plunging the Japanese economy into stagnancy.

\(^{12}\) The interest rate spread is defined as the difference between the borrowing interest rate, which is interest payments and discounts paid divided by the short-term borrowings, long-term borrowings, bonds outstanding, and bills receivable discounted outstanding, minus the yield rate on financing bills reported in The Financial and Economic Statistics (The Bank of Japan).
Table 1. Descriptive statistics of fixed investment rate by firm size.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Manufacturing Industries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small firms</td>
<td>4.10</td>
<td>4.47</td>
<td>2.69</td>
<td>3.74</td>
</tr>
<tr>
<td>Medium firms</td>
<td>3.72</td>
<td>4.03</td>
<td>2.69</td>
<td>3.47</td>
</tr>
<tr>
<td>Large firms</td>
<td>3.58</td>
<td>3.90</td>
<td>3.00</td>
<td>3.46</td>
</tr>
<tr>
<td><strong>(%)</strong></td>
<td>(0.98)</td>
<td>(0.74)</td>
<td>(0.63)</td>
<td></td>
</tr>
<tr>
<td><strong>Non-manufacturing Industries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small firms</td>
<td>4.19</td>
<td>5.40</td>
<td>3.19</td>
<td>4.11</td>
</tr>
<tr>
<td>Medium firms</td>
<td>4.24</td>
<td>4.38</td>
<td>3.29</td>
<td>3.98</td>
</tr>
<tr>
<td>Large firms</td>
<td>4.02</td>
<td>4.78</td>
<td>3.77</td>
<td>4.09</td>
</tr>
<tr>
<td><strong>(%)</strong></td>
<td>(0.99)</td>
<td>(0.69)</td>
<td>(0.58)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: The values in parentheses are standard deviation.

Table 2. Descriptive statistics of the rate of change in total borrowing by firm size.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Manufacturing Industries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small firms</td>
<td>1.23</td>
<td>2.27</td>
<td>0.31</td>
<td>1.14</td>
</tr>
<tr>
<td>Medium firms</td>
<td>0.42</td>
<td>1.19</td>
<td>0.26</td>
<td>0.51</td>
</tr>
<tr>
<td>Large firms</td>
<td>−0.23</td>
<td>−0.58</td>
<td>0.07</td>
<td>−0.21</td>
</tr>
<tr>
<td><strong>(%)</strong></td>
<td>(1.37)</td>
<td>(0.91)</td>
<td>(1.39)</td>
<td></td>
</tr>
<tr>
<td><strong>Non-manufacturing Industries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small firms</td>
<td>1.92</td>
<td>4.02</td>
<td>0.49</td>
<td>1.87</td>
</tr>
<tr>
<td>Medium firms</td>
<td>1.49</td>
<td>2.75</td>
<td>0.33</td>
<td>1.37</td>
</tr>
<tr>
<td>Large firms</td>
<td>0.89</td>
<td>2.77</td>
<td>−0.15</td>
<td>0.92</td>
</tr>
<tr>
<td><strong>(%)</strong></td>
<td>(1.61)</td>
<td>(1.39)</td>
<td>(1.48)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: The values in parentheses are standard deviation.
Table 3. Descriptive statistics of the rate of change in land stock at market price by firm size.

<table>
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<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Manufacturing Industries</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Small firms</td>
<td>1.14</td>
<td>4.56</td>
<td>−2.45</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2.97)</td>
</tr>
<tr>
<td>Medium firms</td>
<td>0.97</td>
<td>4.12</td>
<td>−2.50</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2.85)</td>
</tr>
<tr>
<td>Large firms</td>
<td>1.05</td>
<td>4.22</td>
<td>−2.47</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2.86)</td>
</tr>
<tr>
<td>Non-manufacturing Industries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small firms</td>
<td>1.23</td>
<td>4.67</td>
<td>−2.14</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2.89)</td>
</tr>
<tr>
<td>Medium firms</td>
<td>1.03</td>
<td>4.40</td>
<td>−2.29</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2.86)</td>
</tr>
<tr>
<td>Large firms</td>
<td>1.03</td>
<td>4.44</td>
<td>−2.10</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2.81)</td>
</tr>
</tbody>
</table>

Notes: The values in parentheses are standard deviation.

Table 4. Descriptive statistics of marginal $q$ by firm size.

