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Working Paper/Document de travail
2007-17

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Bank of Canada Working Paper 2007-17

March 2007

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ISSN 1701-9397

Acknowledgements

This is taken from one of the chapters of my PhD thesis at LSE. I thank Kosuke Aoki, Charles Goodhart and Nobuhiro Kiyotaki for their helpful advice, and Ian Christensen, Jenny Corbett, Césaire Meh, Alex Michaelides, Ryuzo Miyao, Miguel Molico, Rachel Ngai, Kalin Nikolov and Alexander Ueberfeldt for their reading the manuscript and their insightful comments. All the errors are my own.

Abstract

This paper analyzes endogenous fluctuations in total factor productivity (TFP) in a dynamic general equilibrium model with heterogeneous agents, and illustrates the interaction of credit market frictions, asset prices, the entry and exit of firms, and fluctuations in TFP in response to firm-level productivity and aggregate credit-market shocks. I also analyze the effect of bankruptcy and foreclosure laws on fluctuations in TFP through their effect on credit market frictions. Implications of the model are consistent with the features of the stagnation in Japan in the 1990s.

JEL classification: D24, E44, G33
Bank classification: Financial stability; Productivity

Résumé

L'auteur analyse les mouvements endogènes de la productivité totale des facteurs (PTF) au moyen d'un modèle d'équilibre général dynamique mettant en présence des agents hétérogènes. Il illustre les interactions qui existent entre les frictions sur le marché du crédit, les prix des actifs, la création et la disparition d'entreprises et les fluctuations de la PTF face aux variations de la productivité intra-entreprise et aux chocs survenant sur le marché du crédit. Il examine aussi comment les lois en matière de faillite et de saisie immobilière font fluctuer la PTF par les frictions qu'elles induisent sur le marché du crédit. Les résultats du modèle cadrent avec les caractéristiques de la période de stagnation que le Japon a traversée dans les années 1990.

Classification JEL : D24, E44, G33
Classification de la Banque : Stabilité financière; Productivité

1 Introduction

Total factor productivity (TFP) is one of the main factors that drive aggregate fluctuations in the economy. A natural question that arises is why TFP fluctuates. Empirical research using longitudinal micro-level data finds that large and persistent productivity differences exist across establishments within an industry, and that resource reallocation across establishments accounts for a significant fraction of the TFP growth rate at the industry level.[1]

This paper constructs a dynamic general equilibrium model with heterogeneous agents, and investigates the interaction of credit market frictions, asset prices, the entry and exit of firms, and fluctuations in TFP in response to firm-level productivity and aggregate credit-market shocks. This analysis contributes to a vast literature that investigates mechanisms behind productivity differences across firms and determination of TFP through resource allocation within industries as observed in the longitudinal micro-level data. A sampling from this literature includes Jovanovic (1982) for the first model with firm-specific shocks, Syverson (2004) and Asplund and Nocke (2006) for the effect of imperfect competition in the goods market, and Melitz (2003) for the effect of trade.

This paper also adds to the analysis on the recent stagnation of the Japanese economy in the 1990s. Hayashi and Prescott (2002) find a productivity slowdown as the main factor for the stagnation. Nishimura, Nakajima and Kiyota (2005) and Fukao and Kwon (2006), using longitudinal micro-level data, find that low-productivity firms kept staying

[1]See Bartelsman and Doms (2000) for a survey of this literature.

in production in the 1990s contributing to the productivity slowdown. At the same time, a large decline in asset prices was observed. This paper illustrates a mechanism behind a fall in the TFP growth rate accompanied by a decline in asset prices and a reduction in exits of low-productivity firms, which characterizes the stagnation of the Japanese economy in the 1990s.

Especially, this paper highlights the effect of bankruptcy and foreclosure laws on a productivity slowdown, motivated by the non-performing loans problem in Japan in the 1990s. The non-performing loans problem was originated from commercial mortgage loans made in the late 1980s and the fall in the real-estate price in the 1990s. The Japanese government identified the Japanese foreclosure laws as an impediment to swift liquidation of collateral real-estate of the non-performing loans, and led the substantial reform of the foreclosure laws in 2003. Empirical research using US data suggests that such legal restriction on liquidating the assets of defaulting borrowers would increase loan-losses to lenders ex-post,[2] and reduce the amount of credit available to borrowers ex-ante.[3] This paper investigates how such ex-ante and ex-post effects of the Japanese foreclosure laws would affect fluctuations in TFP.[4] Besides the Japanese foreclosure laws, this analysis

[2]Clauretie and Herzog (1990) find in US data that if the state laws require judicial foreclosure, then loan-losses from mortgage loans tend to be larger in the state.

[3]This ex-ante effect is found in both bankruptcy and foreclosure laws. For example, see Pence (2006) for the adverse effect of US state laws that require judicial foreclosure. See White (2005, pp.64-68) for a survey of the adverse effect of bankruptcy laws.

[4]For the role of the non-performing loans problem in the productivity slowdown in Japan, Caballero, Hoshi and Kashyap (2006) argue that Japanese banks slowed down liquidation of their non-performing loans to hide loan losses letting insolvent and inefficient firms stay in production. Empirical research by Sekine, Kobayashi and Saita (2003), Hosono and Sakuragawa (2003) and Peek and Rosengren (2005) also finds slow liquidation of financially distressed firms by Japanese banks in the 1990s.

also contributes to a recent literature on general equilibrium analysis of bankruptcy laws, such as Bolton and Rosenthal (2002) and Biais and Mariotti (2003).

I consider a simple dynamic general equilibrium model with heterogeneous agents. In the model, each agent can produce goods. Each agent's productivity level changes over time, following an AR(1) process with agent-specific shocks. Then, each agent endogenously chooses whether to enter or remain in production, if her productivity level is sufficiently high, or to exit if productivity is low. The producing agents invest fixed-supplied capital into production, financing the cost by borrowing from the non-producing agents. But borrowers can borrow only up to the collateral value of capital they own. The bankruptcy and foreclosure laws affect the collateral value of capital by determining how much collateral capital lenders can liquidate when borrowers default.

There are five main results. First, credit market frictions cause persistent productivity differences across producers. The collateral constraints on borrowers prevent the most-productive agents from financing the cost in order to use as much capital as they wish. This reduces the aggregate expenditure on capital and then the price and the user cost of capital. The lower user cost of capital makes it viable for some less-productive agents to remain in production.

Second, when a negative shock hits productivity of each agent, credit market frictions propagate a fall in the TFP growth rate in response to the shock. The negative productivity shock reduces net-worth of producing agents, which diminishes their borrowing capacity and expenditure on capital. This effect lowers the user cost of capital more than proportionally to the productivity shock, which decreases the lower-bound of the productivity level for agents to remain in production. This increases the share of low-productivity agents in aggregate production, and reduces the TFP growth rate.

Third, legal restriction on liquidating collateral capital mitigates the fall in the TFP growth rate in response to the negative productivity shock. While some of the borrowers involuntarily default because the shock reduces the price of capital they own, the legal restriction prevents liquidation of the defaulting borrowers' capital by the lenders. As borrowers are the more-productive in the economy, the legal restriction mitigates a resource shift to the less-productive agents through liquidation and the fall in the TFP growth rate in response to the shock. This is an ex-post effect of the legal restriction.

Forth, if the legal restriction on liquidating collateral capital is intensified, then it reduces the collateral value of capital and tightens borrowing constraints on agents. This credit market shock intensifies productivity differences across producers by reducing the user cost of capital and inducing more low-productivity agents to stay in production. This causes an endogenous fall in the TFP growth rate. This is an ex-ante effect of the legal restriction.

Finally, the model implies that if each agent's productivity level becomes more persistent, it allows high-productivity agents to accumulate higher net-worth, and raises the user cost of capital inducing low-productivity agents to exit from production. This shifts up the TFP level increasing the TFP growth rate in the level-up process. However, the ex-ante effect of the legal restriction on liquidating collateral capital limits the leverage taken by the high-productivity agents and slows down the accumulation of their new-worth. This effect of the legal restriction delays the rise of the TFP level dampening the size of the increase of the TFP growth rate after the shock.

These findings are related to Kiyotaki and Moore (1997). I show that Kiyotaki and Moore's propagation mechanism under credit market frictions is closely linked with the effect of credit market frictions on dynamics of the entry and exit of firms and TFP. Among the other related works, Caselli and Gennaioli (2003) consider the long-run effect of credit market frictions on the TFP level, and Jeong and Townsend (forthcoming) show that a series of financial innovations increases the TFP level over time. Also, Caballero and Hammour (2005) analyze dynamics of resource reallocation across heterogeneous firms under both labor and credit market frictions. In comparison with these works, the contribution of this paper is to analyze endogenous dynamics of TFP with the asset price.

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 analyzes the dynamics of the model in response to a productivity shock. Section 4 explains the dynamics in response to a credit market shock. Section 5 considers the dynamics in response to a shock that increases persistence of each firm's productivity level. Section 6 discusses implications of the model for the productivity slowdown in Japan. Section 7 concludes.

2 Model

Consider a discrete-time economy with homogeneous and perishable goods and a continuum of agents. Each agent is risk-neutral, and maximizes the following utility function:

$$E_t \left(\sum_{s=t}^{\infty} \beta^{s-t}\, c_{i,s} \right), \tag{1}$$

where i is the index for each agent, $c_{i,s}$ consumption at date s, $\beta \in (0,1)$ a discount factor for future consumption, and E_t a conditional expectation operator at date t.

