ESSAYS ON TECHNOLOGY, FISCAL POLICY, AND THE BUSINESS CYCLE

by

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To Momoko, Riko, and Mari

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Abstract

This dissertation empirically investigates macroeconomic fluctuations. In particular, it focuses on identifying technology shocks and fiscal shocks and understanding the effects of these shocks.

In the first chapter, I propose a new method to investigate how technology and nontechnology shocks work in the business cycles. It is popular to identify technology shocks as the sole source of permanent movement of labor productivity in a structural vector autoregression (SVAR). However it potentially misidentifies nontechnology shocks that permanently affect capital-labor ratio, e.g., a capital tax shock, as technology shocks. I call such shocks nontechnology permanent shocks. I show that the nontechnology permanent shocks bring nonstationarity of nominal investment-output ratio and are identified by the additional restriction that those permanently affect real investment-output ratio together with investment-specific technology shocks. My method suggests that the nontechnology permanent shocks don't work much in U.S., which is consistent with other evidences in the literature. The only country with significant nontechnology permanent shocks within the G-7 countries is Japan. When permanent technology and nontechnology shocks are separately identified for Japan, the response of hours worked to technology improvement changes from significantly positive to insignificant. Furthermore technology shocks lose the dominant role to explain Japan's stagnant economy in the 1990s.

In the second chapter, I measure U.S. technology in 1891-2006 with a series of Solow residuals, which are purified from the effects of varying utilization of capital and labor, nonconstant scales, and imperfect competition and find the following three facts. First, when technology improves, hours worked change little on impact in the periods including pre-W.W.II years and fall in the post-W.W.II period. Second, technology regressed by 4.8 percent from 1929 to 1933 in the Great Depression period, which is less than one-third of 15.5 percent fall in the standard Solow residuals series. Third, the average growth rate of technology in 1929-1941 was highest in U.S. economic history.

In the third chapter, I revisits U.K. Wartime Economy in the Pre-World War I period and study the nature of fiscal shocks. Wartime rises in the interest rate in pre-World War

I U.K. have been interpreted as supporting a theoretical effect of a positive government goods purchases shock in the standard neoclassical model, since wars accompany large increases in military goods purchase. However, I find that U.K. industrial production fell during wars in the pre-W.W.I period and show that the standard neoclassical model generates only one of the two phenomenons in response to most kinds of fiscal shocks. A positive shock to government employment, which is also generated in the wartime economy by large increases in military employment, leads to a fall in the industrial production, but not to a rise in the interest rate. When I give the model the shocks corresponding to average behavior of military spending and military employment across U.K. war episodes in the pre-W.W.I period, the model generates falls in the private output and the interest rate. I propose the hypothesis that the falls in the industrial production were due to military employment and the rises in interest rate were due to risk premium.

Chapter 1

Roles of Technology and Nontechnology Shocks in the Business Cycles

1.1 Introduction

A lot of studies have empirically examined the roles of technology shocks in the business cycles in order to evaluate the plausibility of the technology-driven real business cycle hypothesis. A seminal work is by Galí (1999), who proposes identifying technology shocks by a bivariate structural vector autoregression (SVAR) model consisting of labor productivity growth and hours worked. He develops the long-run restriction that only technology shocks permanently affect the level of labor productivity.[1] This idea is very attractive in that the restriction seems theoretically robust and the method doesn't use Solow residuals, which may be affected by nontechnological factors such as unobservable factor utilization variations. By applying the SVAR to U.S. data, he shows that identified technology shocks dampen hours worked. This result has attracted much attention, since it is opposite to the prediction of the standard real business cycle model. In the subsequent work, Galí (2005) shows that the result is basically common across the G-7 countries except for Japan.

Many researchers have investigated potential flaws in his method. Broadly speaking, those are categorized into three classes. The first is a bias due to reducing 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,

[1]The SVAR with the long-run restriction is originally developed by Blanchard and Quah (1989) and Shapiro and Watson (1988).

and Vigfusson (2006) show that the bias appears to be not so problematic or be methodologically reduced. The second is that results derived from the long-run restriction are extraordinarily affected by the low frequency correlation between variables in the system, even if the correlation is not causal. This is examined by Fernald (2007) and Francis and Ramey (2008). The third is the possible misidentification of nontechnology shocks as technology shocks. Such misidentification can happen since certain types of nontechnology shocks permanently affect labor productivity via the level of capital-labor ratio. The shock examined often in the literature is a capital tax shock. This paper calls such shocks as the *nontechnology permanent shocks* and develops a method to identify those. The method is applied to the G-7 countries' data.