<table>
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<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Manufacturing Industries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small firms</td>
<td>1.66</td>
<td>1.92</td>
<td>0.93</td>
<td>1.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.47)</td>
</tr>
<tr>
<td>Medium firms</td>
<td>1.09</td>
<td>1.06</td>
<td>0.64</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.28)</td>
</tr>
<tr>
<td>Large firms</td>
<td>0.96</td>
<td>1.06</td>
<td>0.75</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.22)</td>
</tr>
<tr>
<td>Non-manufacturing Industries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small firms</td>
<td>1.54</td>
<td>1.94</td>
<td>1.16</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.36)</td>
</tr>
<tr>
<td>Medium firms</td>
<td>0.91</td>
<td>0.98</td>
<td>0.48</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.27)</td>
</tr>
<tr>
<td>Large firms</td>
<td>0.80</td>
<td>0.93</td>
<td>0.57</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.17)</td>
</tr>
</tbody>
</table>

Notes: The values in parentheses are standard deviation.
The sample average of the gross investment rate, given in Table 1, was highest in the second subperiod and lowest in the third subperiod, for manufacturing, as well as for non-manufacturing, industries. The volatility of fixed investment was highest among small firms, for both manufacturing and non-manufacturing industries.

The average rate of change in total borrowing, given in Table 2, was highest in the second subperiod, with the exception of that for large firms in manufacturing industries. It was highest for small firms in non-manufacturing industries and amounted to four percent per quarter, or 16% per annum. By contrast, the average rate of change was negative for large firms in manufacturing industries for the entire sample period, with the exception of the third subperiod. This may reflect a shift in financing for large manufacturing firms, from bank loans to equity or bonds.

Table 3 gives the sample average of the rate of change in land stocks at market prices. There is no discernible difference across firm groups, the reason for which is as follows. The change in land stock can be broken down into two factors: the increment or decrement of a given firm’s land stock in real terms and the change in land prices common to all firms. Similar movements in the change of land stock across firms of varying size suggest that the latter component dominated. The average rate of change in land stock was highest in the second subperiod and lowest in the third subperiod.

Finally, Table 4 gives the sample average for marginal $q$. Marginal $q$ is constructed by estimating a VAR model of the profit rate and the discount rate, as was originally done by Abel and Blanchard (1986). It should be noted that the marginal $q$ of small firms was much larger than that of medium or large firms.

5. Estimates of agency cost and their association with firm activities

Three observation equations relating agency cost to investment, borrowing, and the interest rate spread, along with the transition equation for agency cost, are estimated in a Bayesian context by means of the Kalman filter for three firm groups (small, medium and large firms) for both manufacturing and non-manufacturing industries. Overall, the estimation results support the theoretical supposition that agency cost is especially important for small firms that are likely to be constrained by the capital market. Details of the estimation results are given in Tables A-1 to A-6 in the Appendix.

The response of investment to agency cost ($\gamma_I$) is negative and significant, in the sense that the 95% “confidence interval” does not include zero, irrespective of firm size and industry. The smaller the firms were in size, the larger in absolute value were the mean responses of investment to agency cost. In other words, the investment of small firms was more sensitive to agency cost. The response of borrowing to agency cost ($\gamma_B$) was also negative and significant, irrespective of firm size and industry. The response of borrowing was larger in absolute value for smaller firms, which implies that the borrowing of small firms was much more

---

13 See Ogawa (2000a) for details of the procedure used to construct the marginal $q$ series.
Figure 1. Agency costs, spreads and the differences.
Figure 1. (continued).

(d) Non-manufacturing small firms

(e) Non-manufacturing medium firms

(f) Non-manufacturing large firms
Figure 2. Contributions of agency costs and marginal $q$ for investments.
Figure 2. (continued).
Figure 3. Contributions of agency costs and marginal $q$ for borrowing.
(d) Non-manufacturing small firms

(e) Non-manufacturing medium firms

(f) Non-manufacturing large firms

Figure 3. (continued).
affected by agency cost.

The collateral role of land in reducing agency cost, as measured by $\gamma_L$, was successfully estimated for all firm sizes and industries. An increase in the market valuation of land reduced agency cost. We could also have negative estimates for the coefficients of error correction term, $\varphi_1$, irrespective of firm size and industry.

