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Roles of Technology and Nontechnology Shocks in the Business Cycles

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Abstract

The empirical study of technology shocks is intensively conducted to evaluate plausibility of the technology-driven real business cycle hypothesis. A popular method is to identify technology shocks by the long-run restriction that those solely have permanent effects on labor productivity in the system consisting of labor productivity growth and hours worked. While it has an advantage of not using Solow residuals which tend to accompany measurement errors, it potentially misidentifies nontechnology shocks, which permanently affect capital-labor ratio such as a capital tax shock, as technology shocks. We show that such shock brings nonstationarity of nominal investment-output ratio and identify it through the additional restriction that it permanently affects real investment-output ratio. Data indicate that the shock works importantly in not U.S. but Japan. In the system for Japan with the shock added, hours worked responses to technology shocks become insignificant. Furthermore the technology shock loses the dominant role in Japan's lost decade. We also study an appropriate treatment of lower-frequency movements in Japan's hours worked due to inter-sectoral labor movements and working hours reductions.

JEL Classification: E10, E32

Key Words: Business cycle; Technology shock

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1 Introduction

The contribution of the technology shock to the business cycles is intensively studied in the macroeconomics because it is decisive in evaluating plausibility of the technology-driven real business cycle hypothesis. There has been much debate on plausibility of the hypothesis for U.S. economy since Prescott (1986) who emphasized it first. Recently the debate has extended to other economy. One of the famous examples is Hayashi and Prescott (2002)'s work which shows that Japanese economic stagnation in the 1990s, which they call as "Japan's lost decade," can be replicated in their growth model mainly by feeding Solow residuals as technology.

On identification of the technology shock, Galí (1999) proposes a bivariate structural vector autoregression (SVAR) model which consists of labor productivity growth and hours worked. His identification is based on the long-run restriction that the technology shock affects the level of labor productivity permanently.[1] This study is influential in both method and results as follows. Methodologically it is attractive since it could identify a technology shock relying on the restriction which seems theoretically robust, not on Solow residuals which generally accompany measurement errors due to unobservable factor utilization and so on. Empirically much researchers have focused the negative effects of identified technology shocks for U.S. hours worked. This is because those are opposite to a prediction of the standard real business cycle model. Galí (2005) applies the method for the other G7 economy too and shows that the results are common except for Japan, where a technology shock is expansionary for hours worked. This finding on Japan is confirmed separately by Braun and Shioji (2004) who apply Uhlig (2001)'s SVAR based on sign restrictions.

While the method has attracted much attention, many researchers have investigated potential flaws of the method. Broadly speaking, those are categorized to two kinds. One of them is a bias due to reduction of the underlying economy to a finite ordered VAR model. This is emphasized by Chari, Kehoe, and McGrattan (2004), although Erceg, Guerrieri, and Gust (2005) and Christiano, Eichenbaum, and Vigfusson (2005) show that the bias appears not to be so problematic. Another flaw is potential misidentification of nontechnology shocks as technology shocks in Galí's bivariate system. This is due to a kind of nontechnology shocks, e.g. a capital tax shock, which affects labor productivity via the level of capital-labor ratio permanently. This paper calls such nontechnology shock as the nontechnology

[1] SVAR with the long-run restriction is originally developed by Blanchard and Quah (1989).

permanent shock and develops a method to identify it.

For example, Francis and Ramey (2005) include a series of capital tax rate as an exogenous variable in the system in order to examine seriousness of misidentification. It results in confirming that Galí's result is unchanged. Galí and Rabanal (2004) also find near-zero correlations between a series of capital tax rate and identified technology shocks.[2]

However this kind of examination is limited to only observable nontechnology factors. Unobservable or nontechnology factors measured with difficulty such as depreciation rates also could affect labor productivity. Therefore this paper proposes to identify the nontechnology permanent shock as a linear combination of all types of underlying nontechnology shocks, which might be observable or not, with the following three long-run restrictions.

With the first restriction, we identifies the investment specific technology shock. It is that the shock is the sole permanent source of relative investment price. This identification is developed by Fisher (2005). The second restriction for identifying the nontechnology permanent shock is that the nontechnology permanent shock and the investment specific technology shock affect the steady state level of *real* investment-output ratio. This new restriction is based on the theoretical steady state property that the determinants of real investment-output ratio, which include the investment specific technology shock, are equivalent to those of capital-labor ratio. The third restriction for identifying the sector neutral technology shock, which Galí originally tries to identify, is that these three shocks permanently affect labor productivity. Therefore the multivariate system consists of four variables: relative investment price growth, real investment-output ratio growth, labor productivity growth, and hours worked per capita. In this four variables system one more identified shock is a nontechnology *temporary* shock which Galí calls as just a nontechnology shock.

In addition to this identification, this paper develops a pre-estimation diagnosis of the nontechnology permanent shock. Theoretically, the nontechnology permanent shock is the sole source of *nominal* investment-output ratio in the long run. Although the investment technology shock might seem to work in the similar way by lowering relative investment price, it stimulates investment and therefore is neutral for the ratio in the long run. Therefore, if the nontechnology permanent shock didn't exist, the series of the ratio should be stationary.

[2] Galí and Rabanal (2004) find insignificant coefficients in an ordinary least squares regression of the tax series on current and lagged identified technology shocks too. Fisher (2005) tests whether the Federal Funds rate, oil shock dates, log-changes in real military spending, and changes in capital tax rate Granger-cause identified technology shocks. He finds that no Granger-causality is not rejected except for oil shock dates.

We find that U.S. nominal investment-output series seems robustly stationary. It suggests that the nontechnology permanent shock is not important in U.S. This finding is exactly consistent with Fisher (2005) and Galí and Rabanal (2004)'s findings of a capital tax rate shock being not an important disturbance in identifying a technology shock. On the other hand, Japanese nominal investment-output ratio seems nonstationary. This suggests that it might not be appropriate for Galí (2005) and Braun and Shioji (2004) to ignore the nontechnology permanent shock. In light of the findings, this paper applies the multivariate system for Japanese economy.

The result is striking. In most specifications, the responses of hours worked to positive technology shocks are negligible initially in the means and statistically insignificant over 8 years. Investment shows positive initial responses to investment specific technology shocks, but insignificant responses to sector-neutral technology shocks. The latter responses are negative in the means in most specifications. These weak effects of technology shocks contrast sharply with the significant positive effects of nontechnology permanent shocks on investment and those of nontechnology temporary shocks on hours worked. This finding doesn't support the technology-driven real business cycle hypothesis for Japan.

Historical decompositions in the systems also cast doubt on the hypothesis. While our bivariate system explains almost all of Japan's lost decade by technology shocks, the multivariate system explains it by nontechnology shocks more than technology shocks.[3] This finding is inconsistent with Hayashi and Prescott (2002)'s assertion. It draws methodological interest too since it is an evidence for a lot of nontechnology shocks to be mislabeled as technology shocks in the bivariate estimation.

In the estimation, this paper pays a special attention on the specification of Japanese hours worked per capita. This is because Japanese labor market faced two kinds of lower-frequency movements beyond business cycles. One of them is the dramatic labor force flows from self-employed work to employed in the 1960s. Therefore employment rate based only on establishments survey data, which is used by Braun and Shioji (2004), is biased so upward in the period as to change the SVAR estimation results. Another lower-frequency movement is two phases of massive reduction of working hours: 1960-1974 and 1988-1993.

This paper proposes to use the household survey data in order to exclude

[3]Hayashi and Prescott's finding might be due to distortions in their computed total factor productivity. Following the method developed by Basu, Fernald, and Kimball (2004), Kawamoto (2004) shows that Solow residuals in Japan adjusted for distortions such as capacity utilization don't decelerate in the 1990s.

the effect of the first movement from the estimation results.[4] On the second movement of the two working hours reductions, we investigate historical episodes. Basically those suggest that the first phase corresponded to the spread of a five or six-day workweek and the second was legally enforced. Therefore the two phases are plausibly interpreted as exogenous events for business cycles. So far several authors have stressed the possibility that such a lower-frequency movement in data contaminates estimated impulse responses. Fernald (2005) forcefully shows that exogenous changes in the mean of U.S. labor productivity growth affect impulse responses of hours worked to identified technology shocks and advocate removing the trend breaks by dummies. Francis and Ramey (2004) show that whether some demographic and social factors in U.S. hours worked are removed or not affects impulse responses and recommend that such factors are pre-removed. Following the spirit of these papers, we use residuals obtained by an ordinary least squares of Japanese hours worked on scheduled working hours in the baseline case. Interestingly, when using the new hours worked series, we find that the effect of a technology shock for hours worked is insignificant even in the bivariate system as well as in the multivariate system.

The paper proceeds as follows. We introduce the identification scheme and examine the nontechnology permanent shock in U.S. and Japan in the next section. Section 3 discusses data selection issue on Japanese hours worked and investigates the property of working hours reductions. Section 4 shows results in the bivariate system and compares those with earlier results. Section 5 shows the multivariate estimation results. Section 6 implements robustness checks. Finally, section 7 contains concluding remarks.

2 Empirical Methodology

2.1 Galí (1999)'s Bivariate System

It is useful to review the theoretical background in Galí (1999)'s identification method first since it makes clear the reason why a nontechnology shock, which we call as the nontechnology permanent shock, is included into Galí's technology shock.

Galí's identification is based on the following steady state condition:

$$v f'\left(\frac{k}{zh}\right) = \frac{\rho}{1-\tau} + \delta \tag{1}$$

[4] The OECD data on Japan which Galí (2005) uses is from the household survey data.

where v is investment specific technology, k is capital stock, z is sector-neutral technology, h is hours worked, ρ is subjective discount rate, τ is capital tax rate, δ is depreciation rate, and $f(\cdot)$ is the production function of output per effective labor input.[5] This condition summarizes two links: one between marginal productivity of capital and real rental rate and another between subjective discount rate and real interest rate. Francis and Ramey (2005) calls it as "MP of capital - time preference link."

Galí (1999) assumes that the capital-labor ratio in the efficiency unit, $k/(zh)$, follows a stationary stochastic process, implicitly regarding the other terms in equation (1) as being constant in the steady state. For later argument, note that the sector-neutral technology, z, cannot affect the steady state level of capital-labor ratio.

Labor productivity, say x, is represented as

$$x \equiv \frac{y}{h} = zf\left(\frac{k}{zh}\right), \tag{2}$$

where y is output.[6] Since $k/(zh)$ is stationary, we know that the level of labor productivity is determined solely by the sector-neutral technology, z, in the long-run. Following this property, Galí (1999) represents the SVAR model as

$$\begin{aligned} \begin{bmatrix} \Delta x_t \\ h_t \end{bmatrix} &= \begin{bmatrix} C^{11}(L) & C^{12}(L) \\ C^{21}(L) & C^{22}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_t^z \\ \varepsilon_t^d \end{bmatrix} \\ &\equiv C(L)\,\varepsilon_t \end{aligned} \tag{3}$$

where $C^{ij}(L)$ are distributed lag polynomials, ε_t^z is a technology shock, and ε_t^d is a nontechnology shock and imposes the restriction of $C^{12}(1) = 0$.[7] This restriction effectively reveals a series of technology shocks under his assumption.

[5] The production function is assumed homogeneous of degree one and the forms are common between the investment goods and consumption goods sectors. The model is explained in detail in an appendix.

[6] In this paper, data on output is evaluated in consumption terms to keep consistency with this model.

[7] Constant terms are suppressed. The shocks are serially uncorrelated, mutually orthogonal structural disturbances whose variances are normalized to unity and hence $E\varepsilon_t\varepsilon_t' = I$.

2.2 Identifying Nontechnology Permanent Shocks in Multivariate System

Galí's identification critically depends on the assumption that the determinants of capital-labor ratio in equation (1), that is, investment specific technology, subjective discount rate, capital tax rate, and depreciation rate, are stationary. However Francis and Ramey (2005) note that it might not be true of a capital tax rate. Furthermore the other unobservable shocks potentially make the capital-labor ratio nonstationary.

In order to identify the sector-neutral technology shock accurately, it is desirable to extract all of the shocks affecting the steady state level of capital-labor ratio from the shocks affecting that of labor productivity. Among those, we can identify the investment specific technology shock with the restriction that it solely affects relative investment price in the long-run, following Fisher (2005).[8] On the other hand, identifying the other shocks is harder since we cannot observe a series of capital-labor ratio in the efficiency unit.

Therefore this paper focuses on *real* investment-output ratio, which can be represented in the steady state as

$$\frac{i}{y} = \frac{\delta k}{zhf\left(\frac{k}{zh}\right)} = \delta \frac{\frac{k}{zh}}{f\left(\frac{k}{zh}\right)}. \tag{4}$$

The numerator comes from the capital accumulation equation, $\dot{k} = i - \delta k$. This equation shows that the shocks affecting the steady state level of real investment-output ratio are exactly same as those of capital-labor ratio, since the determinants of capital-labor ratio necessarily include the depreciation rate, δ, as seen in equation (1). In other words, we can identify all of the shocks affecting the steady state level of capital-labor ratio, which we call as nontechnology permanent shocks, by incorporating the real investment-output ratio into the system.[9]

[8] In the paper, he shows that an investment specific technology shock has a significant positive impact on hours worked as soon as that occurs but a sector-neutral technology shock doesn't. Galí and Rabanal (2004)'s reasoning is as follows: the sector-neutral technology shock enhances the efficiency of labor inputs directly and therefore reduces labor inputs required to produce output under a price rigidity which hinges smooth expansion of demand. On the other hand, the investment specific technology shock enhances the labor productivity only with newly purchased goods and therefore the negative impact on the input is not necessarily negative. These literature shows that it is imporatant to cosider investment specific technology separately.