The factor of production in the economy is land. If an agent i invests $l_{i,t}$ units of land into production at date t, then she harvests an amount $A_{i,t}l_{i,t}$ of goods at date $t+1$. The agent knows the value of $A_{i,t}$ when she invests land into production. After the harvest, the agent can start new production.

After production at every date, she receives an agent-specific shock that determines her productivity level for the following period. $A_{i,t}$ follows an autoregressive process such that

$$\ln \left(\frac{\hat{A}_{i,t}}{1-\hat{A}_{i,t}} \right) = \rho \ln \left(\frac{\hat{A}_{i,t-1}}{1-\hat{A}_{i,t-1}} \right) + \epsilon_{i,t}, \quad \rho \in (0,1), \quad \epsilon_{i,t} \sim \text{i.i.d.} N(0,\sigma^2), \tag{2}$$

$$A_{i,t} = (1+g)^t \hat{A}_{i,t}, \tag{3}$$

where g is an aggregate productivity growth rate, ρ is an autoregressive coefficient, and g and ρ are constant and common to all the agents. Let $\epsilon_{i,t}$ denote an idiosyncratic productivity shock to each agent. This process assures that $\hat{A}_{i,t}$ always takes a value between 0 and 1.[5] A positive value of ρ implies that each agent's productivity level is persistent. Hereafter, I omit the agent index i to simplify the notation.

As in Kiyotaki and Moore (1997), I assume that production requires a specific skill of the agent who has initiated production. If a producing agent borrows from another agent and then walks away from production, then the lender can only repossess the borrower's land. I assume that agents cannot collectively exclude the defaulting agent from the credit market, and that the borrower can renegotiate the repayment of borrowing down to the collateral value of her land by the threat to walk away from production. The lender anticipates the renegotiation and only lends up to the collateral value of the borrower's land. This limits each agent's borrowing to

$$b_{t+1} \leq E_t v_{t+1} l_t, \tag{4}$$

where b_{t+1} is the repayment of borrowing, and v_{t+1} the collateral value per unit of land at date $t+1$.

In the right-hand side of (4), the amount of borrowing is limited by the expected value of collateral rather than the realized value. This is because I assume agents must work with their specific skills in production before knowing realized shocks to the economy at date $t+1$ and the realized value of v_{t+1}. Hence, the borrower's liability is predetermined

[5] An alternative specification of the productivity transition process is

$$\ln(\hat{A}_{i,t}) = \rho \ln(\hat{A}_{i,t-1}) + \epsilon_{i,t}.$$

But under this process, the detrended productivity level of the most productive agent explodes to infinity. I find this makes the detrended aggregate output explode to infinity and the steady state is not well-defined.

and becomes a debt. This assumption follows Kiyotaki and Moore (1997), who model collateralized debt contracts under unexpected shocks.

To specify the collateral value of land, I assume that the laws in this economy allow the lender to liquidate only a fraction θ ($\in [0,1]$) of the defaulting borrower's land per date. Implicitly, I assume that the laws and the court system are inefficient, and do not allow swift foreclosure on the collateral land by the lender. The unliquidated fraction of the collateral land remains at the disposal of the borrower until the next date.[6] Under this assumption, the collateral value of a unit of land for the lender is[7]

$$v_t = \theta q_t + E_t \left[\frac{(1-\theta)\theta q_{t+1}}{1+r_t} + ... \right] = \theta q_t + (1-\theta) \frac{E_t v_{t+1}}{1+r_t}, \tag{5}$$

where q_t is the price of land at date t, and r_t the interest rate between dates t and $t+1$. I assume that the interest rate is competitively determined in the credit market, and taken as given by agents.[8]

[6] This assumption models the foreclosure laws, but the mechanisms in the model would be applicable to the effect of bankruptcy laws, as long as they restrict liquidation of collateral assets by the lenders.

[7] v_t would be the market price of debts per unit of the collateral land, if the lender sold her lending to other agents.

[8] It is only after making investment that the borrower gains the bargaining power to renegotiate the contract with the lender. The interest rate is competitively determined in the credit market, which opens before agents invest into production and gain the bargaining power.

2.1 Agent's behavior

The agent's optimization problem at date t is defined as

$$\begin{aligned} \max_{\{c_s, l_s, b_{s+1}\}_{s=t}^{\infty}} \quad & E_t \left(\sum_{s=t}^{\infty} \beta^{s-t} \, c_s \right) \\ \text{s.t.} \quad & c_s + q_s l_s = A_{s-1} l_{s-1} + q_s l_{s-1} - b_s + \frac{b_{s+1}}{1+r_s} \\ & b_{s+1} \leq E_s v_{s+1} l_s \\ & c_s, l_s \geq 0, \end{aligned} \tag{6}$$

where c_s is consumption, l_s the units of land invested into production, b_s the amount of debt-repayment, r_s the interest rate, q_s the price of land, v_s the collateral value of a unit of land, and A_{s-1} the productivity level of current production at date s. If b_s is negative, then it is an amount of debt-repayment from borrowers to the agent. The agent takes the current and expected future values of q_s, r_s and v_s as given. The first constraint is the flow-of-funds constraint. The second constraint is the borrowing constraint. The third constraint is the non-negativity constraint for consumption and investment of land.

By solving the optimization problem (6) I can show that an agent's consumption, borrowing (lending), and investment depend on the two state variables of the agent, A_t

and net-worth, such that[9]

$$(c_t,\ l_t,\ b_{t+1}) = \begin{cases} \left(0,\ \frac{A_{t-1}l_{t-1}+q_t l_{t-1}-b_t}{q_t-\frac{E_t v_{t+1}}{1+r_t}},\ E_t v_{t+1} l_t\right) & \text{if } \hat{A}_t \in [\underline{A}_t^P, 1). \\ (0,\ 0,\ -(1+r_t)(A_{t-1}l_{t-1}+q_t l_{t-1}-b_t)) & \text{if } \hat{A}_t \in [\overline{A}_t^C, \underline{A}_t^P). \\ (A_{t-1}l_{t-1}+q_t l_{t-1}-b_t,\ 0,\ 0) & \text{if } \hat{A}_t \in (0, \overline{A}_t^C), \end{cases} \tag{7}$$

where $\underline{A}_t^P$ is the lower-bound of the detrended productivity level to engage in production, $\overline{A}_t^C$ the upper-bound to consume their net-worth,[10] and $\underline{A}_t^P > \overline{A}_t^C$. See appendix for the detail of the optimization.

The intuition for this behavior of agents is that when an agent has a sufficiently high detrended productivity level ($\geq \underline{A}_t^P$), she finds the production cost implied by the interest rate and the price of land relatively cheap compared to the high productivity of her investment. Then, she engages in production and borrows up to the limit so as to invest as much as possible. I can show $\underline{A}_t^P$ equals the detrended user cost of land:

$$\underline{A}_t^P = \frac{(1+r_t)q_t - q_{t+1}}{(1+g)^t}. \tag{8}$$

If an agent has a medium detrended productivity level ($\in [\overline{A}_t^C, \underline{A}_t^P)$), then she does not find it profitable to invest into production, and exits from or does not enter production. But she expects that her productivity will recover in the near future, and saves her net-worth for future investment. If an agent has a low detrended productivity level ($< \overline{A}_t^C$), then she expects that her productivity will stay low for the future, because the

[9]I numerically confirm (7) under the parameter values I will specify later.

[10]I assume the marginal agents with $\underline{A}_t^P$ and $\overline{A}_t^C$ choose the corner solutions. This is weakly optimal and does not affect the aggregate outcome, because the size of these agents in the economy is zero.

productivity level is persistent as indicated by the productivity transition process (2). Since she discounts future consumption, she finds it optimal to consume all the net-worth in her hands immediately, rather than waiting for recovery of her productivity.[11] The comparison between the rate of return to lending and the marginal utility of consumption makes $\overline{A}_t^C$ depend on current and future interest rates and current and future prices of land. See appendix for the implicit function that determines $\overline{A}_t^C$.

2.2 Equilibrium conditions

Here I consider the market clearing conditions of the land and the credit markets. Given the behavior of agents specified in (7), I can obtain the land market clearing condition as

$$\int_{\underline{A}_t^P}^{1} L_t(\hat{A}_t)d\hat{A}_t = 1, \tag{9}$$

where $L_t(\hat{A}_t)$ is the land-investment distribution function at date t. The left-hand side of the equation is aggregate land demand, and the right-hand side is aggregate supply. I assume that aggregate supply of land in the economy is fixed and normalized to be 1.

The credit market clearing condition is

$$\int_{\overline{A}_t^C}^{\underline{A}_t^P} S_t(\hat{A}_t)d\hat{A}_t = \frac{E_t v_{t+1}}{1+r_t} \int_{\underline{A}_t^P}^{1} L_t(\hat{A}_t)d\hat{A}_t, \tag{10}$$

[11] Equation (7) implies that if the agents consume, the agents make no investment or lending, so that their net-worth at the next date is zero. Given the borrowing constraint, the flow-of-funds constraint implies that such agents cannot do any economic activity from the next-date. Hence, consumption is an endogenous exit from the economy. To keep the population of the economically-active agents in the economy positive, I assume there are new-entrants into the economy every date with an arbitrarily small amount of net-worth. Hence, the equilibrium obtained above is the limit case when I take the new-entrants' net-worth to zero at the limit. I consider the limit case to simplify the analysis, as generally the net-worth of the new firms is not large in the data compared to the incumbents.

where $S_t(\hat{A}_t)$ is the lending distribution function at date t. The left-hand side of the equation is aggregate lending, and the right-hand side is aggregate borrowing.