The effect of marginal $q$ on investment ($\beta_I$) was significantly positive for all the firm groups. Marginal $q$ also had a significantly positive effect on borrowing for all the firm groups.

**Estimates of agency cost**

Appendix table gives variance of the measurement error for agency cost by firm size. It should be noted that the variance gets larger as the firm size becomes small. In the manufacturing industry, the mean of the variance is 0.397 and 0.379 for small and medium-sized firms, while it is 0.245 for large firms. In non-manufacturing industry, the mean of the variance is 0.770 for small firms, while it is 0.278 and 0.268 for medium-sized and large firms. Figure 1 shows the estimates of agency cost as well as measurement error from the first quarter of 1976 to the first quarter of 1998, by different firm groups for both manufacturing and non-manufacturing industries. The increasing trend in agency cost in the 1990s, when land prices plummeted, is common to all firms. Furthermore, the agency cost of small firms was significantly larger than the observable interest rate spread in the late 1990s, while there was no discernible difference for large firms. This suggests that the agency cost of small firms has an extra premium that is not well covered by the interest rate spread. It might reflect sharp deterioration of collateralizable net worth of small firms. We also observed a declining trend in agency cost in the late 1980s for all the firm groups except for large firms in manufacturing industries and medium-sized firms in non-manufacturing industries. Note that land prices soared in the late 1980s. Agency cost started to fall at the beginning of the 1980s for large firms in manufacturing industries. The development of financial markets that began in the 1980s lowered agency cost and thus enabled large manufacturing firms to finance their activities cheaply using a variety of funding sources.

**The association of agency cost with firm activities**

We now turn to the relationship of agency cost to firm attributes and activities, such as investment and borrowing. It can be examined by calculating the contribution of change in agency cost in total change in investment and borrowing.\(^{14}\)

The effect of agency cost as well as marginal $q$ on investment is illustrated in Fig. 2. The real line of each figure shows the change in investment rate and the shaded areas corresponding to the contribution of agency cost and marginal $q$. It can be seen that the increase in agency cost that occurred in the 1990s depressed investment to a large extent. Note that this effect is especially great

\(^{14}\) Change in investment, borrowing and agency cost is measured relative to the mean of change in the corresponding variables.
for small and medium-sized firms. We also observe that the fall in agency cost that occurred in the late 1980s was associated with vigorous investment.

The effect of agency cost on borrowing is illustrated in Fig. 3. It is clear that the rise in agency cost that occurred in the 1990s drastically reduced the borrowing of small and medium-sized firms in manufacturing industries and small firms in non-manufacturing industries. Conversely, the fall in agency cost that occurred in the late 1980s led to an increase in the borrowing of small and medium-sized firms. It should be noted that the borrowing of large firms was unaffected by agency cost. In fact agency cost of large firms increased steadily in the 1990s, as is seen from Figure 1, but it did not necessarily lead to decline in borrowings, possibly due to ever-greening of loans by their main banks burdened with non-performing loans.\textsuperscript{15}

6. Concluding remarks

In this study, we attempted to estimate a “state space model” of investment and borrowing in a Bayesian framework and extract the unobservable agency costs faced by Japanese firms of differing size. Our approach appears to be successful, given that we were able to explain the investment and borrowing behavior of firms in the late 1980s and early 1990s by taking into consideration the movement of agency cost. We found that agency cost exhibited a declining trend in the late 1980s, and an increasing trend in the 1990s, irrespective of firm size. We also found that fluctuations in agency cost are affected by the market value of land. Furthermore, we found that the investment and borrowing behavior of small firms was considerably affected by their agency costs in the late 1980s and early 1990s. In particular, our results shed light on the cause of the stagnancy in business activities by small firms in the 1990s. In the 1990s, land prices plummeted, and the collateral value of land fell drastically, which in turn severely affected the investment and borrowing of small firms by raising their agency costs. Our evidence suggests that imperfections in the capital market were important for small firms in Japan.

Acknowledgements

The authors are grateful to Satoru Kanou, Tsutomu Miyagawa, two anonymous referees, the associate editor of this journal and the participants of the Kobe University 2003 Summer Institute, the Japan Economic Association Annual Meeting at Meiji University in October 2003, and Business Cycle Date Meeting at Kitakyusyu in February 2004 for extremely valuable comments and suggestions on an earlier version of the paper. This research was partially supported by Grants-in-Aid for Scientific Research 12124207 and 16330038 of the Ministry of Education. Any remaining errors are the sole responsibility of the authors.