The literature finds that the nontechnology permanent shocks don't appear to be reflected in U.S. technology shocks identified by Galí's method. Francis and Ramey (2005) include a series of capital tax rate as an exogenous variable in the system and confirm that Galí's result is unchanged. Galí and Rabanal (2004) find near-zero correlation between a capital tax rate series and an identified technology shocks series. They also find insignificant coefficients in an ordinary least squares regression of the tax series on current and lagged identified technology shocks. Fisher (2006) tests whether the series of Federal Funds rate, oil shock dates, log-changes in real military spending, and changes in capital tax rate Granger-cause identified technology shocks and finds that no Granger-causality is not rejected except for oil shock dates.

However these studies focus only on observable nontechnological factors. The factors that are unobservable or measured with difficulty, e.g., a depreciation rate, potentially affect labor productivity. Therefore this paper proposes identifying the nontechnology permanent shocks as a series of linear combination of all types of underlying nontechnology shocks with the following three long-run restrictions.

The first restriction is that only investment-specific technology shocks affect relative investment price permanently. This restriction is developed by Fisher (2006). The second restriction, which is a main contribution of this paper, is that only nontechnology permanent shocks and investment-specific technology shocks affect the steady state level of *real* investment-output ratio. This restriction is based on the theoretical steady state property that the determinants of real investment-output ratio, which include the investment specific technology shocks, are equivalent to those of capital-labor ratio. The third restriction for identifying sector-neutral technology shocks is that only these three types of shocks, which Galí interpret as technology shocks as a whole, permanently affect labor productivity. Therefore our multivariate system consists of four variables: relative investment price growth, real investment-output ratio growth, labor productivity growth, and hours worked per capita. The remaining shock identified in this four-variable system is the nontechnology *temporary* shock, which Galí simply calls as the nontechnology shock.

Another contribution of this paper is to develop a diagnosis of the nontechnology permanent shocks. Theoretically, only nontechnology permanent shocks affect *nominal* investment-output ratio in the long run. Although the investment-specific technology shocks might seem to work in the similar way by lowering relative investment price, those stimulate real investment and therefore are neutral for the nominal ratio in the long-run. Therefore, if the nontechnology permanent shocks didn't happen, the nominal ratio should be stationary. In other words, if the nominal investment-output ratio is nonstationary, one should use our four-variable system instead of Galí's two-variable system.

We apply these methods to G-7 countries' data and find the followings. First, standard, univariate hypothesis tests suggest that the nominal investment-output ratio of all G-7 countries may be nonstationary. Hence we re-examine Galí's results using G-7 countries' data with our four-variable system incorporating the nontechnology permanent shocks. Second, applying our four-variable system to U.S., Canada, and European countries' data doesn't change results from applying Galí's two-variable system: hours worked fall to technology improvement on impact when hours worked are assumed to have a unit root. This finding suggests that the nontechnology permanent shocks don't work much in these countries' business cycles. Note that the result for U.S. is consistent with the findings in the literature that Galí's method doesn't misidentify nontechnology factors as technology shocks. Third, in the case of Japan's data, the four-variable system produces the negative impact response of hours worked to a positive technology shock, while the two-variable system produces positive one. This result indicates that the nontechnology permanent shocks work in Japan much more than in the other G-7 countries. In addition, historical decomposition based on the four-variable system shows that negative nontechnology shocks as well as negative technology shocks dampen output in the 1990s, so called Japan's lost decade, while two-variable system attributes the cause of stagnation in that period almost only to negative technology shocks. It casts doubt on the plausibility of Hayashi and Prescott's (2002) assertion that technological regress is the main cause of Japan's stagnation.

We add some thoughts on the source of the nontechnology permanent shocks in Japan. Shocks to capital tax rate are not reflected in the nontechnology permanent shocks. Instead, historical episodes suggest that a kind of news shock, that is, revision to optimistic or pessimistic expectation may originate the nontechnology permanent shocks.

The paper proceeds as follows. We introduce our econometric strategy in the next section. Section 1.3 examines the time series property of G-7 countries' nominal investment-output ratio. Section 1.4 introduces data and argues specification issues. Section 1.5 shows estimation results. Section 1.6 considers the sources of nontechnology permanent shocks. Section 1.7 contains concluding remarks.