[9] Capital stock-output ratio also moves one to one with capital-labor ratio in the efficiency unit. However, as known well, a series of capital stock potentially contains large measurement errors. Therefore we don't use the variable here.

In sum, we impose the following three restrictions in order to identify the investment specific technology shock, the nontechnology permanent shock, and the sector-neutral technology shock:

Restriction 1. The relative price of investment goods, v, moves only with the investment specific technology shock, ε^v, in the long-run.

Restriction 2. The real investment-output ratio, i/y, moves only with the investment specific technology shock, ε^v, and the nontechnology permanent shock, ε^p, in the long-run.

Restriction 3. The labor productivity, x, moves only with the investment specific technological shock, ε^v, the nontechnology permanent shock, ε^p, and the sector-neutral technology shock, ε^z, in the long-run.

In a multivariate system:

$$\begin{bmatrix} \Delta v_t \\ \Delta \frac{i_t}{y_t} \\ \Delta x_t \\ h_t \end{bmatrix} = C(L) \begin{bmatrix} \varepsilon_t^v \\ \varepsilon_t^p \\ \varepsilon_t^z \\ \varepsilon_t^d \end{bmatrix}, \tag{5}$$

where ε^d is the nontechnology temporary shock, those restrictions imply that $C(1)$ is a lower-triangular matrix.[10,11]

Our estimation follows Doan (2000). Defining u and ε as the vectors of variables and shocks respectively, we can write the model as

$$\begin{aligned} u_t &= \left(I - \sum \Phi_s L^s\right) c + \sum \Phi_s L^s u_t + B\varepsilon_t \\ \text{where} \quad C(L) &\equiv \left(I - \sum \Phi_s L^s\right)^{-1} B \quad \text{and} \quad BB' = \Sigma. \end{aligned} \tag{6}$$

Define $\Phi(L) \equiv I - \sum \Phi_s L^s$. Then the assumption of $C(1)$ being a lower triangular matrix implies that $\Phi(1)^{-1} B$ is the Choleski factor of $\Phi(1)^{-1} \Sigma \Phi(1)^{-1\prime}$

[10] The representative candidate of the nontechnology temporary shock is the demand shock such as the monetary shock and the government purchases shock. As seen in the equation (1), these shocks don't have permanent effects on the capital-labor ratio and hence are not included to the nontechnology permanent shock.

[11] The nontechnology permanent and temporary shocks are identified in the forms of linear combinations of underlying shocks. The conditions for the identification to work well are described by Blanchard and Quah (1989) and Faust and Leeper (1997). Basically they say that the responses of variables to different underlying shocks are sufficiently similar. This paper simply assumes that the conditions are satisfied following the research using the long-run restriction.

and ε_t is recovered by B. We choose the lag length of 8 following Blanchard and Quah (1989).

2.3 Evidence for Nontechnology Permanent Shocks

The multivariate system is superior to the original bivariate system if the nontechnology permanent shock exists. An easy but effective test is to check the time series property of *nominal* investment-output ratio since the series is stationary if the long-run movement of real investment-output ratio is explained solely by investment specific technology.

It's easily shown with production function defined as $y = zh\left(\frac{k}{zh}\right)^{\alpha}$ and equation (1) rewritten as

$$\alpha v \left(\frac{k}{zh}\right)^{\alpha-1} = \frac{\rho}{1-\tau} + \delta. \tag{7}$$

With (4), this relationship leads to the nominal investment-output ratio represented as

$$\frac{p_i i}{p_c y} = \frac{1}{v}\delta\frac{\frac{k}{zh}}{\left(\frac{k}{zh}\right)^{\alpha}} = \frac{\alpha\delta}{\frac{\rho}{1-\tau}+\delta}. \tag{8}$$

where p_c and p_i are consumption and investment goods prices respectively. This expression tells us that all of the determinants of the real investment-output ratio but investment specific technology, v, are same as those of the nominal investment-output ratio. Therefore, unless the nominal investment-output ratio shows nonstationary behavior, we shouldn't believe in the nontechnology permanent shock.

Figure 1.A. shows long-run nominal investment-output ratios in U.S. and Japan. The U.S. series seems robustly stationary. This finding implies that the nontechnology permanent shock doesn't exist in U.S. economy. It is consistent with the results of Galí and Rabanal (2004) and Francis and Ramey (2005) that capital tax rate series are uncorrelated with technology shocks identified in the bivariate systems.[12]

On the other hand, Japanese series follows a strong upward trend until the 1950s before it flattens and suggests that we need to consider the nontechnology permanent shock. Even if we limit the Japanese sample to post-W.W.II

[12] Christiano, Eichenbaum, and Vigfusson (2003) and Erceg, Guerrieri, and Gust (2005) recommend to add the nominal level of investment-output ratio into the system in order to reduce an estimation bias by making the series resemble a persistent unobservable movement of capital stock per technology. This strategy implicitly assumes that nominal investment-output ratio series is stationary and hence the nontechnology permanent shock doesn't exist.

data of which we can obtain quarterly series, we can see nonstationarity. As shown in Figure 1.B., the mean in the 1950s is apparently different from that in the post-1960s.[13,14] Also, the ADF t-test statistic is -2.68 for the 5 percent critical value -2.88 and therefore it's difficult to reject the null of unit root.[15] Based on these observation, we apply the multivariate system for Japanese economy.

3 Hours Worked Per Capita in Japan

In this section we examine the property of Japanese hours worked per capita in preparation for estimations. Lower-frequency movements in the series potentially contaminate estimation results as shown in Fernald (2005), who focuses on U.S. trend productivity growth, and Francis and Ramey (2004), who focus on demographic and social factors in U.S. hours worked per capita. We avoid such problem by an appropriate data selection and a kind of detrending.

3.1 Data Selection

In Japan, we have two alternatives for calculating hours worked per capita. The first is using the Labor Force Survey (LFS, hereafter) data which is based on questionnaires for sample households and published by the Statistics Bureau in the Ministry of Internal Affairs and Communications. The second is using the Monthly Labor Survey (MLS, hereafter) data which is based on questionnaires for sample establishments and published by the Ministry of Health, Labour and Welfare. Braun and Shioji (2004) take the second strategy. However the MLS doesn't cover self-employed workers and family workers, while the LFS does. The difference is very important in calculating pre-1970 hours worked per capita since self-employed and family workers

[13] The investment data covers not only equipments but also construction goods purchased by private enterprises. The equipments data is published only annually in Japan.

[14] What we should note is that Japanese economy might not be close to the steady state in the 1950s because of disruption after W.W.II. If it is the case, nominal investment-output ratio could be seemingly nonstationary. However what happens if we apply the bivariate system for such economy? It should misidentify the momentum returning labor productivity to the steady state level as technology shocks. In this sense, even if the nonstationarity is seeming, it would be appropriate to identify the momentum as the nontechnology permanent shock in the multivariate system.

[15] The specification is one with 2 lags and an intercept. The number is selected by the Schwartz information criterion from up to 15 lags which I choose as the maximum lags following Hayashi (2000, pp.594).

occupy the half of all workers. Especially ones in the agriculture and forestry sector amount to one third in 1960. More importantly, the share of self-employed workers show rapid decreases in the 1960s while that of employees increases at the same time. Consequently, as seen in Figure 2.C., hours worked per capita based on the MLS, which is the product of hours worked per workers and the share of workers in all persons 15 years old or more, exhibit a biased upward tendency until the 1960s. On the other hand, the data based on the LFS in Figure 2.B1. follows the declining trend with some breaks. Therefore we will use the LFS data in this paper, although we discuss the implication of the data selection problem for estimation results later again.[16]

3.2 Historical Episodes on Working Hours Reduction and Detrending

As noted in the introduction, Japanese hours worked per capita reflect two phases of massive reduction in scheduled working hours seen in Figure 2.B2.[17] Those matter in imposing long-run restrictions since those constitute lower-frequency movement in hours worked per capita which potentially affects estimation results wrongly. If we believed that those are business cycle phenomena, we should leave those. But if it's not the case, we should remove the information from a series of hours worked per capita. In order to examine the property, we study historical episodes of the scheduled working hours reductions.

Spread of Five or Six-Day Workweek from 1960 to 1974. This is a major custom shift in Japan under changes in workers' preference, the government's policy, and management. First of all, a union in the textile sector, Zen-Sen Domei, requested a 15 minutes reduction in hours worked per day in March 1957. Ministry of Labour (1959), Fujimoto (1963), and Okabe (1972) argue that this event is the first request for reduced working hours in the Japanese labor movement. Subsequently, Ministry of Labour started to enforce six-day workweek on small and medium-sized enterprises in 1958.[18]

[16] One fault of hours worked per worker data from the LFS is the large volatility in the monthly basis which is mainly due to changes of the sample. In order to deal with the problem, we remove some of volatile components as outliers in a seasonally adjustment by the X-12-ARIMA program of U.S. Census Bureau with the absolute values of the t-statistics above 3.5, which tends to detect more numbers than the defaut.

[17] Scheduled working hours are defined as actual number of hours worked during normal working hours which are stated in the work regulation of the establishment or individual employment contract.

[18] Ministry of Labour (1962).

Finally, in January 1960, the founder and president of Matsushita Electric Industrial Company, Konosuke Matsushita, announced his plan to introduce five-day workweek. It was based on his thought that taking a rest on both Saturday and Sunday like in U.S. would bring higher labor productivity.[19] Yamamoto (1982) argues that it was a break for the wider spread of five-day workweek. The adoption of five or six-day workweek had spread until around 1974. The reason for pause of the spread in 1974 is not so clear but an oil shock led by the October War in 1973 is the most plausible candidate which triggered it.

Law-Enforced Reduction of Hours Worked from 1988 to 1993. This was caused by the 1987 revision of the Labor Standards Law The related ordinance enforced firms to reduce working hours from 48 hours per week to 46 hours in April 1988 and from 46 hours to 44 hours in April 1991. Furthermore another revision of the ordinance in 1993 provided that the working hours were reduced to 40 hours in April 1994. Exceptionally small and medium enterprises were allowed to postpone the reduction until Mach 1997 and therefore further small decline in scheduled working hours is observed after April 1997.

These episodes strongly suggest that both phases of scheduled working hours reduction are not the results of feedback from Japanese business cycles but lower frequency phenomena beyond those.[20,21] Based on this consideration, we assume in the baseline specification that the series of scheduled working hours is exogenous. We try other specifications of hours worked per capita in robustness checks.

[19] Matsushita (1992).

[20] Galí (2005) suggests that the secular decline in hours worked per capita observed in most countries would seem orthogonal to the business cycle phenomena.

[21] The exogeneity of working hours reduction gives an answer for a specification problem of whether variables enter in levels or growths into the VAR system. In general, if the variables in the system are cointegrated, those should enter the system in the levels. But Blanchard and Quah (1989)'s long-run restriction method requires the variables in the system to be stationary. In this sense, if the trend in hours worked per capita due to working hours reduction made cointegrating relationship with labor productivity, our estimations would be problematic.

I inspected some model properties with different sources of exogenous working hours reductions (not shown). One of them was an exogenous movement of scheduled working hours esplicitly defined in the model. The others were a wedge between the marginal product of labor and real wage, a wedge between household's marginal rate of substitution and real wage, and a preference shock, all of which are presented by Galí (2005). In any cases, the condition (1) was not affected at all and therefore labor productivity was also irrelevant to working hours reduction in the long run. Therefore it doesn't seem harmful to include the varables in the stationary forms.

The baseline specification is

$$\begin{bmatrix} \Delta v_t \\ \Delta \frac{i_t}{y_t} \\ \Delta x_t \\ h_t \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \alpha h_t^s \end{bmatrix} + C(L) \begin{bmatrix} \varepsilon_t^v \\ \varepsilon_t^p \\ \varepsilon_t^z \\ \varepsilon_t^d \end{bmatrix}, \tag{9}$$

where h_t^s is scheduled working hours. In estimation of the system, we regress hours worked per capita on scheduled working hours first and use the residual series as a detrended hours worked per capita series. The residual series is shown in Figure 2.B3. The ADF t-test statistic is -3.46 for the 1 percent critical value -2.58.[22] So we can safely reject the null of unit root.[23]

4 Bivariate System Results

This section shows results of estimating the bivariate system consisting of labor productivity growth and the new detrended hours worked per capita. In the system we identify the technology shock and the nontechnology temporary shock following Galí (1999).[24] The first objective is to compare the results with multivariate system results which will be shown later. The second is to compare those with Galí (2005)'s result based on a series of hours worked growth, in order to clarify how important the extraction of information on working hours reduction is. The third is to compare those, which are based on LFS data, with those based on MLS data which is used by Braun and Shioji (2004) in order to show what effects the data selection has.