\textsuperscript{15} See Peek and Rosengren (2005) for evidence supporting ever-greening of loans.
### Table A-1. Manufacturing small firms

<table>
<thead>
<tr>
<th>Parameters&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Prior</th>
<th>Posterior distribution</th>
<th>95% bands&lt;sup&gt;d&lt;/sup&gt;</th>
<th>CD&lt;sup&gt;e&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>S.D. &lt;sup&gt;c&lt;/sup&gt;</td>
<td>mean</td>
<td>S.D. &lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>φ&lt;sub&gt;1&lt;/sub&gt;</td>
<td>0.184</td>
<td>0.178</td>
<td>-0.184</td>
<td>0.178</td>
</tr>
<tr>
<td>φ&lt;sub&gt;2&lt;/sub&gt;</td>
<td>-0.068</td>
<td>0.166</td>
<td>-0.068</td>
<td>0.166</td>
</tr>
<tr>
<td>φ&lt;sub&gt;3&lt;/sub&gt;</td>
<td>-0.011</td>
<td>0.161</td>
<td>-0.011</td>
<td>0.161</td>
</tr>
<tr>
<td>θ&lt;sub&gt;1&lt;/sub&gt;</td>
<td>0.068</td>
<td>0.177</td>
<td>0.068</td>
<td>0.177</td>
</tr>
<tr>
<td>θ&lt;sub&gt;2&lt;/sub&gt;</td>
<td>-0.080</td>
<td>0.244</td>
<td>-0.080</td>
<td>0.244</td>
</tr>
<tr>
<td>θ&lt;sub&gt;3&lt;/sub&gt;</td>
<td>-0.068</td>
<td>0.176</td>
<td>-0.068</td>
<td>0.176</td>
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<tr>
<td>φ&lt;sub&gt;1&lt;/sub&gt;</td>
<td>-0.040</td>
<td>0.037</td>
<td>-0.040</td>
<td>0.037</td>
</tr>
<tr>
<td>γ&lt;sub&gt;L&lt;/sub&gt;</td>
<td>-0.915</td>
<td>0.166</td>
<td>-0.915</td>
<td>0.166</td>
</tr>
<tr>
<td>γ&lt;sub&gt;B&lt;/sub&gt;</td>
<td>1.141</td>
<td>0.307</td>
<td>1.141</td>
<td>0.307</td>
</tr>
<tr>
<td>β&lt;sub&gt;1&lt;/sub&gt;</td>
<td>0.120</td>
<td>0.033</td>
<td>0.120</td>
<td>0.033</td>
</tr>
<tr>
<td>β&lt;sub&gt;2&lt;/sub&gt;</td>
<td>1.215</td>
<td>0.210</td>
<td>1.215</td>
<td>0.210</td>
</tr>
<tr>
<td>σ&lt;sup&gt;2&lt;/sup&gt;&lt;sub&gt;f&lt;/sub&gt;</td>
<td>0.219</td>
<td>0.060</td>
<td>0.219</td>
<td>0.060</td>
</tr>
<tr>
<td>σ&lt;sup&gt;2&lt;/sup&gt;&lt;sub&gt;AC&lt;/sub&gt;</td>
<td>0.397</td>
<td>0.078</td>
<td>0.397</td>
<td>0.078</td>
</tr>
</tbody>
</table>

Note:
<sup>a</sup>The first 1000 iterations of Gibbs sampler are discarded to guarantee convergence and the next 5000 iterations are taken as our sample.
<sup>b</sup>See equations (2.6), (2.7), (2.8), and (2.9) for the notations of parameters.
<sup>c</sup>S.D. refers to standard deviation.
<sup>d</sup>95% bands refers to 95% posterior probability bands.
<sup>e</sup>The convergence diagnostic (CD) statistics is derived from the i-th draw of a parameter \(\theta^{(i)}\) in the recorded 5000 draws. The statistics is defined as 
\[
CD = \frac{\theta_A - \theta_B}{\sqrt{\sigma_A^2/n_A + \sigma_B^2/n_B}},
\]
where \(\theta_A = \frac{1}{n_A} \sum_{i=1}^{n_A} \theta^{(i)}\), \(\theta_B = \frac{1}{n_B} \sum_{i=n_A+1}^{n_A+n_B} \theta^{(i)}\), and \(\sqrt{\sigma_A^2/n_A}, \sqrt{\sigma_B^2/n_B}\) are standard deviation of \(\theta_A\), \(\theta_B\). Here we set \(n_A = 1000\) and \(n_B = 2500\). The CD of converged posterior distribution must be asymptotically standard normal distribution. See Geweke (1992).
<sup>f</sup>The prior distributions of variance \(\sigma^2\) are inverted gamma distribution, \(IG(8,6)\). See Bauwens et al. (1999, p. 292).
### Table A-2. Manufacturing medium firms