To specify the aggregate land demand and the aggregate lending, I need to obtain the land-investment distribution function $L_t(\hat{A}_t)$ and the lending distribution function $S_t(\hat{A}_t)$. To do so, I first aggregate the flow-of-funds constraints in the optimization problem (6) to obtain aggregate net-worth of agents such that

$$W_t(\hat{A}_t) = \int_{\underline{A}_{t-1}^P}^{1} (A_{t-1} + q_t - E_{t-1}v_t) L_{t-1}(\hat{A}_{t-1}) f(\hat{A}_t|\hat{A}_{t-1}) d\hat{A}_{t-1} + \int_{\overline{A}_{t-1}^C}^{\underline{A}_{t-1}^P} (1 + r_{t-1}) S_{t-1}(\hat{A}_{t-1}) f(\hat{A}_t|\hat{A}_{t-1}) d\hat{A}_{t-1}, \quad (11)$$

where

$$f(\hat{A}_t|\hat{A}_{t-1}) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{\left\{ \ln\left(\frac{\hat{A}_t}{1-\hat{A}_t}\right) - \rho \ln\left(\frac{\hat{A}_{t-1}}{1-\hat{A}_{t-1}}\right) \right\}^2}{2\sigma^2} \right) \left| \frac{d\left[\rho \ln\left(\frac{\hat{A}_{t-1}}{1-\hat{A}_{t-1}}\right)\right]}{d\hat{A}_{t-1}} \right|, \quad (12)$$

which is the conditional probability to have $\hat{A}_t$ given $\hat{A}_{t-1}$ implied by the productivity transition process (2),[12] and $W_t(\hat{A}_t)$ is the aggregate net-worth distribution function at date t.

From the aggregate net-worth, I can obtain the land-investment and the lending distribution functions as follows:

$$L_t(\hat{A}_t) = \frac{W_t(\hat{A}_t)}{q_t - \frac{E_t v_{t+1}}{1+r_t}} \quad \text{for } \hat{A}_t \in [\underline{A}_t^P,\ 1), \quad (13)$$

$$S_t(\hat{A}_t) = W_t(\hat{A}_t) \quad \text{for } \hat{A}_t \in [\overline{A}_t^C, \underline{A}_t^P). \quad (14)$$

[12]The last term in (12) is a Jacobian in order to take the integrals in (11) over $\hat{A}_{t-1}$.

Given the parameter values of the model (β, g, ρ, σ, θ), and the initial conditions on $\underline{A}^P_{-1}$, $\overline{A}^C_{-1}$, $E_{-1}v_0$, $L_{-1}(A_{-1})$ and $(1+r_{-1})S_{-1}(A_{-1})$, I define an equilibrium as:

- $\{c_s, l_s, b_{s+1}\}_{s=0}^{\infty}$ solves the optimization problem (6), given the current and future prices $\{q_s, r_s, v_s\}_{s=0}^{\infty}$; Consequently, $\{\underline{A}^P_s, \overline{A}^C_s\}_{s=0}^{\infty}$ is derived;
- (11)-(14) recursively determine $\{L_s(\hat{A}_s), S_s(\hat{A}_s)\}_{s=0}^{\infty}$, given $\{q_s, r_s, E_s v_{s+1}, \underline{A}^P_s, \overline{A}^C_s\}_{s=0}^{\infty}$, and the initial conditions;
- $\{q_s, r_s, v_s\}_{s=0}^{\infty}$ is determined in order to satisfy the market clearing conditions (9) and (10) and the definition of v_s (5);
- agents form rational expectations of the future prices $\{q_s, r_s, v_s\}_{s=t+1}^{\infty}$ at every date t;
- there is no bubble in the price of land, so that at every date t,

$$\lim_{s\to\infty} E_t\left[\frac{q_s}{\prod_{h=t}^{s-1}(1+r_h)}\right] = 0. \tag{15}$$

The goods market clears in equilibrium by Walras' Law. In what follows, I analyze dynamics of TFP in response to unexpected shocks to the parameters at date 0. There is no aggregate uncertainty from date 0 onward, and agents have perfect foresight of the future prices.

2.3 Definition of TFP

I define TFP as the average productivity of land since land is the only factor of production in the model. Because the supply of land is fixed to be 1, TFP coincides with aggregate output. Aggregate output and TFP are derived as

$$TFP_t = Y_t = \int_{\underline{A}_{t-1}^P}^1 A_{t-1} L_{t-1}(\hat{A}_{t-1}) d\hat{A}_{t-1}, \tag{16}$$

where TFP_t is the TFP level and Y_t is aggregate output at date t. This implies that TFP is a weighted average of individual productivity levels of producers.

2.4 Renegotiation of debts after unexpected shocks

In some cases, the price of land declines so much in response to an unexpected shock that some borrowers involuntarily default at date 0. Since the borrower has already worked with her specific skill in production, she cannot renegotiate her debt by the threat to walk away from production. The lender can take all the defaulting borrower's output, and liquidate the defaulting borrower's land up to a fraction θ under the legal restriction on liquidating collateral land.

The lender and the defaulting borrower renegotiate how much of the remaining debt should be repaid at the next date. Without renegotiation, the payoff for the lender at the next date would be $E_0 v_1$ per unit of the unliquidated fraction of land. I assume that the borrower has strong bargaining power and can reduce the remaining debt to this value. This assumption implies that if the size of the unliquidated fraction of land is $(1-\theta)l_{-1}$, then the lender rolls over the amount $[E_0 v_1/(1+r_0)](1-\theta)l_{-1}$ of the remaining debt, and writes off the rest of the remaining debt. Overall, the debt of the borrower is reduced to $A_{-1} + \theta q_0 + (1-\theta)E_0 v_1/(1+r_0)$ per land at date 0, which equals $A_{-1} + v_0$. I assume lenders incur loan losses proportional to their lending.

This assumption implies that the aggregate net-worth function in (11) at date 0 is modified to

$$W_0(\hat{A}_0) = \int_{\underline{A}^P_{-1}}^{1} (A_{-1} + q_0 - \min\{E_{-1}v_0,\ A_{-1} + v_0\}) L_{-1}(\hat{A}_{-1}) f(\hat{A}_0|\hat{A}_{-1}) d\hat{A}_{-1} + \int_{\overline{A}^C_{-1}}^{\underline{A}^P_{-1}} \min\left\{1, \frac{A_{-1} + v_0}{E_{-1}v_0}\right\} (1 + r_{-1}) S_{-1}(\hat{A}_{-1}) f(\hat{A}_0|\hat{A}_{-1}) d\hat{A}_{-1}, \qquad (17)$$

given the market clearing conditions (9) and (10) are satisfied for $t = -1$.

3 Dynamics in response to a productivity shock

In this section, I analyze endogenous dynamics of TFP in response to an exogenous fall in the long-run TFP growth rate of each agent. The motivation for this analysis is to see how credit market frictions propagate a productivity shock through resource reallocation across agents, including their entry and exit. This is related to Hayashi and Prescott (2002), who analyze the effect of exogenous falls in the TFP growth rates in a neo-classical growth model for the stagnation of the Japanese economy in the 1990s.

3.1 Calibration

Since it is not possible to obtain an analytical solution for dynamics of the model, I numerically compute the dynamics. I adopt the base-line parameter values in Table 1. The frequency of the model is annual. I choose a standard value for β. The value of g is the average TFP growth rate for 1983-1991 in Japan estimated by Tomura (2006). I obtain the values of ρ and σ by matching the steady state of the model with the productivity transition matrix of Japanese manufacturing firms estimated by Fukao and Kwon (2006), given the other parameter values. The value of θ implies that the loan-to-value ratio of agents' borrowing equals to 81.6% at the steady state.[13] This value is broadly consistent with the observation in Japan. See appendix for more detail of calibration of the values of ρ, σ and θ.

Table 1: The base-line parameter values for numerical calculation.

β	g	ρ	σ	θ
0.96	0.016	0.9	0.48	0.1

For the productivity shock, I consider an unexpected permanent decline in g from 0.016 to 0.004 at date 0, as 0.4% is the average TFP growth rate for 1991-98 estimated by Tomura (2006).

[13] The loan-to-value ratio in the model is $[v_{t+1}/(1+r_t)]/q_t$. I can show that this equals $\theta/\{(1+r_t)/(1+g)-(1-\theta)\}$ at the steady state.

3.2 Computational method

I assume that the economy is at the steady state before the shock at date 0. When I numerically compute dynamics of the model in response to the shock, I calculate the equilibrium sequence of $\{q_s, r_s, \underline{A}_s^P, \overline{A}_s^C\}_{s=0}^{200}$ which converges to the new steady state under the new value of g. In the iteration to find this sequence, I approximate the integrals in the market clearing conditions (9) and (10) and the aggregate net-worth function (11) by the Legendre-quadrature. I use 50 nodes for each integral. See appendix for more detail of computation.

3.3 Dynamics of the economy

Figure 1 shows dynamics of the model in response to the shock under different levels of θ. I choose high, middle and low values of θ, which are 1, 0.5 and 0.1, respectively.