The responses of variables in the system to positive technology and nontechnology shocks are plotted in Figure 3. The estimation is based on the sample of 1954:1-2004:4. The most striking feature is that the response of hours worked to a positive technology shock is initially negative in the mean and statistically insignificant over 8 years. As shown in Figure 4.A., this result is unchanged even if the sample period is limited to 1972:1-2004:4 following Galí (2005).

For the purpose of comparison, we replicate Galí (2005)'s results by estimating the system with hours worked growth in Figure 4.B. Regardless of

[22] The specification is one with 1 lag and no intercept. Again, the number of lag is selected by the Schwartz criterion from up to 14 lags which I choose as the maximum lags following Hayashi (2000).

[23] This specification implies ignoring feedbacks from the endogenous variables to scheduled working hours. We confirm statistical exogeneity of scheduled working hours in an appendix.

[24] Variables are per capita base hereafter except for analysis in section 7.1 where total hours base and per capita base are distinguished.

sample periods, the responses of hours worked to positive technology shocks are positive in the means and statistically significant around 1 year after the initial periods. This suggests that whether the movements of working hours reduction are removed or not has important effects on the estimation results.

Also for the comparison, we estimate a system with hours worked growth from MLS data and plot the response of hours worked to a positive technology shock in Figure 4.C. The persistent negative response in the mean makes clear contrast with the results based on hours worked growth from LFS data. The difference between the results being exclusively due to data selection suggests that Braun and Shioji (2004)'s results based on MLS data, which show the expansionary effects of technology shocks on hours worked, should be reexamined with the LFS data.

We now turn to the responses of other variables and variance decompositions. First, we should note the strongly expansionary effect of a positive nontechnology shock on hours worked in Figure 3.B. Second, variance decompositions in Table 1 show that the effect of technology shocks on hours worked is small over all horizons while nontechnology shocks work somewhat on GDP at relatively short horizon and considerably on hours worked over all horizons. For example, technology shocks account for less than 5 percent of hours worked at all horizons. On the other hand, nontechnology shocks account for more than 20 percent of GDP up to 1 year and more than 90 percent of hours worked over all horizons. These results suggest that the nontechnology shock is a very important driving force of Japan's business cycles. For the comparison with multivariate system results in the next section, note that almost all of labor productivity movement is explained by technology shocks over all horizons.

The historical decomposition is also very effective in evaluating relative importance of technology shocks. Figure 5 decomposes the detrended historical movements of hours worked and GDP into technology and nontechnology components. The decomposition is implemented following the procedure in Christiano, Eichenbaum, and Vigfusson (2003): the detrended movements of variables are obtained by simulating the estimated system with all estimated shocks, say ε_t^z and ε_t^d for all t, while each shock component is obtained by simulating the system with technology shocks, ε_t^z, and nontechnology shocks, ε_t^d, respectively. This procedure excludes drift components from variables and makes historical sources of business cycles visible.

First we can confirm that almost all of hours worked movement is explained by nontechnology shocks. This shows that positive technology shocks don't have much expansionary effects on hours worked and is inconsistent with the basic real business cycle model in which the technology shock is the main driving force of the business cycles. On the other hand, the dominant component of GDP is the technology shock over the sample period. But this result will be dramatically modified once the nontechnology permanent shock which contaminates the estimated technology shock is explicitly considered in the next section.

In sum, with appropriate data selection and the removal of information on working hours reduction, Japanese hours worked aren't explained much by technology shocks. We will extend this bivariate system to the multivariate system and examine the source of the Japan's business cycles in more detail below.

5 Multivariate System Results

In this section, following the strategy introduced in section 2, we add the growth rates of relative investment price and real investment-output ratio into the system in order to identify investment specific technology and nontechnology permanent shocks.

A striking feature in impulse responses shown in Figure 6 is that the initial responses of hours worked to both types of technology shocks are insignificant. Furthermore the mean initial response of hours worked to an investment specific technology shock and that of investment to a sector-neutral technology shock are both negative. It is difficult to replicate these results by the standard real business cycle model, as emphasized by Basu, Fernald and Kimball (2004).[25] On the other hand, the responses of investment to a nontechnology permanent shock and those of hours worked to a nontechnology temporary shock are both significantly positive. These results show the expansionary effects of nontechnology shocks and the negative or insignificant effects of technology shocks.

Variance decompositions in Table 2 show that portions explained by nontechnology permanent shocks in labor productivity, GDP, investment-output ratio, and investment are well above 50 percent in most horizons. Comparison of these results with those in the bivariate system lets us know that there is large possibility to misidentify the nontechnology shock as the technology shock in the bivariate system. On the other hand, more than half of movement of hours worked is still explained by nontechnology temporary shocks.

[25] The negative mean impulse response of hours worked to an investment specific technology shock makes a stark contrast with the U.S. results discussed in a note of section 2. Following Galí and Rabanal (2004)'s reasoning, we might explain this result by smooth introduction of new technology-embedded equipment in Japan and the large contractionary effect on labor inputs.

Turning to historical decompositions in Figure 7, we still see dominance of nontechnology shocks in the movement of hours worked. More striking feature is that decline of GDP in the 1990s is explained by nontechnology shocks more than by technology shocks. In detail, nontechnology permanent shocks depress GDP almost all over the 1990s. On the other hand, investment specific technology shocks also depress GDP in the first half of the 1990s but sector-neutral technology shocks pull up GDP at the same time. As a result, technology shocks are not enough to be the main source of Japan's lost decade.[26]

6 What Is the Nontechnology Permanent Shock?

The new multivariate system is proposed because it could capture nontechnology permanent shocks, whether observable or unobservable, through real investment-output ratio. Therefore investigating the sources of the nontechnology shock in detail is basically beyond the scope of this paper. But it's worth analyzing it from some aspects.

One way is to correspond the historical decompositions to historical episodes. Actually the decompositions of GDP and investment are suggestive. Nontechnology permanent shocks raise GDP and investment until the beginning of the 1990s and in turn depress drastically between 1991 and 1994. This period corresponds to the well-known Japan's bubble economy and the collapse. It's also impressive that nontechnology temporary shocks have negative effects in a few years since 1998. In the period, a lot of firms faced credit crunch.

Another way is to examine a relationship between the identified nontechnology permanent shock and an observable candidate of the shock. The representative is a capital tax rate shock, as already noted in the introduction. Therefore we calculate a series of effective capital tax rate of Japan by a method developed by Mendoza, Razin, and Tesar (1994), which is explained in an appendix. Although it's bounded between 0 to 100 by definition, we take the unit root specification as a statistical approximation. Actually it shows very persistent behavior in Figure 8.

A difficulty in examining relationship between the nontechnology permanent shock and the capital tax rate shock is that the tax rate series is calculated in an effective term and therefore affected by endogenous responses

[26] The insignificant responses of hours worked and investment to a technology shock and the dominance of nontechnology shocks in Japan's lost decade hold even if the sample is limited to post-1974 period.

of the economy to other shocks. That is, it might not be exogenous.[27] In order to cope with it, we assume the following process of the capital tax rate series here:

$$\Delta\tau_t = A(L)\begin{bmatrix} \varepsilon_t^v \\ \varepsilon_t^z \\ \varepsilon_t^\tau \end{bmatrix},$$

where ε_t^v and ε_t^z are investment specific and sector neutral technology shocks respectively and ε_t^τ are capital tax rate shocks. The portion explained by the capital tax rate shock is obtained in the form of a residual series based on a regression of the differenced tax rate series on both types of technology shocks identified in the multivariate system with eight lags. Then we estimate an eight-order autoregressive process for the residual series and get the capital tax rate shock as a new residual series.

The estimated capital tax rate shock was used for regressing the nontechnology permanent shock on it. But the result was not suggestive. The estimated coefficient was negative, that is -0.02, as expected, but insignificant. Therefore at least this *observable* capital tax rate shock doesn't seem important in our explaining the nontechnology permanent shock.

However we cannot still throw out the possibility that *unobservable* capital tax rate shocks work as the nontechnology permanent shock. For example, Klenow and Rodríguez-Clare (1997) argue that distortions like bribes, risk of expropriation, and corruption contribute an effective tax rate and might generate cross-country differences in investment-output ratio. In general changes in the government policies are infrequent. Therefore such shocks can have very persistent effects on investment-output ratio.[28]

7 Robustness Checks

7.1 Estimation with Other Series of Hours Worked

So far we have used hours worked per capita detrended by the scheduled working hours in the multivariate system so far. In the first robustness check of the results, other four series of hours worked are used: hours worked per capita from which statistically detected breaks in a constant term and a linear trend are removed, hours worked per capita growth, total hours worked from which the information of a linear trend and scheduled working hours are removed, and first differenced total hours worked.

[27] Galí and Rabanal (2004) take this view.

[28] This argument is suggested by Richard A. Braun.

Using the first series is a response to the potential criticism that scheduled working hours might have business cycle properties and therefore the baseline estimation results, in which hours worked per capita are detrended by scheduled working hours, might be unreliable. We construct the first series by detecting breaks of a constant term and a linear trend following Bai and Perron (2003)'s multiple structural change analysis and removing the breaks from the original hours worked per capita series. Interestingly the first four chosen breaks are 1952:3, 1962:2, 1974:1, and 1990:3, the latter three of which could be related to the historical episodes of working hours reduction. This suggests that the episodes are very important determinants of regimes in hours worked per capita.

The second series, hours worked per capita growth, is already used in the bivariate system. The series is used in Galí (2005) and might be affected by the non-business cycle phenomenon of working hours reduction, as already explained.

The other two series are based on total hours as the product of hours worked per workers and the number of workers. One of them is the residual series obtained by regressing total hours worked on a linear trend and a scheduled working hours series. The series isn't affected by lower frequency components of population growth represented by the linear trend and working hours reduction represented by scheduled working hours series. Another is first differenced total hours worked which might be affected by working hours reduction.

We estimate the system using the two series of hours worked per capita and show impulse responses of hours worked and investment per capita in Figure 9 and historical decompositions of GDP per capita in Figure 10. Regardless of the detrending methods, the initial responses are insignificant except for the initial response of investment to an investment specific technology shock. Furthermore the portions of GDP per capita explained by both nontechnology shocks in the 1990s are almost same as those by both technology shocks. These features are common to those in the baseline case. We find that the results are almost unchanged in Figure 11 and 12 even if estimating the systems with the total hours worked series[29]. Overall we have been able to confirm that the insignificant initial effects of technology shocks on inputs and the non-dominance of technology shocks in Japan's lost decade are almost robust.

[29] One might note that total hours worked show more positive responses in the mean under estimation with the first differenced series. As shown in the bivariate estimation, information on working hours reduction contained in the first differenced series might distort the responses.

7.2 Estimation with Nominal Variables

The second robustness check is to test possibility of insufficient number of variables in the system. We include call rate and the growth rate of consumption deflator additionally. As shown in Figure 13, the initial responses of hours worked and investment to both types of technology shocks are still insignificant and the mean initial responses of hours worked are negative. Interestingly the mean responses of the deflators to an investment specific technology shock are weaker than to a neutral technology shock. Consistently call rates which represent the stance of monetary policy respond in less tightening way to an investment specific technology shock in the mean.

Historical decompositions in Figure 14 also support our findings in the baseline specification. That is, the stagnation of GDP in 1990s is due to not only technology shocks but also nontechnology shocks to almost same extent. That the dominant source of movement in hours worked is the nontechnology shock still holds too. Overall the results in the baseline specification have been unchanged in this robustness check.

7.3 Scheduled Working Hours Shock

In the specification where we regard the scheduled working hours as being exogenous, the scheduled working hours shock is implicitly identified as a part of the nontechnology temporary shock. Instead we can model an explicit scheduled working hours shock as follows:

$$\begin{bmatrix} \Delta v_t \\ \Delta \frac{i_t}{y_t} \\ \Delta x_t \\ h_t \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \alpha h_t^s \end{bmatrix} + C(L) \begin{bmatrix} \varepsilon_t^v \\ \varepsilon_t^p \\ \varepsilon_t^z \\ \zeta_1 \varepsilon_t^d + \zeta_2 \Delta h_t^s \end{bmatrix}$$

which is rewritten as

$$\begin{bmatrix} \Delta v_t \\ \Delta \frac{i_t}{y_t} \\ \Delta x_t \\ h_t \end{bmatrix} = \begin{bmatrix} B_1(L)\Delta h_t^s \\ B_2(L)\Delta h_t^s \\ B_3(L)\Delta h_t^s \\ \alpha h_t^s + B_4(L)\Delta h_t^s \end{bmatrix} + \tilde{C}(L) \begin{bmatrix} \varepsilon_t^v \\ \varepsilon_t^p \\ \varepsilon_t^z \\ \varepsilon_t^d \end{bmatrix}.$$

Since an exogenous working hours movement doesn't affect the steady state variables related to labor productivity as mentioned in a note of section 3, we should impose the restrictions of

$$B_i(L) = \tilde{B}_i(L)(1-L) \text{ for i=1, 2, 3,}$$

where $\tilde{B}_i(L)$ for i=1, 2, 3 are polynomials of order 7 in the lag operator while $B_4(L)$ is a polynomial of order 8.