1.2 Econometric Strategy

1.2.1 The Model

We start with constructing the standard neoclassical two-sector model in order to understand the theory behind Galí's long-run restriction and its limitation and develop a method to overcome it. The model consists of consumption goods sector and investment goods sector.

Consumption goods sector. The numeraire is the consumption goods. The firm in the consumption goods sector solves the following profit maximization problem.

$$\max k_{c,t}^{\alpha} \left(z_t h_{c,t}\right)^{1-\alpha} - W_t h_{c,t} - R_t k_{c,t}$$

where z is the sector-neutral technology, k is capital stock, h is hours worked per capita, W is nominal wage, and R is rental rate. The subscript c indicates the consumption goods sector. The first order conditions are the followings:

$$z_t (1-\alpha) \left(\frac{k_{c,t}}{z_t h_{c,t}}\right)^{\alpha} = W_t \tag{1.1}$$

and

$$\alpha \left(\frac{k_{c,t}}{z_t h_{c,t}}\right)^{\alpha-1} = R_t. \tag{1.2}$$

Investment goods sector. Let P_i and v be the investment goods price and investment-specific technology respectively. We assume that the form of production function is same as that in the consumption goods sector. Then the firm in the investment goods sector solves the following profit maximization problem.

$$\max P_{i,t} v_t k_{i,t}^{\alpha} \left(z_t h_{i,t}\right)^{1-\alpha} - W_t h_{i,t} - R_t k_{i,t}$$

where the subscript i indicates the investment goods sector. The first order conditions are the followings:

$$P_{i,t} v_t z_t (1-\alpha) \left(\frac{k_{i,t}}{z_t h_{i,t}}\right)^{\alpha} = W_t \text{ and} \tag{1.3}$$

$$P_{i,t} v_t \alpha \left(\frac{k_{i,t}}{z_t h_{i,t}}\right)^{\alpha-1} = R_t. \tag{1.4}$$

Factor intensity, relative price, aggregate output, and labor productivity. Dividing equation (1.1) by (1.2) and (1.3) by (1.4) brings the following condition:

$$\frac{k_{c,t}}{z_t h_{c,t}} = \frac{k_{i,t}}{z_t h_{i,t}}.$$

This condition means that the factor intensity is same across two sectors. Define

$$x_t \equiv \frac{k_{i,t}}{z_t h_{i,t}} = \frac{k_{c,t}}{z_t h_{c,t}}. \tag{1.5}$$

Noting this property and dividing equation (1.4) by (1.2), we can get

$$p_{i,t} = \frac{1}{v_t}. \tag{1.6}$$

This condition means that the relative price of investment goods p_i moves only with the investment-specific technology. Fisher (2006) uses this property as a long-run restriction and we will adopt the same strategy.

Next, we will derive goods market equilibrium conditions. The investment goods market equilibrium condition and the consumption goods market equilibrium condition are represented as follows.

$$v_t k_{i,t}^{\alpha} \left(z_t h_{i,t}\right)^{1-\alpha} = i_t \text{ and}$$

$$k_{c,t}^{\alpha}\left(z_t h_{c,t}\right)^{1-\alpha} = c_t$$

where i and c are aggregate investment and consumption. Then aggregate output is represented as

$$y_t \equiv c_t + p_{i,t} i_t = z_t \left(\frac{k_{c,t}}{z_t h_{c,t}}\right)^{\alpha} h_{c,t} + \frac{1}{v_t} v_t z_t \left(\frac{k_{i,t}}{z_t h_{i,t}}\right)^{\alpha} h_{i,t} = z_t h_t x_t^{\alpha}. \tag{1.7}$$

where h_t is the aggregate labor demand, that is, $h_{i,t} + h_{c,t}$. For later use, note that labor productivity is represented as follows:

$$\frac{y_t}{h_t} = z_t x_t^{\alpha}. \tag{1.8}$$

Rental firm. The rental firm solves the following profit maximization problem.