The figure shows that the growth rate of TFP_t endogenously falls below the new value of g after the shock under all levels of θ. The mechanism is as follows. First, agents form rational expectations and take into account that the productivity slowdown reduces future land productivity. This causes an immediate fall in the price of land, which in turn reduces net-worth of borrowers. Because this prevents borrowers from borrowing as much as before, this lowers the aggregate expenditure on land and propagates the fall in the price of land. By this propagation, the user cost of land falls more than proportionally to the size of the productivity shock. This raises the rate of return to investment for each agent, and induces low-productivity agents to stay in production. Hence the level of $\underline{A}_t^P$ is lowered as shown in Figure 1.[14] This propagates the fall in the TFP growth rate.[15]

Note that this mechanism is related to the propagation mechanism found by Kiyotaki and Moore (1997), by which the user cost of land falls more than proportionally to a productivity shock. Here, I show this mechanism affects exits of low-productivity agents and propagates the fall in the TFP growth rate.

In addition, Figure 1 shows a fall in r_t in response to the shock. This is because the decline in the future price of land reduces the collateral value of land and then borrowing of agents.

3.4 Effect of bankruptcy and foreclosure laws

Figure 1 shows that the lower the level of θ, the smaller the fall in the TFP growth rate in response to the shock. While some of the borrowers default due to the fall in the price of land, a lower value of θ prevents lenders from enforcing debt-repayment by liquidating the collateral land. This lets the borrowers retain more net-worth as shown in Figure 2. As borrowers are the more-productive in the economy, the legal restriction on liquidating collateral land mitigates a resource shift to the less-productive agents and the fall in the TFP growth rate in response to the shock. On the flip side of the coin, the lenders suffer

[14] Figure 1 also shows that $\underline{A}_t^C$ increases in response to the shock. This is because the decline in g reduces the payoffs for the low-productivity agents to wait until they become high-productive and engage in production again in the future.

[15] As a related result, Barseghyan (2002) shows that if agents in the economy expect a severe financial crisis in the future, then they refrain from investment, which lowers the wage and induces entry of low-productivity producers.

from larger loan losses as θ is lower, as shown in Table 2. This result is consistent with Clauretie and Herzog (1990), who find in the US data that if the state laws require judicial foreclosure, then loan-losses from mortgage loans tend to be larger in the state.

Table 2: The loan-loss rate at date 0 in response to the shock to g.

θ	1	0.5	0.1
Loan-loss rate	31.82%	32.48%	36.38%

4 Dynamics in response to a credit market shock

In this section, I analyze dynamic responses of the model when the legal restriction on liquidating collateral land is tightened. In the model, this is captured by a fall in the value of θ. This reduces the collateral value of land and tightens the borrowing constraints on agents. Hence this is a credit market shock.

I consider an unexpected permanent decline in θ from 0.1 to 0.093 at date 0. This shock reduces the loan-to-value ratio of agents' borrowing by 1% from 81.6% to 80.6% at the steady state. This experiment is motivated by the fact that the supreme court rulings in 1989 and 1991 in Japan strengthened protection of borrowers by the foreclosure laws.[16]

[16] Under the Japanese foreclosure laws, a foreclosure on a mortgaged property rescinds lease contracts on it, if the lender had placed the mortgage before the lease contracts. But until the reform of the foreclosure laws in 2003, the laws had protected the lease contracts preceded by mortgages against foreclosures if the maturities of the lease contracts were less than 3-5 years. One way to prevent the borrower from abusing this protection was to write a contract that would automatically activate a lease contract between the lender and the borrower if the borrower defaulted. However, the supreme court in 1989 denied the validity of such a contract. Also, the supreme court in 1991 ruled that lenders could

Because a supreme court ruling has a persistent effect on interpretation of laws, I consider a case that agents perceive the legal shock as a permanent shock.

I use the base-line parameter values in Table 1 except the value of θ. I assume that the economy is at the steady state before the shock at date 0, and calculate the equilibrium dynamics of the model converging to the new steady state under the new value of θ.

Figure 3 shows dynamics of the model in response to the shock. TFP_t and q_t in the figure are % deviations from the original trends before the shock. The figure shows the TFP trend levels down in response to the shock. This is because a decline in θ reduces the collateral value of land and tightens the borrowing constraints on agents. This prevents high-productivity agents from borrowing as much as before to buy land, and reduces the price of land. This mechanism also decreases the user cost of land and induces low-productivity agents to remain in production, as shown by a decline in $\underline{A}_t^P$ in Figure 3. In the process of this level-down, the TFP growth rate endogenously drops. In addition, the real interest rate falls in response to the shock because aggregate borrowing declines due to the tightened borrowing constraints.

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not expel tenants from mortgaged properties before foreclosures even if the tenancy agreements abused the protection of lease contracts. The ruling in 1991 had been in effect until the supreme court in 1999 reversed it.

5 Dynamics after productivity levels of firms become more persistent

In this section, I analyze dynamics of the economy when each agent's productivity level becomes more persistent. This exercise is consistent with Fukao and Kwon (2004),[17] who find a rise in the persistence of individual productivity levels of Japanese manufacturing firms during the 1990s.

I consider an unexpected permanent increase of ρ from 0.9 to 0.91 at date 0. I use the base-line parameter values in Table 1 except the value of ρ. I assume that the economy is at the steady state before the shock at date 0, and calculate the equilibrium dynamics of the model converging to the new steady state under the new value of ρ.

Figure 4 shows dynamics of the model in response to the shock. TFP_t and q_t in the figure are % deviations from the original trends before the shock. The TFP growth rate increases in response to the shock. This is because high-productivity agents accumulate higher net-worth and increase their expenditure on land. This raises the price of land and the user cost of land, which induces low-productivity agents to exit from production. This is shown by an increase of $\underline{A}_t^P$ under each level of θ in Figure 4.

The comparison across different levels of θ in Figure 4 shows that the lower the level of θ, the smaller the positive effect of the increase in ρ on the TFP growth rate. This is because a lower level of θ reduces the collateral value of land and limits the leverage

[17] This is a working paper version of Fukao and Kwon (2006).

that high-productivity agents can take. This slows down the net-worth accumulation of high-productivity agents and delays the rise of the TFP trend.

6 Implications for the productivity slowdown in Japan

In this section, I discuss implications of the model for the recent productivity slowdown in Japan in the 1990s.

6.1 Features of the productivity slowdown in Japan

The Japanese economy experienced a long stagnation in the 1990s. Investigating the reason for the stagnation, Hayashi and Prescott (2002) estimate the TFP growth rates of the Japanese economy by the Solow residuals, and find that there was a productivity slowdown behind the stagnation. The first row of Table 3 shows the estimates of Hayashi and Prescott. As the Solow residuals contain the effect of unobservable capacity utilization, Tomura (2006) estimates the TFP growth rates using the method of Basu and Kimball (1997) that controls for fluctuations in unobservable capacity utilization of both labour and capital.[18] The estimates of Tomura are shown in the second row of Table 3. The estimates confirm that there was a productivity slowdown.

[18]To my knowledge, Kawamoto (2005) is the first paper that applies the Basu and Kimball's method to the Japanese data. While his estimates show that unobservable capacity utilization explains the fall in the Solow residuals in the 1990s without a productivity slowdown, Tomura (2006) takes into account the fall in the statutory workweek of labour since 1988 when using working-hours of labour as the proxy for unobservable capacity utilization. In Tomura (2006), I also find a productivity slowdown in Japan in a separate estimation that uses the energy-input as the proxy for unobservable capacity utilization.

Table 3: Average annual TFP growth rates in Japan

	1960-73	1973-83	1983-91	1991-2000
Hayashi and Prescott (2002)	6.5%	0.8%	3.7%	0.3%
Tomura (2006)	–	1.4%	1.6%	0.4% (1991-98)

Behind the productivity slowdown, Nishimura, Nakajima and Kiyota (2005) and Fukao and Kwon (2006) find that low-productivity firms kept staying in production in the 1990s. For example, Fukao and Kwon report that the difference in the log of the TFP level between the 75 and the 25 percentile firms in each manufacturing industry increased from 0.130 in 1994 to 0.141 in 2001 on average.[19] They also find that productivity levels of exiting firms were higher than continuing firms on average. This is shown in Table 4 as a negative exit effect in the TFP growth decomposition for 1994-2001.[20] This finding can be interpreted as the average productivity level of continuing firms was lowered by a decline in the threshold level of productivity for firms to stay in production, and exits of firms were driven by shocks independent of productivity.[21]

[19] Fukao and Kwon (2006) only analyze the data of manufacturing firms.

[20] In Table 4, Fukao and Kwon (2006) use the method of Baily, Hulten and Campbell (1992) and Foster, Haltiwanger and Krizan (2001). Average TFP growth rate is the weighted average of the average TFP growth rates over the sample period across the manufacturing industries. Ideally, I should compare the exit effects between the 1980s and the 1990s, but the sample period of Fukao and Kwon's longitudinal database is limited for 1994-2001.

[21] One of the possible reasons for exits of firms independent of productivity is that high-productivity firms had borrowed more than low-productivity firms on average, and were more financially-fragile against negative shocks to their balance sheets. This phenomenon occurs in an extended model described in Section 6.4.

Table 4: TFP growth decomposition for the manufacturing sector for 1994-2001

	Average annual TFP growth rate	Within effect	Reallocation effect	Entry effect	Exit effect
Fukao and Kwon (2006)	0.31%	0.17%	0.05%	0.16%	-0.07%

6.2 Explaining the feature of the productivity slowdown with the fall in the price of land

Another feature of the Japanese economy in the 1990s was a fall in the price of land (Figure 6). The results of the model explain the features of the Japanese economy, as both the productivity shock and the credit market shock cause a fall in the price of land, and an accompanying decline in the user cost of land endogenously reduces the TFP growth rate by inducing low-productivity agents stay in production.