In order to see how explicitly specified working hours shocks affect the estimation results, we regress Δv_t , $\Delta \frac{i_t}{y_t}$ and Δx_t on $\Delta^2 h_t^s$ with 7 lags and h_t on Δh_t^s with 8 lags and h_t^s respectively and estimate a SVAR model with the residuals.

The results are almost same as in the baseline case as shown in Figure 15. The initial effects of both types of technology shocks on hours worked and investment are insignificant and, in the means, negative except for one of an investment specific technology shock on investment. Historical decompositions also show dominance of technology as well as nontechnology shocks in Japan's lost decade. These imply that the scheduled working hours shock isn't so important in Japanese business cycles.

8 Conclusion

This paper's methodological contribution is proposing to discriminate technology and nontechnology permanent shocks by adding real investment-output ratio into the bivariate SVAR developed by Galí (1999). Furthermore we show that examining nonstationarity of nominal investment-output ratio is very effective in detecting the nontechnology permanent shock. Empirically the stationarity of U.S. series shows non-importance of such shock and therefore supports the literature showing that a capital tax rate, which is a plausible candidate of the nontechnology permanent shock, is irrelevant to the bivariate SVAR estimation results. On the other hand, Japanese nominal investment-output ratio is nonstationary and suggests existence of the nontechnology permanent shock. Including the shock into the multivariate system, we show that responses of hours worked to technology shocks are insignificant and the nontechnology shocks explain Japan's lost decade not less than the technology shocks. Even if we ignore the shock, pre-excluding the lower-frequency movement due to working hours reduction from hours worked data makes the hours worked responses to the technology shocks insignificant. These results cast serious doubt on the literature showing significantly positive responses of hours worked to technology shocks in Japanese economy and attributing Japan's lost decade to technology shocks.

We should note a general warning and a future direction arising from this research. The warning for researchers who are applying the bivariate SVAR for the other countries is that they should check whether the nontechnology permanent shock exists or not in advance by examining stationarity of nominal investment-output ratio. At least Galí (2005)'s results based on application of the bivariate SVAR for the other G7 countries should be reexamined. The direction of future research is to investigate empirically what the nontechnology permanent shock is. It should be generating large swings in investment-output ratio.

Appendix

A The Model

A model on which identification in the paper is based is as follows, for example.

The household's problem is

$$\max \int_0^\infty e^{-\rho t} u\left(c,h\right) dt$$
$$\text{s.t. } \dot{a} = (1-\tau)ra + wh - c \tag{10}$$

where a is asset. Time subscripts are abbreviated and the other notations are same as in the paper unless indicated. The Hamiltonian is

$$H = u\left(c,h\right) + \lambda\left[\left(1-\tau\right)ra + wh - c\right].$$

Then the first order conditions are the followings:

$$u_c = \lambda \tag{11}$$

$$u_h = -\lambda w \tag{12}$$

$$\frac{\dot{\lambda}}{\lambda} = \rho - \left(1-\tau\right) r \tag{13}$$

The firm's problem is

$$\max \int_0^\infty e^{-rt}\left[zh^c f\left(\frac{k^c}{zh^c}\right) + vzh^i f\left(\frac{k^i}{zh^i}\right) - w\left(h^c + h^i\right) - i\right]$$
$$\text{s.t. } \dot{k} = i - \delta k \tag{14}$$
$$k = k^c + k^i \tag{15}$$
$$i = vzf\left(\frac{k^i}{zh^i}\right) \tag{16}$$

where the Hamiltonian is

$$\begin{aligned} H &= zh^c f\left(\frac{k^c}{zh^c}\right) + vzh^i f\left(\frac{k^i}{zh^i}\right) - w\left(h^c + h^i\right) - i \\ &\quad + q\left(i - \delta k\right) + \eta\left(k - k^c - k^i\right) + \mu\left[i - vzh^i f\left(\frac{k^i}{zh^i}\right)\right]. \end{aligned}$$

The first order conditions are as follows:

$$z\left[f\left(\frac{k^c}{zh^c}\right) - \frac{k^c}{zh^c}f'\left(\frac{k^c}{zh^c}\right)\right] = w \tag{17}$$

$$(1-\mu)\,vz\left[f\left(\frac{k^i}{zh^i}\right) - \frac{k^i}{zh^i}f'\left(\frac{k^i}{zh^i}\right)\right] = w \tag{18}$$

$$q + \mu = 1 \tag{19}$$

$$f'\left(\frac{k^c}{zh^c}\right) = \eta \tag{20}$$

$$(1-\mu)\,vf'\left(\frac{k^i}{zh^i}\right) = \eta \tag{21}$$

$$\dot{q} = (r + \delta)\,q - \eta. \tag{22}$$

The equilibria for consumption goods market and labor market are

$$c = zh^c f\left(\frac{k^c}{zh^c}\right) \tag{23}$$

and

$$h = h^c + h^i. \tag{24}$$

Dividing equations (18) and (17) by (21) and (20) respectively, we get

$$\frac{z\left[f\left(\frac{k^i}{zh^i}\right) - \frac{k^i}{zh^i}f'\left(\frac{k^i}{zh^i}\right)\right]}{f'\left(\frac{k^i}{zh^i}\right)} = \frac{w}{\eta} = \frac{z\left[f\left(\frac{k^c}{zh^c}\right) - \frac{k^c}{zh^c}f'\left(\frac{k^c}{zh^c}\right)\right]}{f'\left(\frac{k^c}{zh^c}\right)}. \tag{25}$$

Therefore capital-labor ratios for two sectors should be equalized as

$$\frac{k^i}{zh^i} = \frac{k^c}{zh^c} = \frac{k}{zh}$$

Then the sum of equations (16) and (23) is

$$c+\frac{i}{v}=zhf\left(\frac{k}{zh}\right). \tag{26}$$

This equation shows that investment specific technology, v, can be represented by the relative price of investment. Fisher (2005)'s identification of investment specific technology shock arises here.

Dividing equation (20) by (21), we get

$$1-\mu=\frac{1}{v} \tag{27}$$

Evaluating equation (13) at the steady state, we get

$$r=\frac{\rho}{1-\tau} \tag{28}$$

Substituting equations (19), (20), (27), and (28) into (22) in the steady state, we get

$$vf'\left(\frac{k}{zh}\right)=\frac{\rho}{1-\tau}+\delta$$

This corresponds to equation (1) in the paper.

B Exogeneity Test for Scheduled Working Hours

In order to confirm the econometric plausibility of regarding scheduled working hours as being exogenous, I tested Granger causality by the following error collection form:

$$\Delta h_t^s=c^h+X(L)\begin{bmatrix}\Delta h_t^s\\ \Delta h_t\end{bmatrix}+\beta\left(h_{t-1}^s-c-\gamma h_{t-1}\right)+Y(L)\,b_t+\varepsilon_t$$

where $X(L)$ and $Y(L)$ are lag operators and b is the vector of the endogenous variables except hours worked per capita, h. First, the significance of β was tested by error correction models for scheduled working hours, h^s, with h, including up to 10 lags and it turned out that t-statistics of coefficients for the cointegrating vector were not above 0.81 in the absolute values. This suggests weak exogeneity of scheduled working hours for hours worked per capita. Second, I checked whether differenced variables Δh and b entered to Δh^s equation significantly and found that the null could not be rejected at 10 percent significance level in models with from 5 to 16 lags. These results imply that scheduled working hours is not Granger caused by other variables and strongly support removing information on scheduled working hours from hours worked per capita.

C Calculation of Capital Income Tax

Calculate the households' average tax rate on total income first:

$$\tau_h = \frac{\text{Taxes on income, wealth, etc. of households}}{\text{Resources of households}}.$$

Then revenue from the capital income tax on individuals is

$$R_i = \tau_h \times \left(\begin{array}{c} \text{Operating surplus and mixed income of households} \\ + \text{ Property income of households} \end{array} \right).$$

Here impossibility to draw a distinction between taxes from compensation and from the other resources enforces us to assume that tax rates for both resources are same. Revenue from the capital income tax on corporations is

$$R_c = \left(\begin{array}{c} \text{Taxes on income, wealth, etc. of the economy} \\ - \text{ Taxes on income, wealth, etc. of households} \end{array} \right).$$

For the economy, capital tax rate, τ, is calculated as the following:

$$\tau = \frac{R_i + R_c}{\text{Operating surplus and mixed income of the economy}}$$

D Data

Data sources are as follows:

Call rate: Data are available at the Bank of Japan's homepage, http://www.boj.or.jp/en/stat/dlong_f.htm.

Japan's GDP and investment at the annual basis: National accounts. Data are available at the Cabinet Office's homepage, http://www.esri.cao.go.jp/index-e.html. Data between 1930 and 1955 are from Japan Statistical Association (1988). Pre-1930 series of GDP is also from Japan Statistical Association (1988). That of investment is from the Bank of Japan (1966). Data based on different sources are linked with ratios of the levels in overlapping years.

Japan's GDP, investment, consumption, and data for calculating capital tax rate at the quarterly basis: National accounts. Data are available at the Cabinet Office's homepage, http://www.esri.cao.go.jp/index-e.html. Data before 1955 are from economic planning agency (1969). Data based on different standards are linked with ratios of the levels in overlapping years. The series of GNP is used as that of GDP before 1955.

Labor Force Survey: Data are available at the Ministry of internal affairs and Communication's homepage, http://www.stat.go.jp/english/data/roudou/index.htm. Data which are not there are obtained from the monthly publications.

Monthly Labor Survey: Data are available at the Ministry of Health, Labour, and Welfare's homepage, http://www.mhlw.go.jp/english/database/db-l/index.html.

U.S.'s GDP and investment: Data are from BEA's homepage. Pre-1929 Data are from the U.S. Bureau of Census (1997). Data based on different sources are linked with ratios of the levels in overlapping years. The sum of series of private non-residential gross construction and gross producers' durables is used as the series of investment before 1929.

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Table 1. Variance Decompositions in the Bivariate System

Hours Worked Per Capita		
Horizon	Tech. Shock	Nontech. Shock
1	4.2	95.8
4	3.0	97.0
8	3.1	96.9
12	3.1	96.9
32	3.7	96.3
100	3.8	96.2

Labor Productivity		
Horizon	Tech. Shock	Nontech. Shock
1	99.4	0.6
4	99.0	1.0
8	99.6	0.4
12	99.8	0.2
32	100.0	0.0
100	100.0	0.0

GDP Per Capita		
Horizon	Tech. Shock	Nontech. Shock
1	69.9	30.1
4	78.3	21.7
8	88.2	11.8
12	92.9	7.1
32	98.5	1.5
100	99.7	0.3

Notes: Tech. Shock: Technology shock. Nontech. Shock: Nontechnology shock. All shocks are identified with the baseline specification.

