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# Productivity Slowdown in Japan's Lost Decades: How Much of It Can Be Attributed to Damaged Balance Sheets?

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# Productivity Slowdown in Japan's Lost Decades: How Much of It Can Be Attributed to Damaged Balance Sheets?*

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**Abstract**

There are two opposing views on the cause of Japan's lost decades, which started in the early 1990s. One view argues that the lost decades were caused by a slowdown of total factor productivity (TFP) growth. The pioneering work by Hayashi and Prescott (2002) has shown that a standard growth model with the TFP decline accounts for the output slump during the lost decades. The other view emphasizes the role of damaged balance sheets of non-financial firms and financial intermediaries (FIs) due to two financial crises: the bubble burst in the early 1990s, and the banking crisis in the late 1990s. In this paper, we reconcile the two views. We construct a New Keynesian model that consists of balance sheets of non-financial firms and FIs, and estimate the model using Japanese data. We find that adverse shocks to balance sheets, in particular those to FI balance sheets, played a quantitatively significant role in lowering TFP. Based on our estimates, the average annual TFP growth rate during the 1990s would have been about twice as high as the actual TFP growth rate if these shocks had not occurred. We also find that shocks to FI balance sheets affected TFP mostly by exacerbating the inefficient allocation of production inputs in the goods-producing sector rather than by increasing the costs associated with financial intermediation.

Keywords: Lost Decades; Total Factor Productivity; Balance Sheet Problem

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# 1 Introduction

The Japanese economy has been burdened with persistent economic stagnation since the beginning of the 1990s, a period known as *the lost decades.* The output growth rate slowed during the early 1990s, and the economy never recovered its growth rate of the 1980s. There are two opposing views on the causes of the lost decades. One view emphasizes the role of the slowdown in total factor productivity (hereafter TFP) growth. Figure 1 shows the time path of TFP measured by the Solow residuals, and the time path of GDP. TFP grew steadily during the bubble boom period in the late 1980s, but then decelerated dramatically in the early 1990s, and continued growing at a low rate in subsequent years.[1] Hayashi and Prescott (2002), in their pioneering work, use the observed actual TFP series and feed the series into a standard growth model in which TFP moves only in response to exogenous technology movements, and show that the model accurately replicates the output slump during the early 1990s and beyond.[2]

The other view highlights the role played by balance sheets of financial intermediaries (FIs) and non-financial firms that were damaged as a result of the financial crises. There were two large financial crises: the bubble burst in February 1991, and the banking crisis that started in November 1997.[3] The first crisis was initiated by a decline in land and stock prices. As documented by Bayoumi (2001), FIs held a majority of their assets in stocks at that time, and non-financial firms held a large portion of their assets in land assets. Consequently, the collapse of asset prices eroded the balance sheets of both FIs and non-financial firms.[4] The second crisis came about with the materialization of bad loans

[1] The average TFP growth rate during the 1980s was 1.78% per year. By contrast, the growth rates during the following two decades were 0.77% and 0.31% per year, respectively.

[2] As in Hayashi and Prescott (2002), our TFP series is computed from the logarithm of output growth less the weighted average of the logarithm of labor input and capital input growth. There are, however, three differences between our TFP and theirs: (*i*) the output series that is used for constructing our TFP series is GDP series, while the output series used for constructing their TFP is GNP less government capital consumption; (*ii*) the capital stock series used for constructing our TFP is adjusted for capacity utilization of the capital stock, while the capital stock series used for constructing their TFP is not adjusted for capacity utilization; and (*iii*) households' residential and foreign assets are not included in our capital stock series, while these two components are included by Hayashi and Prescott (2002).

[3] Throughout this paper, we refer February 1991 as the period when the bubble economy burst. This is because it is the peak of the business cycle boom that started in the late 1980s. There is, however, no consensus regarding when the bubble economy ended. For instance, Okina, Shirakawa, and Shiratsuka (2001) consider the period from 1987 to 1990 as the "emergence and expansion of the bubble period," because simultaneous rise in stock and land prices, economic activity, and money supply was observed during the period.

[4] Figure 2 shows the time path of asset prices in the upper panel, and in the lower panel, the asset

from the years after the first crisis. Triggered by the failure of a securities house, Sanyo Securities—the first default in the history of the interbank market in Japan— the interbank market stopped functioning, and interest rates rose. A large number of financial institutions defaulted due to solvency problems.[5] Both episodes damaged balance sheets, in particular those of the FI sector, leading to a disruption in financial intermediation. Figure 3 shows the time series of the net worth of FIs and firms. In the two crisis periods, the net worth declined significantly, which indicates that their balance sheets were damaged. Figure 4 displays the time path of two diffusion indices. One index shows the financial position of non-financial firms, which is calculated by subtracting "tight" from "easy," and the other index shows the lending attitude of FIs, calculated by subtracting "severe" from "accommodative." Both series indicate that there were disruptions in financial intermediation at the time of the crises when the net worth of the two sectors was damaged.[6]

In this paper, we attempt to reconcile these two views.[7] We do this by examining two potential channels through which damaged balance sheets may lower TFP. The first channel is the direct consequence of disruptions to financial intermediation. A large number of firms and FIs faced repayment problems and defaulted as a result of damaged balance sheets. Other things being equal, an increase in borrower defaults or default probability affects the value-added of FIs not only by reducing the net interest flows from their assets, therefore directly reducing the value-added of FIs, but also by making financial intermediation less efficient ex-post, as it forces lenders to pay additional costs. This is because lenders need to intensify their monitoring of borrowers' activities or liquidate defaulting entities.[8,9]

holdings of financial institutions and non-financial institutions as of 1990, one year before the first financial crisis occurred. The two panels suggest that asset price declines severely damaged the balance sheets of these two sectors.

[5] See Nakaso (2001) and Hoshi and Kasyap (2010) for details of how the second crisis occurred.

[6] See the discussion in Peek and Rosengren (1997) regarding how the damaged balance sheets of FIs in Japan resulted in a reduction in FI lending to borrowers overseas.

[7] Some studies, such as Jinushi et al. (2000) point out that monetary policy was not sufficiently accommodative to offset the economic downturn during the early 1990s. Fujiwara et al. (2007) conduct a counter-factual simulation, using a large-scale dynamic general equilibrium model called the Japanese Economic Model (JEM) used in the Bank of Japan (BOJ), and examine if the downturn would have been moderate if the BOJ had implemented a more accommodative policy at that time. They found that the effects would have been quantitatively limited.

[8] See, for example, Berger and DeYoung (1997). They use the data of commercial banks in the US to show that high levels of non-performing loans Granger-causes reductions in measured cost efficiency, arguing that this observation is consistent with the extra costs of administering these loans.

[9] It is typically the case that the liquidation value is quite low. See, for example, Ramey and Shapiro (2001) for the case of an aerospace plant.

The efficiency of the FIs, that is the volume of financial intermediation made for given production inputs, also declines, as more resources are spent on these activities. The upper panel of Figure 5 shows the time path of credit cost relative to GDP, and that to total lending outstanding. The ratios started to increase from 1990, reached their peak around the period of the second financial crisis, and gradually declined in subsequent years. At its peak, the size of loan loss was equal to about 4% of GDP. Other things being equal, therefore, financial intermediation became less efficient during the lost decades. Another way to see this point is to look directly at the productivity of the FI sector. The lower panel of Figure 5 shows the productivity of the FI sector and that of total industries measured by EU KLEMS.[10,11] The decline in productivity from the 1980s to the lost decades is significantly larger in the FI sector than for total industries.

The second channel is the indirect effect originating from inefficient allocation of production inputs. Here, we borrow the argument made by Basu (1995). He argues that when an economy has three particular features, an input-output production structure, imperfect competition, and a countercyclical markup, a deflationary shock lowers TFP by reducing the efficient usage of intermediate inputs in goods production. Suppose that the damaged balance sheets of FIs weaken aggregate demand and cause deflation. This mechanism provides one other linkage between balance sheets and TFP slowdown. Figure 6 shows the time path of usage of intermediate goods and primary inputs. The decline in growth rates of intermediate goods from the 1980s to the 1990s onwards is larger than that of primary inputs, indicating that the substitution of production inputs actually occurred.

As shown in Figures 5 and 6, there is some evidence to suggest that the two channels played a role in TFP movements. Their quantitative impacts are, however, not directly measurable. We therefore construct a dynamic stochastic general equilibrium (DSGE) model that incorporates the two channels and assess them quantitatively by estimating the model using Japanese data. Our model is a standard New Keynesian sticky price model augmented with the financial accelerator framework developed by Bernanke, Gertler, and

[10] This productivity series is constructed from the logarithm of output growth less weighted average of the logarithm of labor input, and that of capital input. See EU KLEMS consortium (2007) for the detailed construction methodology. Unlike capital input series in our TFP series, capital input is not adjusted for capacity utilization.

[11] See also Jorgenson and Nomura (2007). They compute industry-level productivities in Japan and show that the productivity growth of the finance and insurance industry slowed down substantially during the early 1990s and beyond.

Gilchrist (1999, hereafter BGG), and the intermediate goods structure framework developed by Basu (1995). As in BGG, there are credit-constrained entrepreneurs that borrow from FIs. In contrast to BGG (1999), FIs are also credit-constrained, and they borrow from households, similar to Hirakata, Sudo, and Ueda (2011, 2013, hereafter HSU).[12] Therefore, there are two types of credit contracts: contracts between FIs and entrepreneurs, and those between FIs and households.[13] Because of the information asymmetry that is present between borrowers and lenders, the borrowing rate is negatively related to the size of the borrowers' net worth. When the borrowers' net worth is impaired, the lenders require a larger premium. The borrowers face a higher borrowing rate and become more likely to default. When the borrowers default, the lenders must pay additional costs to assess and seize the defaulting borrowers' assets. Following BGG (1999), we call this cost monitoring costs, and interpret them as the cost of bankruptcy.[14] Monitoring costs are paid in terms of goods, but not counted as a part of the GDP. Other things being equal, therefore, an increase in the monitoring costs reduces TFP. Regarding the second channel, in our model, there are three key features discussed in Basu (1995). The model exhibits endogenous falls in TFP in response to deflationary (non-technological) shocks, including negative shocks to net worth in FIs, entrepreneurs, or both. When balance sheets are damaged, inflation falls, increasing the markup of intermediate goods in the short-run. As a result, usage of intermediate input falls, lowering TFP.

We use Japanese data from 1980:2Q to 2011:4Q to estimate our model parameters, including the size of monitoring costs, and time series of structural shocks, including shocks to the balance sheets of FIs and the goods-producing sector.[15,16] We first show that the model with the estimated parameters delivers a substantial decline in TFP in response to a

[12]In terms of model structure, our model is close to Gertler and Kiyotaki (2010) and Gertler and Karadi (2011) as well as to HSU (2011 and 2013). The difference between these two models and our own is that our model provides channels through which FI balance sheet conditions affect not only GDP, or other GDP components, but also TFP.

[13]As we explain below, we make a technical assumption that households make credit contracts with the FI only indirectly through risk-neutral agents called investors. Investors collect households' deposits, lend them to FIs, and monitor FI activities on behalf of households.

[14]BGG (1999) discuss that this monitoring cost includes cost of auditing, accounting, and legal costs, as well as losses associated with asset liquidation and interruption of business.

[15]Because our estimation strategy is not able to take into account the non-linearity in monetary policy rules due to the zero lower bound of the monetary policy rate, we estimate parameters regarding the policy rules using time series data ending 1998:4Q.

[16]Throughout this paper, we use the term "shocks to the balance sheets" and "shocks to the net worth" interchangeably.

negative shock to the balance sheets of both FIs and the goods-producing sector, through the following two mechanisms. First, an increase in defaulting borrowing entities due to damaged balance sheets makes financial intermediation less efficient, resulting in lower output and TFP. Second, deflationary pressure caused by negative shocks to balance sheets leads the goods-producing sector to substitute away from intermediate goods inputs in its goods production and reduces TFP. Next, we investigate the quantitative significance of shocks to balance sheets by decomposing the actual TFP growth rate into the contribution of each of the fundamental shocks. We find that if the contribution of shocks to balance sheets had been absent, TFP growth rates during the 1990s would have been on average 0.81 percentage points higher than the actual TFP growth rate. In particular, we find that if the contribution of shocks to the balance sheets of FIs had been absent, TFP growth rates would have been on average 0.74 percentage points higher than the actual TFP growth rate. Given that the actual TFP growth rate during the 1990s was on average 0.77%, this means that TFP growth rate would have been almost twice as high as it actually was. We also compare the role of two channels, the monitoring costs channel and the production inputs channel. We find that the quantitative impact of the first channel was less than half the impact of the second. That is, while shocks to balance sheets played an important role in the TFP growth slowdown during the lost decades, their effects came mostly from the indirect channel rather than the direct channel.

Our findings are consistent with existing empirical studies that emphasize the importance of non-technological factors in accounting for the TFP slowdown. They include Nakakuki et al. (2004), Kwon et al. (2015), Kawamoto (2005), and Caballero, Hoshi, and Kashyap (2008). In particular, our study is closely related to the last two studies. Kawamoto (2005) constructs the purified Solow residuals of the Japanese economy following the construction methodology proposed by Basu, Fernald, and Kimball (2006). He reports that cyclical variations in the utilization of inputs, including intermediate inputs, have played an important role in lowering the observed TFP growth rate below that which does not take into account these variations. Our results extend the findings of Kawamoto (2005) in which shocks to balance sheets were found to play an important role in reducing the observed TFP decline. Caballero, Hoshi, and Kashyap (2008) propose an alternative channel through which banks' damaged balance sheets result in a lower level of TFP. They argue that with balance sheets damaged due to the collapse of asset prices, the fear of falling below the capital standards led banks to continue to extend credit to insolvent borrowers, and lowered productivity.[17] Though our model does not explicitly incorporate this zombie lending channel, our results concur with theirs in emphasizing the relationship between the damaged balance sheets of FIs and the TFP decline.

Our paper has two important implications for financial stability policy, such as macroprudential policy. First, it provides an alternative methodology to gauge the size of a financial crisis due to financial imbalances. Existing studies, including Boissay, Fabrice, and Smets (2016), gauge the size of a financial crisis by comparing the output decline during the crisis episode and that during the recession of the business cycle. This methodology however does not disentangle the output decline due to financial imbalances from that due to other factors such as policy reactions that have the potential to affect the size of the crisis. By contrast, using the structural model, we identify the size of a financial crisis due to financial imbalances, that is the portion of the output decline explained by shocks to balance sheets. Second, it provides the time path of shocks to balance sheets. Existing studies on macroprudential policy, such as Curdia and Woodford (2010) and Angelini, Neri, Panetta (2012), agree that it is important to identify the nature of the underlying shocks to conduct a better policy. This is because the choice of the optimal policy reaction depends on what type of shocks hit the economy in a specific period. The estimated time path of shocks obtained in this paper therefore provides a basis as to what sort of policy reaction was needed during the period.

This paper is divided into four sections, the first being this introduction. Section 2 describes our model. Section 3 estimates our model using Japanese data and shows how TFP in our model responds to shocks to balance sheets of the FI and the goods-producing sectors. It also assesses the quantitative contribution of shocks to balance sheets on the TFP slowdown in Japan during the early 1990s and beyond. Section 4 draws some conclusions.

## 2 The economy

The economy consists of four sectors: the household sector, the financial intermediary (FI) sector, the goods-producing sector, and the government sector. The household sector

[17] Based on an analysis of plant-level micro data of manufacturers in Japan, Kwon et al. (2015) argue that extensive use of primary inputs, in particular labor inputs, by zombie firms caused aggregate productivity to decline.

consists of a continuum of households and investors. Each household supplies labor inputs to the goods-producing sector, earns wages, makes deposits to the investors, and receives repayments in return. The investors collect deposits from the households at risk-free rates and lend them to the FI sector by making credit contracts with the FI sector, which we call IF contracts. The FIs raise external funds from the investors through the IF contracts and lend these funds, as well as their net worth, to the entrepreneurs in the goods-producing sector by making credit contracts, which we call FE contracts. The goods-producing sector consists of the entrepreneurs, the capital goods producers, and the goods producers. The entrepreneurs raise external funds from the FIs, purchase capital goods from the capital goods producers, and lend them to the goods producers for the rental price. The capital goods producer purchases final goods from the goods producers and converts them into capital goods. The goods producers produce goods from labor inputs, capital inputs, and intermediate goods. The government sector consists of the government, which collects taxes from households and spends it on government purchases, and the central bank, which adjusts the nominal interest rate so as to stabilize the inflation rate. An outline of the model structure is shown in Figure 7.

## 2.1 Credit contracts

We borrow the settings of credit contracts from HSU (2011, 2013) and Christiano, Motto, and Rostagno (2014, hereafter CMR), which incorporate the model of BGG (1999) in a full-fledged dynamic stochastic general equilibrium model. Credit contracts, both IF and FE contracts, are chosen by an FI so as to maximize its profits. For convenience, we start by explaining the structure of each of the contracts and explain the profit maximization problem faced by FIs. An outline of the credit contracts is shown in Figure 8.

### 2.1.1 FE contracts

**Setting**

In period $t$, each type $i$ FI offers a loan contract to an infinite number of group $j_i$ entrepreneurs.[18] An entrepreneur in group $j_i$ owns net worth $N_{E,j_i,t}$ and purchases capital

[18] We assume that the size of the monitoring cost associated with the credit contracts between a type $i$ FI and group $j_{i^*}$ entrepreneurs for $i \neq i^*$ is so high that group $j_{i^*}$ entrepreneurs do not choose to raise funds from a type $i$ FI. By the same assumption, a direct credit contract between the investors and the entrepreneurs is left out from our analysis.

of $Q_t K_{j_i,t}$, where $Q_t$ is the price of capital and $K_{j_i,t}$ is the quantity of capital purchased by a group $j_i$ entrepreneur. If the net worth $N_{E,j_i,t}$ is smaller than the amount of the capital purchase $Q_t K_{j_i,t}$, the entrepreneur raises the rest of the fund $Q_t K_{j_i,t} - N_{E,j_i,t}$ by making a credit contract with the type $i$ FI.[19] In period $t+1$, a group $j_i$ entrepreneur receives return of $R_{E,t+1}\omega_{E,j_i,t+1}$ from holding the capital $K_{j_i,t}$, where $R_{E,t+1}$ is the aggregate return on capital and $\omega_{E,j_i,t+1}$ is an idiosyncratic productivity shock that is specific to the group $j_i$ entrepreneurs.[20] There are informational asymmetries, and a type $i$ FI cannot observe the realization of its borrower's idiosyncratic shock $\omega_{E,j_i,t+1}$, unless it pays the monitoring cost. As in the conventional costly state verification problem, a type $i$ FI specifies:

- the amount of debt that a group $j_i$ entrepreneur borrows from a type $i$ FI, $Q_t K_{j_i,t} - N_{E,j_i,t}$, and
- the cut-off value of idiosyncratic productivity shock $\omega_{E,j_i,t+1}$, which we denote by $\overline{\omega}_{E,j_i,t+1}$, such that a group $j_i$ entrepreneur repays its debt if $\omega_{E,j_i,t+1} \geq \overline{\omega}_{E,j_i,t+1}$ and declares a default if otherwise.

**Entrepreneur's participation constraint**

A group $j_i$ entrepreneur joins an FE contract only when the return from joining the contract is at least equal to the opportunity cost. In the FE contract, if the entrepreneur does not default, *ex post,* it receives

$$\left(\omega_{E,j_i,t+1} - \overline{\omega}_{E,j_i,t+1}\right) R_{E,t+1} Q_t K_{j_i,t}.$$

The entrepreneurial loan rate $r_{E,j_i,t+1}$ is therefore given by

$$r_{E,j_i,t+1} \equiv \frac{\overline{\omega}_{E,j_i,t+1} R_{E,t+1} Q_t K_{j_i,t}}{Q_t K_{j_i,t} - N_{E,j_i,t}}. \tag{1}$$

Instead of participating in the contract, a group $j_i$ entrepreneur can purchase capital using its own net worth $N_{E,j_i,t}$ and receive the return from holding the capital. In this case,

[19] As in BGG (1999), we assume below that net worth does not accumulate infinitely and that the entrepreneurs always raise external funds at the equilibrium. The same argument applies to FIs in the IF contracts.

[20] Following BGG (1999), the idiosyncratic productivity shock is a unit mean, lognormal random variable distributed independently over time and across entrepreneurs. We express its density function by $f_E(\bullet)$ and its cumulative distribution function by $F_E(\bullet)$.

*ex ante,* the entrepreneur expects to receive the earning $\mathrm{E}_t\left[\omega_{E,j_i,t+1}R_{E,t+1}N_{E,j_i,t}\right]$, which is equal to $\mathrm{E}_t\left[R_{E,t+1}N_{E,j_i,t}\right]$, and *ex post* it receives the earning $\omega_{E,j_i,t+1}R_{E,t+1}N_{E,j_i,t}$. The FE contract is agreed by a group $j_i$ entrepreneur therefore only when the following inequality holds:

$$\mathrm{E}_t\left[\left(\int_{\overline{\omega}_{E,j_i,t+1}}^{\infty}\left(\omega_E-\overline{\omega}_{E,j_i,t+1}\right)dF_E\left(\omega_E\right)\right)R_{E,t+1}Q_tK_{j_i,t}\right]\geq \mathrm{E}_t\left[\omega_{E,j_i,t+1}R_{E,t+1}N_{E,j_i,t}\right]\text{ for }\forall j_i. \tag{2}$$

Note that $\mathrm{E}_t$ is the expectation operator.

**FIs' earning from FE contracts**

The earning of a type $i$ FI from FE contracts is repayments from non-defaulting entrepreneurs minus monitoring cost paid to assess defaulting entrepreneurs' assets. The expected earnings of a type $i$ FI from FE contracts with group $j_i$ entrepreneurs is thus described as follows

$$\mathrm{E}_t\left[\Phi_{E,i,t+1}R_{E,t+1}Q_tK_{j_i,t}\right],$$

where

$$\Phi_{E,i,t+1}\equiv\int_{\overline{\omega}_{E,j_i,t+1}}^{\infty}\overline{\omega}_{E,j_i,t+1}dF_E\left(\omega_E\right)+\int_0^{\overline{\omega}_{E,j_i,t+1}}\omega_E dF_E\left(\omega_E\right)-\mu_E\int_0^{\overline{\omega}_{E,j_i,t+1}}\omega_E dF_E\left(\omega_E\right). \tag{3}$$

$\Phi_{E,i,t+1}$ in the equation (3) has three terms. The first term stands for the repayment made by the non-defaulting entrepreneurs, the second term stands for realized returns of the defaulting entrepreneurs, and the third term stands for the monitoring cost that the FI pays. The total monitoring cost paid by the FI is given by the third term multiplied by $R_{E,t+1}Q_tK_{j_i,t}$, and the parameter $\mu_E$ governs the size of the monitoring cost.

It is also notable that because of constant returns to scale in production and monitoring technology, a type $i$ FI makes contracts with an infinite number of group $j_i$ entrepreneurs with the same size of cut-off value $\overline{\omega}_{E,j_i,t+1}$. In the discussion below, therefore, we drop the subscript $j_i$.

#### 2.1.2 IF contracts

**Setting**

An IF contract is made between an investor and a continuum of the FIs. As explained above, in period $t$, each type $i$ FI, holding the net worth $N_{F,i,t}$, makes loans to group $j_i$ entrepreneurs at an amount of $Q_t K_{i,t} - N_{E,i,t}$, where $K_{i,t}$ is the total amount of capital purchased by group $j_i$ entrepreneurs, and $N_{E,i,t}$ is the total amount of net worth held by group $j_i$ entrepreneurs. An FI $i$'s net worth is smaller than its loans to the entrepreneurs and it raises the external funds $Q_t K_{i,t} - N_{E,i,t} - N_{F,i,t}$ from the investor. After receiving earnings from the FE contracts, an FI is hit by an idiosyncratic productivity shock $\omega_{F,i,t+1}$ that represents technological differences across FIs regarding, for example, those associated with management of credit and liquidity risk or loan securitization. Consequently, *ex post,* the FI's revenue from the FE contracts after the realization of the idiosyncratic productivity shock is given by[21]

$$\omega_{F,i,t+1} \Phi_{E,i,t+1} R_{E,t+1} Q_t K_{i,t}.$$

There are informational asymmetries between the investor and the FI. The investor can observe the realization of the idiosyncratic shock only if it pays the monitoring cost. Under these circumstances, as with FE contracts, the IF contract specifies:

- the amount of debt that a type $i$ FI borrows from the investor, $Q_t K_{i,t} - N_{E,i,t} - N_{F,i,t}$, and
- the cut-off value of idiosyncratic shock $\omega_{F,i,t+1}$, which we denote by $\overline{\omega}_{F,i,t+1}$, such that the FI repays its debt if $\omega_{F,i,t+1} \geq \overline{\omega}_{F,i,t+1}$ and declares a default if otherwise.