$$\max \sum_{t=0}^{\infty} \prod_{s=0}^{t} \left(\frac{1}{1+r_s}\right) \left(R_t k_t - p_{i,t} i_t\right)$$

$$\text{s.t. } k_{t+1} = i_t + (1-\delta) k_t \tag{1.9}$$

where r is the real interest rate. Letting q be the Lagrangian, the first order conditions are the followings:

$$q_t = p_{i,t} \text{ and} \tag{1.10}$$

$$-q_t + \frac{1}{1+r_{t+1}} \left(R_{t+1} + q_{t+1}(1-\delta)\right) = 0. \tag{1.11}$$

Household. The household solves the following utility maximization problem.

$$\max \sum_{t=0}^{\infty} \beta^t u\left(c_t, h_t\right)$$

$$\text{s.t. } a_{t+1} = a_t + (1-\tau) r_t a_t + W_t h_t - c_t$$

where a is the amount of asset and τ is the capital tax rate. Letting λ be the Lagrangian, the first order conditions are as follows.

$$u_c = \lambda_t,$$

$$u_h = \lambda_t W_t \text{ and}$$
$$-\lambda_t + \beta\lambda_{t+1}\left(1 + (1-\tau)\, r_{t+1}\right) = 0. \tag{1.12}$$

Steady state conditions. The steady state real interest rate is derived from the equation (1.12) as follows.

$$r_* = \frac{\frac{1}{\beta} - 1}{1-\tau}. \tag{1.13}$$

The asterisk in the subscript indicates that the variable is at the steady state. Evaluating the equation (1.11) at the steady state, we get

$$R_* = q_*\left(r_* + \delta\right). \tag{1.14}$$

From the equations (1.4), (1.5), (1.10), (1.13), and (1.14),

$$\alpha v_* x_*^{\alpha-1} = \frac{\frac{1}{\beta} - 1}{1-\tau} + \delta. \tag{1.15}$$

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."

1.2.2 Galí's Method

The equation (1.15) indicates that, in the steady state, the factor intensity x is determined by the investment-specific technology v and nontechnological factors β, τ, and δ. Galí assumes that the nontechnological factors follow stationary stochastic processes. It implies that, although he doesn't distinguish investment-specific technology from sector-neutral technology z, the steady state level of factor intensity x moves only with investment-specific technology. Then, as known from the equation (1.8), labor productivity is determined only by the sector-neutral technology and the investment-specific technology in the long-run.

This is the theory behind the Galí's long-run restriction that only the technology shocks affect the labor productivity in the long-run.

Galí represents his SVAR model as

$$\begin{bmatrix} \Delta y_t - \Delta h_t \\ h_t \end{bmatrix} = C(L) \begin{bmatrix} \varepsilon_t^z \\ \varepsilon_t^d \end{bmatrix} \tag{1.16}$$

where $C(L)$ is the matrix of distributed lag polynomials, ε_t^z is a linear combination of shocks to the sector-neutral technology and the investment-specific technology, and ε_t^d is the nontechnology shock. Galí's long-run restriction means $C^{12}(1) = 0$.[2]

Galí's system identifies technology shocks as a linear combination of shocks to the sector-neutral technology and the investment-specific technology, since he doesn't explicitly deal with the latter technology. On the other hand, Fisher (2006) notes that U.S. relative investment price follows a nonstationary process, and asserts that shocks to investment-specific technology v are important in the business cycle since, as seen in the equation (1.6), the investment-specific technology moves in a way one-to-one with the relative investment price. He proposes to add the restriction that investment-specific technology shock ε^v solely affects relative investment price in the long-run to Galí's restriction. Therefore his system is

$$\begin{bmatrix} \Delta p_{i,t} \\ \Delta y_t - \Delta h_t \\ h_t \end{bmatrix} = C(L) \begin{bmatrix} \varepsilon_t^v \\ \varepsilon_t^z \\ \varepsilon_t^d \end{bmatrix} \tag{1.17}$$

where ε_t^z is the sector-neutral technology shock alone. Fisher's long-run restrictions mean that $C(1)$ is a lower-triangular matrix.

1.2.3 Identifying Nontechnology Permanent Shocks with Real Investment-Output Ratio

Galí and Fisher assume that nontechnology shocks don't affect the steady state level of labor productivity. However, Galí and Rabanal (2004), Francis and Ramey (2005), and Fisher note that, among the nontechnological factors, a capital tax rate shows nonstationary behavior and hence concern that it may be misidentified as technology by Galí's method.

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

They examine the correlation between a series of identified technology shocks and a series of capital tax, although they find that there seems to be no correlation.