Table 2. Variance Decompositions in the Modified System

Hours Worked Per Capita				
Horizon	I.S.	N.	N.P.	N.T.
1	24.7	3.3	0.3	71.7
4	17.2	3.3	7.0	72.6
8	15.8	3.1	12.2	68.9
12	15.2	3.7	12.5	68.6
32	15.0	3.8	12.0	69.3
100	15.0	3.8	12.0	69.3

Labor Productivity				
Horizon	I.S.	N.	N.P.	N.T.
1	24.3	23.5	49.6	2.7
4	13.2	18.6	64.1	4.1
8	16.4	22.4	57.5	3.8
12	20.3	22.2	54.7	2.8
32	28.8	19.9	50.5	0.8
100	32.6	18.9	48.4	0.1

GDP Per Capita				
Horizon	I.S.	N.	N.P.	N.T.
1	4.5	33.4	52.8	9.3
4	3.8	19.2	62.0	15.1
8	7.5	21.4	58.7	12.5
12	12.6	22.1	56.3	9.1
32	26.6	21.1	52.9	4.8
100	32.2	18.9	48.5	0.4

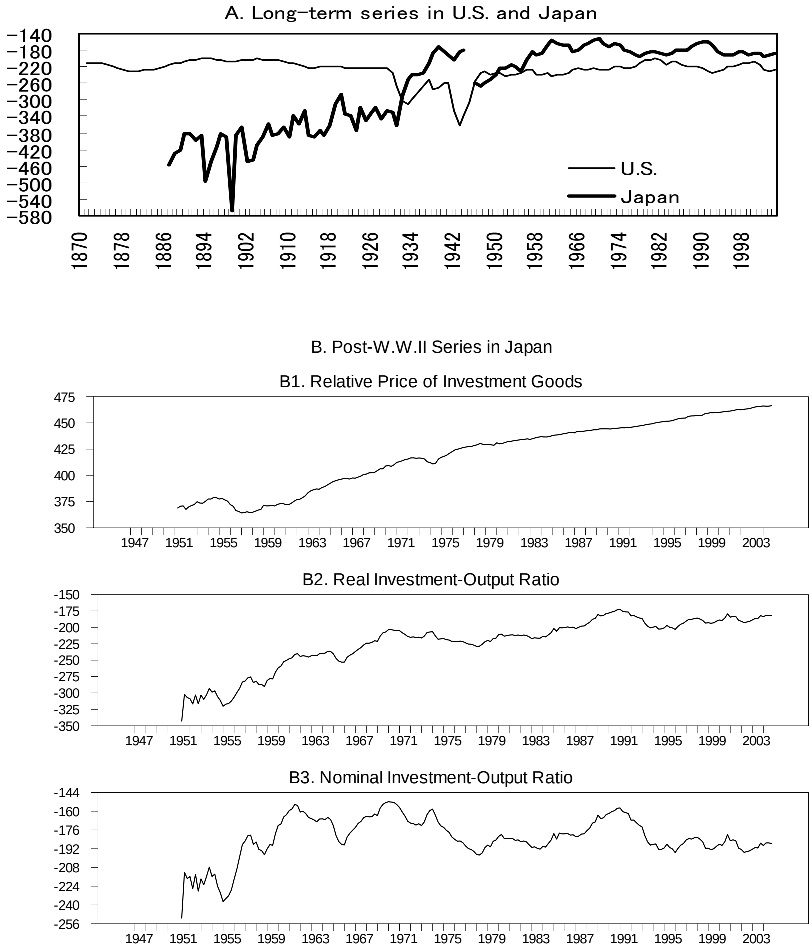
Investment-Output Ratio				
Horizon	I.S.	N.	N.P.	N.T.
1	7.1	53.7	30.1	9.1
4	5.8	25.4	60.2	8.6
8	4.7	12.7	75.1	7.5
12	4.8	9.2	80.1	5.8
32	11.1	3.8	82.8	2.3
100	16.8	1.0	81.5	0.6

Investment Per Capita				
Horizon	I.S.	N.	N.P.	N.T.
1	10.2	11.8	62.7	15.3
4	6.3	4.7	75.8	13.2
8	6.3	1.9	81.0	10.7
12	8.0	2.8	81.3	7.8
32	19.3	3.5	74.7	2.5
100	25.9	4.9	68.6	0.5

Relative Investment Goods Price				
Horizon	I.S.	N.	N.P.	N.T.
1	50.1	5.4	33.0	11.5
4	51.6	1.3	43.2	3.9
8	58.1	3.6	37.1	1.3
12	66.8	4.9	27.5	0.8
32	86.0	2.6	11.1	0.3
100	96.1	0.7	3.1	0.1

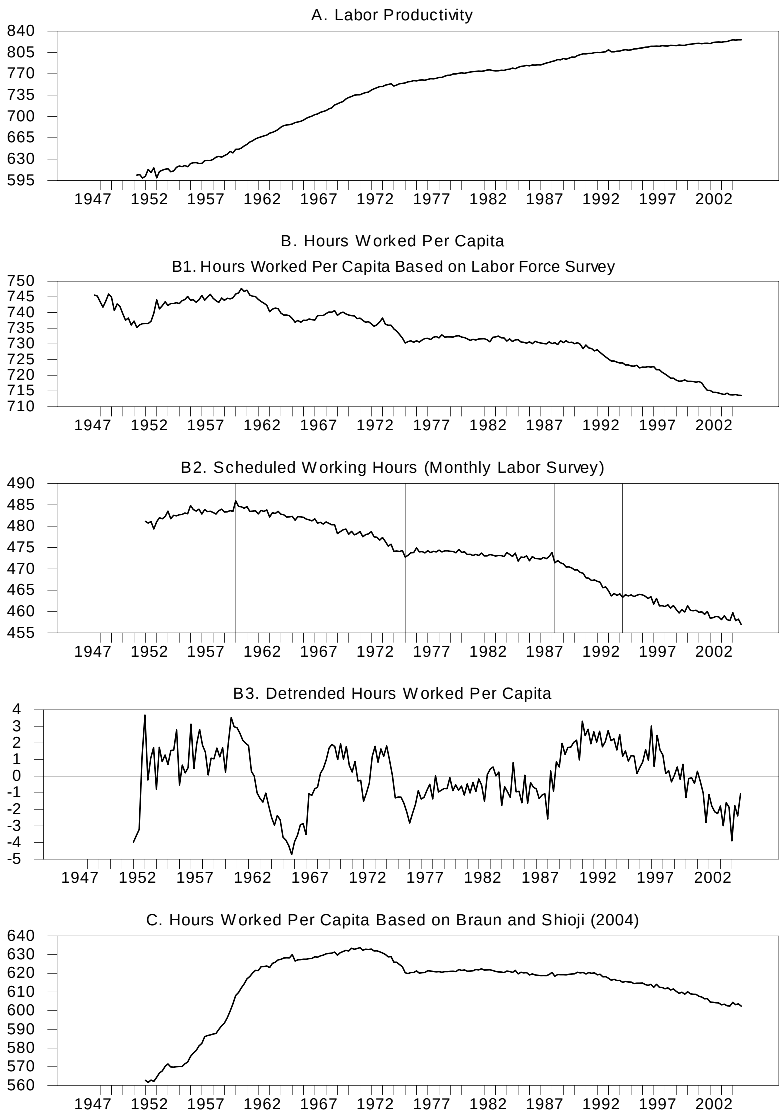
Notes: I.S.: Investment specific technology shock. N.: Neutral technology shock. N.P.: Nontechnology permanent shock. N.T.: Nontechnology temporary shock. All shocks are identified in the modified system.

Figure 1. Investment-Output Ratio in U.S. and Japan



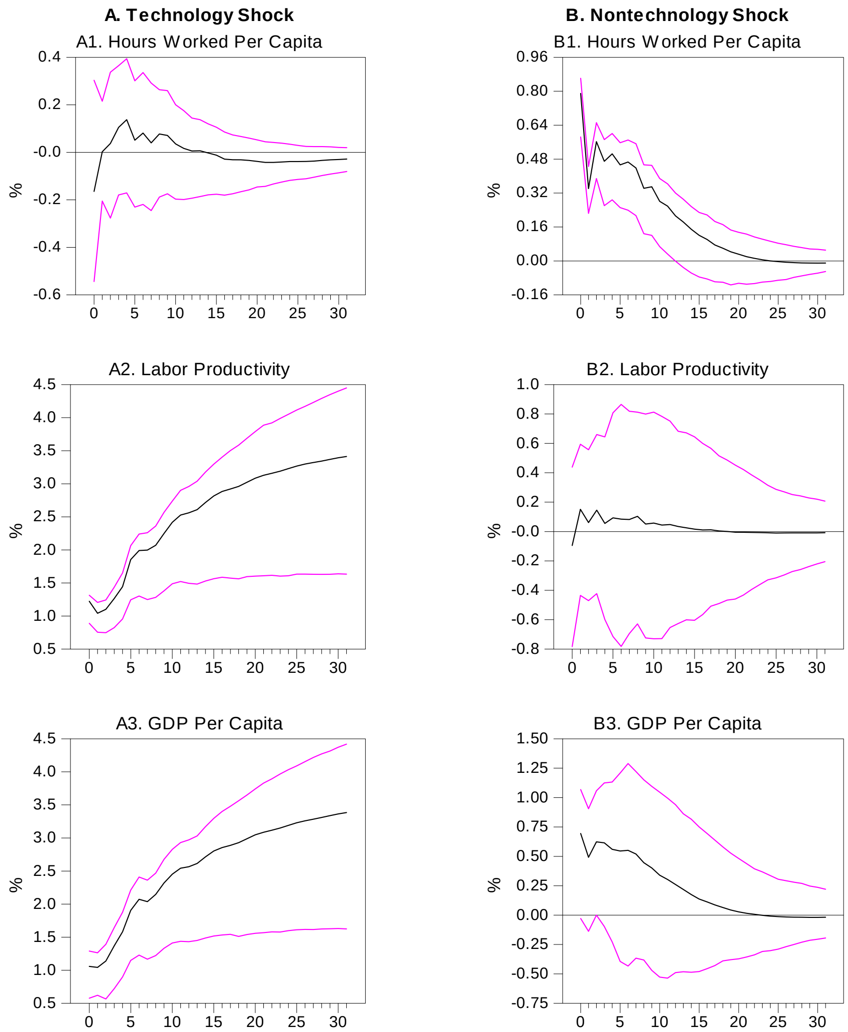
Notes:The vertical axis shows log-levels multiplied by 100. Lon-term series is annual basis. U.S. pre-1929 data are averages for sub-periods which are plotted at every 5 years and 1871. Relative investment price is the ratio of consumption deflator to investment deflator. Real investment-output ratio is the ratio of real investment to GDP which is evaluated in consumption unit.

Figure 2. Labor Productivity and Hours Worked Per Capita



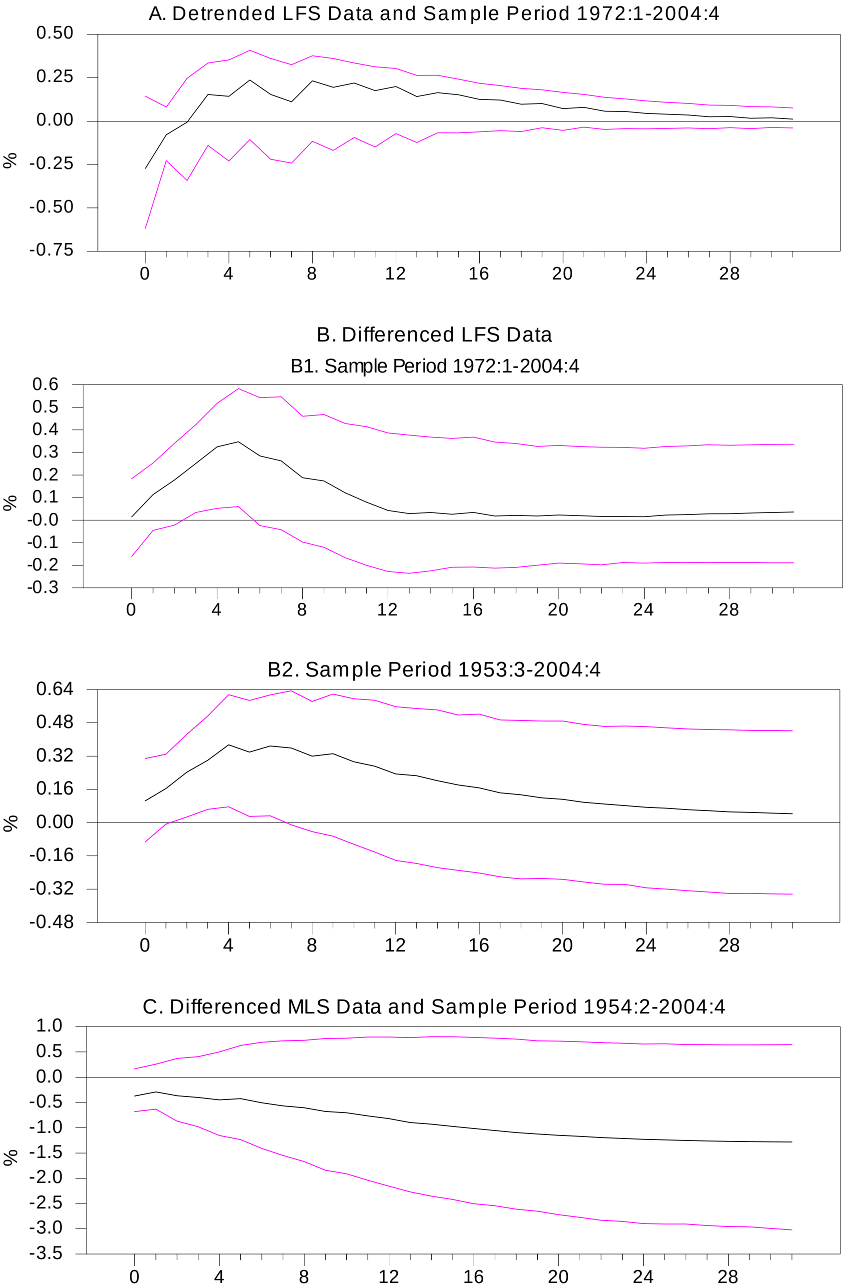
Note: Vertical axes indicate log-levels multiplied by 100.