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Prior mean</th>
<th>S.D.</th>
<th>Posterior Distribution</th>
<th>95% bands</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_1$</td>
<td>0.175</td>
<td>0.155</td>
<td>0.106 (−0.059, 0.183)</td>
<td>−0.089</td>
<td></td>
</tr>
<tr>
<td>$\phi_2$</td>
<td>0.040</td>
<td>0.162</td>
<td>−0.026 (−0.031, 0.286)</td>
<td>−0.193</td>
<td></td>
</tr>
<tr>
<td>$\phi_3$</td>
<td>0.042</td>
<td>0.161</td>
<td>0.041 (−0.268, 0.360)</td>
<td>0.642</td>
<td></td>
</tr>
<tr>
<td>$\theta_1$</td>
<td>0.059</td>
<td>0.172</td>
<td>0.058 (−0.276, 0.393)</td>
<td>−1.484</td>
<td></td>
</tr>
<tr>
<td>$\theta_2$</td>
<td>0.009</td>
<td>0.248</td>
<td>−0.012 (−0.499, 0.481)</td>
<td>1.203</td>
<td></td>
</tr>
<tr>
<td>$\theta_3$</td>
<td>0.136</td>
<td>0.041</td>
<td>−0.134 (−0.484, 0.200)</td>
<td>−0.170</td>
<td></td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>−0.048</td>
<td>0.044</td>
<td>−0.035 (−0.168, −0.091)</td>
<td>0.789</td>
<td></td>
</tr>
<tr>
<td>$\gamma_2$</td>
<td>−1.000</td>
<td>0.178</td>
<td>−0.093 (−1.369, −0.677)</td>
<td>1.450</td>
<td></td>
</tr>
<tr>
<td>$\gamma_3$</td>
<td>−0.046</td>
<td>0.012</td>
<td>−0.045 (−0.069, −0.024)</td>
<td>0.619</td>
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</tr>
<tr>
<td>$\beta_1$</td>
<td>1.862</td>
<td>0.210</td>
<td>1.863 (1.456, 2.284)</td>
<td>2.761</td>
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</tr>
<tr>
<td>$\beta_2$</td>
<td>0.756</td>
<td>0.269</td>
<td>0.759 (0.231, 1.266)</td>
<td>3.063</td>
<td></td>
</tr>
<tr>
<td>$\sigma^2_I^f$</td>
<td>2.256</td>
<td>0.121</td>
<td>0.257 (0.180, 0.367)</td>
<td>2.714</td>
<td></td>
</tr>
<tr>
<td>$\sigma^2_B^f$</td>
<td>2.256</td>
<td>0.121</td>
<td>0.196 (0.118, 0.310)</td>
<td>−0.001</td>
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</tr>
<tr>
<td>$\sigma^2_L^f$</td>
<td>2.256</td>
<td>0.121</td>
<td>0.379 (0.260, 0.540)</td>
<td>−1.053</td>
<td></td>
</tr>
<tr>
<td>$\sigma^2_AC^f$</td>
<td>2.256</td>
<td>0.121</td>
<td>0.097 (0.058, 0.156)</td>
<td>1.174</td>
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</tbody>
</table>

Note: See the Note of Table A-1.