6.3 Role of restrictive foreclosure laws in the productivity slowdown

In the dynamic analysis, I have considered endogenous fluctuations in TFP by the shocks to the two deep parameters θ and ρ. The falls in the TFP growth rate and the price of land in response to the decline in θ imply that the supreme court rulings in 1989 and 1991 that strengthened protection of borrowers under the Japanese foreclosure laws help to explain the features of the productivity slowdown. Also, the dynamics in response to the shock to ρ suggests that the restrictive Japanese foreclosure laws contributed to the productivity slowdown by preventing the rise in the persistence of individual productivity levels of Japanese manufacturing firms from increasing the TFP growth rate.

6.4 Extension: why did the borrowing-output ratio fall in the 1990s?

In this section, I discuss the reason for the fall in the borrowing-output ratio of Japanese firms in the 1990s (Figure 7). This issue has been discussed in the literature on the stagnation of the Japanese economy. One explanation is that firms reduced their demand for credit and that there was no role for a crunch in credit supply (e.g. Motonishi and Yoshikawa [1999] and Hayashi and Prescott [2002].) Another explanation is that the borrowing constraints on firms were tightened, and that this contributed to the fall in the borrowing-output ratio. (e.g. Ogawa [2003] and Nagahata and Sekine [2005].)

Hayashi and Prescott (2002) find that Japanese firms kept financing their investment by internal reserves in the 1990s. This implies that if firms' demand for credit had fallen in the 1990s, then it would have been because of some cost of excess borrowing. I model this cost by introducing a shock to the agents' production function that causes debt-overhang, and investigate how agents' demand for credit changes under productivity slowdowns.

I modify the production function of agents as follows. If an agent invests l_t units of land into production at date t, then she harvests an amount $A_t l_t$ of goods at date $t+1$

with probability μ, but the harvest is delayed until date $t+2$ with probability $1-\mu$. The shock of the delay is idiosyncratic. If the delay occurs, the agent needs to reinvest land into production. If she reinvests l_{t+1} of land at date $t+1$, then she will harvest an amount $(1+g)A_t l_{t+1}$ of goods at date $t+2$. I assume that the agents hit by the delay in production can only continue the initial investment at the previous date, so that l_{t+1} cannot exceed l_t. Table 5 summarizes the production function. This production function is similar to the one considered by Dewatripont and Maskin (1995).

Table 5: Production function

date t			date $t+1$		date $t+2$
l_t of land	$\nearrow$	(w.p. μ)	$A_t l_t$ of goods		
(A_t is known.)	$\searrow$	(w.p. $1-\mu$)	No goods		
			l_{t+1} of land ($\leq l_t$)	$\rightarrow$	$(1+g)A_t l_{t+1}$ of goods

The agent's productivity level changes at each date following the productivity transition process (2), except for the agents hit by the shock of delay. These agents can continue working on the production they initiated and their detrended productivity levels do not change as specified above.

I assume that the shock of delay in production is uninsurable, and consider the same borrowing constraint (4) as before. Having the other assumptions unchanged, I can show that all the agents with delayed production continue production borrowing up to the limits in the dynamics simulated below. The intuition is that reinvesting into delayed production is profitable since it produces goods at the next date with probability 1 without changing the detrended productivity level.

The behavior of agents without delayed production is such that[22]

$$
(c_t,\ l_t,\ b_{t+1}) =
\begin{cases}
\left(0, \quad \dfrac{y_t + q_t l_{t-1} - b_t}{q_t - \frac{E_t v_{t+1}}{1+r_t}}, \quad E_t v_{t+1} l_t\right) & \text{if } \hat{A}_t \in [\underline{A}_t^{SPH}, 1). \\
\left(0, \quad \dfrac{y_t + q_t l_{t-1} - b_t}{q_t - E_t\left[\frac{v_{t+2}}{(1+r_t)(1+r_{t+1})}\right]}, \quad E_t\left[\dfrac{v_{t+2}}{1+r_{t+1}}\right] l_t\right) & \text{if } \hat{A}_t \in [\underline{A}_t^{SPL}, \underline{A}_t^{SPH}). \\
(0, \quad 0, \quad -(1+r_t)(y_t + q_t l_{t-1} - b_t)) & \text{if } A_t \in [\overline{A}_t^{SC}, \underline{A}_t^{SPL}). \\
(y_t + q_t l_{t-1} - b_t, \quad 0, \quad 0) & \text{if } \hat{A}_t \in (0, \overline{A}_t^{SC}),
\end{cases}
\tag{18}
$$

where y_t is the output at date t, $\underline{A}_t^{SPH}$ the lower-bound of the productivity level to borrow up to the limit, $\underline{A}_t^{SPL}$ the lower-bound to engage in production, $\overline{A}_t^{SC}$ the upper-bound to consume their net-worth, and $\underline{A}_t^{SPH} > \underline{A}_t^{SPL} > \overline{A}_t^{SC}$.

The relatively less-productive agents in $[\underline{A}_t^{SPL}, \underline{A}_t^{SPH})$ do not borrow up to the limits, because if an agent making the initial investment borrows up to the limit, then she needs to liquidate her land to repay the debt when she is hit by the delay in production at the next date. This is debt-overhang. The liquidation of land without reinvestment implies that the agent had spent her net-worth on liquidated land for producing nothing. This

[22] As before, I assume the marginal agents with $\underline{A}_t^{SPH}$, $\underline{A}_t^{SPL}$ and $\underline{A}_t^{SC}$ choose the corner solutions.

becomes too costly, if the productivity level of the initial investment is low and the return from taking high leverage is small. This is why the relatively less-productive agents refrain from borrowing up to the limits and avoid the debt-overhang.

Here I simulate the dynamic responses of the model to the same shocks to g and θ as considered above. I choose $\mu = 0.95$ and the base-line values for the parameters except the shock parameter in each experiment. The responses of the TFP growth rate, the price of land and the interest rate are all similar to the previous results shown above. Figure 5 shows dynamics of the borrowing-output ratio and the size of the credit-unconstrained producers in $[\underline{A}_t^{SPL}, \underline{A}_t^{SPH})$ measured by the net-worth share and the gap between $\underline{A}_t^{SPL}$ and $\underline{A}_t^{SPH}$. Both measures suggest that the size of the credit-unconstrained producers declines with the fall in the borrowing-output ratio. The reason is that the fall in the user cost of land in response to the shocks to g and θ increases the rate of return to investment for each agent. This makes more agents willing to borrow up to the limits, despite the risk of debt-overhang. But as the price of land falls, the borrowing limits of agents fall as well, and hence the borrowing-output ratio declines.

Note that the decline in the user cost of land is also the reason for low-productivity agents to stay in production. Hence this result suggests that the same mechanism is the key to understand the decline in exits of low-productivity firms and the fall in the borrowing-output ratio in Japan in the 1990s.

7 Conclusion

This paper has investigated the role of credit market frictions in generating endogenous fluctuations in TFP in response to productivity and credit market shocks. The key mechanism is closely related to the propagation mechanism of Kiyotaki and Moore (1997). I show that this propagation mechanism reduces the user cost of land and raises the rate of return to investment for each agent in response to both negative productivity and credit market shocks. This makes it viable for low-productivity agents to stay in production, and causes an endogenous fall in the TFP growth rate. I find that this mechanism helps to explain the features of the stagnation of the Japanese economy in the 1990s, such as a productivity slowdown, a decline in exits of low-productivity firms from production, and a fall in the price of land.

This paper has also investigated the effect of restrictive bankruptcy and foreclosure laws on a productivity slowdown. Restrictive foreclosure laws were observed in Japan until 2003, and also the supreme court rulings in 1989 and 1991 strengthened the restriction on liquidating collateral assets under the Japanese foreclosure laws. I find that such a legal shock as the supreme court rulings causes a negative credit market shock and an endogenous fall in the TFP growth rate. I also show that if individual productivity levels of firms become more persistent as Fukao and Kwon (2004) observe in Japan in the 1990s, then this increases the TFP growth rate. But restrictive bankruptcy and foreclosure laws reduce the size of such an increase of the TFP growth rate.

A remaining question with regard to the productivity slowdown in Japan is why it was accompanied by the lasting decline in the price of land. The results of the model imply that the price of land immediately falls in response to both persistent productivity and credit market shocks because forward-looking agents correct their expectations of future land productivity. In the data, the price of land in Japan has been gradually falling for more than a decade.

A possible reason for the gap between the model and the data is that in the model renegotiation over non-performing loans is completed immediately after the shocks. In reality, renegotiation only sluggishly took place as demonstrated by the prolonged non-performing loans problem in Japan. This feature of the Japanese economy was emphasized by Caballero, Hoshi and Kashyap (2006). Their result implies that sluggish renegotiation lets insolvent firms stay in production, which increases aggregate demand for factors of production and raises factor prices. Even though the rise of factor prices are inconsistent with the declining real price of land since 1991 and the declining real wage since 1998 in Japan, this result suggests that if I integrate sluggish renegotiation into the model, then it would keep the price of land high at the impact of the shocks. As renegotiation gradually takes place, the price of land would slowly decline converging to the path simulated in this paper without sluggish renegotiation. This extension is left for future research.