Figure 3. Impulse Responses to a Positive Shock in the Bivariate System



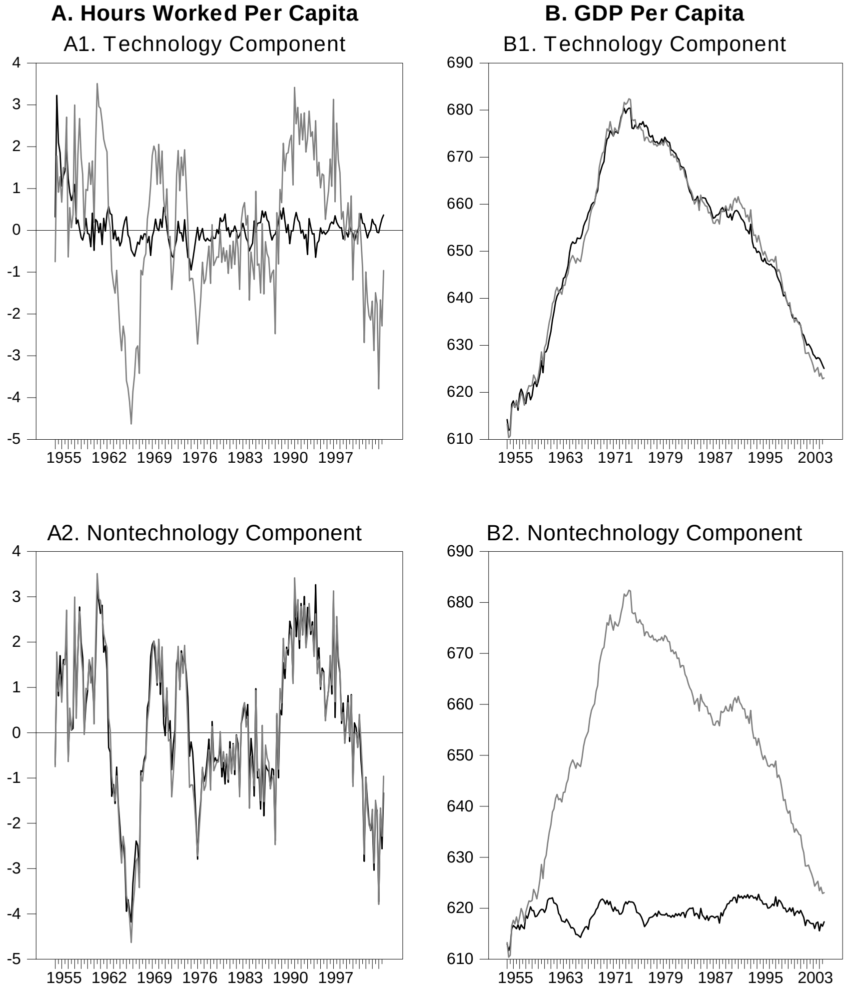
Note: The sample period is 1954:1-2004:4. Dotted lines show 90 percent confidence intervals based on a bootstrap Monte Carlo procedure with 1000 replications

Figure 4. Effects of a Positive Technology Shock to Hours Worked Per Capita with Various Data Sets



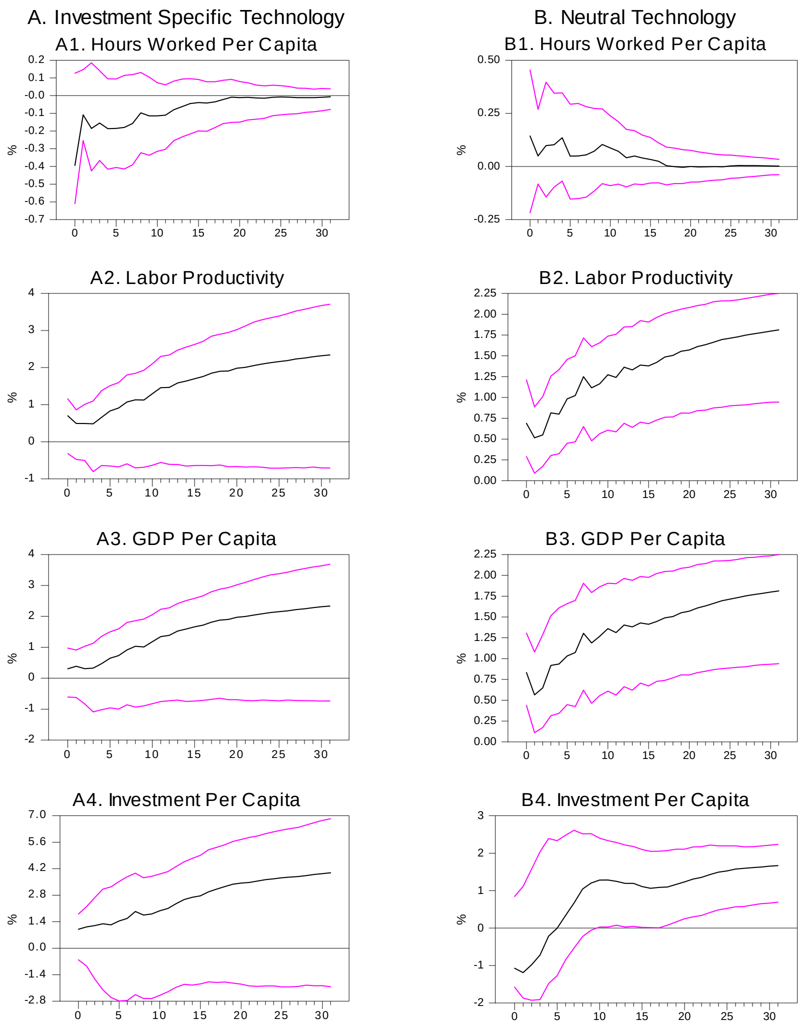
Note: Dotted lines show 90 percent confidence intervals based on a bootstrap Monte Carlo procedure with 1000 replications

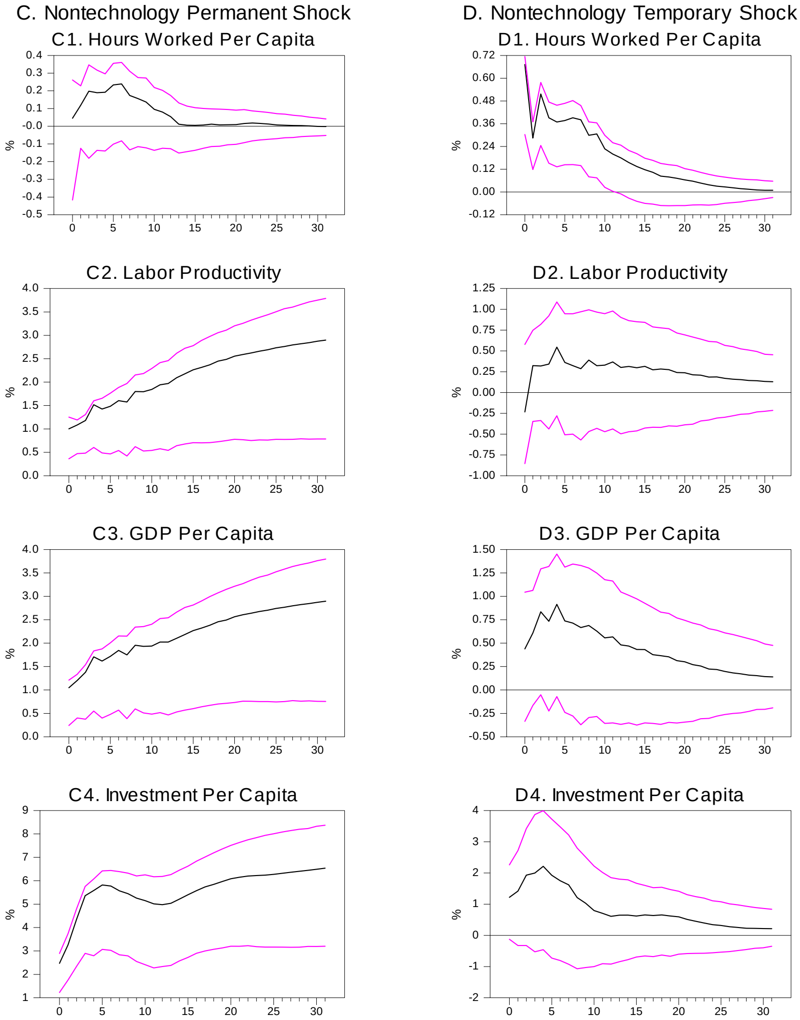
Figure 5. Historical Decompositions in the Bivariate System



Note: Solid lines show each shock component and dotted lines show all shocks component. Vertical axes indicate log-levels multiplied by 100.

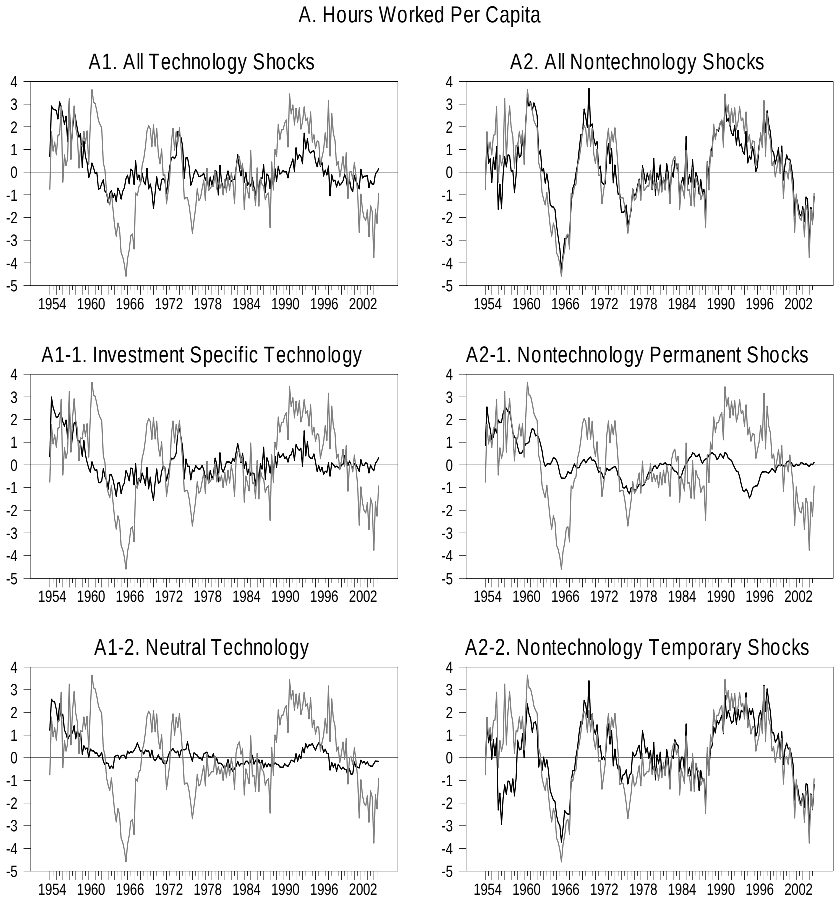
Figure 6. Impulse Responses to Purified Positive Shocks



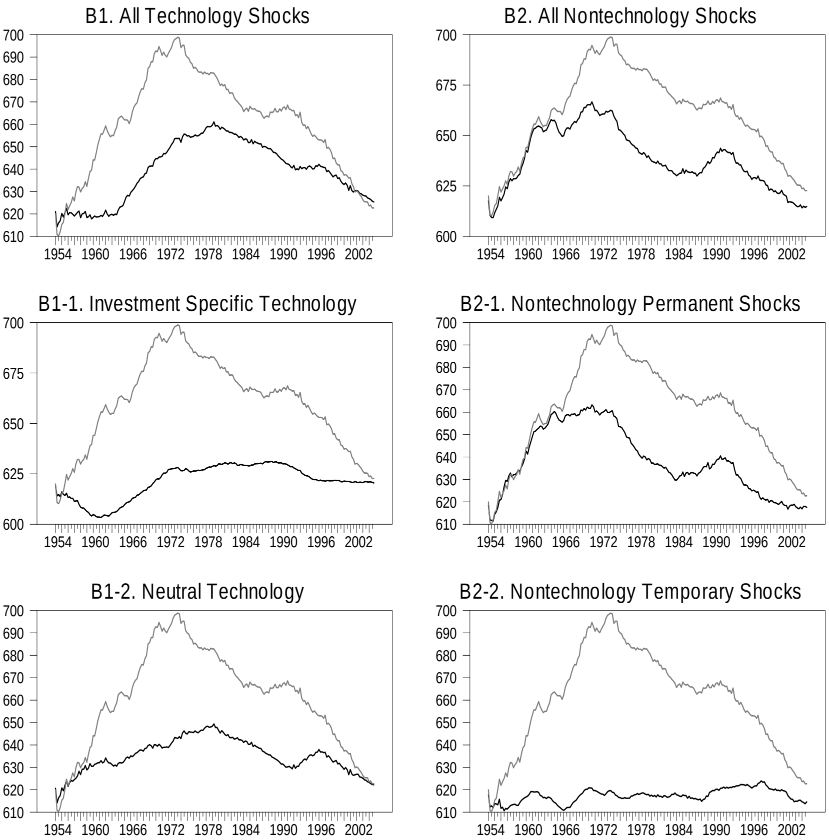


Note: Dotted lines show 90 percent confidence intervals based on a bootstrap Monte Carlo procedure with 1000 replications. Sample period is 1954:1-2004:4.