As a result of the IF contracts, a portion of the FIs $\int_{\overline{\omega}_{F,i,t+1}}^{\infty} dF_F(\omega_F)$ do not default, while the remainder default. *Ex post,* a default FI $i$ receives nothing and a non-default FI $i$ receives the earnings shown below:

$$\left(\omega_{F,i,t+1} - \overline{\omega}_{F,i,t+1}\right) \Phi_{E,i,t+1} R_{E,t+1} Q_t K_{i,t}. \tag{4}$$

[21] We assume that the FI's idiosyncractic productivity shock is a unit mean, lognormal random variable distributed independently over time and across type $i$ FI. Its density function and its cumulative distribution function are given by $f_F(\bullet)$ and $F_F(\bullet)$, respectively.

The loan rate that is paid by a non-default FI $i$ to an investor is therefore given by

$$r_{F,i,t+1} \equiv \frac{\overline{\omega}_{F,i,t+1}\Phi_{E,i,t+1}R_{E,t+1}Q_tK_{i,t}}{Q_tK_{i,t} - N_{E,i,t} - N_{F,i,t}}. \tag{5}$$

**Investor's participation constraint**

An investor participates in an IF contract only when the IF contract is more advantageous. Denoting the risk-free rate in the economy by $R_t$, an investor's net receipt from the IF contracts must at least equal the return from a risk-free investment. That is for $\forall i$,

$$\Phi_{F,i,t+1}\Phi_{E,i,t+1}R_{E,t+1}Q_tK_{i,t} \geq R_t\left[Q_tK_{i,t} - N_{E,i,t} - N_{F,i,t}\right], \tag{6}$$

where

$$\Phi_{F,i,t+1} \equiv \int_{\overline{\omega}_{F,i,t+1}}^{\infty} \overline{\omega}_{F,i,t+1} dF_F\left(\omega_F\right) + \int_0^{\overline{\omega}_{F,i,t+1}} \omega_F dF_F\left(\omega_F\right) - \mu_F \int_0^{\overline{\omega}_{F,i,t+1}} \omega_F dF_F\left(\omega_F\right). \tag{7}$$

$\Phi_{F,i,t+1}$ has a similar structure to $\Phi_{E,i,t+1}$, as shown in the equation (3). In particular, it is notable that the third term of $\Phi_{F,i,t+1}$ multiplied by the term $\Phi_{E,i,t+1}R_{E,t+1}Q_tK_{i,t}$ shows the total amount of monitoring cost paid by an investor. These costs are used to monitor the outputs of defaulting FIs rather than those of defaulting entrepreneurs.[22][23]

### 2.1.3 Optimal credit contracts chosen by FIs

At the end of period $t$, given its own net worth $N_{F,i,t}$ and entrepreneurial net worth $N_{E,i,t}$, a type $i$ FI chooses the terms of the IF and FE contracts so as to maximize its expected profit at the end of the period $t+1$. The terms consist of the amount of loans $Q_tK_{i,s} - N_{E,i,s}$ and borrowings $Q_tK_{i,t} - N_{E,i,t} - N_{F,i,t}$, and the cut-off values $\overline{\omega}_{F,i,t+1}$ and $\left\{\overline{\omega}_{E,j_i,t+1}\right\}_{j_i=1}^{\infty}$. As shown in equation (4), the FI's expected profit is given by the FI's revenue minus

[22] The two terms $\Phi_{F,i,t}$ and $\Phi_{E,i,t}$ are interpreted as the net share of profits going to the lender in the IF and FE contracts respectively.

[23] It is important to note that, as in BGG (1999), we assume that both FE and IF contracts are contingent on aggregate states and the participation constraints (2) and (6) hold with equality state by state. See for example footnote 16 of CMR (2014) for a related discussion. Regarding the IF contracts, we further assume that investors face perfect competition, and at the equilibrium, their earnings from the IF contracts are equal to the amount of repayment to households in every state of the economy.

repayment to investors:

$$\mathrm{E}_t \left[ \left( \int_{\overline{\omega}_{F,i,t+1}}^{\infty} \left( \omega_F - \overline{\omega}_{F,i,t+1} \right) dF_F \left( \omega_F \right) \right) \Phi_{E,i,t+1} R_{E,t+1} Q_t K_{i,t} \right] \tag{8}$$

The FI maximizes the term (8) subject to the investor's participation constraint (6) and entrepreneurial participation constraint (2) for all of the group $j_i$ entrepreneurs. As discussed in HSU (2011, 2013) and Ueda (2012), because of constant returns to scale in production and monitoring technology, the expected profit of a type $i$ FI is the same as that of other types of FIs. In what follows, therefore, we drop the subscript $i$ as well.

#### 2.1.4 Dynamic behavior of net worth

The main source of net worth accumulation for the FIs and the entrepreneurs is the earnings from the credit contracts discussed above. In addition, there are two other sources of earnings. First, the FIs and entrepreneurs inelastically supply a unit of labor to the goods producers and receive in return labor income that is depicted by $W_{F,t}$ and $W_{E,t}$, respectively.[24] Second, the net worth accumulation is affected by exogenous disturbances $\varepsilon_{N_{F,t+1}}$ and $\varepsilon_{N_{E,t+1}}$. These shocks are i.i.d. and orthogonal to the earnings from the credit contracts. Existing studies, such as Gilchrist and Leahy (2002) and Nolan and Thoenissen (2009), have already given interpretations of this class of shocks. The interpretations include "asset bubble and burst of asset bubble," "irrational exuberance," or an "innovation in the efficiency of credit contracts." Our preferred interpretation is that they capture shocks to balance sheets of FIs and the goods-producing sector that occurred in the two financial crises. The aggregate net worths of the FIs and the entrepreneurs then evolve according to equations below:

$$N_{F,t+1} = \gamma_F V_{F,t+1} + \frac{W_{F,t}}{P_t} + \varepsilon_{N_{F,t+1}}, \text{ and} \tag{9}$$

$$N_{E,t+1} = \gamma_E V_{E,t+1} + \frac{W_{E,t}}{P_t} + \varepsilon_{N_E,t+1}, \tag{10}$$

with

[24] See BGG (1999) for the reason for introducing inelasitc labor supply from the FIs and the entrepreneurs.

$$V_{F,t+1} \equiv (1-\Gamma_F(\overline{\omega}_{F,t+1}))\,\Phi_E(\overline{\omega}_{E,t+1})\,R_{E,t+1}Q_tK_t, \text{ and}$$
$$V_{E,t+1} \equiv (1-\Gamma_E(\overline{\omega}_{E,t+1}))\,R_{E,t+1}Q_tK_t,$$

where

$$\Gamma_F(\overline{\omega}_{F,t+1}) \equiv \int_{\overline{\omega}_{F,t+1}}^{\infty} \overline{\omega}_{F,t+1}dF_F(\omega_F) + \int_0^{\overline{\omega}_{F,t+1}} \omega_F dF_F(\omega_F), \text{ and}$$
$$\Gamma_E(\overline{\omega}_{E,t+1}) \equiv \int_{\overline{\omega}_{E,t+1}}^{\infty} \overline{\omega}_{E,t+1}dF_E(\omega_E) + \int_0^{\overline{\omega}_{E,t+1}} \omega_E dF_E(\omega_E).$$ [25]

Here, $P_t$ denotes the nominal price of consumption goods. Note that we assume that FIs and entrepreneurs survive into the next period with a probability $\gamma_F$ and $\gamma_E$, and those who are in business in period $t$ and fail to survive into period $t+1$ consume $(1-\gamma_E)V_{E,t+1}$ and $(1-\gamma_F)V_{F,t+1}$ and exit from the economy.

## 2.2 Households

### Settings

There is a continuum of households indexed by $h \in [0,1]$. A household $h$ is an infinitely-lived representative agent with preferences over consumption $C_t(h)$ and labor input $L_t(h)$ as described in the expected utility function, (11)

$$U_t \equiv \mathrm{E}_t\left[\sum_{s=0}^{\infty}\beta^q\left[\ln(C_{t+q}(h)) - \varphi\frac{L_{t+q}(h)^{1+v}}{1+v}\right]\right], \tag{11}$$

where $\beta \in (0,1)$ is the discount factor, $v > 0$ is the inverse of the Frisch labor-supply elasticity, and $\varphi$ is the weighting assigned to leisure. The budget constraint for household $h$ is given by

$$C_t(h) + S_t(h) \leq \left[\begin{array}{c} \frac{W_t(h)L_t(h)}{P_t} - \frac{\kappa_w}{2}\left(\frac{W_t(h)}{W_{t-1}(h)} - 1\right)^2\frac{W_tL_t}{P_t} \\ +R_{t-1}S_{t-1}(h) + \frac{\Omega_t(h)-\tau_t(h)}{P_t} \end{array}\right], \tag{12}$$

where $S_{t-1}(h)$ is the real saving, $R_t$ is the real interest rate on deposit, $\Omega_t(h)$ is the nominal profit returned to the household, and $\tau_t$ is the lump-sum nominal tax taken by the government. $W_t(h)$ is the nominal wage set by a household $h$ and $W_t$ is the aggregate index of the nominal wage. The second term in the right hand side of the equation stands for the nominal cost associated with adjusting nominal wage $W_t(h)$, and $\kappa_w$ is the parameter that governs the size of the adjustment cost.

**Labor supply decision**

A household $h$ has monopolistic power in its differentiated labor input $L_t(h)$. The demand of the differentiated labor is given by

$$L_t(h) = \left(\frac{W_t(h)}{W_t}\right)^{-\theta_{W,t}} L_t, \tag{13}$$

where $L_t$ is the aggregate index of labor inputs that is defined as

$$L_t = \left[\int_0^1 L_t(h)^{(\theta_{W,t}-1)/\theta_{W,t}}\, dh\right]^{\theta_{W,t}/(\theta_{W,t}-1)},$$

where $\theta_{W,t} \in (1, \infty)$ is the time-varying elasticity of labor demand for differentiated labor input with respect to wages.

## 2.3 Goods producers

**Settings**

The goods producers are standard except that the goods they produce serve not only as final goods but also as intermediate goods, as in Huang et al.(2004), and goods used for financial intermediation activity, as in CMR (2014). We assume that the goods-producing sector comprises a continuum of firms, each producing differentiated products, as indexed by $l \in [0, 1]$. We use $Y_{g,t}$ to denote the gross output of composite that is produced from the differentiated products $\{Y_{g,t}(l)\}_{l\in[0,1]}$. The production function of the composite is

$$Y_{g,t} = \left[\int_0^1 Y_{g,t}(l)^{(\theta_{P_Y,t}-1)/\theta_{P_Y,t}}\, dl\right]^{\theta_{P_Y,t}/(\theta_{P_Y,t}-1)},$$

where $\theta_{P_Y,t} \in (1, \infty)$ denotes the time-varying elasticity of substitution between differentiated products. The composite is produced by an aggregator that faces perfect competition. The demand function for the differentiated product produced by firm $l$ is derived from the optimization behavior of the aggregator and is represented by

$$Y_{g,t}(l) = \left[\frac{P_t(l)}{P_t}\right]^{-\theta_{P_Y,t}} Y_{g,t}, \tag{14}$$

where $\{P_t(l)\}_{l\in[0,1]}$ is the nominal price of the differentiated products. These prices are related to the nominal price of the final goods by

$$P_t = \left[\int_0^1 P_t(l)^{1-\theta_{P_Y,t}}\, dl\right]^{\frac{1}{1-\theta_{P_Y,t}}}.$$

The composite serves either as final goods, such as consumption goods and investment goods, as intermediate production inputs, or as goods that are used for financial intermediation activity, namely monitoring costs. The allocation of the gross output is given by

$$\begin{aligned} Y_{g,t} \;=\; & C_t + \frac{I_t}{A_{I,t}} + G_t + \int_0^1 \Psi_t(l)\, dl + \frac{\left(\kappa_U (A_{U,t}U_t)^{\gamma_U+1} - 1\right)}{\Upsilon_U + 1} K_{t-1} \\ & + \mu_E \left(\int_0^{\overline{\omega}_{E,t}} \omega_E dF_E(\omega_E)\right) R_{E,t} Q_{t-1} K_{t-1} + \mu_F \left(\int_0^{\overline{\omega}_{F,t}} \omega_F dF_F(\omega_F)\right) \Phi_{E,t} R_{E,t} Q_{t-1} K_{t-1} \\ & + (1-\gamma_F) V_{F,t} + (1-\gamma_E) V_{E,t}. \end{aligned} \tag{15}$$

where $I_t$ is aggregate investment, $A_{I,t}$ is investment specific technology, $G_t$ is government expenditure, and the fourth term represents intermediate production inputs used by the differentiated firms. The fifth term is the adjustment cost associated with the capacity utilization rate of capital inputs, which will be discussed below. It is notable that, as in CMR (2014), the composite is used in monitoring costs as well. The monitoring costs are shown in the seventh and eighth terms. The last two terms are resources consumed by the exiting FIs and entrepreneurs, respectively.

**Production function**

The inputs used by a differentiated firm are labor, capital, and intermediate inputs. The production function of a firm $l$ is given by

$$Y_{g,t}(l) = Z_t A_t \Psi_t(l)^{\gamma} \left[L_t(l)^{\alpha}\right]^{1-\gamma} \left[(K_{t-1}(l)\, U_t(l))^{1-\alpha-\alpha_E-\alpha_{FI}}\right]^{1-\gamma} - F_t \tag{16}$$

Here, $Z_t$ is a non-stationary component of technology, and $A_t$ is a stationary component of technology. $L_t(l)$, $K_{t-1}(l)$ ,and $U_t(l)$ are labor inputs, capital stock, and capacity utilization rate of the capital stock in firm $l$. Parameters $\gamma$ and $\alpha$ are the cost share of intermediate inputs and labor inputs, respectively, and $F_t$ is a fixed cost which is exogenous to firms.[26]

Firms in the goods-producing sector are price-takers in the input markets. The cost-minimization problem of firm $l$ therefore yields the following marginal cost function $MC_t(l)$:

$$MC_t(l) = \frac{\bar{\phi} P_t^{\gamma}}{A_t Z_t} \left[ W_t^{\alpha} W_{E,t}^{\alpha_E} W_{F,t}^{\alpha_{FI}} \tilde{R}_{E,t}^{1-\alpha-\alpha_E-\alpha_{FI}} \right]^{1-\gamma}, \tag{17}$$

where $\bar{\phi}$ is a constant and $\tilde{R}_{E,t}$ is the nominal gross return to capital inputs, $K_{t-1}(l)\, U_t(l)$.

The total capacity utilization rate of capital stock is determined by entrepreneurs. We assume that entrepreneurs need to pay the real cost of

$$\frac{\kappa_U \left(A_{U,t} U_t\right)^{\Upsilon_U+1} - 1}{\Upsilon_U + 1},$$

in choosing the capacity utilization rate of capital $U_t$. Here $\kappa_U$, $\Upsilon_U$ are parameters and $A_{U,t}$ represents the technology for adjusting the capacity utilization rate. The real net return on capital $K_{t-1}$ received by the entrepreneurs can then be expressed by the following equation.

$$R_{E,t} = \frac{\frac{U_t \tilde{R}_{E,t}}{P_t} - \frac{\left(\kappa_U \left(A_{U,t} U_t\right)^{\Upsilon_U+1} - 1\right)}{\Upsilon_U+1} + (1-\delta)\, Q_t}{Q_{t-1}}.$$

**Price setting**

Differentiated firms in the goods-producing sector are monopolistic competitors in the products market. A firm $l$ sets the price for its products $P_t(l)$ in reference to the demand given by (14) . It can reset the prices solving the following problem:

[26] Following Huang et al. (2004) and CMR (2010, 2014), the size of the fixed cost $F_t$ is set so that the profits from operating in the goods-producing sector are zero at the steady state. Following CMR (2010, 2014), we further assume that the fixed cost $F_t$ exogenously grows at the same growth rate as does the non-stationary component of $Y_{g,t}(l)$ , that is $Z_t^{\frac{1}{\alpha(1-\gamma)}}$ , and that firms stop producing goods if the fixed cost exceeds the first term of the equation 16.

$$\max_{P_t(l)} \mathrm{E}_t \left[ \sum_{q=0}^{\infty} \beta^{t+q} \frac{\Lambda_{t+q}}{\Lambda_t} \frac{\Pi_{t+q}(l)}{P_{t+q}} \right] \tag{18}$$

$$s.t.\ \Pi_{t+q}(l) = P_{t+q}(l) Y_{g,t+q}(l) - MC_{t+q}(l) \left(Y_{g,t+q}(l) + F\right) - \frac{\kappa_p}{2} \left( \frac{P_{t+q}(l)}{P_{t+q-1}(l)} - 1 \right)^2 P_{t+q} Y_{g,t+q} \tag{19}$$

where $\Lambda_{t+q}$ is the Lagrange multiplier associated with budget constraint (12) in period $t+q$, and $\kappa_p$ is the parameter associated with price adjustment.

## 2.4 Capital goods producer

Capital goods producers purchase final goods $I_t/A_{I,t}$ from goods producers, convert them to capital goods $K_t$, using technology $F_{I,t}$, and sell them to the entrepreneurs at price $Q_t$. The capital goods producers' problem is to maximize the profit function as shown below:

$$\max_{I_t} \mathrm{E}_t \left[ \sum_{q=0}^{\infty} \beta^{t+q} \frac{\Lambda_{t+q}}{\Lambda_t} \left[ Q_{t+q} \left( K_{t+q} - (1-\delta) K_{t+q-1} \right) - \frac{I_{t+q}}{A_{I,t+q}} \right] \right].$$

Capital depreciates in each period and the total capital evolves as follows:

$$K_t = \left(1 - F_I(I_t, I_{t-1})\right) I_t + (1-\delta) K_{t-1}, \tag{20}$$

where $F_I$ is defined as follows:

$$F_I(I_{t+q}, I_{t+q-1}, Z_{I,t+q}) \equiv \frac{\kappa_I}{2} \left( \frac{I_{t+q} Z_{I,t+q}}{I_{t+q-1}} - 1 \right)^2.$$

Here, $\delta \in (0,1)$ is the depreciation rate of the capital stock, and $\kappa_I$ and $Z_{I,t+q}$ are the constant and the time-varying components of investment adjustment cost, respectively.[27]

## 2.5 Defining aggregate variables

As with CMR (2010), the real GDP $Y_t$ in the model is given as follows:

[27] Note that a term for used capital $K_t$ sold by the entrepreneurs at the end of the period $t-1$ to the capital goods producers does not appear in this equation. This is because, following BGG (1999), we assume that the price of capital that the entrepreneurs sell back to the capital goods producers, say $\overline{Q}_t$, is close to the price of newly produced capital $Q_t$ around the steady state.

$$Y_t = C_t + \frac{I_t}{A_{I,t}} + G_t, \tag{21}$$

The CPI $\pi_t$ is defined by

$$\pi_t = \frac{P_t}{P_{t-1}}. \tag{22}$$

The real interest rate $R_t$ is given by the Fisher equation that connects the nominal interest rate $R_{n,t}$ and the expected inflation $\mathrm{E}_t[\pi_{t+1}]$:

$$R_t = \frac{R_{n,t}}{\mathrm{E}_t[\pi_{t+1}]}.$$

The aggregate TFP $\lambda_t$ in the model is measured as below following a conventional treatment:

$$\lambda_t = \frac{Y_t}{(L_t)^{\psi_L} (K_{t-1}U_t)^{1-\psi_L}}, \tag{23}$$

where $\psi_L$ is the steady state labor share of income.

## 2.6 Government sector

The government collects a lump-sum tax $\tau_t$ from households to finance government purchase $P_tG_t$ whose amount is exogenously given. We assume that a balanced budget is maintained in each period $t$ as follows:

$$P_tG_t = \tau_t$$

The central bank adjusts the policy rate according to the following Taylor rule:

$$R_{n,t} = R_{n,t-1}^{\rho} \pi_t^{(1-\rho)\varphi_\pi} \exp(\epsilon_{R_n,t}). \tag{24}$$

Here, $\rho \in (0,1)$ is the persistency parameter of the monetary policy rule, $\varphi > 1$ is the policy weight attached to the inflation rate and $\epsilon_{R_n,t}$ is an i.i.d. shock to the rule.

## 2.7 Fundamental shocks

We consider eleven fundamental shocks. There are three classes of shocks: technology shocks in the goods-producing sector, financial shocks, and other shocks. The first class of shocks includes shocks to the stationary and non-stationary components of technology in the goods producers' production function $Z_t$ and $A_t$. The second class of shocks includes shocks to net worth in the FI and goods-producing sectors $\varepsilon_{N_F,t}$ and $\varepsilon_{N_E,t}$. The third class of shocks includes shocks to investment-specific technology $A_{I,t}$, technology for capacity utilization of capital inputs $A_{U,t}$, government spending $G_t$, the investment adjustment cost $Z_{I,t}$, the price markup $\theta_{P_Y,t}$, and the wage markup $\theta_{W,t}$ as well as i.i.d. monetary policy shocks $\epsilon_{R_n,t}$. Note that while the first class of shocks directly affects TFP, the other two classes of shocks indirectly affect TFP through the two channels discussed below. The laws of motion for these shocks are given by the equations below:

$$
\begin{aligned}
\ln Z_t &= \ln Z_{t-1} + u_{Z,t},\ u_{Z,t} = \rho_Z u_{Z,t-1} + \epsilon_{Z,t}, \\
\ln A_t &= (1-\rho_A)\ln A + \rho_A \ln A_{t-1} + \epsilon_{A,t}, \\
\varepsilon_{N_\zeta,t} &= \rho_{N_\zeta}\varepsilon_{N_\zeta,t-1} + \epsilon_{N_\zeta,t},\ \text{for } \zeta = F \text{ and } E, \\
\ln A_{I,t} &= (1-\rho_{A_I})\ln A_I + \rho_{A_I}\ln A_{I,t-1} + \epsilon_{A_I,t}, \\
\ln A_{U,t} &= (1-\rho_{A_U})\ln A_U + \rho_{A_U}\ln A_{U,t-1} + \epsilon_{A_U,t}, \\
\ln G_t &= (1-\rho_G)\ln G + \rho_G \ln G_{t-1} + \epsilon_{G,t}, \\
\ln Z_{I,t} &= (1-\rho_I)\ln Z_I + \rho_{Z_I}\ln Z_{I,t-1} + \epsilon_{Z_I,t}, \\
\ln \theta_{P_Y,t} &= (1-\rho_{P_Y})\ln \theta_{P_Y} + \rho_{P_Y}\ln \theta_{P_Y,t-1} + \epsilon_{P_Y,t}, \\
\ln \theta_{W,t} &= (1-\rho_W)\ln \theta_W + \rho_W \ln \theta_{W,t-1} + \epsilon_{W,t},
\end{aligned}
$$

where $\rho_Z$, $\rho_A$, $\rho_{N_F}$, $\rho_{N_E}$, $\rho_{A_I}$, $\rho_{A_U}$, $\rho_G$, $\rho_{\kappa_I}$, $\rho_{P_Y}$ and $\rho_W \in (0,1)$ are the autoregressive root of the corresponding shocks, and $\epsilon_{Z,t}$, $\epsilon_{A,t}$, $\epsilon_{N_{F,t}}$, $\epsilon_{N_E,t}$, $\epsilon_{A_I,t}$, $\epsilon_{AU,t}$, $\epsilon_{G,t}$, $\epsilon_{Z_I,t}$, $\epsilon_{P_Y,t}$, and $\epsilon_{W,t}$ are the exogenous i.i.d. shocks that are normally distributed with mean zero.

## 2.8 Equilibrium

An equilibrium consists of a set of prices, $\{P_t,\ W_t,\ W_{E,t},\ W_{F,t},\ R_{E,t},\ \tilde{R}_t,\ R_t,\ Q_t,\ r_{E,t}, r_{F,t}\}_{t=0}^{\infty}$, and the allocations $\{Y_t, C_t, I_t, Y_{g,t}, Y_{g,t}(l), \Psi_t(l), L_t(l), K_t(l), U_t(l)\}_{t=0}^{\infty}$, for all $l \in [0,1]$, for given government policy $\{G_t,\ \tau_t,\ R_{n,t}\}_{t=0}^{\infty}$, realization of exogenous variables

$\{\epsilon_{Z,t},\ \epsilon_{A,t},\ \epsilon_{A_I,t},\ \epsilon_{AU,t},\ \epsilon_{N_F,t},\ \epsilon_{N_E,t},\ \epsilon_{G,t},\ \epsilon_{\kappa_I,t},\ \epsilon_{P_Y,t},\ \epsilon_{W,t},\ \epsilon_{R_n,t}\}_{t=0}^{\infty}$, and initial conditions $\{N_F\left(s^{-1}\right)\}$, $\{N_E\left(s^{-1}\right)\}\}$ such that for all $t$, the following conditions are satisfied.