### Table A-3. Manufacturing large firms

<table>
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<tr>
<th>Parameters</th>
<th>Prior mean</th>
<th>S.D.</th>
<th>Posterior Distribution</th>
<th>95% bands</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_1$</td>
<td>−0.206</td>
<td>0.177</td>
<td>−0.207 (−0.555, 0.139)</td>
<td>−0.738</td>
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</tr>
<tr>
<td>$\phi_2$</td>
<td>−0.101</td>
<td>0.172</td>
<td>−0.100 (−0.444, 0.231)</td>
<td>−0.437</td>
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<tr>
<td>$\phi_3$</td>
<td>−0.011</td>
<td>0.166</td>
<td>−0.011 (−0.335, 0.316)</td>
<td>0.324</td>
<td></td>
</tr>
<tr>
<td>$\theta_1$</td>
<td>−0.064</td>
<td>0.228</td>
<td>−0.067 (−0.507, 0.399)</td>
<td>2.120</td>
<td></td>
</tr>
<tr>
<td>$\theta_2$</td>
<td>−0.011</td>
<td>0.330</td>
<td>−0.009 (−0.667, 0.632)</td>
<td>−0.650</td>
<td></td>
</tr>
<tr>
<td>$\theta_3$</td>
<td>−0.037</td>
<td>0.228</td>
<td>−0.039 (−0.487, 0.403)</td>
<td>−0.675</td>
<td></td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>−0.032</td>
<td>0.031</td>
<td>−0.022 (−0.112, −0.001)</td>
<td>−0.387</td>
<td></td>
</tr>
<tr>
<td>$\gamma_2$</td>
<td>−0.267</td>
<td>0.077</td>
<td>−0.266 (−0.419, −0.120)</td>
<td>−0.176</td>
<td></td>
</tr>
<tr>
<td>$\gamma_3$</td>
<td>−0.043</td>
<td>0.041</td>
<td>−0.031 (−0.149, −0.001)</td>
<td>−0.528</td>
<td></td>
</tr>
<tr>
<td>$\gamma_4$</td>
<td>−1.108</td>
<td>0.016</td>
<td>−0.108 (−0.140, −0.077)</td>
<td>−0.109</td>
<td></td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>1.110</td>
<td>0.264</td>
<td>1.110 (0.599, 1.634)</td>
<td>0.602</td>
<td></td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>0.213</td>
<td>0.174</td>
<td>0.169 (0.007, 0.653)</td>
<td>0.983</td>
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<tr>
<td>$\sigma^2_I^f$</td>
<td>2.256</td>
<td>0.121</td>
<td>0.284 (0.204, 0.385)</td>
<td>−1.843</td>
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<tr>
<td>$\sigma^2_B^f$</td>
<td>2.256</td>
<td>0.121</td>
<td>0.659 (0.493, 0.883)</td>
<td>0.327</td>
<td></td>
</tr>
<tr>
<td>$\sigma^2_L^f$</td>
<td>2.256</td>
<td>0.121</td>
<td>0.456 (0.322, 0.732)</td>
<td>0.636</td>
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</tr>
<tr>
<td>$\sigma^2_AC^f$</td>
<td>2.256</td>
<td>0.121</td>
<td>0.245 (0.164, 0.372)</td>
<td>−0.951</td>
<td></td>
</tr>
</tbody>
</table>

Note: See the Note of Table A-1.
Table A-4. Non-manufacturing small firms\(^a\).