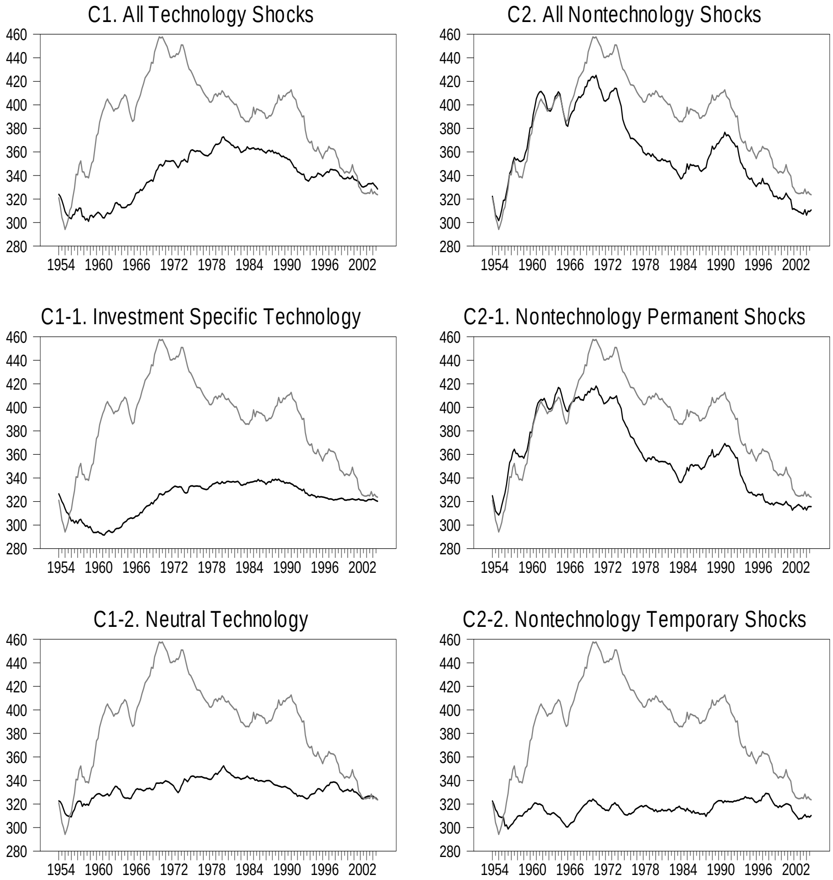
Figure 7. Historical Decompositions by Purified Shocks



B. GDP Per Capita



C. Investment Per Capita



Notes: Solid lines show each shock component and dotted lines show all shocks component. Vertical axes indicate log-levels multiplied by 100.

Figure 8. Capital Tax Rate

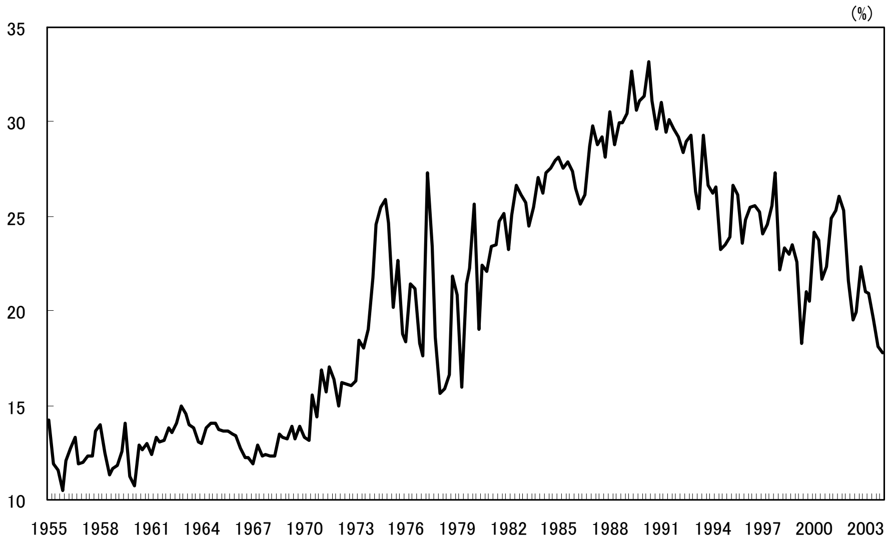
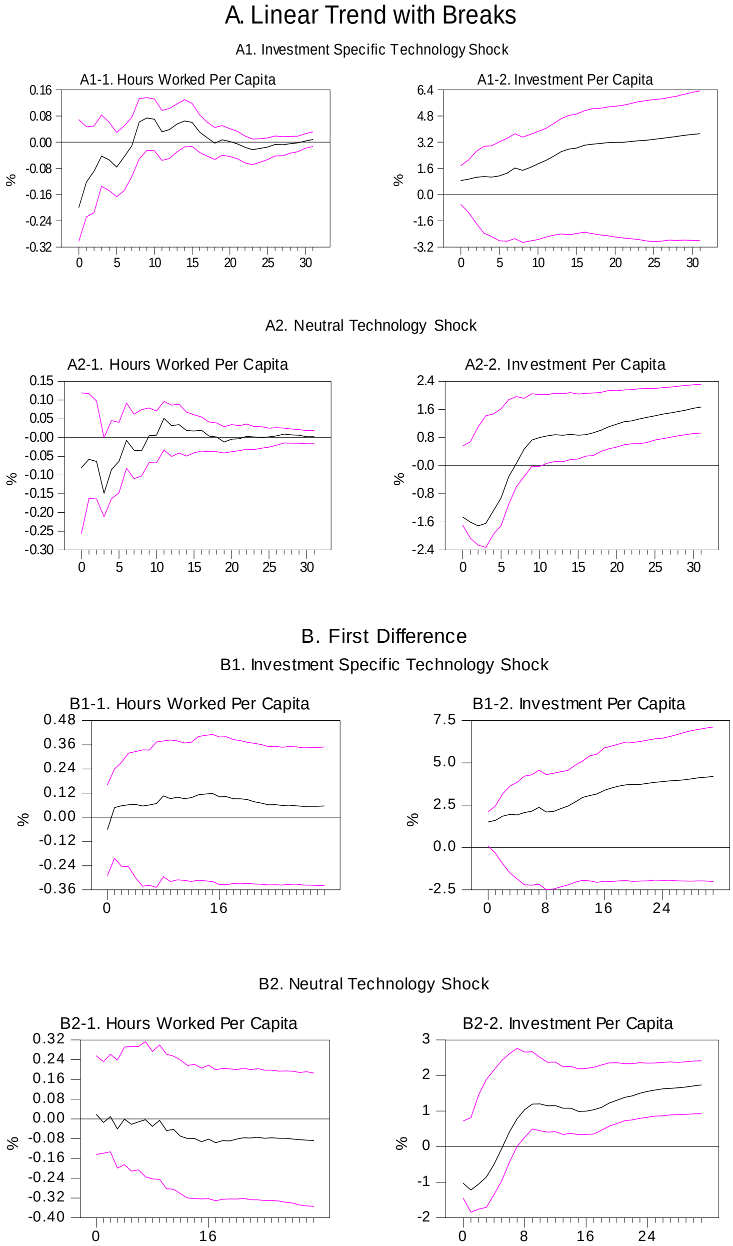
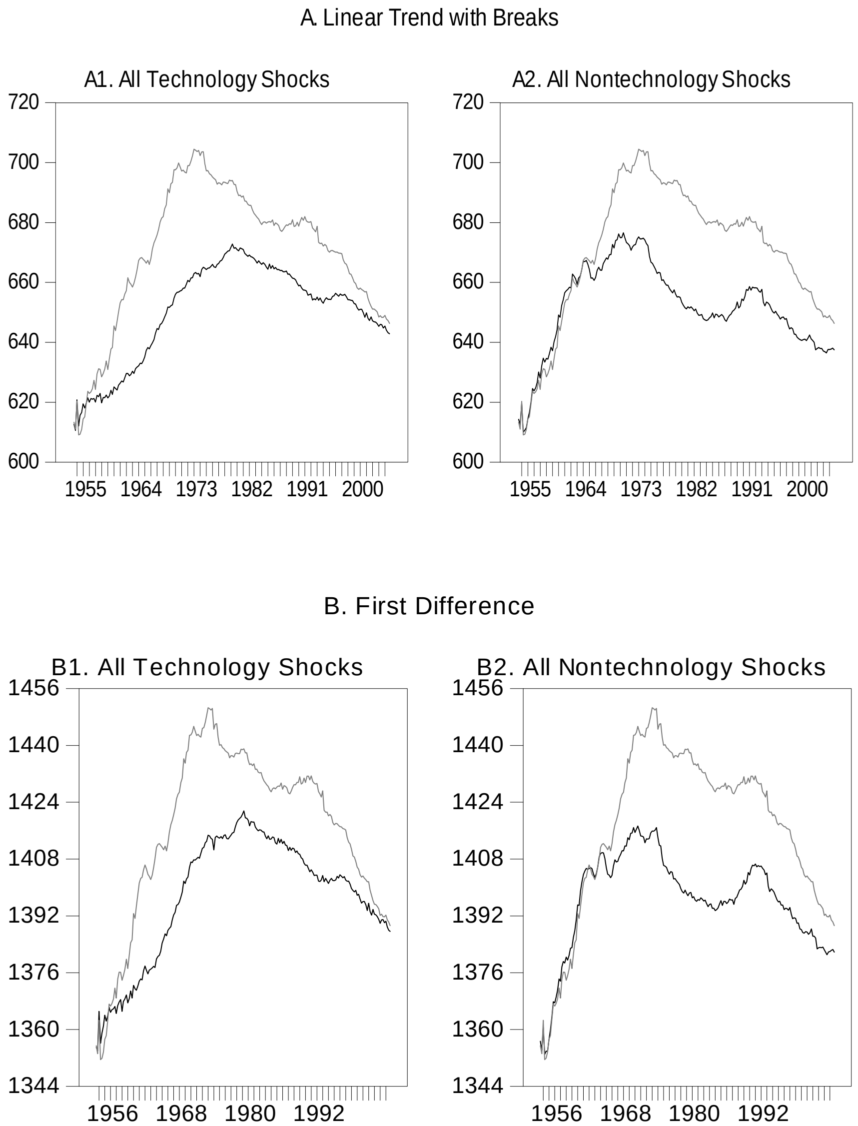


Figure 9. Impulse Responses to Purified Positive Shocks Estimated with Other Detrending



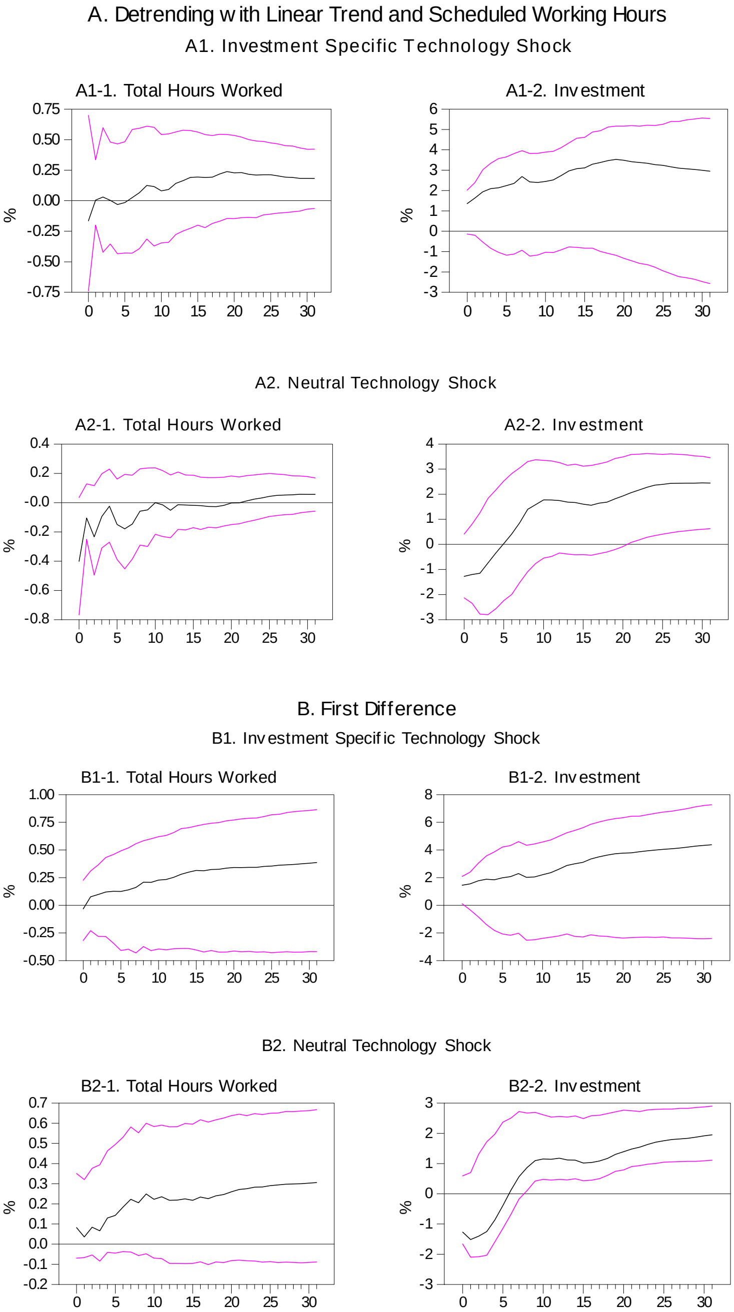
Note: Dotted lines show 90 percent confidence intervals based on a bootstrap Monte Carlo procedure with 1000 replications. Sample periods are 1953:3-2004:4.