($i$) each household $h$ maximizes its utility given prices;

($ii$) each FI $i$ maximizes its profits given prices and its net worth;

($iii$) each entrepreneur $j_i$ in the goods-producing sector maximizes its profits given prices and its net worth;

($iv$) each goods producer $l$ in the goods-producing sector maximizes its profits given prices;

($v$) each capital goods producer in the goods-producing sector maximizes its profits given prices;

($vi$) the government budget constraint holds;

($vii$) the central bank sets the policy rate following the Taylor rule; and

($viii$) markets clear.

## 2.9 Endogenous response of TFP to non-technology shocks

Unlike a standard growth model in which TFP movements are fully attributed to exogenously driven technology shocks, TFP in our model also varies with non-technology shocks through the two channels discussed below.

**Monitoring costs channel**

The first channel is monitoring costs associated with the financial intermediation activity.[28] The total amount of monitoring costs spent in the economy is given as the sum of the sixth and the seventh term in equation (15). Because of information asymmetry between lenders and borrowers, in both the IF and FE contracts, lenders of the credit contracts pay monitoring costs to observe the output of defaulting borrowers (costly state verification). These monitoring costs are spent in the form of the gross output that would otherwise serve as value-added, such as consumption and investment, or as intermediate inputs. Since TFP is measured by the value-added divided by the primary inputs, other things being equal, TFP changes with any change in monitoring costs.

How then are monitoring costs influenced by the economic environment, in particular

[28] This channel is also present in other models that employ the costly state verification framework. See for instance CMR (2010, 2014).

by the condition of the balance sheets of FIs and entrepreneurs? It is clear from equation (15) that monitoring costs increase with the cut-off values specified in the credit contracts, $\overline{\omega}_{E,t}$ and $\overline{\omega}_{F,t}$. This is because when cut-off values are high, a larger proportion of borrowers default, and a larger amount of final goods is spent on the monitoring of borrowers. How are the cut-off values chosen? In the FI's maximization problem described in (8), high cut-off values are chosen when borrowers hold a limited amount of net worth relative to what they borrow from lenders.[29] This is because from the lender's perspective, it is risky to extend credit to borrowers with a lower amount of net worth. To illustrate this point, we conduct a numerical analysis on the relationship between the monitoring costs and net worth of borrowers. We compute the size of default probability and monitoring cost chosen by FIs when they conduct investment $Q_t K_t$ for two given but different net worths, $N_{E,t}$ and $N_{F,t}$. The results are shown in Figure 9.[30] The horizontal axis represents the net worth-to-capital ratio $N_{E,t}/\left(Q_t K_t\right)$ or $N_{F,t}/\left(Q_t K_t\right)$. Note that this ratio increases when $N_{E,t}$ or $N_{F,t}$ increases for a fixed amount of $Q_t K_t$. For the sake of simplicity, we keep the net worth-to-capital ratio in one sector unchanged when we compute default probabilities and monitoring costs, changing the net worth-to-capital ratio in the other sector. The vertical axis indicates the monitoring costs spent in the economy (left axis) and the default probability of borrowers (right axis). For a given size of investment $Q_t K_t$, it is clear that a decline in net worth in either of the two sectors leads to an increase in monitoring costs through an increase in default probability. In other words, monitoring costs are high when borrowers' net worth is damaged.[31]

**Production inputs channel**

The second channel through which non-technology shocks affect TFP is the one proposed by Basu (1995). In his model, as in ours, three features play an important role; the input-output production structure, imperfect competition, and countercyclical markup. In our model, they are seen in the production function of goods producers, shown in equation

[29] The negative relationship between cut-off value and net worth is also seen in BGG (1999).

[30] In this exercise, we use the parameter values estimated in the next section.

[31] In addition to monitoring costs, as discussed in Basu, Fernald, and Shapiro (2001), certain types of adjustment costs, including those of price and wage adjustment, incur a similar class of real cost and reduce TFP. Because these adjustments are assumed to incur the zero cost at the steady state, however, these costs bring about no first-order effect on the resource constraint in our model. By contrast, the monitoring costs take a positive value at the steady state and bring about a nonzero first-order effect on the resource allocation in our model.

(14), and in nominal wage and price rigidity, shown in equations (12) and (19) , respectively.

It is notable that, even at the initial equilibrium, our economy is not efficient. This is because, due to the monopolistic competition, goods producers set their prices as a markup on marginal cost and they use too few intermediate goods in goods production. In dynamics, the economy may experience further inefficiency depending on the type of shock. Suppose that there is a contractionary monetary policy shock. If goods prices are adjusted at a slower rate than the marginal cost, which as shown in equation (17) is a function of prices of production inputs, the markup of intermediate goods increases in the short-run. Because intermediate goods becomes more expensive, the goods producers use fewer intermediate goods and more primary inputs. This moves the economy further away from the efficient allocation of production inputs, thereby reducing TFP.

To see this channel analytically, let us assume for a moment that gross output $Y_{g,t}$ is produced only from intermediate inputs and labor input.[32] Then, from the resource constraint (15) and the production function (16) , we can derive an expression that relates TFP $\lambda_t$ with the proportion of intermediate goods used in goods production relative to total gross output $\left(\int_0^1 \Psi_t(l)\, dl\right)/Y_{g,t}$:

$$\lambda_t = [Z_t A_t]^{\frac{1}{1-\gamma}} \times \left[\left(\int_0^1 \Psi_t(l)\, dl\right)/Y_{g,t}\right]^{\frac{\gamma}{1-\gamma}} \times \left[1 - \left(\int_0^1 \Psi_t(l)\, dl\right)/Y_{g,t}\right]. \qquad (25)$$

Next, by taking the first derivative of both sides of the equations around the steady state, we obtain the following expression:

$$\begin{aligned} d\ln\lambda_t \quad \approx \quad & \frac{1}{1-\gamma}\left[d\ln Z_t + d\ln A_t\right] \\ & + \left[\frac{\gamma(\mu-1)}{(1-\gamma)(\mu-\gamma)}\right] d\ln\left(\left(\int_0^1 \Psi_t(l)\, dl\right)/Y_{g,t}\right), \end{aligned} \qquad (26)$$

where $dx$ denotes the first derivative of a variable $x$, $\mu$ is the steady state gross markup set by the goods producers in the goods-producing sector that is greater than one, and $\gamma$ is the share of intermediate inputs in goods production that is smaller than one. The equation thus indicates that even when technology is unchanged, that is $d\ln Z_t = d\ln A_t = 0$, TFP

[32] By assuming that intermediate inputs and labor input are the only production input, we implicitly assume that the parameter $\alpha$ takes unity, and parameters $\alpha_E$, and $\alpha_F$ as well as the last four terms in equation (15) are zero.

increases if a larger portion of gross output is used as intermediate goods. When there is a shock that decreases the proportion of intermediate goods, for instance, by increasing the price of intermediate inputs relative to that of primary inputs, then TFP falls.

How is this channel related to the balance sheets of FIs and the goods-producing sector? As we see below, in our model, a negative shock to the net worth of FIs or that of the goods-producing sector generates deflationary pressure on the economy by damaging the balance sheets of these sectors. Because the intermediate goods price $P_t$ falls sluggishly compared with price of primary inputs, with estimated parameter values of nominal wage and price rigidity, less intermediate input is used for goods production, and TFP falls.

# 3 Quantitative analysis

In this section, we investigate our model's quantitative implications, in particular the two mechanisms through which damaged balance sheets lead to a lower level of TFP. Using Japanese data, we estimate the model's parameters and extract the time series of structural shocks, including shocks to balance sheets, using Bayesian methods. Based on the estimated model, we first show how TFP responds to shocks to the balance sheets and then examine how TFP would have looked if such shocks had been absent from the economy during the lost decades.

## 3.1 Estimation strategy

We first detrend the model variables by dividing them by the I(1) deterministic trend term. We then log-linearize the detrended model around the deterministic steady state. All of the equilibrium conditions are shown in the appendix. We then conduct a Bayesian estimation following existing studies, including CMR (2014). To do this, we first write the equilibrium conditions of the model in a state-space representation and derive the likelihood function of the system of equilibrium conditions using the Kalman filter. Next, we combine the likelihood function with the priors for the parameters to obtain the posterior density function numerically. In this process, we use the random walk Metropolis-Hastings algorithm.

### 3.2 Data

We use time series of 11 variables from 1980:2Q to 2011:4Q. We display the data series used for estimation in Figure 10.[33] The data includes 9 aggregate variables and two variables that are balance sheet data of the FIs and goods-producing sectors: (1) real GDP $Y_t$, (2) real investment $I_t$, (3) GDP deflator $P_t$, (4) deflator of investment $P_t/A_{I,t}$, (5) nominal wage per unit of labor $W_t$, (6) working hours $L_t$, (7) capacity utilization rate of capital stock $U_t$, (8) policy rate $R_{n,t}$, (9) Solow residual that is not adjusted for the capacity utilization of the capital stock $Y_t\left((L_t)^{\psi_L}(K_{t-1})^{1-\psi_L}\right)^{-1}$, (10) real net worth of the FI sector $N_{F,t}P_t^{-1}$, and (11) real net worth of the entrepreneurs in the goods-producing sector $N_{E,t}P_t^{-1}$.

The data source of these series, unless otherwise noted, is the System of National Accounts (hereafter SNA) released by the Cabinet Office of Japan. Series (5) is constructed from the compensation of employees based on the SNA, divided by series (6). Series (6) is obtained from the number of employees based on the Labour Force Survey, multiplied by hours worked per employee based on the Monthly Labour Survey. Series (7) is obtained from the utilization rate of capital stock in the manufacturing sector, based on the Index of Industrial Production multiplied by 0.6. This construction methodology is the same as that used in Sugo and Ueda (2008).[34] Series (8) is the uncollateralized overnight call rate, which is the main policy tool for the Bank of Japan. Because this series is available only from 1985:3Q and beyond, it is extended backward before 1985:3Q using the collateralized overnight call rate. The construction methodology of series (9) is similar to TFP $\lambda_t$ for which the methodology is explained in the introduction. The only difference between series (9) and TFP $\lambda_t$ defined in equation (23) is that the effects of variations in capacity utilization of the capital stock $U_t$ are taken into account in the latter series and not in the former. Instead, we include series (7) in our list of observables. We choose this estimation strategy so that we can distinguish between variations in TFP due to changes in the capacity utilization rate of the capital stock, TFP variations due to other causes. Series (10) and (11), the two net worth series, are constructed from the outstanding of shares issued by depository corporations and non-financial corporations, respectively. They are

[33] In Figure 10, all of the series other than series (8) is displayed on a year-on-year basis. Note, however, that we use a quarter-on-quarter change rather than a year-on-year change of a variable in our estimation. We use the level series for series (8) in our estimation.

[34] Because the data series for the capacity utilization rate of capital stock is only available for manufacturing firms in Japan, we follow Sugo and Ueda (2008) and assume that non-manufacturing firms adjust the rate to a lesser extent than non-manufacturing firms.

taken from the Flow of Funds Accounts. In the Flow of Funds Accounts, the reported series of outstanding of shares are those evaluated not at market value, but at book value before 1995:4Q for depository corporations and before 1994:4Q for non-financial corporations. We therefore extend each series evaluated at market value backward using the quarterly growth rate of the market capitalization of banks and of non-financial firms.

In estimating the model, we take the first difference for all of the series except for series (8). To convert the nominal series into the quantity series, we employ the GDP deflator. We also divide all of the quantity series by the number of the population over 15 reported in the Labor Force Survey to obtain the series on a per-capita basis. We demean all the series other than (8) to remove the deterministic trend.

### 3.3 Calibration, Prior Distribution, and Posterior Distribution

**Calibrated parameters**

Some parameter values are calibrated following existing studies. These include the discount factor $\beta$, the elasticity of substitution between differentiated products $\theta_{P_Y}$, the elasticity of substitution between differentiated labor inputs $\theta_W$, the depreciation rate of the capital stock $\delta$, the share of the intermediate input, labor input, entrepreneurial labor input and the FI labor input in goods production $\gamma$, $\alpha$, $\alpha_E$ and $\alpha_F$, and the utility weight on leisure $\varphi$. Values for $\gamma$ and $\alpha$ are constructed using the historical average of intermediate goods usage divided by gross output, both of which are reported in an input-output table, and the compensation of employees divided by GDP in SNA, respectively. In addition, we set $\kappa_U$ so that the utilization rate of capital stock is unity at the steady state. See the lower part of Table 1 for the values of these parameters.

**Estimated parameters**

We estimate the remaining parameters. See the upper part of Table 1 for the values of these parameters. The type, mean, and standard deviation of the prior distribution are mostly taken from existing studies such as Edge et al. (2008). They are given in the first to the third columns. In estimating the six parameters that are related to the IF and FE contracts, that include two parameters that govern monitoring costs $\mu_F$ and $\mu_E$, variance of idiosyncratic shocks to borrowers $\sigma_F$ and $\sigma_E$, and survival rates $\gamma_F$ and $\gamma_E$, we follow HSU (2011) and set the prior mean of these parameters so that they satisfy the six equilibrium conditions stated below at the steady state: (1) the annualized spread between the FIs' borrowing rate and the risk-free rate $r_F - R$ is 56 bps; (2) the ratio of net worth held by FIs to aggregate capital stock $N_F/(QK)$ is 0.1; (3) the ratio of net worth held by the entrepreneurs in the goods-producing sector to aggregate capital stock $N_E/(QK)$ is 0.6; (4) the annualized failure rate of the FIs is 1%; (5) the annualized failure rate of the entrepreneurs in the goods-producing sector is 1%; and (6) the annualized spread between the FI loan rate and the FI borrowing rate $r_E - r_F$, equals 442 bps. Except for conditions (4) and (5), the conditions above are chosen so that they are consistent with the historical average of Japanese data.[35] We borrow condition (5) from BGG (1999) and assume that the same condition holds in the FI sector as well. This can be seen in condition (4).

**Zero lower bound of the policy rate**

The policy rate in Japan was set and maintained close to zero in February 1999 and beyond. If we disregard the zero lower bound of policy rate and simply use the full sample data for the estimation, then the estimated parameters in the Taylor rule will be biased. We therefore estimate the posterior distribution of policy weight $\varphi_\pi$ and smoothing parameter $\rho$ in the Taylor rule using the subsample that covers the period from 1980:2Q to 1998:4Q. We estimate the posterior distributions of the other parameters using the full sample, from 1980:2Q to 2011:4Q, with a policy weight and a smoothing parameter in the Taylor rule fixed to the mean of the distribution obtained from the subsample estimation.[36]

**Posterior distribution**

To calculate the posterior distribution and to evaluate the marginal likelihood of the model, we employ the Metropolis-Hastings algorithm. To do this, we create a sample of 400,000 draws, disregarding the initial 200,000 draws. Estimated posterior distributions of

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[35] We take the numbers for conditions (2) and (3) from the Flow of Funds Accounts. We use the long-term prime lending rate and the deposit rate adopted by the Bank of Japan to obtain conditions (1) and (6), respectively.

[36] The parameter values as well as estimated time paths of structural shocks are little changed from the values reported in Table and figures shown in Figure 11, if the data from 1980:2Q to 1998:4Q is alternatively used for our estimation. See also Hirose and Inoue (2016) for the related issue. They analyze to what extent parameter estimates can be biased in a model that omits the zero lower bound constraint on the nominal interest rate, by estimating a New Keynesian sticky price model. They find that such biases are not quantitatively significant.

parameters are shown in the upper section of Table 1. The last three columns of the table display the posterior mean and the confidence intervals for the estimated parameters.

### 3.4 Estimated shocks to balance sheets

In Figure 11, we show the time path of shocks to the balance sheets of the FI and goods-producing sectors. In the figure, we also show the time path of the Financial Position Index of firms based on the Short-Term Economic Survey of Enterprises, shown in Figure 4, and indicate the timings of the outbreak of the two financial crises by bars.

The net worth shocks to FIs took large positive values continuously from the late 1980s to the early 1990s. From the early 1990s, they started to take negative values, indicating that the balance sheets of FIs had been damaged. The size of the negative shocks gradually increased, reaching a peak during the late 1990s. The shocks remained negative until the mid-2000s, becoming positive in the mid-2000s. These realizations of the shocks are in line with the observations made by Hoshi and Kashyap (2010). They point out that the acute phase of the Japanese banking crisis was from 1997:4Q to 1999:1Q, and that the phase when the crisis bottomed out was from 1999:1Q to early 2003. It is also important to note that time paths of the estimated net worth shocks to the FI and Financial Position Index roughly coincide over the estimation period. During and after each of the two financial crises, the index decreased, indicating that financial positions became tightened, and large negative shocks occurred in the net worth of the FI sector. In contrast to shocks to the balance sheets of the FI sector, shocks to the balance sheets of the goods-producing sector took large negative values during the early 1990s, and relatively small negative values during the late 1990s.

### 3.5 Impulse response functions

Using the estimated parameters, we next show how the key macroeconomic variables, including TFP, respond to unanticipated shocks to net worth as well as the technology level.

**Responses to a net worth shock in the FI sector**

We begin with an analysis of the consequences of a net worth shock to the FIs $\epsilon_{N_F,t}$. This shock arises from the FI sector and is described as an innovation to equation (9).

It first influences the terms of credit contracts and then affects the rest of the economy, including TFP, by changing the volume of financial intermediation. Figure 12 shows the impulse response function of macroeconomic variables to a negative shock to the FI net worth. As the FI net worth becomes significantly reduced because of the shock, the FIs are more likely to default on their loans. The investors then require a higher external finance premium in the IF contracts, which results in a higher borrowing rate $r_{F,t}$. Since the higher borrowing rate in the IF contracts is translated to the borrowing rate in the FE contracts $r_{E,t}$, the entrepreneurs in the goods-producing sector reduce their external funding from the FIs and purchase less capital goods $Q_t K_t$. Consequently, capital goods supply to the goods-producers decreases. With a lower capital input, investment and GDP are dampened. Inflation also falls, reflecting the weak aggregate demand. A decline in GDP causes the second round effect to emerge. That is, the economic downturn due to the shock hampers the net worth accumulation in the two sectors since the retained earnings in these sectors diminish as equations (9) and (10) indicate. The deteriorated net worth results in a further rise in the external finance premium and in the two borrowing rates $r_{F,t}$ and $r_{E,t}$, further dampening GDP.

The shock lowers TFP through the two channels, the monitoring costs channel and the production inputs channel. To illustrate the presence of the monitoring costs, we define a measure of monitoring costs as follows and show the impulse response function of this measure in the panel (11).

$$\left(\mu_E\left(\int_0^{\overline{\omega}_{E,t}}\omega_E dF_E\left(\omega_E\right)\right)R_{E,t}Q_{t-1}K_{t-1}+\mu_F\left(\int_0^{\overline{\omega}_{F,t}}\omega_F dF_F\left(\omega_F\right)\right)\Phi_{E,t}R_{E,t}Q_{t-1}K_{t-1}\right)\times Y_{g,t}^{-1}.$$

This measure captures the proportion of gross output $Y_{g,t}$ that is used for the monitoring costs. In response to the shock, this measure rises. As the net worth in the FIs deteriorates, the investors require a higher cut-off value in the IF contracts because lending to the FIs becomes riskier. The FI borrowing rate $r_{F,t}$ rises, reflecting the increase in the cut-off value $\overline{\omega}_{F,t}$. As discussed above, a higher cut-off value implies that a greater amount of resources is spent as monitoring costs in the IF contracts. Consequently, TFP falls. In addition, since the net worth shock to FIs also leads to an endogenous deterioration of net worth in the goods-producing sector, the cut-off value in the FE contracts $\overline{\omega}_{E,t}$ increases, which results in a further decline in TFP.

The presence of the production inputs channel is indicated in the increase in the markup of the goods-producing sector shown in panel (5). The markup is defined by the goods price $P_t$ divided by the marginal costs shown in the equation (17) . Note that the intermediate goods price is high relative to that of primary inputs when the markup is high. Though both goods price and nominal wage are adjusted in a sluggish manner in our model, the response of the markup indicates that a nominal marginal cost adjusts more rapidly than goods prices.[37] Consequently, the production inputs channel works. As addressed in Basu (1995), an increased markup of goods makes goods producers hire more primary inputs and less intermediate inputs than otherwise, exacerbating the inefficiency of production inputs. Consequently, TFP falls.

**Responses to a net worth shock in the goods-producing sector**

We next discuss the model's response to an unexpected net worth disruption in the goods-producing sector $\epsilon_{N_E,t}$. Figure 13 shows the impulse response function of the variables to the shock. Similar to an adverse net worth shock to the FIs, the shock delivers a decline in TFP as well as in output. The working mechanism is similar to the case of the net worth shocks to the FIs. That is, entrepreneurs in the goods-producing sector with damaged balance sheets face higher external finance premium in the FE contracts and borrow less, which results in a smaller capital goods supply to the economy. Consequently, investment and GDP fall. As GDP falls, the second round effect discussed above emerges and the net worth of the FIs and the entrepreneurs endogenously deteriorates. Since the two borrowing sectors become less creditworthy than before, a greater amount of resources is spent as monitoring costs, reducing TFP. In addition, as the shock brings about deflationary pressure on the economy, the markup increases in the short-run, reducing TFP further through the production inputs channel.

**Responses to a permanent technology shock**

We also briefly discuss how a technology shock affects the economy. Figure 14 displays the economic response to a negative shock to the technology growth rate $\epsilon_{Z,t}$. Because a technology slowdown directly lowers the productivity of goods production as indicated

[37] This can also be seen in the estimation results for the adjustment cost of price and nominal wage $\kappa_p$ and $\kappa_w$. As shown in Table 1, the estimated adjustment cost of price is far greater than that of wages.

by equation (16), GDP falls. In addition, as panels (5) and (11) in the figure show, the markup and the monitoring costs increase in response to the shock. These observations suggest that some proportion of the TFP decline shown in the panel (6) is a result of the endogenous decline in TFP through the monitoring costs channel and the production inputs channel, rather than being a direct effect of the shock.

### 3.6 Role of damaged balance sheets in TFP decline during the lost decades

Using the distilled time series of shocks to net worth in the FI and the good-producing sectors shown in Figure 11, we explore the quantitative contributions of these shocks to the TFP slowdown during the lost decades.

**Role of net worth shocks to the FI sector and the goods-producing sector**

In order to assess the contributions of net worth shocks, we compute three TFP measures, which we call TFP I, TFP II, and TFP III, respectively. These TFP series are defined as follows:

- TFP I: the actual TFP series $\lambda_t$ for the period before the bubble burst, namely $t$ =1980:2Q, ... , 1991:1Q, and the actual TFP series $\lambda_t$ less the portion of TFP variations attributed to shocks to FIs' net worth $\epsilon_{N_{F,t}}$ for the period after the bubble burst, which spans from 1991:2Q and beyond. Note that because the model is log-linearized around the steady state in our estimation, variations in the growth rate of TFP $\lambda_t$ over the sample period can be expressed as a linear combination of the contribution of each of the estimated 11 fundamental shocks described in Section 2.7. In computing this TFP I series, we first calculate the entire contribution of all of the fundamental shocks to variations in the TFP growth rate for $t$ =1980:2Q, ... , 2011:4Q and then set the contribution of shocks $\epsilon_{N_{F,t}}$ to zero only for $t$ = 1991:2Q, ... , 2011:4Q.

- TFP II: the actual TFP series $\lambda_t$ for $t$ =1980:2Q, ... , 1991:1Q, and the actual TFP series $\lambda_t$ less the portion of TFP variations attributed to shocks to entrepreneurial net worth $\epsilon_{N_{E,t}}$ from 1991:2Q and beyond. In computing the time path of TFP II, we first calculate the entire contribution of all the fundamental shocks to variations in the TFP growth rate for $t$ =1980:2Q, ... , 2011:4Q and then set the contribution of shocks $\epsilon_{N_{E,t}}$ to zero only for $t$ =1991:2Q,...,2011:4Q.

- TFP III: the actual TFP series $\lambda_t$ for $t$ =1980:2Q, ... , 1991:1Q, and the actual TFP series $\lambda_t$ less portion of TFP variations attributed to shocks to the FIs' net worth $\epsilon_{N_{F,t}}$ and the entrepreneurial net worth $\epsilon_{N_{E,t}}$ from 1991:2Q and beyond. In computing the time path of TFP III, we first calculate contribution of all of the fundamental shocks to variations in TFP growth rate for $t$ =1980:2Q, ... , 2011:4Q and then set contribution of shocks $\epsilon_{N_{F,t}}$ and that of shocks $\epsilon_{N_{E,t}}$ to zero only for $t$ =1991:2Q,...,2011:4Q.