Appendix

A. Foreclosure laws in Japan

In this part, I describe restriction on liquidating collateral assets under the foreclosure laws in Japan, referring to the report issued by the Ministry of Justice in 2002, "A supplementary note for the interim proposal for the Law to Revise a Part of the Civil Laws for a Reform of the Mortgage and Civil Execution System."

(Protection of short-term lease contracts.) Foreclosures of mortgaged land properties and buildings rescind lease contracts on the mortgaged properties, if the mortgages precede the lease contracts. But before the revision of laws in 2003, the Civil Law protected the lease contracts preceded by mortgages, if the maturities of the contracts were within a certain length (5 years for the land lease, and 3 years for the building lease) and if the lenders did not suffer from losses by this protection. Even though existence of such protected lease contracts would reduce the liquidation values of the mortgaged properties, the court did not necessarily recognize it as the losses to the lenders. By the revision of the laws in 2003, the maximum maturity of the protected lease contracts is reduced to 6 months, unless the lenders agree to extend the duration of the protection in advance.

(Protection of buildings on mortgaged land properties.) Before the revision of the laws in 2003, lenders could not sell non-mortgaged buildings on foreclosed land properties altogether at the auction in the foreclosure process, unless the borrowers constructed the buildings after the placement of the mortgages. In this case, the buyers of the foreclosed land properties had to obtain the court orders to destroy the buildings. By the revision of the laws in 2003, this protection of the buildings was abolished.

(Civil Execution Law.) The court order to remove occupants from a foreclosed property has to correctly identify the occupants. This requirement let malicious borrowers to deter foreclosures of the properties by keeping changing the occupants. By the revision of the laws in 2003, this requirement was relaxed.

(Judicial foreclosure.) Lenders have to follow the judicial foreclosure process. The court sets a minimum price for the bids at every auction of foreclosed properties. Idee and Taguchi (2002) find that the improvement of the auction procedure that took place in 1998, including a relaxation of the minimum price rule, had a positive effect on the success rate of foreclosures.

(Compulsory foreclosure.) Before the revision of the laws in 2003, if the borrower sold or leased a mortgaged property to a third party, then the third party could offer to pay the lender for canceling the mortgage. To decline the offer, the lender had to foreclose on the mortgaged property. If the lender could not sell it for more than 110% of the value offered by the third party, then she had to buy it by herself for 110% of the offered value. In effect, the third party could force the timing of foreclosure on the lender. By the revision of the laws in 2003, the lender does not have to buy the property by herself even if the auction is not successful.

(Administration of mortgaged properties.) Before the revision of the laws in 2003, lenders were not entitled to administer mortgaged properties before foreclosures, and could seize the payments from tenants to the defaulting borrowers who own the properties. But the payments included the administration fees of the properties, so that the seizures of the payments could hamper the administration of the properties and lower the liquidation values of the properties if multiple lenders run for the administration fees. By the revision of the laws in 2003, lenders can request the court to appoint administrators to mortgaged properties when borrowers default.

See the footnote 16 for the supreme court rulings on the foreclosure laws in 1989 and 1991, which intensified the protection of short-term lease contracts.

B. Solving the agent's optimization problem

Here, I describe the agent's optimization problem in the model in the section 2. The recursive form of the agent's optimization problem is

$$V_t(\hat{A}_{t-1}l_{t-1} + \hat{q}_t l_{t-1} - \hat{b}_t,\ \hat{A}_t) = \max_{\{\hat{c}_t, l_t, \hat{b}_{t+1}\}} \hat{c}_t + \hat{\beta} E_t V_{t+1}(\hat{A}_{t-1}l_{t-1} + \hat{q}_t l_t - \hat{b}_{t+1},\ \hat{A}_{t+1}) \tag{19}$$

$$\text{s.t. } \hat{c}_t + \hat{q}_t l_t = \hat{A}_{t-1}l_{t-1} + \hat{q}_t l_{t-1} - \hat{b}_t + \frac{\hat{b}_{t+1}}{1+\hat{r}_t}$$

$$\hat{b}_{t+1} \leq \hat{v}_{t+1} l_t$$

$$\hat{c}_t, l_t \geq 0$$

where

$$\hat{\beta} = \beta(1+g), \quad 1+\hat{r}_t = \frac{1+r_t}{1+g}, \quad \hat{A}_t = \frac{A_t}{(1+g)^t} \quad \text{and } \hat{z}_t = \frac{z_t}{(1+g)^{t-1}} \text{ for the other variables.}$$

The value function V_t is time-indexed as the prices vary over time. First, consider the steady state where all the prices are constant and the value function is identical over time. After obtaining the optimum conditions at the steady state, I consider the dynamics converging to the steady state after the shock. By recursively applying the Lagrange method and the envelope theorem, I obtain the shadow values of the net-worth for the agents such that

$$\lambda_{1,t}(\hat{A}_t) = \frac{E_t\left[\hat{\beta}(\hat{A}_t + \hat{q}_{t+1} - \hat{v}_{t+1})\lambda_{t+1}(\hat{A}_{t+1})\right]}{\hat{q}_t - \frac{E_t \hat{v}_{t+1}}{1+\hat{r}_t}} \tag{20}$$

$$\lambda_{2,t}(\hat{A}_t) = \hat{\beta}(1+\hat{r}_t)E_t[\lambda_{t+1}(\hat{A}_{t+1})] \tag{21}$$

$$\lambda_{3,t}(\hat{A}_t) = 1 \tag{22}$$

$$\lambda_t(\hat{A}_t) = \max\left\{\lambda_{1,t}(\hat{A}_t),\ \lambda_{2,t}(\hat{A}_t),\ \lambda_{3,t}(\hat{A}_t),\right\} \tag{23}$$

$\lambda_{j,t}$ is the Lagrange multiplier for the flow-of-funds constraint of the agent who invests, saves or consumes given $\hat{A}_t$, respectively for $j = 1, 2, 3$. $\lambda_t(\hat{A}_t)$ is the value of the Lagrange multiplier when the agent takes the optimal behavior.

$\lambda_{1,t}(\underline{A}_t^P) = \lambda_{2,t}(\underline{A}_t^P)$. This implies that $\underline{A}_t^P = (1+\hat{r}_t)\hat{q}_t - \hat{q}_{t+1}$. $\overline{A}_t^C$ is determined at the level where $\lambda_{2,t}(\overline{A}_t^C)$ equals 1.

C. Calculating the equilibrium dynamics.

I describe the computational method to calculate the transitory dynamics between the steady states. To simplify the notation, I denote $\hat{q}_t - \hat{v}_{t+1}/(1+\hat{r}_t)$ by $\hat{u}_t$. I conduct the following iteration:

1. Calculate the steady states under the parameter values before and after the shock. The steady state before the shock provides the initial condition of the economy. Use the new steady-state values for $\hat{q}_0$, $\hat{v}_{t+1}$ and $\{\underline{A}_s^P, \overline{A}_s^C\}_{s=t-1}^t$ in the next step.

2. From date 0 onward, I calculate $\hat{u}_t$ and $\hat{r}_t$ from (9)-(14) until they converge to the new steady-state levels, given $\hat{q}_0$, $\hat{v}_{t+1}$ and $\{\underline{A}_s^P, \overline{A}_s^C\}_{s=t-1}^t$ obtained in the step 3 in the previous

iteration and $\hat{W}_{t-1}(\hat{A}_{t-1})$, $\hat{u}_{t-1}$ and $\hat{r}_{t-1}$ at each date t. $\hat{W}_{t-1}(\hat{A}_{t-1})$, $\hat{u}_{t-1}$ and $\hat{r}_{t-1}$ are updated forward within this step.

3. From the date of convergence toward date 0, I calculate $\hat{u}_t$, $\hat{r}_t$, $\underline{A}_t^P$ and $\overline{A}_t^C$ from (9)-(14) and (20)-(23), given $\hat{W}_{t-1}(\hat{A}_{t-1})$, $\hat{u}_{t-1}$ and $\hat{r}_{t-1}$ obtained in the step 2, $\underline{A}_{t-1}^P$ and $\overline{A}_{t-1}^C$ obtained in the previous step 3, and $\hat{q}_{t+1}$, $\hat{v}_{t+1}$ and $\lambda_{t+1}(\hat{A}_{t+1})$ at each date t. $\hat{q}_{t+1}$, $\hat{v}_{t+1}$ and $\lambda_{t+1}(\hat{A}_{t+1})$ are updated backward within this step. $\hat{q}_0$ is also calculated.

4. Check the convergence of the series of $\{\hat{u}_s,\ \hat{r}_s\}_{s=t}^{200}$ at the steps 2 and 3 to the series at the step 3 in the previous iteration. I find all the series in each iteration converge to the new steady-state by date 200. The convergence criterion is $1e-6$ in ratio. If they do not converge, return to the step 2.

By (20)-(23), I can show that the value of $\lambda_t(\hat{A}_t)$ only depends on $\{\hat{u}_s, \hat{r}_s\}_{s=t}^{\infty}$. Hence, I only need to check the convergence of $\{\hat{u}_s, \hat{r}_s\}_{s=0}^{\infty}$ in the step 4.

D. Calibration of the values for ρ, σ and θ

Fukao and Kwon report the productivity transition matrix for the continuing Japanese manufacturing firms between 1994 and 2001. Although ideally I should use the data for all the industries before 1990, the sample period of their data is for 1994-2001, and they only investigate the data of manufacturing firms. I construct a similar matrix for the agents who continue production for 7 dates at the steady state of the model, assuming the numbers of the agents across the productivity levels are distributed by a normal distribution at the steady state. Note that only the distribution of the agent's net-worth matters to the equilibrium of the model, and that any distribution of the numbers of agents across the productivity levels can be consistent with the equilibrium.