Figure 10. Historical Decompositions of GDP Per Capita by Purified Shocks Estimated with Other Detrending



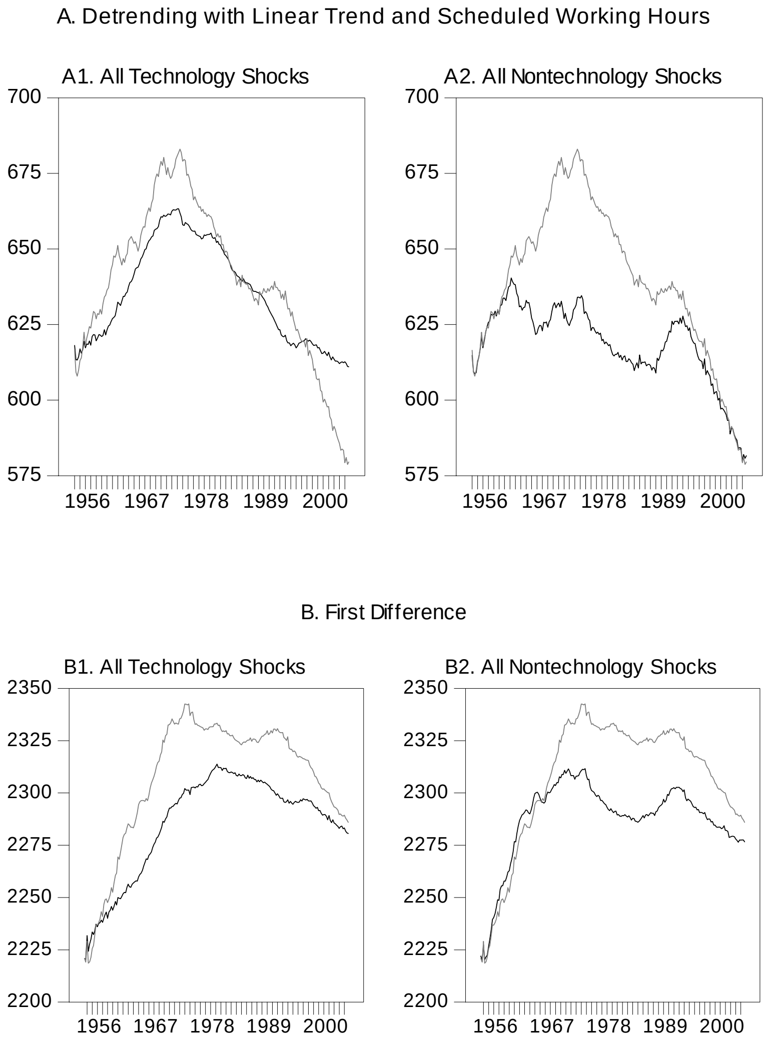
Notes: Solid lines show each shock component and dotted lines show all shocks component. Vertical axes indicate log-levels multiplied by 100.

Figure 11. Impulse Responses to Purified Positive Shocks Estimated with Total Hours



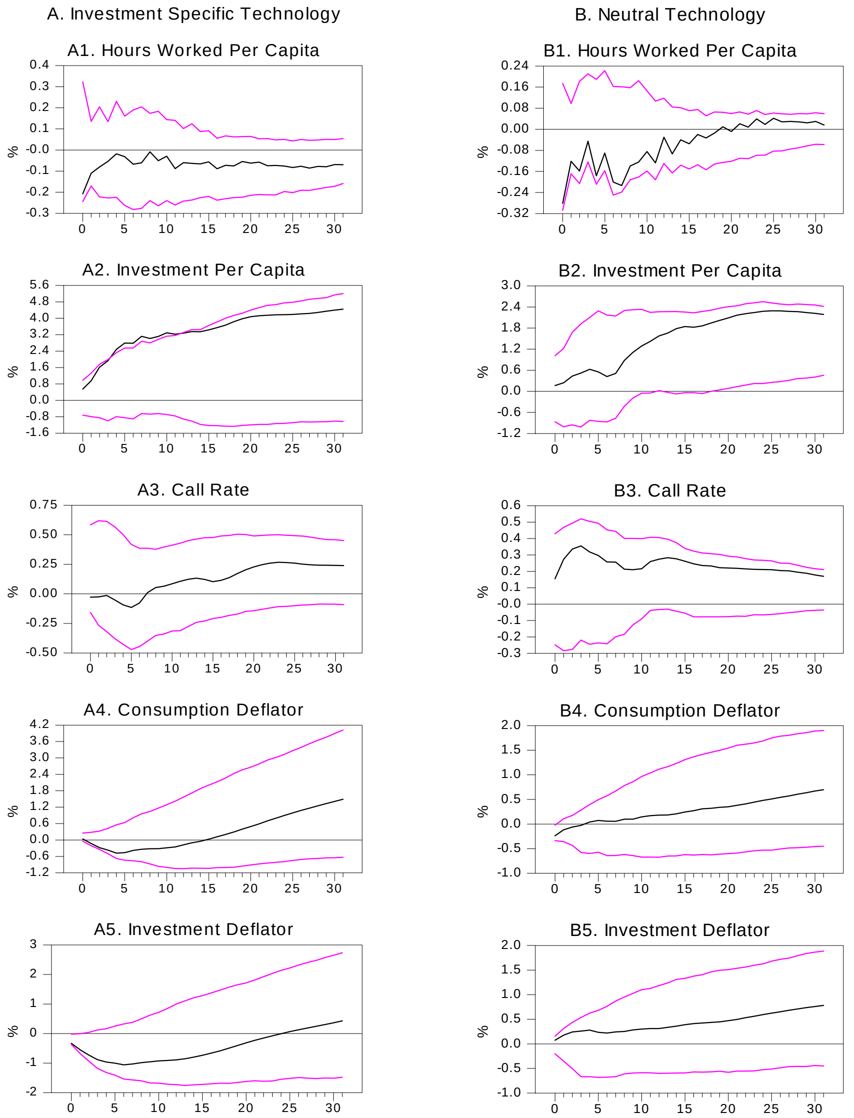
Note: Dotted lines show 90 percent confidence intervals based on a bootstrap Monte Carlo procedure with 1000 replications. Sample periods are 1954:1-2004:4 for the first four panels and 1953:3-200:4 for the others.

Figure 12. Historical Decompositions of GDP Per Capita by Purified Shocks Estimated with Total Hours



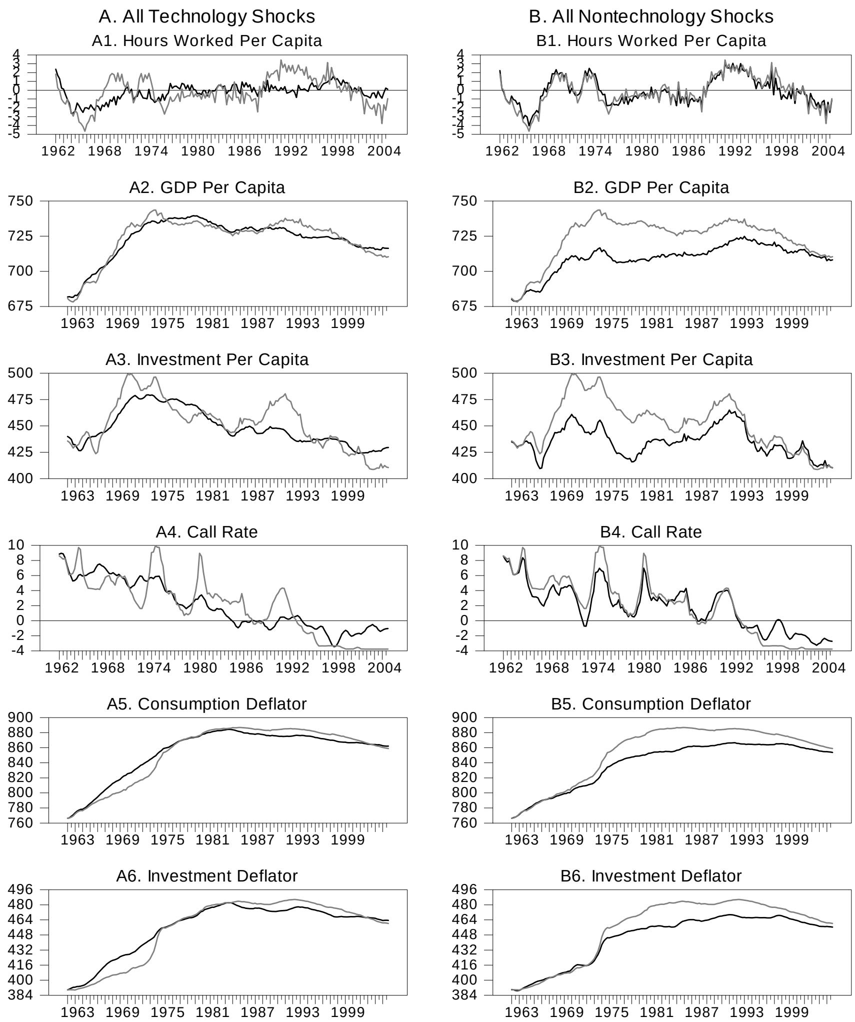
Notes: Solid lines show each shock component and dotted lines show all shocks component. Vertical axes indicate log-levels multiplied by 100.

Figure 13. Impulse Responses to Purified Positive Shocks Estimated with Nominal Variables



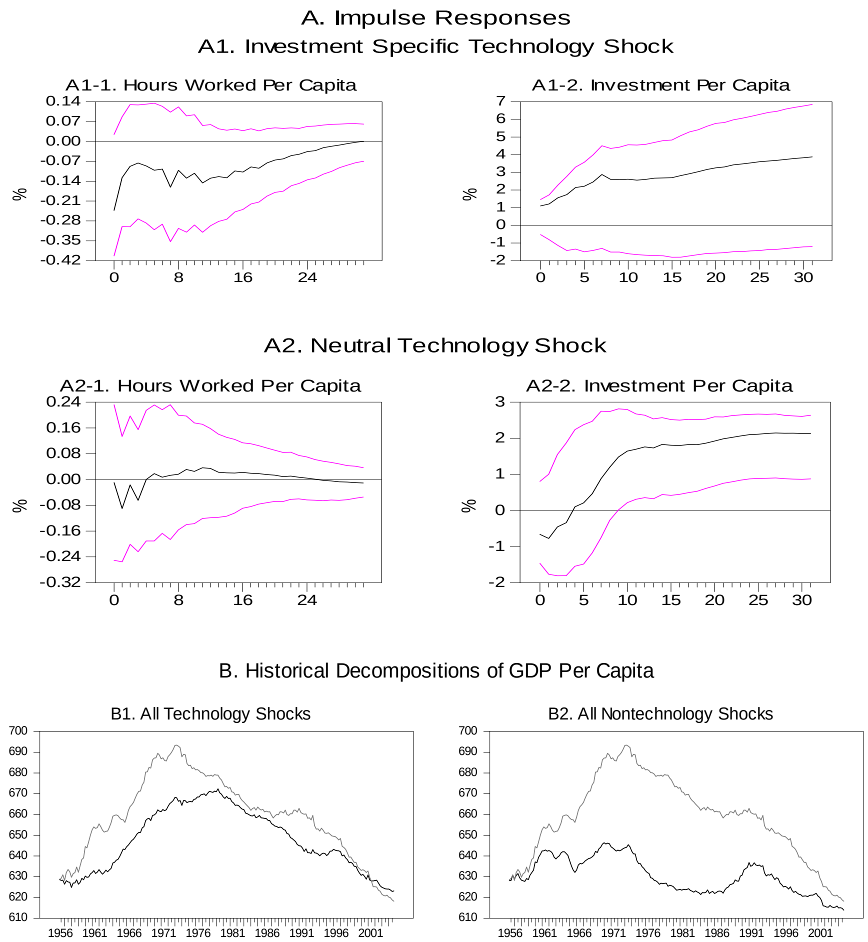
Note: Dotted lines show 90 percent confidence intervals based on a bootstrap Monte Carlo procedure with 1000 replications. Sample period is 1962:1-2004:4.

Figure 14. Historical Decompositions by Purified Shocks Estimated with Nominal Variables



Notes: Solid lines show each shock component and dotted lines show all shocks component. Vertical axes indicate log-levels multiplied by 100.

Figure 15. Estimation with Scheduled Working Hours Shock



Note: Dotted lines show 90 percent confidence intervals based on a bootstrap Monte Carlo procedure with 1000 replications. Sample period is 1954:2-2004:4.