<table>
<thead>
<tr>
<th>Parameters (^b)</th>
<th>Prior</th>
<th>Posterior distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\phi_1)</td>
<td>0 1</td>
<td>-0.381 0.189 -0.382 -0.759 -0.012 -2.518</td>
</tr>
<tr>
<td>(\phi_2)</td>
<td>0 1</td>
<td>-0.164 0.182 -0.167 -0.527 0.195 -1.136</td>
</tr>
<tr>
<td>(\phi_3)</td>
<td>0 1</td>
<td>-0.085 0.173 -0.086 -0.417 0.253 -0.435</td>
</tr>
<tr>
<td>(\theta_1)</td>
<td>0 1</td>
<td>0.037 0.263 0.038 -0.470 0.540 -0.901</td>
</tr>
<tr>
<td>(\theta_2)</td>
<td>0 1</td>
<td>-0.142 0.306 -0.143 -0.749 0.459 1.389</td>
</tr>
<tr>
<td>(\theta_3)</td>
<td>0 1</td>
<td>0.025 0.261 0.027 -0.486 0.533 -1.836</td>
</tr>
<tr>
<td>(\varphi_1)</td>
<td>0 1</td>
<td>-0.054 0.055 -0.037 -0.200 -0.012 0.470</td>
</tr>
<tr>
<td>(\gamma_1)</td>
<td>0 1</td>
<td>-0.712 0.150 -0.706 -1.035 -0.439 -0.756</td>
</tr>
<tr>
<td>(\gamma_B)</td>
<td>0 1</td>
<td>-3.751 0.535 -3.744 -4.833 0.195 -1.136</td>
</tr>
<tr>
<td>(\gamma_2)</td>
<td>0 1</td>
<td>-0.822 0.017 -0.811 -1.117 -0.049 -0.664</td>
</tr>
<tr>
<td>(\beta_1)</td>
<td>0 1</td>
<td>1.533 0.230 1.660 (1.180 2.080) -0.034</td>
</tr>
<tr>
<td>(\beta_B)</td>
<td>0 1</td>
<td>2.357 0.736 2.362 (0.880 3.785) 0.006</td>
</tr>
<tr>
<td>(\sigma^2_{\text{I}})</td>
<td>2 2</td>
<td>0.303 0.051 0.298 (0.216 0.415) -1.659</td>
</tr>
<tr>
<td>(\sigma^2_{\text{B}})</td>
<td>2 2</td>
<td>2.076 0.773 1.971 (0.883 3.895) -0.270</td>
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<tr>
<td>(\sigma^2_{\text{L}})</td>
<td>2 2</td>
<td>0.300 0.068 0.291 (0.190 0.453) 0.693</td>
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<tr>
<td>(\sigma^2_{\text{S}})</td>
<td>2 2</td>
<td>0.770 0.159 0.750 (0.505 1.114) -0.033</td>
</tr>
<tr>
<td>(\sigma^2_{\text{AC}})</td>
<td>2 2</td>
<td>0.292 0.073 0.282 (0.183 0.467) -0.030</td>
</tr>
</tbody>
</table>

Note: See the Note of Table A-1.

Table A-5. Non-manufacturing medium firms\(^a\).

<table>
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<tr>
<th>Parameters (^b)</th>
<th>Prior</th>
<th>Posterior distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\phi_1)</td>
<td>0 1</td>
<td>-0.241 0.178 -0.243 -0.588 0.115 0.131</td>
</tr>
<tr>
<td>(\phi_2)</td>
<td>0 1</td>
<td>-0.086 0.171 -0.089 -0.412 0.254 1.015</td>
</tr>
<tr>
<td>(\phi_3)</td>
<td>0 1</td>
<td>-0.040 0.165 -0.038 -0.360 0.287 1.248</td>
</tr>
<tr>
<td>(\theta_1)</td>
<td>0 1</td>
<td>-0.050 0.199 -0.049 -0.434 0.330 -1.275</td>
</tr>
<tr>
<td>(\theta_2)</td>
<td>0 1</td>
<td>-0.007 0.267 -0.008 -0.543 0.516 0.727</td>
</tr>
<tr>
<td>(\theta_3)</td>
<td>0 1</td>
<td>0.042 0.195 0.041 -0.338 0.430 0.161</td>
</tr>
<tr>
<td>(\varphi_1)</td>
<td>0 1</td>
<td>-0.037 0.032 -0.028 -0.120 -0.001 -1.342</td>
</tr>
<tr>
<td>(\gamma_1)</td>
<td>0 1</td>
<td>-0.494 0.079 -0.490 -0.660 -0.348 -0.971</td>
</tr>
<tr>
<td>(\gamma_B)</td>
<td>0 1</td>
<td>-1.844 0.325 -1.834 -2.513 -1.244 -2.062</td>
</tr>
<tr>
<td>(\gamma_2)</td>
<td>0 1</td>
<td>-0.014 0.011 -0.013 -0.039 -0.001 -0.950</td>
</tr>
<tr>
<td>(\beta_1)</td>
<td>0 1</td>
<td>1.771 0.170 1.771 (1.428 2.093) -1.960</td>
</tr>
<tr>
<td>(\beta_B)</td>
<td>0 1</td>
<td>3.453 0.558 3.465 (2.321 4.511) -1.743</td>
</tr>
<tr>
<td>(\sigma^2_{\text{I}})</td>
<td>2 2</td>
<td>0.124 0.022 0.122 (0.088 0.174) -1.296</td>
</tr>
<tr>
<td>(\sigma^2_{\text{B}})</td>
<td>2 2</td>
<td>1.765 0.379 1.727 (1.113 2.590) -1.521</td>
</tr>
<tr>
<td>(\sigma^2_{\text{L}})</td>
<td>2 2</td>
<td>0.418 0.091 0.407 (0.271 0.621) -0.690</td>
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<tr>
<td>(\sigma^2_{\text{S}})</td>
<td>2 2</td>
<td>0.278 0.060 0.270 (0.185 0.416) 0.877</td>
</tr>
<tr>
<td>(\sigma^2_{\text{AC}})</td>
<td>2 2</td>
<td>0.121 0.035 0.115 (0.070 0.202) -0.003</td>
</tr>
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</table>

Note: See the Note of Table A-1.
Table A-6. Non-manufacturing large firms.