In Figure 15, we show the three TFP series, TFP I, II, and III as well as the actual TFP series in levels. Note that the actual TFP series coincides with the TFP series in an economy where the entire contribution of all the fundamental shocks is present during the full sample period. The discrepancy between the actual TFP series and TFP III therefore captures the contribution of two types of net worth shocks to variations in the actual TFP during the 1990s and beyond. Similarly, the discrepancy between the actual TFP series and TFP I and TFP II captures the contribution of the net worth shocks to the FI sector and the goods-producing sector respectively to variations in the actual TFP during the 1990s and beyond. Quantitatively, as the figure shows, the discrepancy between the actual TFP and TFP I is substantial, while the discrepancy between the actual TFP and TFP II is minor. This observation suggests that net worth shocks to the FI sector played an important role in the TFP decline, while net worth shocks to the goods-producing sector played only a limited role. It can also be seen that the gap between the actual TFP series and TFP I was small in the early 1990s, but started to widen from the latter half of the 1990s. This observation accords well with an assessment by Hoshi and Kashyap (2010) that the latter half of the 1990s was the "acute phase" of the banking crisis in Japan.

The table in Figure 15 shows the average annual growth rate of the actual TFP and the three TFP measures, TFP I, TFP II, and TFP III, in the 1980s, 1990s, and 2000s and beyond. The table also shows, for each of the four TFP measures, the difference in the average annual growth rates between the 1980s and the 1990s, and that between the 1980s and the 2000s and beyond. Among the three TFP measures, the growth rate decline during the lost decades is largest in TFP II, while the growth rate decline in the other two measures is moderate. Quantitatively, if not for the net worth shocks to the FI had been absent, the slowdown in TFP growth rate from the 1980s to the 1990s would have been more moderate by an average of 0.74 percentage points. Similarly, if not for the net worth shocks to the goods-producing sector had been absent, TFP slowdown during the same period would have been more moderate only by an average of 0.07 percentage points.

Shocks to FI balance sheets also had an important effect on the slowdown of GDP $Y_t$. To illustrate this, we construct three GDP measures, GDP I, GDP II, and GDP III, that correspond respectively to each of the three TFP measures above. We do this by first decomposing the actual GDP growth rates into the contribution of the 11 fundamental shocks, and set the contribution of the relevant shocks to zero from 1991:2Q and beyond. That is, GDP I is the GDP series in which the contribution of shocks to FI net worth $\epsilon_{N_{F,t}}$ is absent from 1991:2Q and beyond, GDP II is the series in which the contribution of shocks to entrepreneurial net worth $\epsilon_{N_{E,t}}$ is absent from 1991:2Q and beyond, and GDP III is the series in which the contribution of both of the two types of net worth shocks $\epsilon_{N_{F,t}}$ and $\epsilon_{N_{E,t}}$ is absent from 1991:2Q and beyond. Figure 16 shows the actual GDP together with the three GDP measures. As with the comparison of TFP measures demonstrated in Figure 15, it is clear that shocks to FI net worth played an important role in lowering the GDP growth rate, particularly during the 1990s. Without the contribution of net worth shocks to FIs, the decline in GDP growth rate from the 1980s to the 1990s would have been mitigated by 1.57 percentage points on average. By contrast, without the contribution of net worth shocks to the goods-producing sector, the decline in GDP growth rate from the 1980s to the 1990s would not have been mitigated in a quantitatively significant manner.[38]

Figures 15 and 16 suggest that the two likely explanations of the cause of Japan's lost decades, the TFP growth rate slowdown and the malfunction of financial intermediation, are not mutually exclusive. On the one hand, as pointed out by Hayashi and Prescott (2002), the TFP growth rate decline played an important role in lowering GDP. On the other hand, as pointed by Bayoumi (2001) and others, the malfunction of financial intermediation played an important role in lowering TFP. The crucial driving force behind the malfunction was an adverse shock to FI balance sheets. As shown in Figure 11, a realization of this type of shock took a high positive value during the 1980s, started to

[38] Kaihatsu and Kurozumi (2014) estimate a financial accelerator model similar to Bernanke, Gertler, and Gilchrist (1999) using Japanese data, where only non-financial firms are credit constrained. They show that damaged balance sheets of non-financial firms played a minor role in the decline in output during the early 1990s. Our result on the quantitative contribution of net worth shocks to the entrepreneurs is therefore in line with their finding.

take a much smaller value in the early 1990s, and took a negative value persistently from the latter half of the 1990 to the early half of the 2000s. As shown in Figure 12, when FI balance sheets were impaired due to these shocks, FIs faced greater monitoring costs. In addition, deflationary pressures due to a decline in FI lending distorted allocation of production inputs, which in turn exacerbated inefficiencies in the goods-producing sector. As a result, the TFP declined.

It is also important to give the explanation for why FI net worth shocks had a persistent effect on TFP and GDP as shown in Figure 15 and 16, even though net worth shocks themselves are transitory shocks as shown in Figure 12 and 13. The key explanation is the way that FI net worth shocks occurred during the sample period. As Figure 11 shows, FI net worth shocks continuously took large positive values up to the bubble burst in 1991. During the early 1990s, FI net worth shocks on average took slightly positive values, which implies that the TFP growth rate increase due to shocks that occurred during this period did not offset the TFP growth rate decline due to the large positive FI net worth shocks that occurred before the bubble burst.[39] During the late 1990s and early 2000s, FI net worth shocks continuously took large negative values which contributed to a further decline in the TFP growth rate.

**Role of monitoring costs channel and production inputs channel in the TFP decline**

We have shown above that the net worth shocks to the FI played an important role in the TFP decline. We now ask which of the two channels, monitoring costs and production inputs, played the more important role in bringing down the TFP. To do this, we construct an additional TFP measure, which we call TFP IV. We construct this series by the following three steps. First, we decompose the growth rate of the monitoring costs, that are given by the sum of the sixth and seventh term of the equation (15), into the contributions of each of the 11 fundamental shocks, and obtain the time path of the contribution of shocks to FI net worth $\epsilon_{N_{F,t}}$ to the growth rate of monitoring costs. We denote the level series of this series by $\mu_{N_{F,t}}$. Second, we multiply this series by the steady-state share of gross output $Y_{g,t}$ that is used as the value-added, which we denote by $(1-\psi_M)$.[40] Third and

[39] Note that as shown in Figure 12 a positive FI net worth shock leads to a positive TFP growth over a few quarters after the shock, and leads to a negative TFP growth beyond that quarter.

[40] Because the portion of the gross output $Y_{g,t}$ serves not only as the final goods, but also as the interme-

finally, we add the series $\mu_{N_{F,t}}$ to the numerator in the formula for computing TFP for the 1990s and beyond to obtain the series TFP IV. TFP IV coincides with the actual TFP up to 1991:1Q and is therefore defined as follows for $t$ =1991:2Q,...,2011:4Q.

$$\text{TFP IV} \equiv \frac{Y_t + (1-\psi_M)\,\mu_{N_{F,t}}}{(L_t)^{\psi_L}\,(K_{t-1}U_t)^{1-\psi_L}}. \tag{27}$$

Note that in contrast to $\lambda_t$ whose definition is given by equation (23), the numerator of the formula for TFP IV shown above includes, in addition to GDP $Y_t$, a term that reflects the monitoring costs incurred as a result of the FI net worth shocks. This TFP measure is hence interpreted as the size of a hypothetical TFP if the monitoring cost is counted as a part of the value-added instead of being counted as costs. The value of this measure clearly increases when the monitoring cost rises. We use the discrepancy between the decline in actual TFP $\lambda_t$ and TFP IV as the proxy for the contribution of the monitoring costs channel to the decline in TFP.

Figure 17 shows three TFP series, the actual TFP series, TFP I, and TFP IV. The discrepancy between TFP I and TFP IV stands for the contribution of the production inputs channel to the total size of a TFP decline that is brought about by shocks to FI net worth. The discrepancy between the actual TFP and TFP IV stands for the contribution of the TFP decline due to shocks to FI net worth that is explained by the monitoring costs channel.

It is clear that the size of the monitoring cost channel is relatively small compared with the size of the production inputs channel. As the bottom row of the table shows, while the absence of contribution of net worth shocks to the FI sector increases the TFP growth rate by 0.74 percentage points from the 1980s to the 1990s on average, the absence of the monitoring costs channel increases the TFP growth rate by only 0.17 percentage points, which in turn indicates that the bulk of the TFP decline due to net worth shocks to the FIs is explained by the production inputs channel. This result implies that while damaged balance sheets played a quantitatively important role in the TFP slowdown, their impacts were mainly transmitted through the indirect channel.

**Role of shocks to net worth and shocks to technology in the TFP decline**

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diate goods, as shown in the equation (15), we make adjustments for this portion by multiplication with the term $1-\psi_M$.

Lastly, we compare the contribution of net worth shocks with the contribution of shocks to technology in the goods-producing sector. To do this, we construct the fifth TFP measure that is defined as below.

- TFP V: the actual TFP series $\lambda_t$ for $t$ =1980:2Q, ... , 1991:1Q and the actual TFP series $\lambda_t$ less the portion of TFP variations attributed to shocks to technology in the goods-producing sector $\epsilon_{Z,t}$ and $\epsilon_{A,t}$. In computing TFP V, we first calculate the entire contribution of all the fundamental shocks to variations in TFP growth rate for $t$ =1980:2Q, ... , 2011:4Q, and then set only the contribution of shocks $\epsilon_{Z,t}$ and $\epsilon_{A,t}$ to zero for $t$ =1991:2Q,...,2011:4Q.

The discrepancy between TFP V and the actual TFP captures the quantitative importance of technology shocks to the goods-producing sector in the TFP decline during the lost decades. Figure 18 shows these two TFP, together with TFP I. The positive gap between TFP V and the actual TFP indicates that shocks to technology played an important role in lowering TFP during the lost decades. The contribution of technology shocks is, however, limited compared with the contribution of shocks to FI net worth.

Our result is consistent with Kawamoto (2005) in concluding that the change in the technology growth rate after the early 1990s was minor. Kawamoto estimates the time path of the aggregate technology growth by taking into account the effects of other non-technology factors, such as intermediate input usage, and argues that the estimated technology growth rate during 1990-1998 was only 0.1% percentage point higher than during 1980-1990. In our estimation, the difference in technology growth rate between the two periods is less than 0.1%, which also indicates that technology played a minor role in the TFP slowdown.

# 4 Concluding remarks

There are two plausible explanations of the lost decades in Japan. The pioneering work by Hayashi and Prescott (2002) argues that TFP growth slowdown played the key role in the economic stagnation. By contrast, several studies, including Bayoumi (2001) and Caballero, Hoshi, and Kashyap (2008), argue that disruptions in financial intermediation due to the damaged balance sheets of non-financial firms or financial intermediaries played the key role.

In this paper, we reconcile the two views by exploring whether the TFP slowdown was brought about by technological regression, or alternatively, by damaged balance sheets of non-financial firms and financial intermediaries. To do this, we first construct a New Keynesian sticky price model by extending the two workhorse models: a financial accelerator model developed by Bernanke, Gertler, and Gilchrist (1999), and a model with an intermediate input structure developed by Basu (1995). We explicitly incorporate the balance sheets of non-financial firms and financial intermediaries into the model and demonstrate the channels through which changes in balance sheet conditions in the two sectors affect TFP.

In the model, damaged balance sheets lower TFP through two channels: the monitoring costs channel and the production inputs channel. The first channel captures the increase in the monitoring costs associated with financial intermediation. When borrowers' balance sheets are damaged, a larger portion of borrowers default, and more resources are spent on monitoring activities. Consequently, fewer resources are left for consumption and investment, which results in a decline in TFP. The second channel is a rather indirect effect which arises from the inefficient use of intermediate inputs. As in the model developed by Basu (1995), deflationary shocks to the economy, including adverse shocks to the balance sheets of non-financial firms and financial intermediaries, increase the markup of the goods-producing sector, distort the intermediate input usage in goods production, and reduce TFP.

We estimate the model parameters and underlying structural shocks using Japanese data including TFP series. To quantitatively assess the role of shocks to balance sheets of non-financial firms and financial intermediaries, we compute the contribution of shocks to balance sheets of these sectors to movements in TFP. We find that if the contribution of shocks to the balance sheets of financial intermediaries had been absent, then TFP growth from the 1980s to 1990s would have been higher by 0.74 percentage points, which means that the TFP growth rate would have been about twice as high as it actually was. Compared to the contribution of shocks to the balance sheets of financial intermediaries, that of shocks to balance sheets of non-financial firms played only a limited role. We also compare the quantitative role of the two channels in the TFP slowdown. We find that the production inputs channel played a quantitatively larger role than the monitoring costs channel.

Our paper shows that the balance sheets condition of financial intermediaries played the most important role in TFP decline during the lost decades. It also shows that the transmission from damaged balance sheets to the reduced TFP came more from the indirect effect of distorting production inputs usage rather than from the direct effect of monitoring costs associated with financial intermediation. It is important, however, to point out that the current paper studies only two channels through which damaged balance sheets affect TFP, and that there may be other potential channels that are not examined in this paper. For instance, Caballero, Hoshi, and Kashyap (2008) argue that the fear of falling below the capital standards led banks to continue to extend credit to insolvent borrowers and lowered productivities. Ogawa (2007), using a panel data of manufacturing firms, argues that there are statistical linkages between the outstanding debt of these firms, their R&D investment, and their firm-level TFP. Extending our framework by incorporating these channels is left as our future research agenda.

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# A Appendix

In this appendix, we describe the equilibrium system of our model. For illustrative purpose, we classify the equilibrium equations into five blocks; (1) equations related to household's problem, (2) equations related to firms' problems, (3) equations related to FIs' problem, (4) shock process, and (5) other equations.

## A.1 Equations related to Household's Problem

- Eular equation

$$\frac{1}{C_t(h)} = \beta \mathrm{E}_t \left\{ \frac{1}{C_{t+1}(h)} R_t \right\}.$$

- Consumption-leisure decision with sticky wage

$$\theta_{W,t}\varphi (L_t)^v = -\tfrac{W_t}{C_t P_t}(1-\theta_{W,t}) + \tfrac{W_t}{C_t P_t}\kappa_w \left(\tfrac{W_t}{W_{t-1}} - 1\right)\tfrac{W_t}{W_{t-1}}$$
$$-\beta \tfrac{W_{t+1}}{C_{t+1}P_{t+1}}\kappa_w \left(\tfrac{W_{t+1}}{W_t} - 1\right)\tfrac{L_{t+1}}{L_t}\tfrac{W_{t+1}}{W_t}.$$

- Fisher equation

$$R_t = \frac{R_{n,t}}{\mathrm{E}_t[\pi_{t+1}]}.$$

## A.2 Equations related to Firms' Problems

- Goods producers' demand equations for production inputs

$$\gamma (Y_{g,t} + F) MC_t = P_t \Psi_t,$$

$$(1-\gamma)\alpha (Y_{g,t} + F) MC_t = W_t L_t,$$

$$(1-\gamma)\,\alpha_E\,(Y_{g,t}+F)\,MC_t = W_{E,t},$$

$$(1-\gamma)\,\alpha_{FI}\,(Y_{g,t}+F)\,MC_t = W_{F,t},$$

$$(1-\gamma)\,(1-\alpha-\alpha_E-\alpha_{FI})\,(Y_{g,t}+F)\,MC_t = \tilde{R}_{E,t}K_{t-1}U_t.$$

- Nominal marginal cost facing goods producers

$$MC_t = \frac{\bar{\phi}P_t^{\gamma}}{A_t Z_t}\left[W_t^{\alpha}W_{E,t}^{\alpha_E}W_{F,t}^{\alpha_{FI}}\tilde{R}_{E,t}^{1-\alpha-\alpha_E-\alpha_{FI}}\right]^{1-\gamma},$$

- Price dynamics

$$1-\theta_{P_Y,t} = -\frac{\theta_{P_{Y,t}}MC_t}{P_t} + \kappa_p\left(\frac{P_t}{P_{t-1}}-1\right)\frac{P_t}{P_{t-1}}$$
$$-\beta\kappa_p\frac{C_t}{C_{t+1}}\left(\frac{P_{t+1}}{P_t}-1\right)\frac{P_{t+1}}{P_t}\frac{Y_{g,t+1}}{Y_{g,t}}.$$

- The first order condition for the entrepreneurial usage of the capacity utilization rate

$$\frac{\tilde{R}_{E,t}}{P_t} = \kappa_U\,(A_{U,t})^{1+\gamma_U}\,(U_t)^{\gamma_U}\,.$$

- The real net return to holding capital $K_{t-1}$ that is received by the entrepreneur

$$R_{E,t} = \frac{\frac{U_t\tilde{R}_{E,t}}{P_t} - \frac{\left(\kappa_U\left(A_{U,t}U_t\right)^{\gamma_U+1}-1\right)}{\Upsilon_U+1} + (1-\delta)\,Q_t}{Q_{t-1}}.$$

- Law of motion for entrepreneurial net worth

$$N_{E,t+1} = \gamma_E V_{E,t+1} + \frac{W_{E,t}}{P_t} + \varepsilon_{N_{E,t+1}},$$

where

$$V_{E,t+1} \equiv (1-\Gamma_E(\overline{\omega}_{E,t+1}))\,R_{E,t+1}Q_tK_t.$$

- The first order condition for capital goods producers

$$
\begin{aligned}
0 &= Q_t \left[1 - \frac{\kappa_c}{2}\left(\frac{Z_{I,t}I_t}{I_{t-1}} - 1\right)^2 - \kappa_c \left(\frac{Z_{I,t}I_t}{I_{t-1}} - 1\right)\frac{Z_{I,t}I_t}{I_{t-1}}\right] \\
&\quad + \beta\kappa_c Q_{t+1}\frac{P_t C_t}{P_{t+1}C_{t+1}}\left(\frac{Z_{I,t+1}I_{t+1}}{I_t} - 1\right)\frac{Z_{I,t+1}I_{t+1}^2}{I_t^2} - \frac{1}{A_{I,t}}.
\end{aligned}
$$

- Law of motion of the capital stock

$$
K_t = \left(1 - \frac{\kappa_I}{2}\left(\frac{I_{t+q}Z_{I,t+q}}{I_{t+q-1}} - 1\right)^2\right) I_t + (1-\delta) K_{t-1}.
$$

### A.3 Equations related to FIs' Problems

- Participating constraint of investors

$$
\Phi_{F,t+1}\Phi_{E,t+1}R_{E,t+1}Q_t K_t = R_t \left[Q_t K_t - N_{E,t} - N_{F,t}\right] \text{ for all states in } t+1
$$

- Participating constraint of entrepreneurs

$$
\begin{aligned}
&\left(\int_{\overline{\omega}_{E,t+1}}^{\infty}\left(\omega_E - \overline{\omega}_{E,t+1}\right) dF\left(\omega_E\right)\right) \times \\
&R_{E,t+1}Q_t K_t = R_{E,t+1}N_{E,t} \text{ for all states in } t+1
\end{aligned}
$$

- The first order condition of FIs (note that the FIs need to meet this condition as well as the two participation constraints above)

$$
\begin{aligned}
0 = \mathrm{E}_t \{ &\left(1 - \Gamma_{F,t+1}\right)\Phi_{E,t+1}R_{E,t+1} \\
&+ \frac{\Gamma'_{F,t+1}}{\Phi'_{F,t+1}}\Phi_{F,t+1}\Phi_{E,t+1}R_{E,t+1} - \frac{\Gamma'_{F,t+1}}{\Phi'_{F,t+1}}R_t \\
&+ \frac{\left\{1 - \Gamma_{F,t+1}\right\}\Phi'_{E,t+1}}{\Gamma'_{E,t+1}}\left(1 - \Gamma_{E,t+1}\right) R_{E,t+1} \\
&+ \left.\frac{\Gamma'_{F,t+1}\Phi_{F,t+1}\Phi'_{E,t+1}}{\Phi'_{F,t+1}\Gamma'_{E,t+1}}\left(1 - \Gamma_{E,t+1}\right) R_{E,t+1}\right\} .
\end{aligned}
$$

where $\Phi_{F,t}$, $\Phi_{E,t}$, $\Phi'_{F,t}$ and $\Phi'_{E,t}$ are given by

$$\begin{aligned}\Phi_{F,t} &\equiv \int_{\overline{\omega}_{F,t}}^{\infty} \overline{\omega}_{F,t} dF\left(\omega_F\right) + \left(1-\mu_F\right) \int_0^{\overline{\omega}_{F,t}} \omega_F dF_F\left(\omega_F\right) \\ &\equiv -\mu_F G_{F,t} + \Gamma_{F,t}\end{aligned}$$

$$\begin{aligned}\Phi_{E,t} &\equiv \int_{\overline{\omega}_{E,t}}^{\infty} \overline{\omega}_{E,t} dF\left(\omega_E\right) + \left(1-\mu_E\right) \int_0^{\overline{\omega}_{E,t}} \omega_E dF_E\left(\omega_E\right) \\ &\equiv -\mu_E G_{E,t} + \Gamma_{E,t}\end{aligned}$$

$$\begin{aligned}\Phi'_{F,t} &\equiv -\mu_F \frac{\partial G_{F,t}}{\partial \overline{\omega}_{F,t}} + \frac{\partial \Gamma_{F,t}}{\partial \overline{\omega}_{F,t}} \\ \Phi'_{E,t} &\equiv -\mu_E \frac{\partial G_{E,t}}{\partial \overline{\omega}_{E,t}} + \frac{\partial \Gamma_{E,t}}{\partial \overline{\omega}_{E,t}}\end{aligned}$$

- Definitions of variables $G_{F,t}$ and $G_{E,t}$

$$G_{F,t} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{\log \overline{\omega}_{F,t} - 0.5\sigma_F^2}{\sigma_F}} \exp\left(-\frac{v_F^2}{2}\right) dv_F,$$

$$G_{E,t} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{\log \overline{\omega}_{E,t} - 0.5\sigma_E^2}{\sigma_E}} \exp\left(-\frac{v_E^2}{2}\right) dv_E,$$

- Definitions of variables $G'_{F,t}$ and $G'_{E,t}$

$$G'_{F,t} \equiv \frac{\partial G_{F,t}}{\partial \overline{\omega}_{F,t}} = \left(\frac{1}{\sqrt{2\pi}}\right) \left(\frac{1}{\overline{\omega}_{F,t} \sigma_F}\right) \exp\left(-.5 \left(\frac{\log \overline{\omega}_{F,t} - 0.5\sigma_F^2}{\sigma_F}\right)^2\right),$$

$$G'_{E,t} \equiv \frac{\partial G_{E,t}}{\partial \overline{\omega}_{E,t}} = \left(\frac{1}{\sqrt{2\pi}}\right) \left(\frac{1}{\overline{\omega}_{E,t} \sigma_E}\right) \exp\left(-.5 \left(\frac{\log \overline{\omega}_{E,t} - 0.5\sigma_E^2}{\sigma_E}\right)^2\right),$$

- Definitions of variables $\Gamma_{F,t}$ and $\Gamma_{E,t}$

$$\Gamma_{F,t} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{\log \overline{\omega}_{F,t} - 0.5\sigma_F^2}{\sigma_F}} \exp\left(-\frac{v_F^2}{2}\right) dv_F + \frac{\overline{\omega}_{F,t}}{\sqrt{2\pi}} \int_{\frac{\log \overline{\omega}_{F,t} + 0.5\sigma_F^2}{\sigma_F}}^{\infty} \exp\left(-\frac{v_F^2}{2}\right) dv_F,$$

$$\Gamma_{E,t} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{\log \overline{\omega}_{E,t} - 0.5\sigma_E^2}{\sigma_E}} \exp\left(-\frac{v_E^2}{2}\right) dv_E + \frac{\overline{\omega}_{E,t}}{\sqrt{2\pi}} \int_{\frac{\log \overline{\omega}_{E,t} + 0.5\sigma_E^2}{\sigma_E}}^{\infty} \exp\left(-\frac{v_E^2}{2}\right) dv_E,$$