The other nontechnological factors also potentially make the labor productivity nonstationary. However it is difficult to study those individually as in the case of a capital tax rate, since those may be unobservable or measured with difficulty. Therefore we develop a method for identifying all types of nontechnology shocks as a linear combination of those.

Our strategy is to observe the behavior of factor intensity x, which is a determinant of the labor productivity as seen in the equation (1.8). The difficulty is that factor intensity x includes unobservable sector-neutral technology z. Hence we need a proxy. Note that, using the equations (1.7) and (1.9), the steady state level of the *real* investment-output ratio is represented as follows:

$$\frac{i}{y} = \frac{\delta k_*}{z_* h_* x_*^{\alpha}} = \delta x_*^{1-\alpha}. \tag{1.18}$$

Since equation (1.15) means that the determinants of factor intensity x include the depreciation rate δ, this equation shows that the shocks that have permanent effects on real investment-output ratio are exactly same as those on factor intensity. It implies that all of the nontechnological shocks affecting the steady state level of factor intensity, which we call as the *nontechnology permanent shock*, can be identified by incorporating the real investment-output ratio into the system.[3]

Note that the investment-specific technology shock, which is another determinant of the steady state level of factor intensity, can still be identified with Fisher's method. Therefore we can identify the investment specific technology shock, the nontechnology permanent shock, and the sector-neutral technology shock by imposing the following three restrictions:

Restriction 1. The relative price of investment goods p_i 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.

[3]Capital stock-output ratio also moves in a way 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.

Restriction 3. The labor productivity y/h 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.

The four-variable system, in which those restrictions can work, is represented as

$$\begin{bmatrix} \Delta p_{i,t} \\ \Delta i_t - \Delta y_t \\ \Delta y_t - \Delta h_t \\ h_t \end{bmatrix} = C(L) \begin{bmatrix} \varepsilon_t^v \\ \varepsilon_t^p \\ \varepsilon_t^z \\ \varepsilon_t^d \end{bmatrix}, \tag{1.19}$$

where ε^d is the nontechnology temporary shock. Those restrictions imply that $C(1)$ is a lower-triangular matrix.[4]

Our estimation follows Doan (2007). Defining u and ε as the vectors of variables and shocks respectively, we can write the model as

$$\begin{aligned} u_t &= \left(I - \sum \Phi_s L^s\right) c + \sum \Phi_s L^s u_t + B\varepsilon_t \\ \text{where} \quad C(L) &\equiv \left(I - \sum \Phi_s L^s\right)^{-1} B \quad \text{and} \quad BB' = \Sigma. \end{aligned} \tag{1.20}$$

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 $\Phi(1)^{-1} \Sigma \Phi(1)^{-1\prime}$ and ε_t is recovered by B.

1.2.4 Nontechnology Permanent Shock and Nominal Investment-Output Ratio

The four-variable system is worth using if the nontechnology permanent shock works in the business cycles. In this section, we show that examining the time series property of *nominal* investment-output ratio is useful in diagnosing it.

[4] 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. As in almost all research using the long-run restrictions, we simply assume that the conditions are satisfied.

From equations (1.6), (1.15) and (1.18), the steady state level of nominal investment-output ratio is represented as

$$\frac{p_{i,*}i_*}{y_*} = \frac{\alpha\delta}{(1/\beta - 1)\,/\,(1-\tau) + \delta}.$$

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. This property arises from the fact that a fall in investment goods price induced by investment-specific technological improvement stimulates real investment and has no effects on the steady state level of nominal investment-output ratio. Therefore only the nontechnology permanent shock affects the nominal investment-output ratio in the long-run. In other words, the nonstationary behavior of nominal investment-output ratio is the sign of the presence of such shock.

The possibility that the steady state level of nominal investment-output ratio depends on determinants of that of labor productivity has an implication for the extended system proposed by Christiano, Eichenbaum, and Vigfusson (2003) (CEV, hereafter). They recommend that the *level* of nominal investment-output ratio is added to the *last* in Galí's system to reduce omitted-variable bias. However, potentially, their ordering overlooks the effects of nontechnology permanent shocks to labor productivity and their level specification incorrectly specifies a nonstationary variable as a stationary variable. In the case of studying economy with the nontechnology permanent shock, the *growth* of nominal investment-output ratio should be added to the *first* in Galí's system. In our four-variable system proposed above, we decompose the growth rate of nominal investment-output ratio into relative investment price growth and real investment-output ratio growth in order to identify both the investment-specific technology shock and the nontechnology permanent shock, and order the two variables first.