<table>
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<tr>
<th>Parameters&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Prior mean S.D.&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Posterior distribution mean S.D.&lt;sup&gt;c&lt;/sup&gt;</th>
<th>median</th>
<th>95% bands&lt;sup&gt;d&lt;/sup&gt;</th>
<th>CD&lt;sup&gt;e&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>φ₁</td>
<td>0 1</td>
<td>-0.169 0.179 -0.170 (-0.517 0.181)</td>
<td>0.158</td>
<td></td>
<td></td>
</tr>
<tr>
<td>φ₂</td>
<td>0 1</td>
<td>-0.083 0.171 -0.082 (-0.414 0.260)</td>
<td>-2.258</td>
<td></td>
<td></td>
</tr>
<tr>
<td>φ₃</td>
<td>0 1</td>
<td>-0.013 0.163 -0.013 (-0.329 0.303)</td>
<td>-0.622</td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ₁</td>
<td>0 1</td>
<td>0.001 0.190 0.002 (-0.377 0.374)</td>
<td>0.398</td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ₂</td>
<td>0 1</td>
<td>-0.093 0.241 -0.094 (-0.575 0.400)</td>
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<tr>
<td>θ₃</td>
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<td>-0.046 0.196 -0.047 (-0.445 0.349)</td>
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<tr>
<td>φ₁</td>
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<td>-0.039 0.037 -0.027 (-0.141 -0.001)</td>
<td>0.570</td>
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<tr>
<td>γ₁</td>
<td>0 1</td>
<td>-0.322 0.103 -0.315 (-0.552 -0.142)</td>
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<td></td>
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<tr>
<td>γ₂</td>
<td>0 1</td>
<td>-0.134 0.120 -0.101 (-0.443 -0.004)</td>
<td>-1.682</td>
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<td></td>
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<tr>
<td>γ₃</td>
<td>0 1</td>
<td>-0.081 0.014 -0.081 (-0.109 -0.053)</td>
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<tr>
<td>β₁</td>
<td>0 1</td>
<td>1.791 0.324 1.795 (1.121 2.407)</td>
<td>-1.810</td>
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<tr>
<td>β₂</td>
<td>0 1</td>
<td>3.924 0.624 3.934 (2.629 5.099)</td>
<td>-0.686</td>
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<td></td>
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<tr>
<td>σ&lt;sup&gt;2&lt;/sup&gt;₂&lt;sub&gt;f&lt;/sub&gt;</td>
<td>2 2</td>
<td>0.152 0.029 0.150 (0.097 0.214)</td>
<td>-1.812</td>
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<tr>
<td>σ&lt;sup&gt;2&lt;/sup&gt;₂&lt;sub&gt;f&lt;/sub&gt;</td>
<td>2 2</td>
<td>1.097 0.181 1.075 (0.795 1.512)</td>
<td>0.120</td>
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<tr>
<td>σ&lt;sup&gt;2&lt;/sup&gt;₂&lt;sub&gt;f&lt;/sub&gt;</td>
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<td>0.311 0.083 0.304 (0.168 0.492)</td>
<td>-1.019</td>
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<tr>
<td>σ&lt;sup&gt;2&lt;/sup&gt;₂&lt;sub&gt;f&lt;/sub&gt;</td>
<td>2 2</td>
<td>0.268 0.070 0.256 (0.168 0.442)</td>
<td>1.317</td>
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<tr>
<td>σ&lt;sup&gt;2&lt;/sup&gt;₂&lt;sub&gt;f&lt;/sub&gt;</td>
<td>2 2</td>
<td>0.140 0.043 0.133 (0.077 0.244)</td>
<td>-0.259</td>
<td></td>
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</table>

Note: See the Note of Table A-1.

REFERENCES