- Definitions of variables $\Gamma'_{F,t}$ and $\Gamma'_{E,t}$

$$\begin{aligned}
\Gamma'_{F,t} &\equiv \frac{\partial \Gamma_{F,t}}{\partial \overline{\omega}_{F,t}} \\
&= \frac{1}{\sqrt{2\pi}\overline{\omega}_{F,t}\sigma_F} \exp\left(-.5\left(\frac{\log \overline{\omega}_{F,t} - 0.5\sigma_F^2}{\sigma_F}\right)^2\right) \\
&\quad + \frac{1}{\sqrt{2\pi}} \int_{\frac{\log \overline{\omega}_{F,t} + 0.5\sigma_F^2}{\sigma_F}}^{\infty} \exp\left(-\frac{v_F^2}{2}\right) dv_F \\
&\quad - \frac{1}{\sqrt{2\pi}\sigma_F} \exp\left(-.5\left(\frac{\log \overline{\omega}_{F,t} + 0.5\sigma_F^2}{\sigma_F}\right)^2\right),
\end{aligned}$$

$$\begin{aligned}
\Gamma'_{E,t} &\equiv \frac{\partial \Gamma_{E,t}}{\partial \overline{\omega}_{E,t}} \\
&= \frac{1}{\sqrt{2\pi}\overline{\omega}_{E,t}\sigma_E} \exp\left(-.5\left(\frac{\log \overline{\omega}_{E,t} - 0.5\sigma_E^2}{\sigma_E}\right)^2\right) \\
&\quad + \frac{1}{\sqrt{2\pi}} \int_{\frac{\log \overline{\omega}_{E,t} + 0.5\sigma_E^2}{\sigma_E}}^{\infty} \exp\left(-\frac{v_E^2}{2}\right) dv_E \\
&\quad - \frac{1}{\sqrt{2\pi}\sigma_E} \exp\left(-.5\left(\frac{\log \overline{\omega}_{E,t} + 0.5\sigma_E^2}{\sigma_E}\right)^2\right).
\end{aligned}$$

- Law of motion for FIs' net worth

$$N_{F,t+1} = \gamma_F V_{F,t+1} + \frac{W_{F,t}}{P_t} + \varepsilon_{N_{F,t+1}},$$

where

$$V_{F,t+1} \equiv \left(1-\Gamma_F\left(\overline{\omega}_{F,t+1}\right)\right)\Phi_E\left(\overline{\omega}_{E,t+1}\right)R_{E,t+1}Q_tK_t.$$

## A.4 Shock process

$$\begin{aligned}
\ln Z_t &= \ln Z_{t-1} + u_{Z,t},\ \ u_{Z,t} = \rho_Z u_{Z,t-1} + \epsilon_{Z,t}, \\
\ln A_t &= (1-\rho_A)\ln A + \rho_A \ln A_{t-1} + \epsilon_{A,t}, \\
\varepsilon_{N_\zeta,t} &= \rho_{N_\zeta}\varepsilon_{N_\zeta,t-1} + \epsilon_{N_\zeta,t},\ \text{ for } \zeta = F \text{ and } E, \\
\ln A_{I,t} &= (1-\rho_{A_I})\ln A_I + \rho_{A_I}\ln A_{I,t-1} + \epsilon_{A_I,t}, \\
\ln A_{U,t} &= (1-\rho_{A_U})\ln A_U + \rho_{A_U}\ln A_{U,t-1} + \epsilon_{A_U,t}, \\
\ln G_t &= (1-\rho_G)\ln G + \rho_G \ln G_{t-1} + \epsilon_{G,t}, \\
\ln Z_{I,t} &= (1-\rho_I)\ln Z_I + \rho_{Z_I}\ln Z_{I,t-1} + \epsilon_{Z_I,t}, \\
\ln \theta_{P_Y,t} &= (1-\rho_{P_Y})\ln \theta_{P_Y} + \rho_{P_Y}\ln \theta_{P_Y,t-1} + \epsilon_{P_Y,t}, \\
\ln \theta_{W,t} &= (1-\rho_W)\ln \theta_W + \rho_W \ln \theta_{W,t-1} + \epsilon_{W,t},
\end{aligned}$$

## A.5 Other equations

- Resource constraint

$$\begin{aligned}
Y_{g,t} &= C_t + \frac{I_t}{A_{I,t}} + G_t + \int_0^1 \Psi_t(l)\,dl + \frac{\left(\kappa_U\left(A_{U,t}U_t\right)^{\gamma_U+1}-1\right)}{\Upsilon_U+1}K_{t-1} \\
&\quad +\mu_E\left(\int_0^{\overline{\omega}_{E,t}}\omega_E dF_E\left(\omega_E\right)\right)R_{E,t}Q_{t-1}K_{t-1} + \mu_F\left(\int_0^{\overline{\omega}_{F,t}}\omega_F dF_F\left(\omega_F\right)\right)\Phi_{E,t}R_{E,t}Q_{t-1}K_{t-1} \\
&\quad +\left(1-\gamma_F\right)V_{F,t} + \left(1-\gamma_E\right)V_{E,t}.
\end{aligned}$$

- Monetary policy

$$R_{n,t} = R_{n,t-1}^{\rho}\pi_t^{(1-\rho)\varphi_\pi}\exp\left(\epsilon_{R_n,t}\right), \tag{28}$$

where

$$\pi_t = \frac{P_t}{P_{t-1}}.$$

- GDP and its component

$$Y_t = C_t + \frac{I_t}{A_{I,t}} + G_t.$$

- Definition of TFP

$$\lambda_t = \frac{Y_t}{(L_t)^{\psi_L} (K_{t-1}U_t)^{1-\psi_L}}.$$

Table 1: Estimated Parameters

(1) Values of Estimated Parameters (Prior and Posterior Distributions)

| | | Prior Distribution | | | Posterior Distribution | | |
|---|---|---|---|---|---|---|---|
| | | Distribution | Mean | S.D. | Mean | 5th Percentiles | 95th Percentiles |
| $\upsilon$ | Elasticity of Labor Supply | gamma | 1 | 0.1 | 1.01 | 0.86 | 1.14 |
| $\kappa_I$ | Capital Stock Adjustment Cost | gamma | 1 | 0.1 | 1.40 | 1.22 | 1.58 |
| $\kappa_p$ | Price Adjustment Cost | gamma | 20 | 10 | 7.08 | 5.17 | 9.10 |
| $\kappa_w$ | Nominal Wage Adjustment Cost | gamma | 20 | 10 | 3.81 | 1.22 | 6.26 |
| $\varphi_\pi$ | Policy Weight on Inflation in Taylor Rule* | gamma | 2 | 0.05 | 2.12 | 2.06 | 2.19 |
| $\rho$ | Monetary Policy Smoothing* | gamma | 0.9 | 0.1 | 0.81 | 0.76 | 0.86 |
| $\gamma_U$ | Inverse Elasticity of Capital Utilization Rate | gamma | 5 | 1 | 6.55 | 4.91 | 8.15 |
| $\sigma_F$ | Riskiness of Idiosyncratic Productivities (FI) | gamma | 0.104 | 0.002 | 0.10 | 0.10 | 0.10 |
| $\sigma_E$ | Riskiness of Idiosyncratic Productivities (Entrepreneurs) | gamma | 0.309 | 0.002 | 0.31 | 0.31 | 0.31 |
| $\mu_F$ | Monitoring Cost (IF Contract) | gamma | 0.539 | 0.01 | 0.53 | 0.52 | 0.55 |
| $\mu_E$ | Monitoring Cost (FE Contract) | gamma | 0.02 | 0.01 | 0.01 | 0.00 | 0.01 |
| $\gamma_F$ | Survival Rates (FI) | beta | 0.923 | 0.001 | 0.93 | 0.92 | 0.93 |
| $\gamma_E$ | Survival Rates (Entrepreneurs) | beta | 0.974 | 0.001 | 0.97 | 0.97 | 0.97 |
| $\rho_Z$ | Permanent Technology Shock AR | beta | 0.5 | 0.15 | 0.07 | 0.02 | 0.11 |
| $\rho_A$ | Temporary Technology Shock (Common) AR | beta | 0.5 | 0.15 | 0.75 | 0.68 | 0.83 |
| $\rho_{A_I}$ | Temporary Technology Shock (Investment Specific) AR | beta | 0.5 | 0.15 | 0.98 | 0.96 | 0.99 |
| $\rho_{N_F}$ | Net Worth Shock (FI) AR | beta | 0.5 | 0.15 | 0.41 | 0.23 | 0.59 |
| $\rho_{N_E}$ | Net Worth Shock (Entrepreneur) AR | beta | 0.5 | 0.15 | 0.12 | 0.05 | 0.19 |
| $\rho_G$ | Demand Shock AR | beta | 0.5 | 0.15 | 0.80 | 0.71 | 0.88 |
| $\rho_{Z_I}$ | Investment Adjustment Shock AR | beta | 0.5 | 0.15 | 0.82 | 0.78 | 0.85 |
| $\rho_{P_Y}$ | Price Markup Shock AR | beta | 0.5 | 0.15 | 0.88 | 0.83 | 0.93 |
| $\rho_W$ | Nominal Wage Markup Shock AR | beta | 0.5 | 0.15 | 0.21 | 0.06 | 0.36 |
| $\rho_{A_U}$ | Utilization Adjustment Cost Shock AR | beta | 0.5 | 0.15 | 0.81 | 0.74 | 0.88 |
| $\sigma_Z$ | Permanent Technology Shock SD | invg | 0.05 | 5 | 0.006 | 0.006 | 0.006 |
| $\sigma_A$ | Temporary Technology Shock (Common) SD | invg | 0.05 | 5 | 0.006 | 0.006 | 0.007 |
| $\sigma_{A_I}$ | Temporary Technology Shock (Investment Specific) SD | invg | 0.05 | 5 | 0.006 | 0.006 | 0.007 |
| $\sigma_{R_n}$ | Monetary Policy Shock SD | invg | 0.01 | 5 | 0.002 | 0.002 | 0.002 |
| $\sigma_{N_F}$ | Net Worth Shock (FIs) SD | invg | 0.02 | 5 | 0.008 | 0.006 | 0.010 |
| $\sigma_{N_E}$ | Net Worth Shock (Entrepreneurs) SD | invg | 0.05 | 5 | 0.03 | 0.02 | 0.03 |
| $\sigma_G$ | Demand Shock SD | invg | 0.3 | 5 | 0.06 | 0.05 | 0.07 |
| $\sigma_{Z_I}$ | Investment Adjustment Shock SD | invg | 0.5 | 5 | 0.18 | 0.15 | 0.21 |
| $\sigma_{P_Y}$ | Price Markup Shock SD | invg | 0.1 | 5 | 0.03 | 0.02 | 0.03 |
| $\sigma_W$ | Nominal Wage Markup Shock SD | invg | 0.1 | 5 | 0.08 | 0.05 | 0.12 |
| $\sigma_{A_U}$ | Utilization Adjustment Cost Shock SD | invg | 0.1 | 5 | 0.02 | 0.02 | 0.03 |

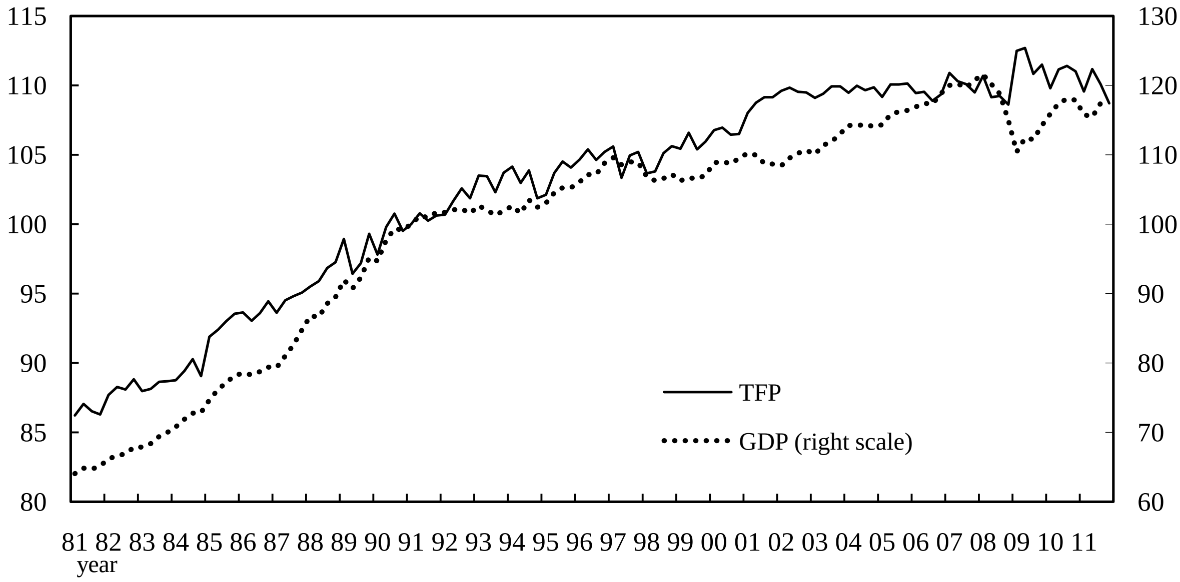
* The posterior distribution for policy weight in Taylor rule and monetary policy smoothing is obtained from Bayesian estimation using pre-ZLB sample, from 1980:2Q to 1998:4Q. The posterior distribution for the other parameters is obtained using full sample, from 1980:2Q to 2011:4Q, with policy weight in Taylor rule and monetary policy smoothing fixed to the mean of the distribution from the pre-ZLB sample estimation.

(2) Values of Calibrated Parameters

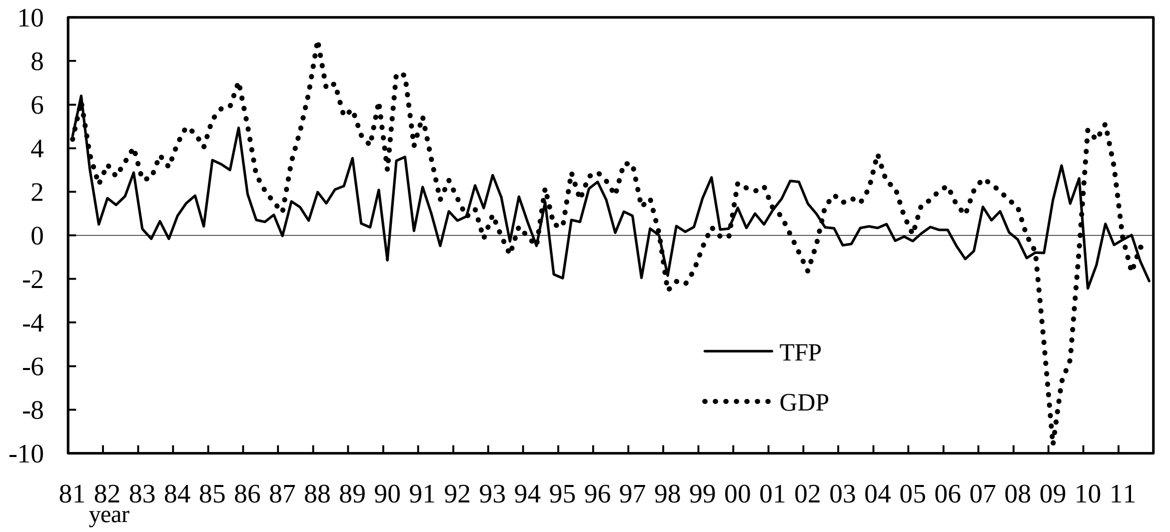
| | | |
|---|---|---|
| $\alpha$ | Labor Share (Household) | 0.6 |
| $\alpha_E$ | Labor Share (Entrepreneur) | 0.02 |
| $\alpha_{FI}$ | Labor Share (FI) | 0.02 |
| $\gamma$ | Share of Intermediate Goods | 0.583 |
| $\kappa_U$ | Scaling of Capital Utilization Adjustment Cost | 0.05 |
| $\varphi$ | Disutility weight on Labor | 0.2 |
| $\beta$ | Households' Discount Factor | 0.99 |
| $\delta$ | Capital Depreciation Rate | 0.028 |
| $\theta_{P_Y}$ | Elasticity of Substitution between Differentiated Products at Steady State | 7 |
| $\theta_W$ | Elasticity of Substitution between Differentiated Labor Inputs at Steady State | 7 |

Figure 1: Total Factor Productivity & GDP

(1) Level (1991:1Q=100)




(2) Growth Rate (year on year % change)




(3) Growth Rate (average of 10 years)

year on year % change

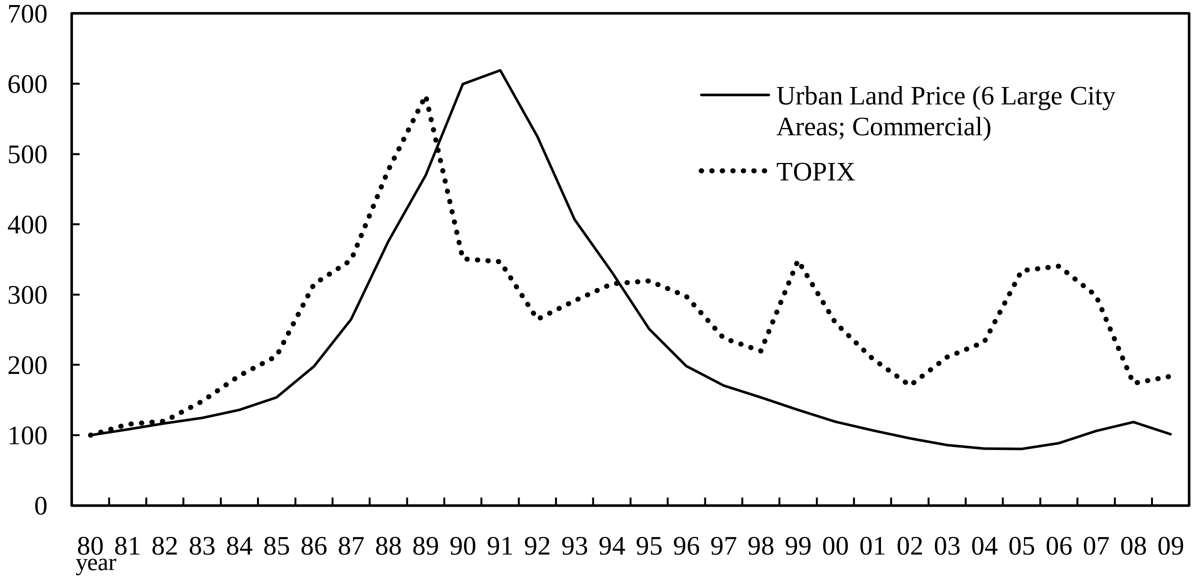
| | 1980s | 1990s | 2000s and beyond |
|---|---|---|---|
| TFP | 1.78 | 0.77<br>*-1.01* | 0.31<br>*-1.47* |
| GDP | 4.44 | 1.42<br>*-3.02* | 0.73<br>*-3.71* |

Notes: Numbers in italics below growth rate figures are differences in growth rate from that in the 1980s.

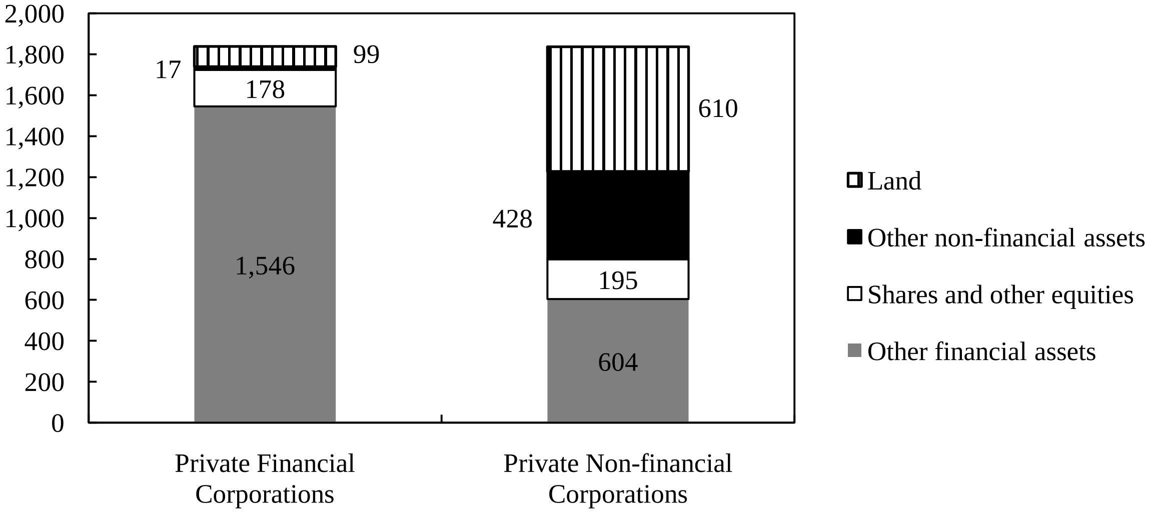
Sources: Cabinet Office, "National Accounts"; Ministry of Health, Labour and Welfare, "Monthly Labour Survey"; Ministry of Internal Affairs and Communications, "Labour Force Survey"; Ministry of Economy, Trade and Industry, "Indices of Industrial Production."

## Figure 2: Asset Prices and Balance Sheets

(1) Asset Prices (Index, 1980=100)




(2) Balance Sheet of Corporations (End of 1990, Trillion Yen)

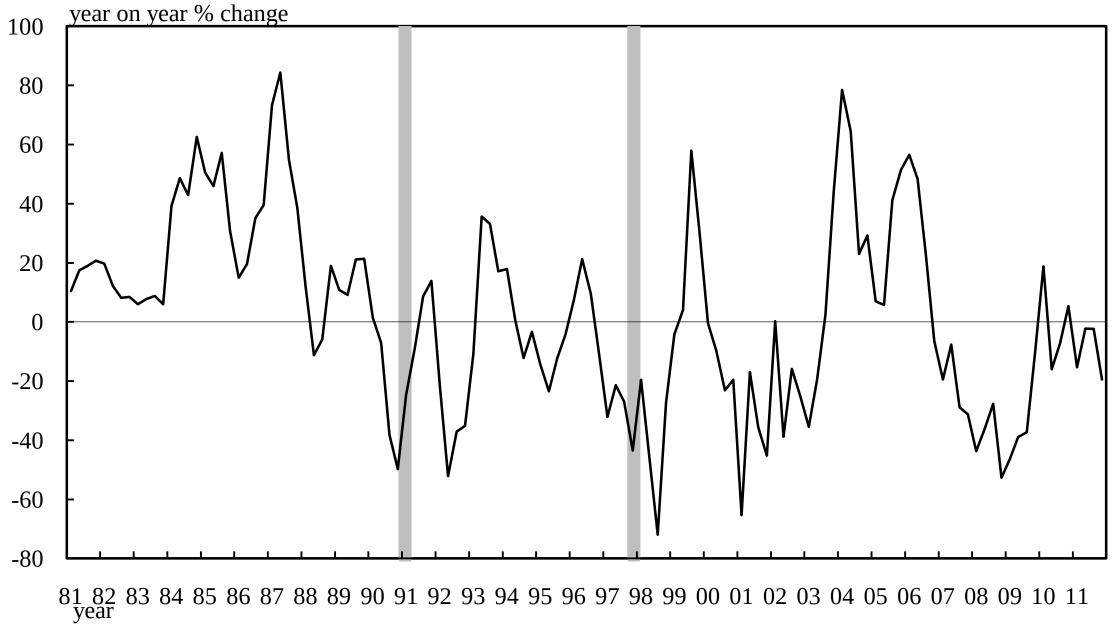



Notes: In the upper panel (1), a figure for the land price is that of the end of March the next year, and a figure for the TOPIX is that of the end of the year.

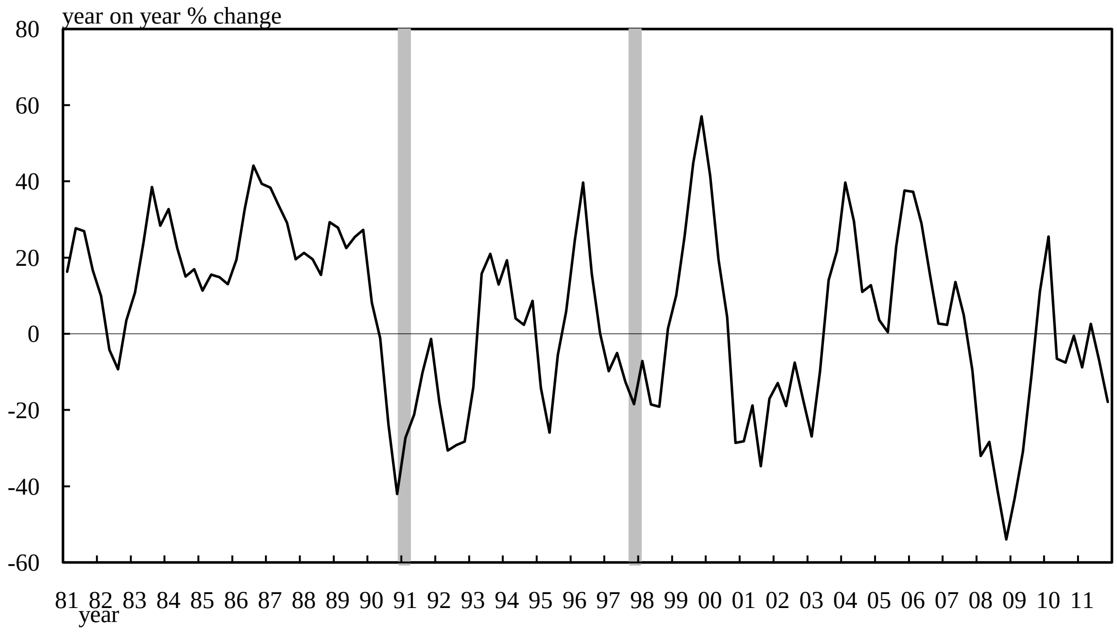
Sources: Japan Real Estate Institute., "Urban Land Price Index," Japan Exchange Group Inc., "TOPIX, Historical Index Value," Cabinet Office, "National Accounts."