I obtain the values of ρ and σ and the mean and the variance of the distribution of the numbers of the agents by minimizing the difference between the matrices from the model and the data. Although the calibration implies ρ is close to 1, I choose to set $\rho = 0.9$. This is because the computation of the equilibrium is difficult when ρ is close to 1. 0.9 is a conservative choice for the value of ρ, because I find an endogenous fall in the TFP growth rate in response to the shocks to g and θ becomes larger as ρ is larger.

For the loan-to-value ratio of the mortgage loans, several banks reported their maxima in their annual reports. The banks I find are Daiichi-Kangyo, Higo, Jyu-Hachi, Kagoshima, Miyazaki, Nara, and Okinawa-Kaiho. The range of the reported loan-to-value ratios is between 56% and 80%. The numbers taken here were issued around 2000. Also, the Financial Service Agency of the Japanese government announces 70% as the healthy loan-to-value ratio in the guideline for their inspection of the banks' balance sheets. Hence, 0.1 is a conservative choice for the value of θ, implying that the loan-to-value ratio at the steady state is 81.6%.

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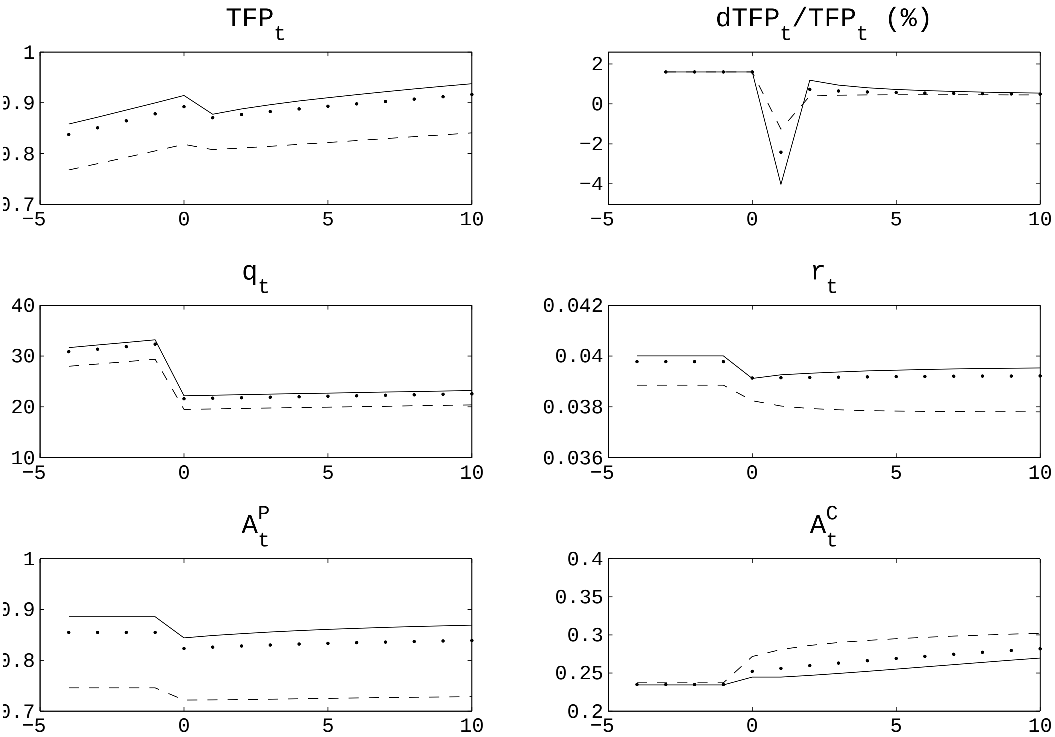
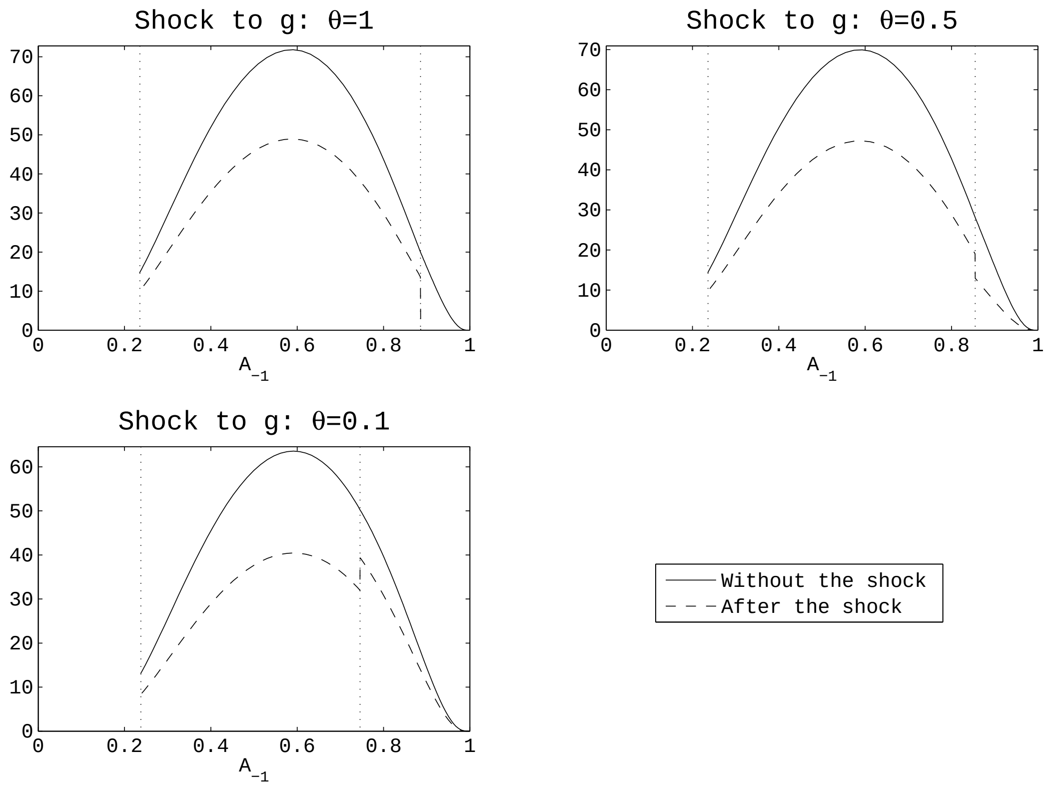
Figure 1: Dynamics of the model in response to the shock to g



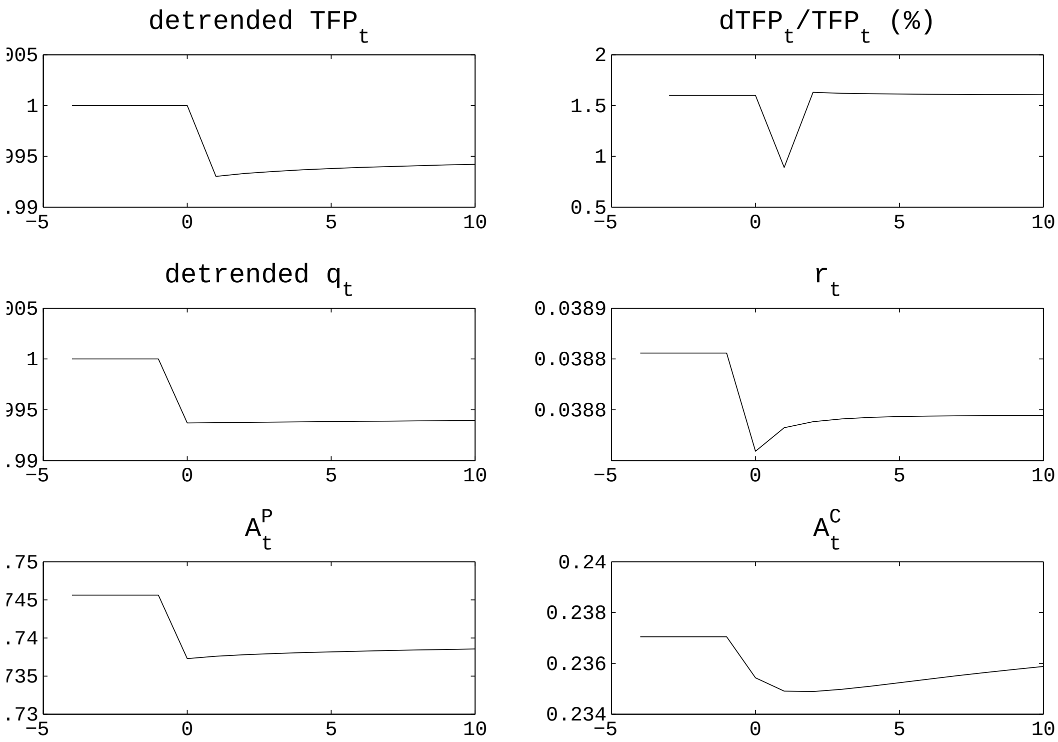
Note: The unit of the horizontal axis is a year. The solid line is for $\theta = 1$, the dotted line for $\theta = 0.5$ and the dashed line for $\theta = 0.1$.