Figure 3: Net Worth of the FI and Goods-Producing Sectors

(1) FI Net Worth




(2) Goods-Producing Sector Net Worth



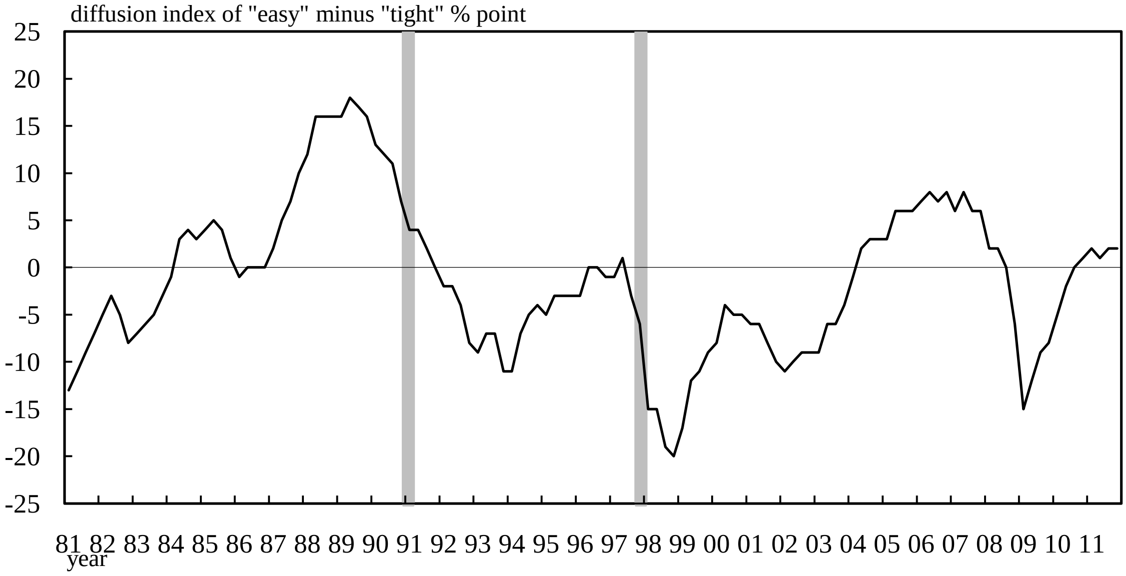

Note: 1. We construct the time series of net worth as follows. We employ the outstandings of shares issued by depository corporations and non-financial corporations from Flow of Funds Accounts for FI net worth and Goods-Producing Sector net worth, respectively. However, the outstandings of shares are evaluated not at market value but at book value basis before 1995:4Q for depository corporations, and before 1994:4Q for non-financial corporations. Thus, we extend each series at market value backward using the market capitalization of banks and that of non-financial firms.

2. Gray bars in the figures (at 1991:1Q and 1997:4Q) show the point where financial crises started.

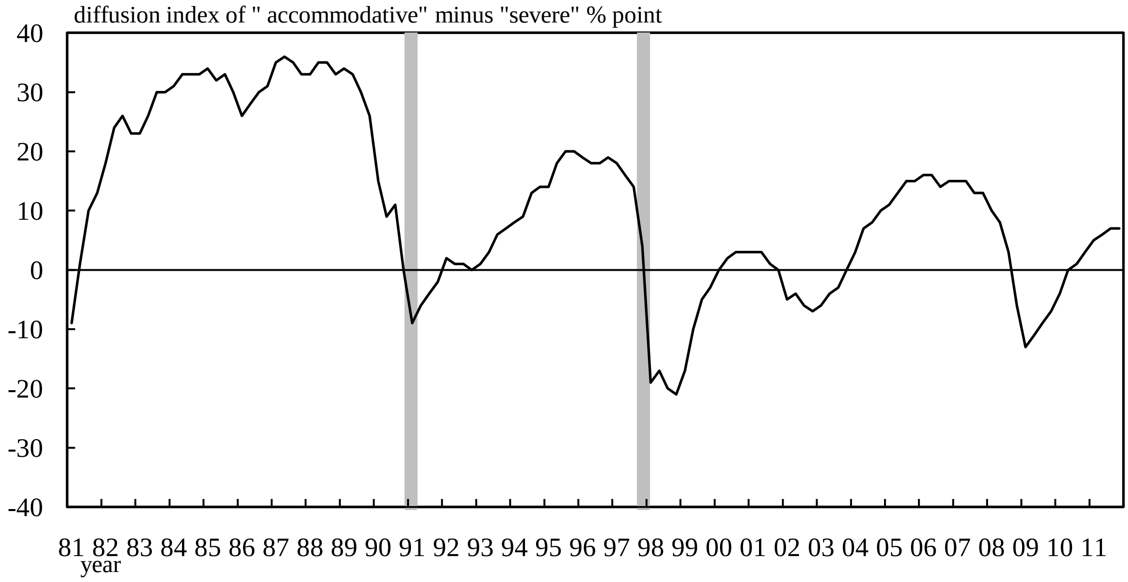
Sources: Japan Exchange Group, Inc., "Market Capitalization"; Bank of Japan, "Flow of Funds Accounts."

Figure 4: Financial Situation of Non-financial Firms

(1) Financial Position (all firms)




(2) Lending Attitude of Financial Institutions (all firms)



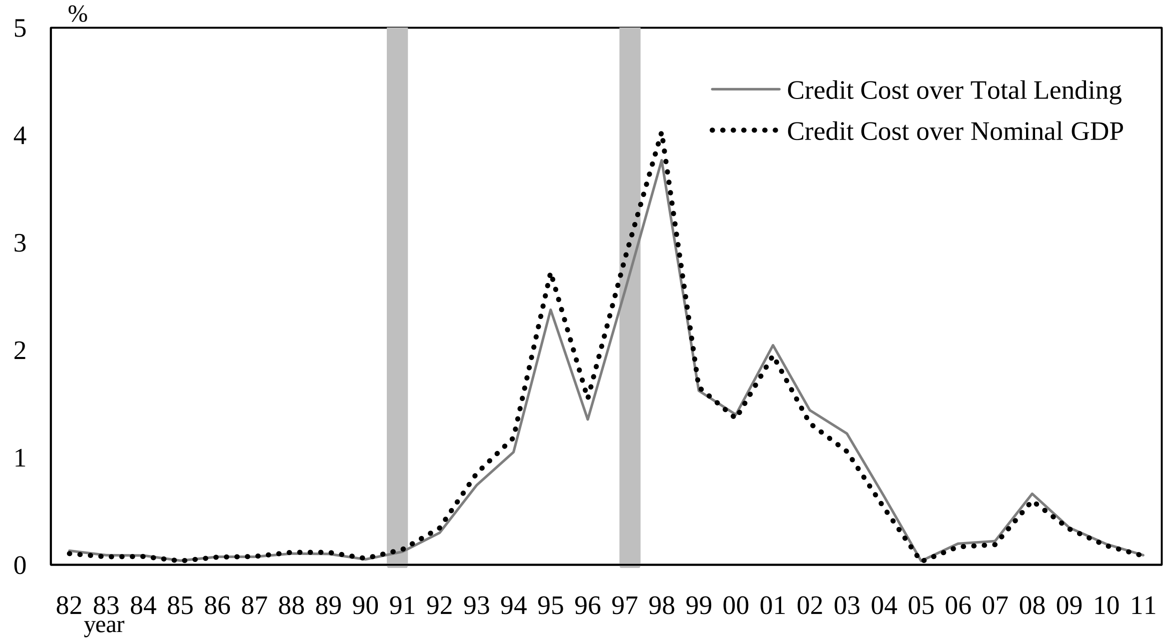

Note: 1. The two diffusion indices are based on the Short-Term Economic Survey of Enterprises in Japan, which is also known as the Tankan, conducted by the Bank of Japan. Regarding financial position, responding enterprises are asked to choose one alternative among three, 1) Easy, 2) Not so tight, and 3) Tight, as the best descriptor of prevailing conditions at the time of the survey, excluding seasonal factors, and expected conditions for the following three months. Financial position refers to the general cash position of the responding enterprise, with respect to level of cash and cash equivalent, the lending attitude of financial institutions, and payment and repayment terms. Regarding the lending attitude of financial institutions, responding enterprises are asked to choose one alternative among three, 1) Accommodative, 2) Not so severe, and 3) Severe. The responses are aggregated into diffusion indices as the percentage share of enterprises responding with alternative 1), minus the percentage share of enterprises responding with alternative 3).

2. Gray bars in the figures (at 1991:1Q and 1997:4Q) show the point where financial crises started.

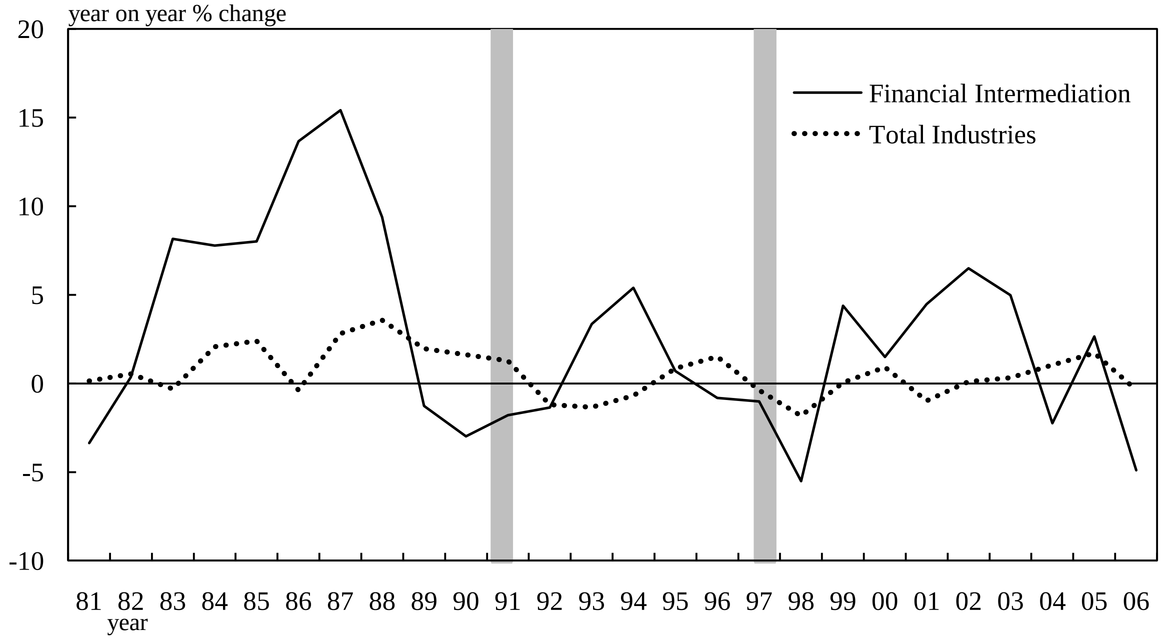
Source: Bank of Japan, "Tankan, Short-term Economic Survey of Enterprises in Japan."

Figure 5: Credit Cost and Productivity of Financial Sector

(1) Credit Cost Ratio of Japanese Banks




(2) Productivity based on EU KLEMS

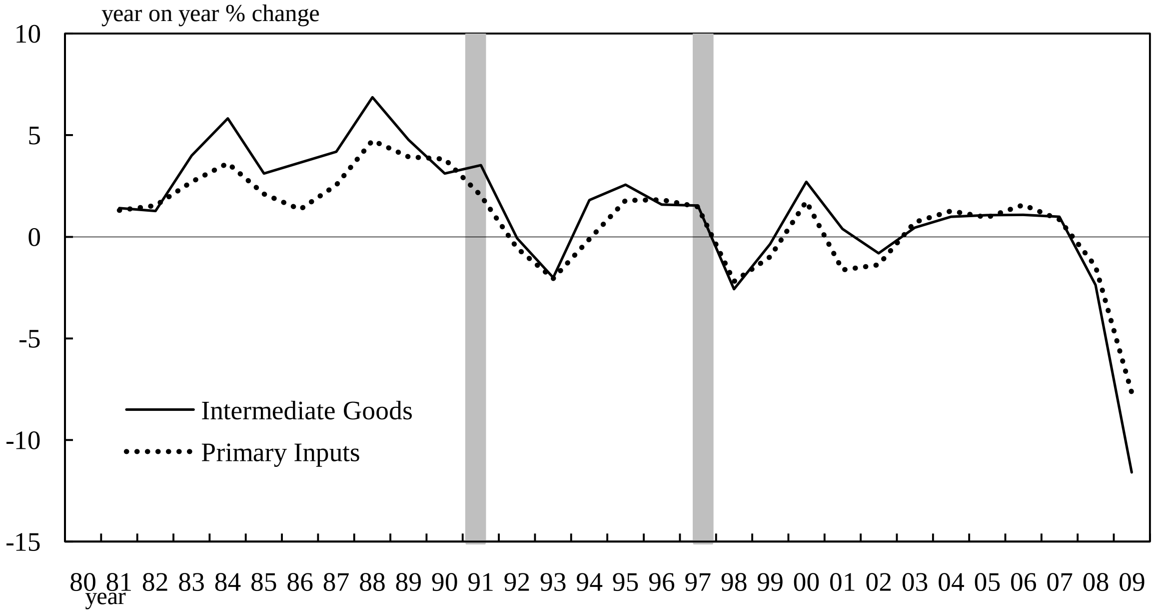



Note: 1. The productivity series are those provided by EU KLEMS at http://www.euklems.net/. These productivity series are constructed from the growth rates of real output (value added) minus the weighted growth rates of labor input and capital input. The two-period average share of each of the primary inputs to the nominal value added is used as the weight. Unlike the capital input series in our TFP series, capital input is not adjusted for variations in capacity utilization of capital stock.

2. Gray bars in the figures (at 1991 and 1997) show the point where financial crises started.

Source: Bank of Japan, "Financial System Report"; Cabinet Office, "National Accounts"; EU KLEMS, “EU KLEMS Growth and Productivity Accounts: November 2009 Release.”

Figure 6: Usage of Intermediate Goods and Primary Inputs
in Gross Output Production




year on year % change

| | 1980s | 1990s | 2000s and beyond |
|---|---|---|---|
| Primary Inputs | 2.65 | 0.50<br>*-2.14* | -0.50<br>*-3.15* |
| Intermediate Goods | 3.90 | 0.91<br>*-2.99* | -0.71<br>*-4.61* |

Note: 1. Numbers in italics below growth rate figures are differences in growth rate from that in the 1980s. The growth rates of primary inputs are constructed from the weighted growth rates of labor input and capital input. We use the average share of each input as the weight. We take variations in capacity utilization of capital stock into account when calculating the growth rates of capital input.
2. Gray bars in the figures (at 1991 and 1997) show the point where financial crises started.

Sources: Cabinet Office, "National Accounts"; Ministry of Health, Labour and Welfare, "Monthly Labour Survey"; Ministry of Internal Affairs and Communications, "Labour Force Survey"; Ministry of Economy, Trade and Industry, "Indices of Industrial Production."

Figure 7: Outline of the Model

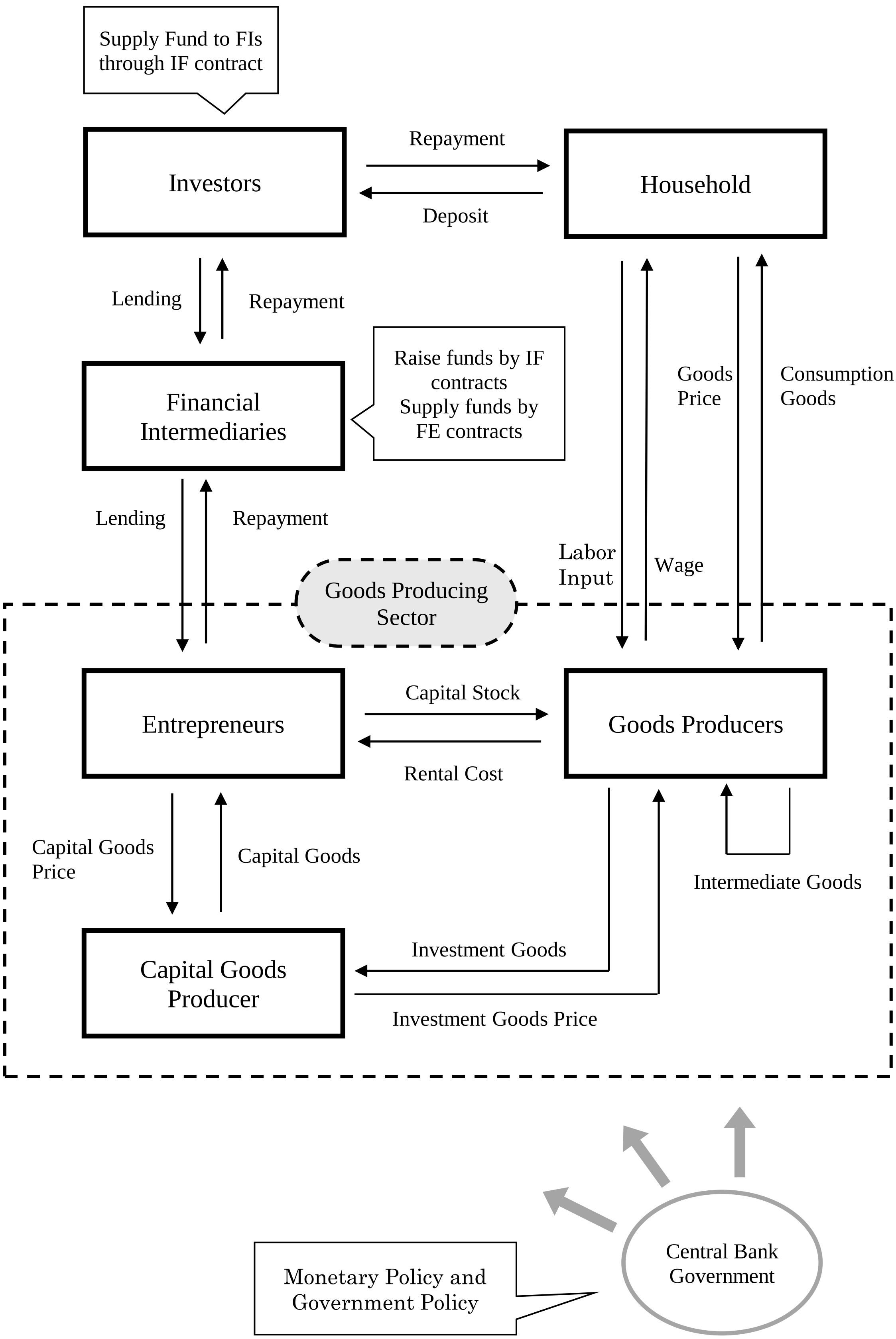
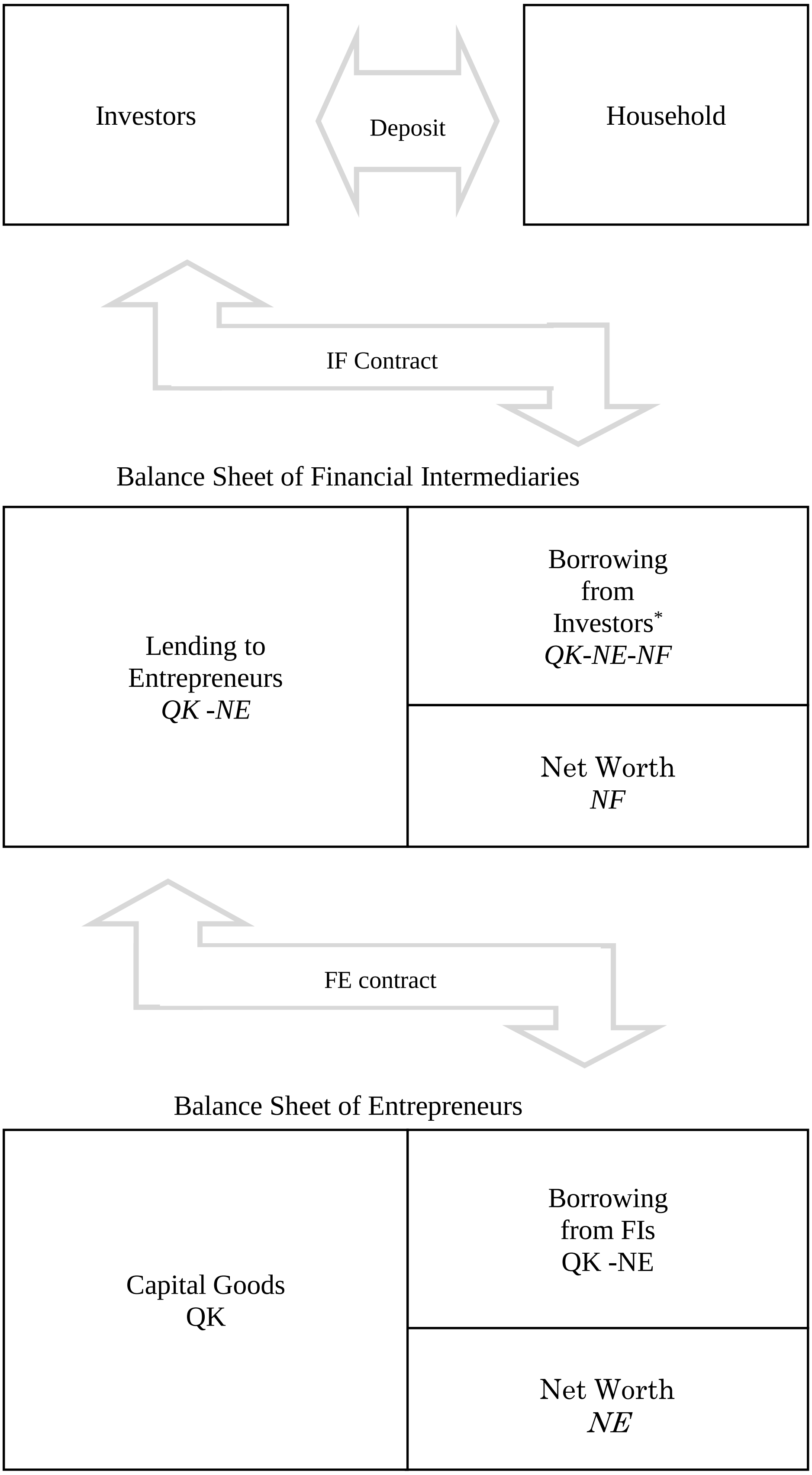


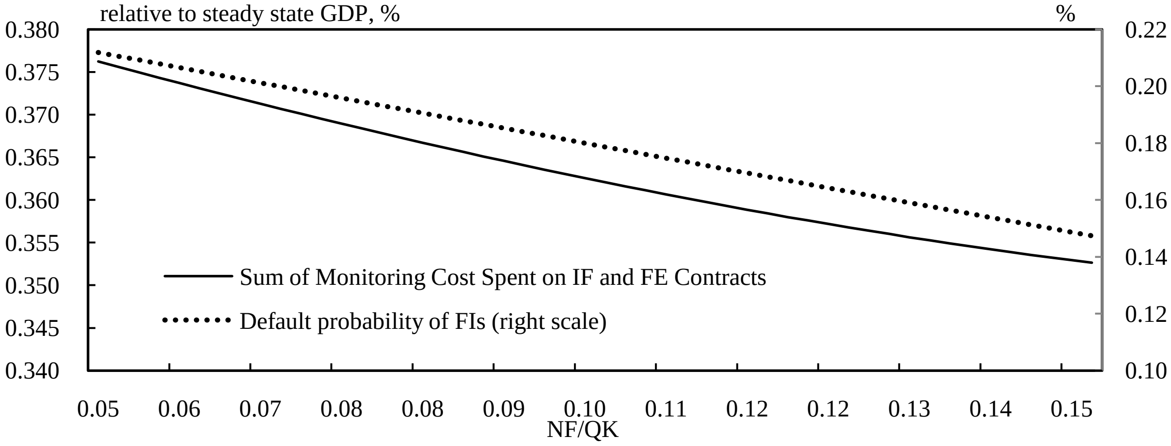
Figure 8: Chained Credit Contract



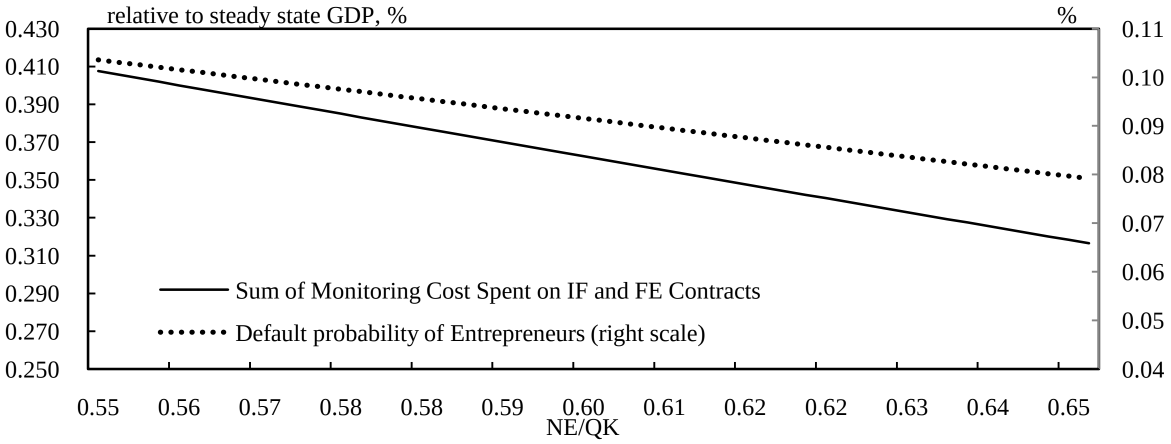

* Investors collect households' deposits and lend all of what they collect to FIs.

Figure 9: Effects of Net Worth on Terms of Financial Contracts

(1) Effects of FI Net Worth on Monitoring Costs and Default Probability of Borrowers



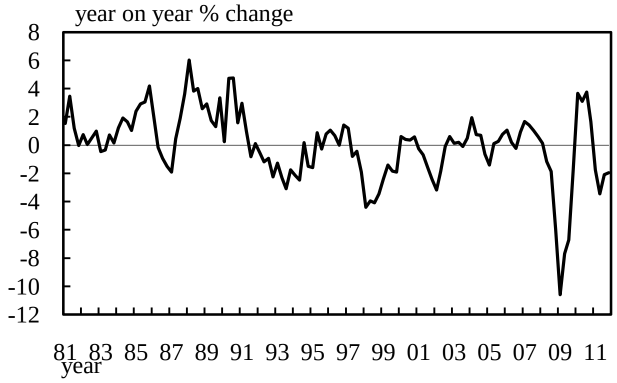

(2) Effects of Entrepreneurs' Net Worth on Monitoring Costs and Default Probability of Borrowers



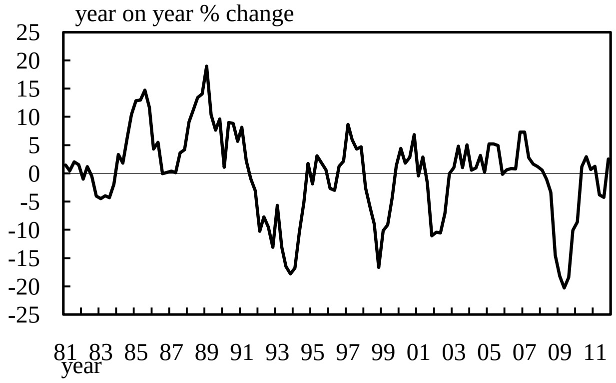

Note: The figures show monitoring costs and probabilities of borrower defaults implied by the optimal IF and FE contracts when FIs choose investment of a fixed size QK for a given but different amount of net worth NF and NE.

## Figure 10: Data Used for Estimation (1)

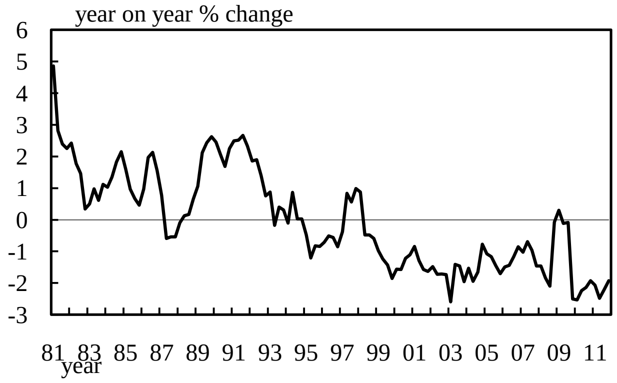
(1) Real GDP



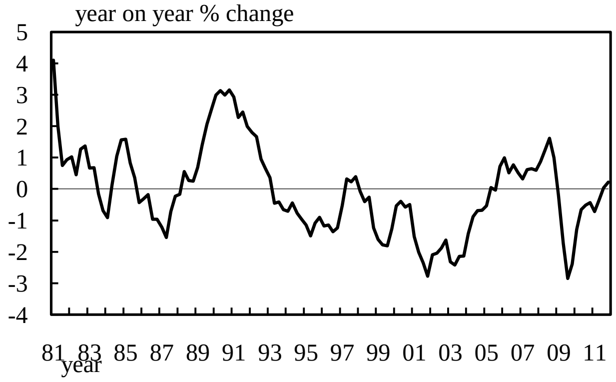

(2) Real Investment



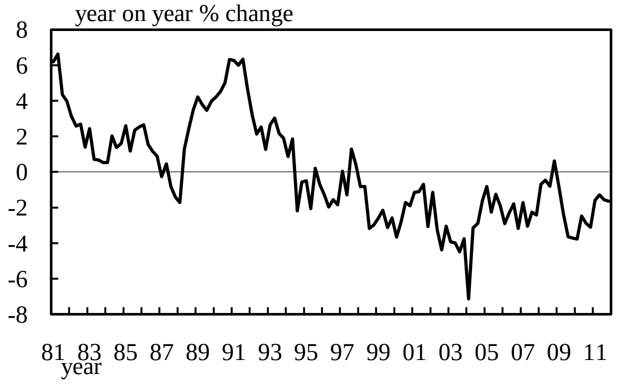

(3) GDP Deflator



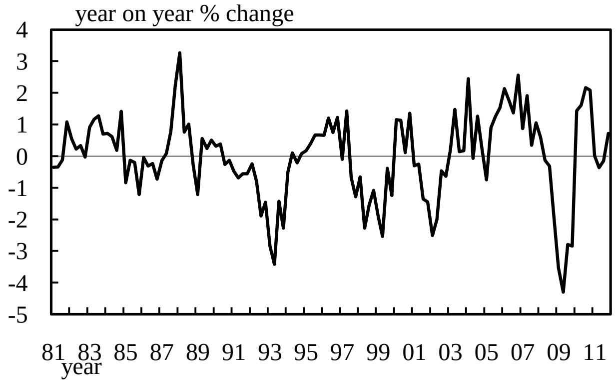

(4) Investment Deflator




(5) Nominal Wage



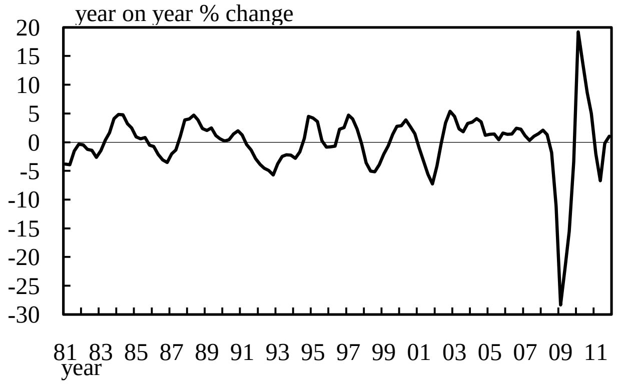

(6) Working Hours



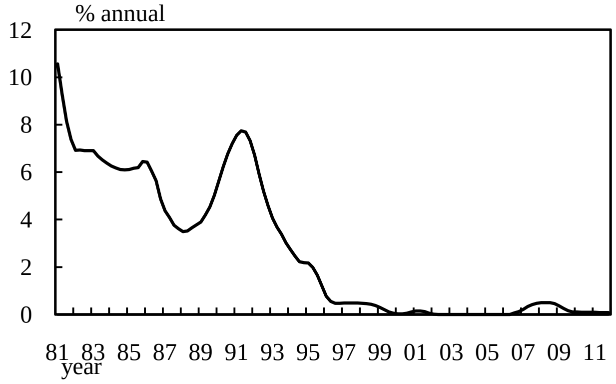

Note: Series (1), (2), and (6) are on a per capita basis using population aged 15 and over. All series are demeaned. For all of the series other than series (8), we use a quarter on quarter % change of the variable rather than a year on year % change the variable in our estimation. We use the level series of series (8) in our estimation.
Sources: Cabinet Office, "National Accounts"; Ministry of Health, Labour and Welfare, "Monthly Labour Survey"; Ministry of Internal Affairs and Communications, "Labour Force Survey."

# Figure 10: Data Used for Estimation (2)

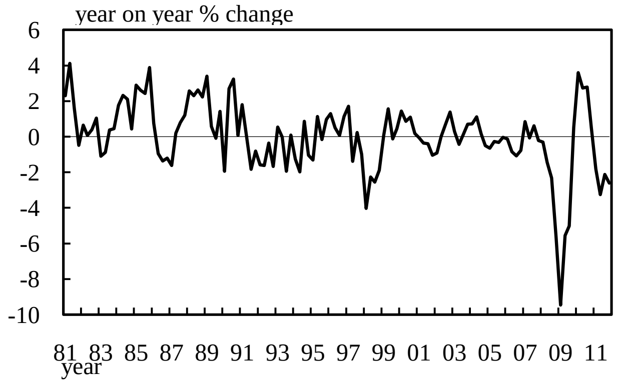
(7) Capacity Utilization Rate of Capital



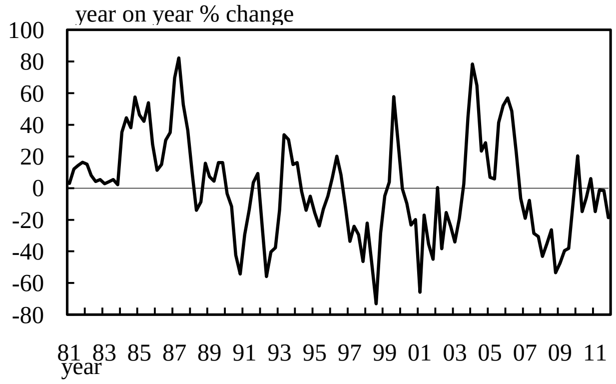

(8) Policy Rate



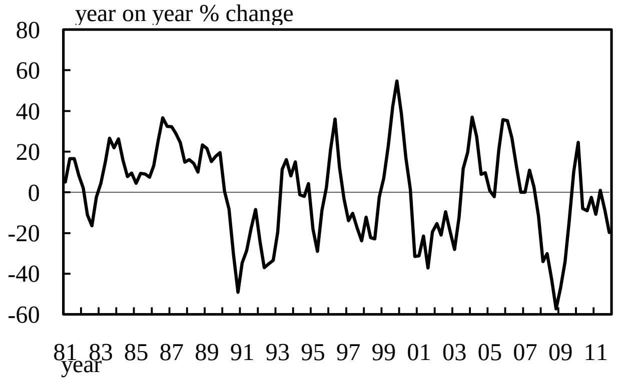

(9) TFP (Capital Utilization Rate Unadjusted)




(10) FI Real Net Worth




(11) Entrepreneurs' Real Net Worth

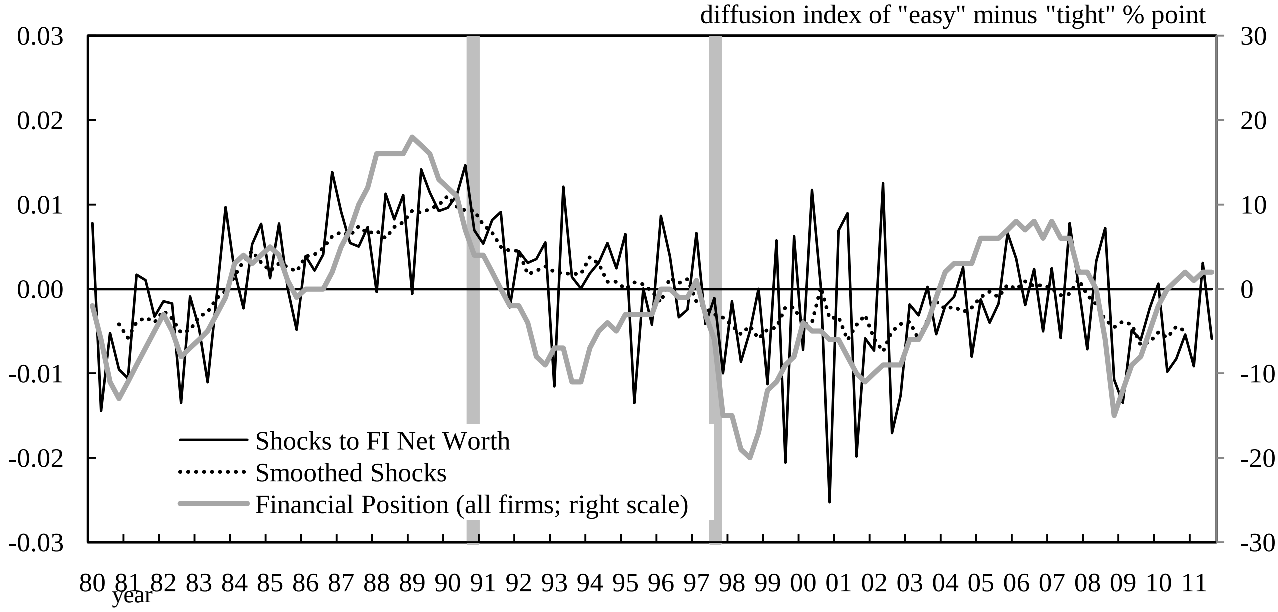



Note: Series (10) and (11) are on a per capita basis using population aged 15 and over. All series are demeaned, except series (8). For all of the series other than series (8), we use a quarter on quarter % change of the variable rather than a year on year % change the variable in our estimation. We use the level series of series (8).

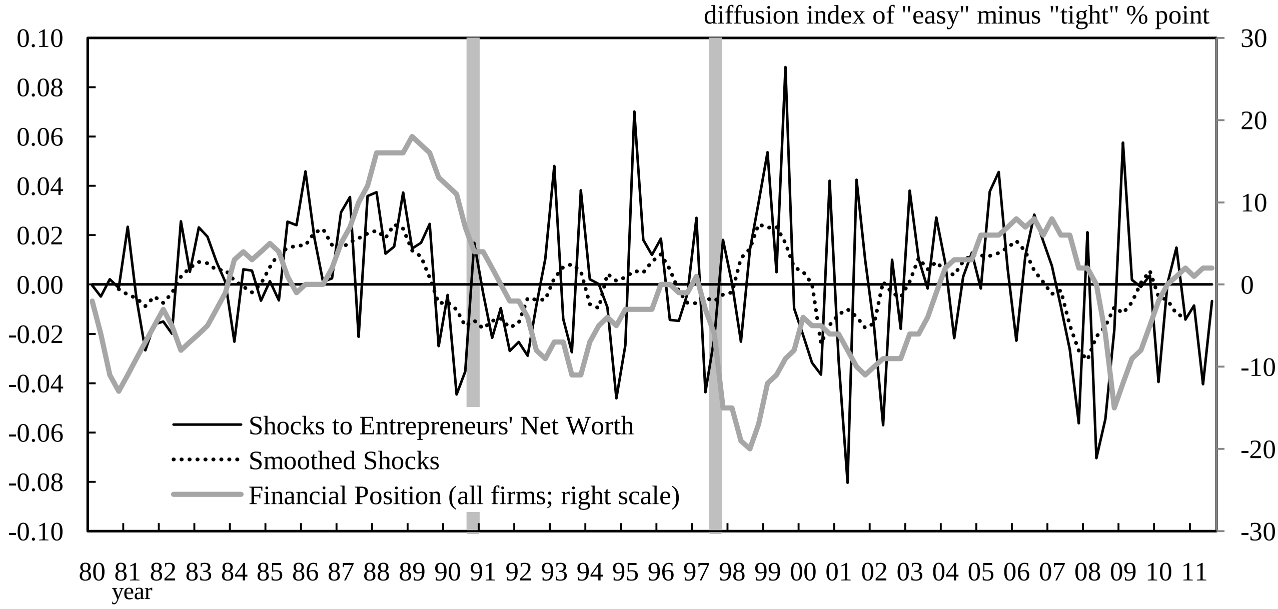
Sources: Cabinet Office, "National Accounts"; Ministry of Health, Labour and Welfare, "Monthly Labour Survey"; Ministry of Internal Affairs and Communications, "Labour Force Survey"; Ministry of Economy, Trade and Industry, "Indices of Industrial Production"; Japan Exchange Group, Inc., "Market Capitalization"; Bank of Japan, "Flow of Funds Accounts," "Call Rates, Uncollateralized Overnight," "Call Rates, Collateralized Overnight, Average."

Figure 11: Estimated Shocks to Net Worth

(1) Shocks to FI Net Worth



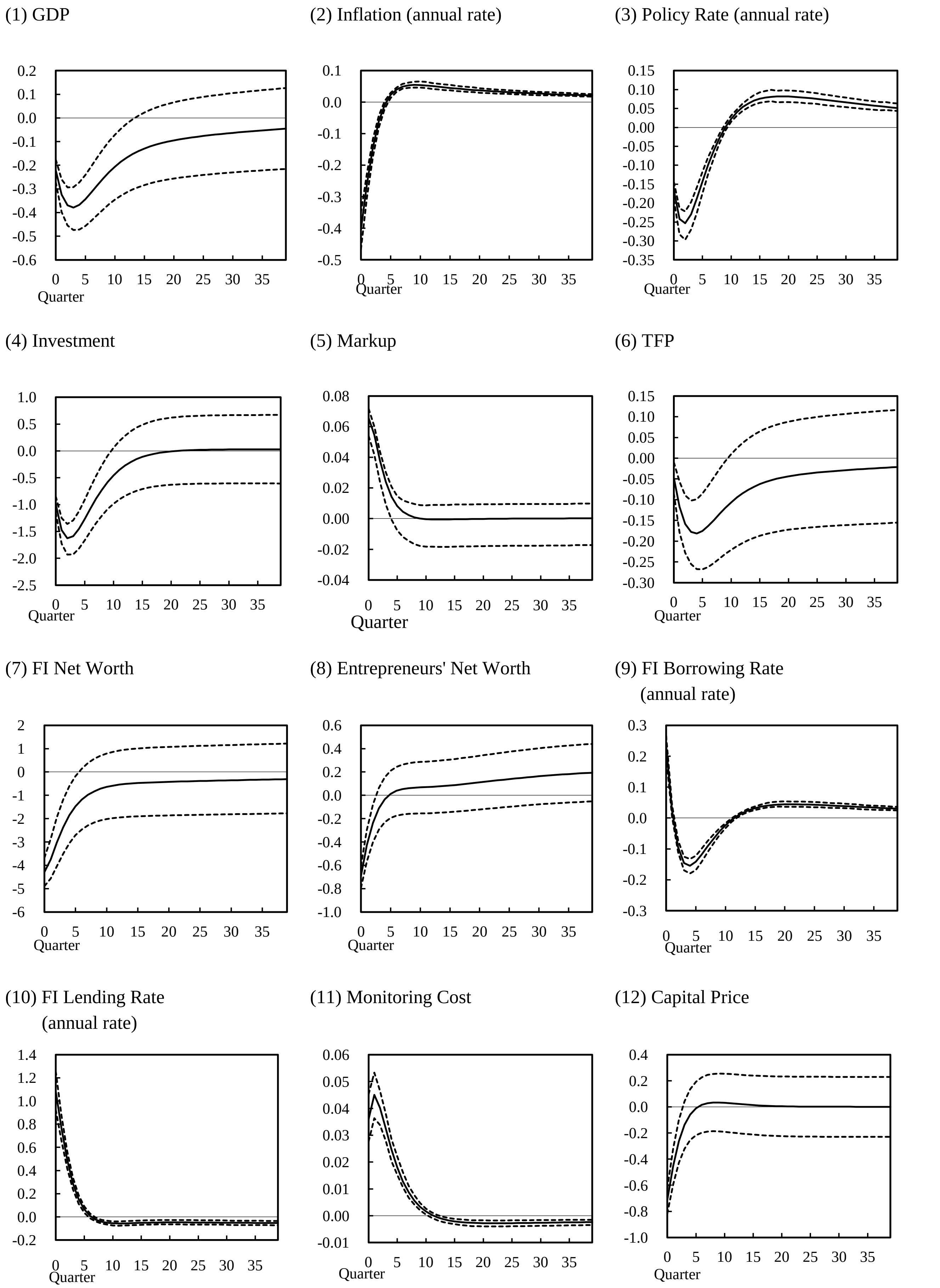

(2) Shocks to Entrepreneurs' Net Worth




Note: 1. Gray bars in the figures (at 1991:1Q and 1997:4Q) show the point where financial crises started.
2. Smoothed shocks are the moving averages of both forward and backward 3 quarters.
3. See footnote of Figure 4 for the index of Financial Position.

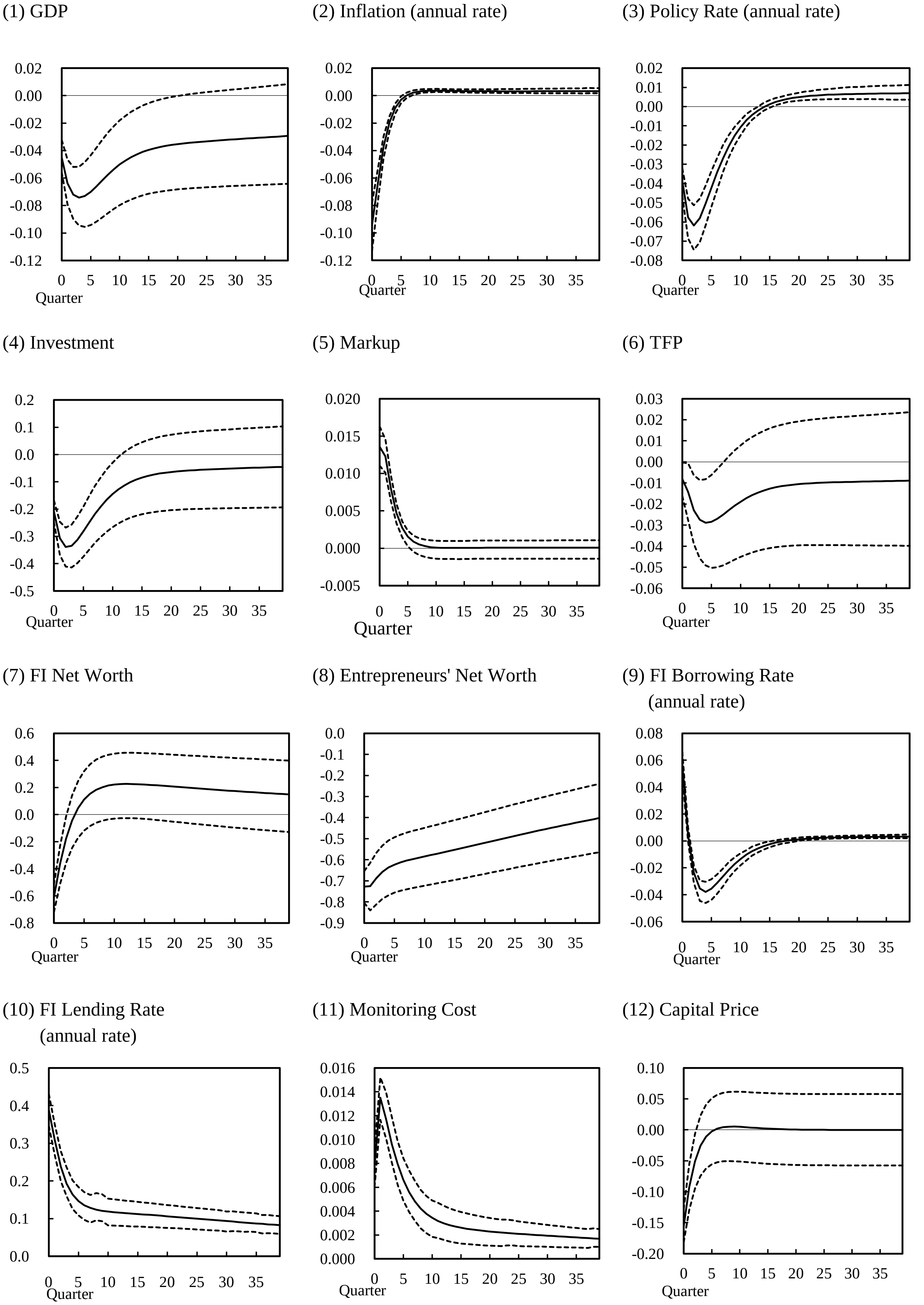
Source: Bank of Japan, "Tankan, Short-term Economic Survey of Enterprises in Japan."