Figure 2: Net-worth distribution at date 0 after the shock to g



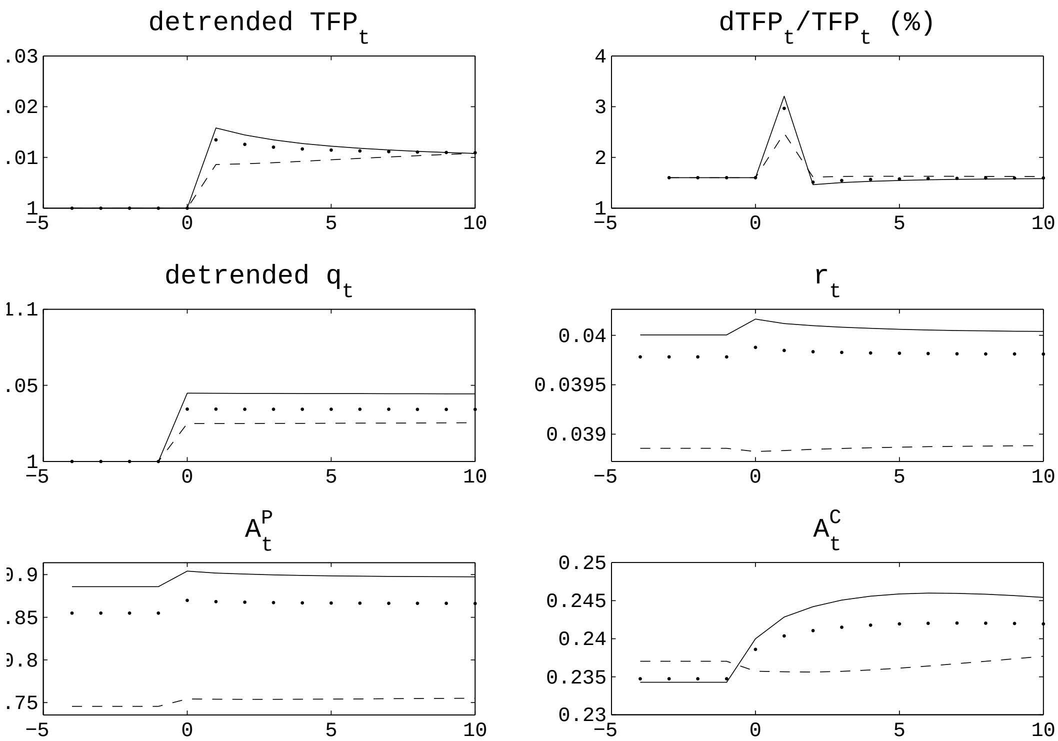
Note: The figure shows the net-worth distributions of the agents at date 0 over $\hat{A}_{-1}$ before the productivity transitions take place at date 0. The solid line is for the case without the shock to g, and the dashed line is for the case with the shock. The left and the right vertical dotted lines in each graph respectively indicate $\overline{A}^{C}_{-1}$ and $\underline{A}^{P}_{-1}$.

Figure 3: Dynamics of the model in response to the shock to θ



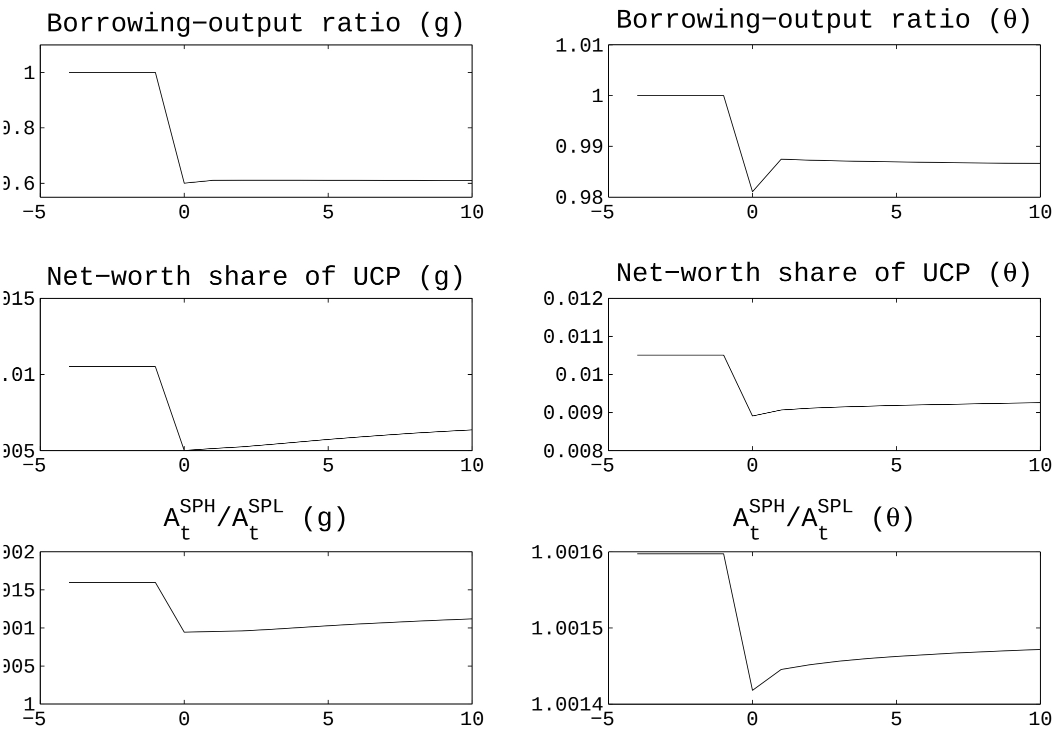
Note: The unit of the horizontal axis is a year. The detrended TFP_t and q_t are % deviations from the original trends before the shock.

Figure 4: Dynamics of the model in response to the shock to ρ



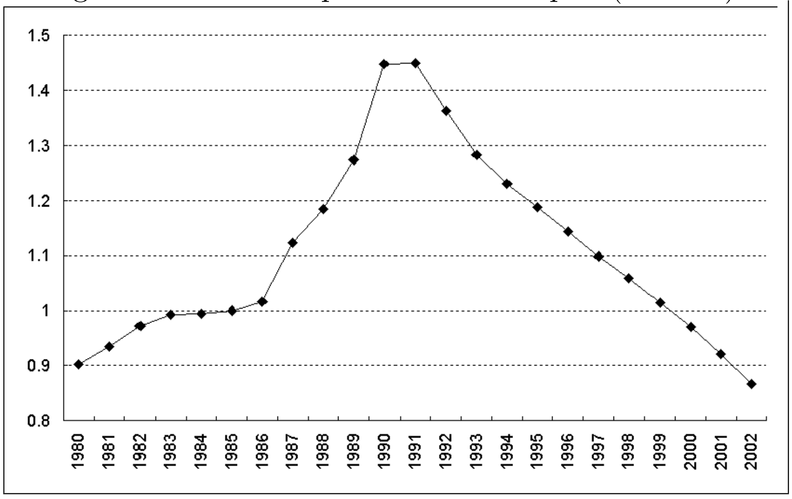
Note: The unit of the horizontal axis is a year. The solid line is for $\theta = 1$, the dotted line for $\theta = 0.5$ and the dashed line for $\theta = 0.1$. The detrended TFP_t and q_t are % deviations from the original trends before the shock.

Figure 5: Borrowing-output ratio, net-worth share of credit-unconstrained producers, and $\underline{A}_t^{SPH}/\underline{A}_t^{SPL}$ after the shock to g



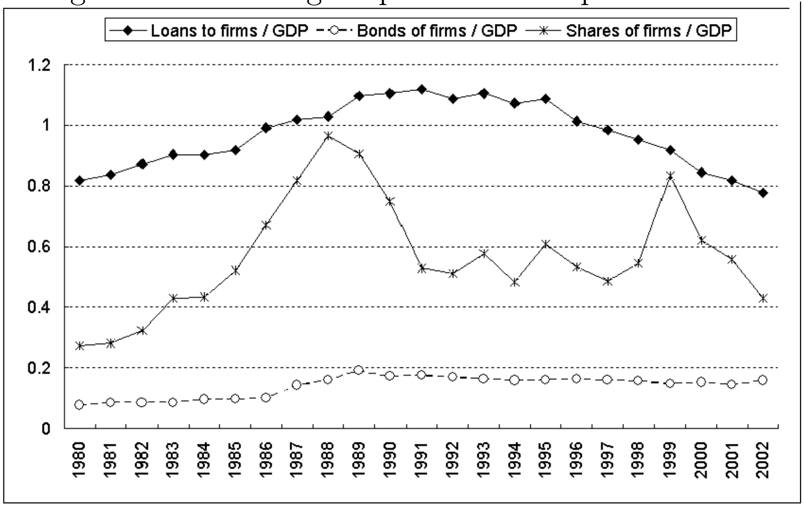
Note: The unit of the horizontal axis is a year. "Borrowing-Output ratio" is % deviation from the steady-state value before the shock. "Net-worth share of UCP" is the net-worth share of the agents between $\underline{A}_t^{SPL}$ and $\underline{A}_t^{SPH}$ making the initial investments. The left column is for the shock to g, and the right column for the shock to θ.

Figure 6: Real land price index in Japan (1985=1)



Source: Japan Real Estate Institute, and National Accounts.
Note: The real land price is the Nationwide City Land Price Index divided by the GDP deflator.

Figure 7: Borrowing-output ratio of Japanese firms



Source: National Accounts and Flow of Funds Statistics.
Notes: "Loans to firms", "Bonds of firms" and "Shares of firms" are taken from the aggregate liabilities of the private firms in Flow of Funds Statistics. Shares include private shares. The output is GDP.