Figure 12: Response to a Negative Shock to FI Net Worth



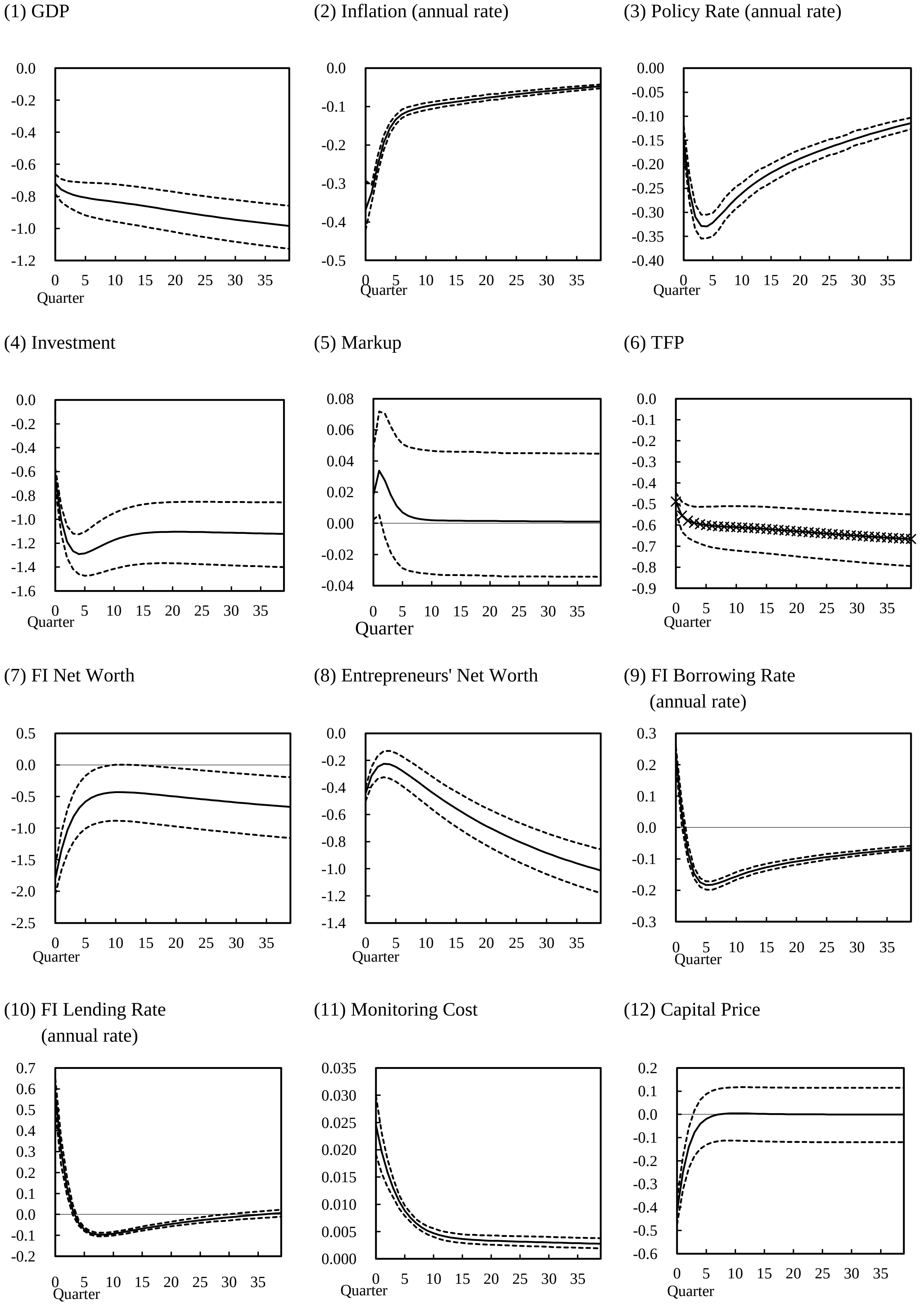

Notes: Interest rates, inflation, and markup are deviation from the non-stochastic steady state. Others are percentage deviation from the non-stochastic steady state. Inflation, policy rate, and FI borrowing and lending rates are on an annual basis.

Figure 13: Response to a Negative Shock to Entrepreneurs' Net Worth



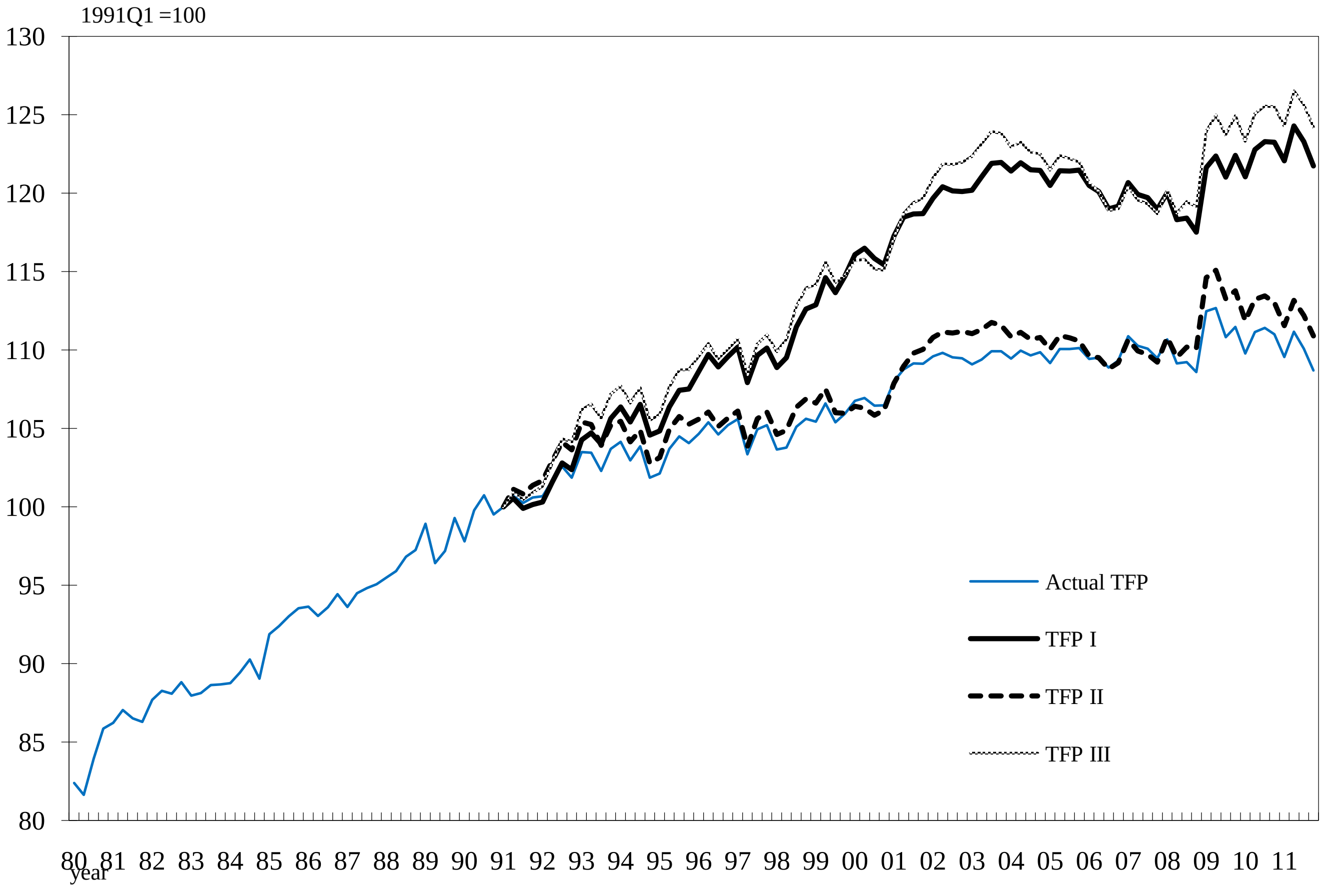

Notes: Interest rates, inflation, and markup are deviation from the non-stochastic steady state. Others are percentage deviation from the non-stochastic steady state. Inflation, policy rate, and FI borrowing and lending rates are on an annual basis.

Figure 14: Response to a Negative Shock to Common Technology Growth




Notes: Interest rates, inflation, and markup are deviation from the non-stochastic steady state. Others are percentage deviation from the non-stochastic steady state. Inflation, policy rate, and FI borrowing and lending rates are on an annual basis.

Figure 15: Counterfactual Simulations for TFP
Contribution of Each Net Worth Shock

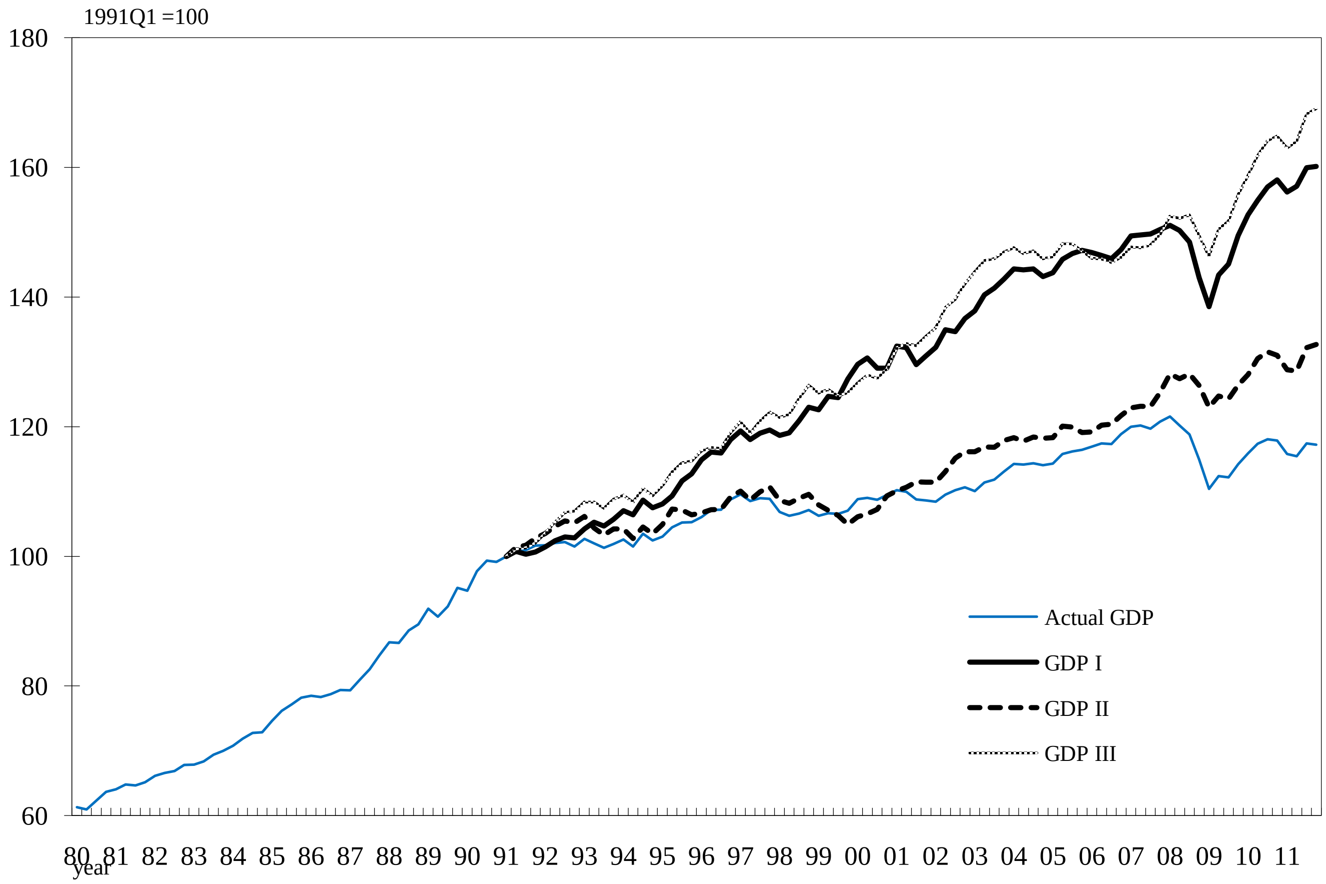



year on year % change

| | 1980s | 1990s | 1st half | 2nd half | 2000s and beyond |
|---|---|---|---|---|---|
| Actual TFP | 1.78 | 0.77<br>*-1.01* | 1.04 | 0.50 | 0.31<br>*-1.47* |
| TFP I | 1.78 | 1.51<br>*-0.27* | 1.53 | 1.50 | 0.62<br>*-1.16* |
| TFP II | 1.78 | 0.84<br>*-0.94* | 1.26 | 0.42 | 0.41<br>*-1.37* |
| TFP III | 1.78 | 1.58<br>*-0.20* | 1.74 | 1.42 | 0.73<br>*-1.05* |

Notes: Numbers in italics below growth rate figures are differences in growth rate from that in the 1980s. TFP I: the actual TFP series less the portion of TFP variations attributed to shocks to FI net worth from 1991:2Q and beyond. TFP II: the actual TFP series less the portion of TFP variations attributed to shocks to entrepreneurial net worth from 1991:2Q and beyond. TFP III: the actual TFP series less the portion of TFP variations attributed to shocks to FI net worth and entrepreneurial net worth from 1991:2Q and beyond.

Figure 16: Counterfactual Simulations for GDP
Contribution of Each Net Worth Shock

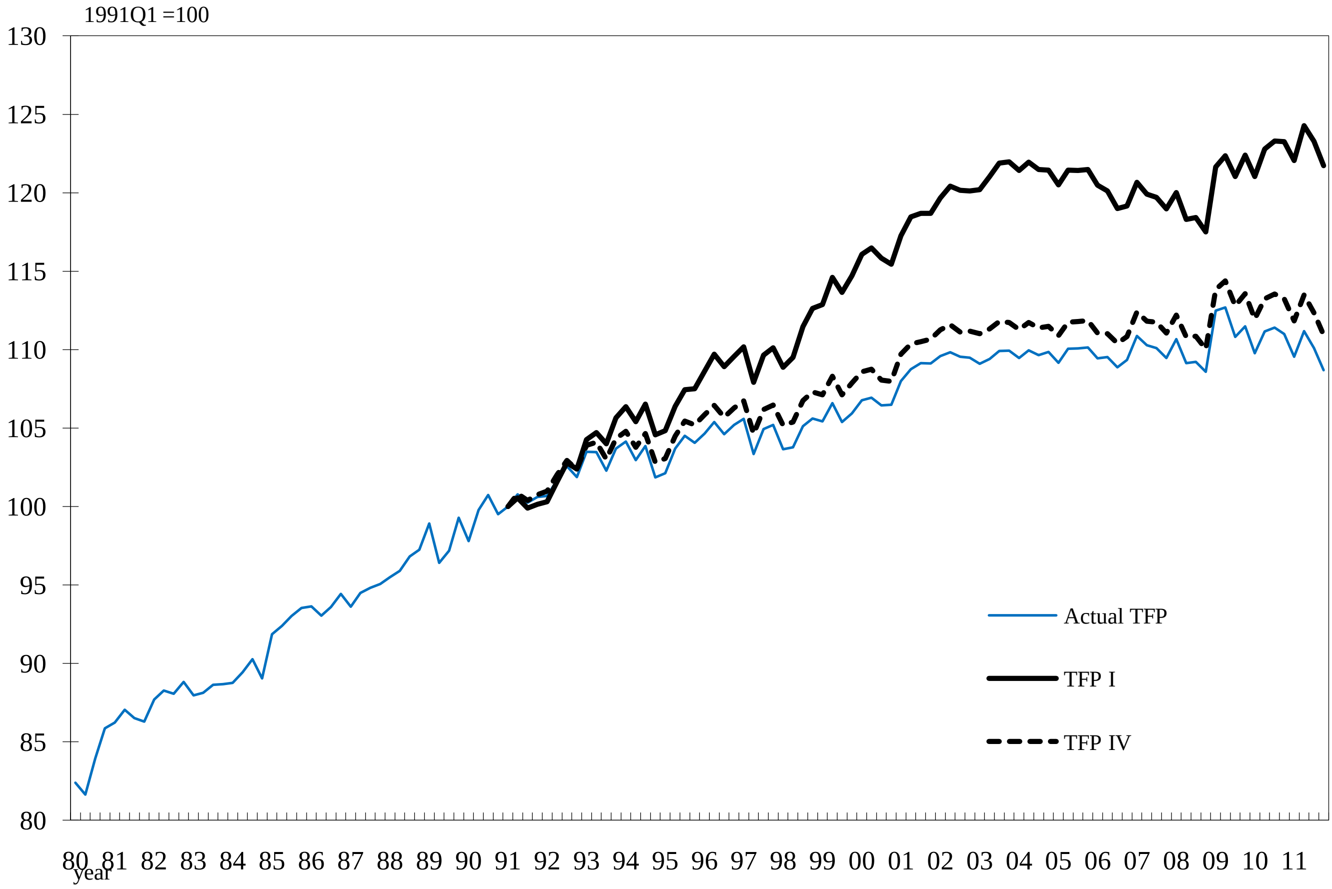



year on year % change

| | 1980s | 1990s | 2000s and beyond |
|---|---|---|---|
| Actual GDP | 4.44 | 1.42<br>*-3.02* | 0.73<br>*-3.71* |
| GDP I | 4.44 | 2.99<br>*-1.45* | 1.99<br>*-2.45* |
| GDP II | 4.44 | 1.42<br>*-3.02* | 1.69<br>*-2.75* |
| GDP III | 4.44 | 3.03<br>*-1.41* | 2.35<br>*-2.09* |

Notes: Numbers in italics below growth rate figures are differences in growth rate from that in the 1980s. GDP I: GDP series in which the contribution of shocks to FI net worth is absent from 1991:2Q and beyond. GDP II: GDP series in which the contribution of shocks to entrepreneurial net worth is absent from 1991:2Q and beyond. GDP III: GDP series in which the contribution of both types of net worth shocks is absent from 1991:2Q and beyond.

Figure 17: Counterfactual Simulations for TFP
Relative Contribution of Each Channel

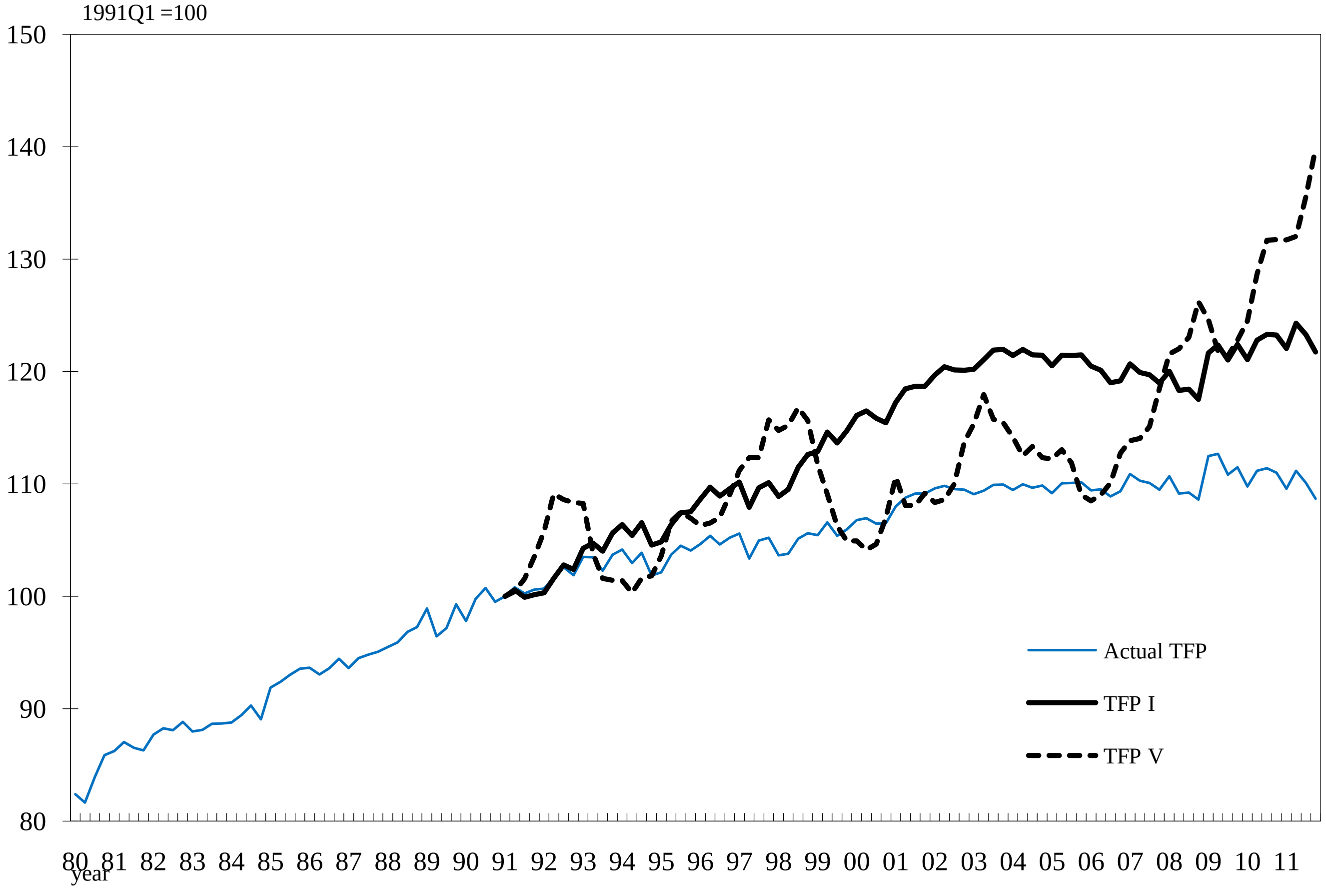



year on year % change

| | 1980s | 1990s | 2000s and beyond |
|---|---|---|---|
| Actual TFP | 1.78 | 0.77<br>*-1.01* | 0.31<br>*-1.47* |
| TFP I | 1.78 | 1.51<br>*-0.27* | 0.62<br>*-1.16* |
| TFP IV | 1.78 | 0.94<br>*-0.84* | 0.34<br>*-1.44* |

Notes: Numbers in italics below growth rate figures are differences in growth rate from that in the 1980s. TFP I: the actual TFP series less the portion of TFP variations attributed to shocks to FI net worth from 1991:2Q and beyond. TFP IV: TFP series in which the monitoring cost incurred by net worth shocks to FIs is counted as a part of the value-added from 1991:2Q and beyond.

Figure 18: Counterfactual Simulations for TFP
Contribution of Net Worth Shocks and Technology Shocks




year on year % change

| | 1980s | 1990s | 2000s and beyond |
|---|---|---|---|
| Actual TFP | 1.78 | 0.77<br>*-1.01* | 0.31<br>*-1.47* |
| TFP I | 1.78 | 1.51<br>*-0.27* | 0.62<br>*-1.16* |
| TFP V | 1.78 | 0.97<br>*-0.81* | 1.85<br>*0.07* |

Notes: Numbers in italics below growth rate figures are differences in growth rate from that in the 1980s. TFP I: the actual TFP series less the portion of TFP variations attributed to shocks to FI net worth from 1991:2Q and beyond. TFP V: the actual TFP series less the portion of TFP variations attributed to shocks to technology of the goods-producing sector from 1991:2Q and beyond.