Ideally, the form and order of nominal investment-output ratio in the system should be determined by knowing the time series property of the variable prior to specifying the SVAR system. However, in their discussion on stationarity of hours per capita, CEV argue that standard classical diagnostic tests on nonstationarity do not convincingly discriminate between competing models. This point will be addressed below.

1.3 Nominal Investment-Output Ratio in G-7 Countries

We begin with looking at the nominal investment-output ratio of each G-7 country, plotted in Figure 1.1. Data are from national sources and some OECD database and explained in the appendix in details. For some European countries, only annual data allow us to use enough long period samples.

Among G-7 countries, it is relatively clear that the nominal investment-output ratios of Japan and Germany don't show mean reversion behavior, which is an important sign of nonstationarity. On the other hand, it is not easy to confirm such behavior with certainty for the other countries.

Table 1.1 shows the results of standard classical diagnostic tests for post-World War II data. We use both the Augmented Dickey-Fuller (ADF) test and the KPSS test (Kwiatkowski et al. (1992)). The former tests the null hypothesis of a unit root and the latter tests the null hypothesis of stationarity.[5]

For the data of U.S., Japan, and Germany, we cannot reject the null of unit root even at the 10 percent significance levels and can reject the null of stationarity safely. French data produce similar results, although the null of stationarity can be rejected at 10 percent significance levels. For the data of Canada, U.K. and Italy, the null of stationarity can be rejected safely, but the null of unit root is rejected at 10 percent significance levels for Canada and UK and at 5 percent significance level for Italy.

The plots of data and these statistical tests suggest that there is a room to assume non-stationarity of nominal investment-output ratio in all the countries, although the plausibility of the assumption differs across countries, in some cases, significantly. Furthermore, as CEV emphasize, it is well known that, for a persistent stationary variable, the power of the ADF test is very weak and the KPSS test rejects the null of stationarity too often. Overall it seems difficult to determine the countries for which the nonstationarity of nominal investment-output ratio is assumed only based on these evidences.

Therefore, we will estimate our four-variable system (1.19) for each G-7 country and compare the impulse responses and variance decompositions with those from Galí's two-variable system (1.16) and Fisher's three-variable system (1.17). The plausibility of non-

[5]The number of lags in ADF test is chosen with BIC. The resulting numbers are 1, 10, 1, 1, 1, 1, 2 for U.S., Japan, Canada, U.K., France, Italy, and Germany respectively. The number of lags in KPSS test is set to 4 for quarterly data and 2 for annual data.

stationary nominal investment-output ratio assumption is reconsidered in the case that the systems produce substantially different results.

1.4 Specification

As for the number of lags in the systems, we adopt four for quarterly data estimation and two for annual data estimation, following the standard in the literature.

Specification of hours worked per capita, which are ordered last in the SVAR systems, has been debated a lot in the literature. For example, CEV argue that U.S. hours worked per capita are stationary and should be entered into the system in the form of level. They show that such system encompasses another system into which hours are entered in the form of first difference. On the other hand, Francis and Ramey (2005) favor hours being in the form of first difference. They show that technology shocks identified under the stationary hours specification are predicted by other variables, which should not be related to technology. The correct specification of hours is important, since the former specification produces a positive response of hours to a positive technology shock and the latter produces a negative one in the two-variable system.

Figure 1.2 shows hours worked per capita in G-7 countries. Hours in Japan, U.K., France, and Germany seem to follow declining trends over the entire periods and so do hours in Italy until the mid-1990s. U.S. hours show a U-shaped pattern. Canada have experienced an upward trend in the later part of the sample. Observing these movements of G-7 countries' hours, Galí (2005) indicates some theoretical sources inducing the non-stationary behavior of hours such as a preference shock. Furthermore he emphasizes the results in the preliminary versions of Fernald (2007) and Francis and Ramey (2008), who show that low frequency correlation between the level of hours and the growth of labor productivity distorts impulse responses estimated by Galí's method. Based on these considerations, he estimates systems for G-7 countries assuming hours following unit root process.

Following Galí, we estimate the systems for G-7 countries with the difference specification. In the case of U.S., for which the specification of hours have been discussed intensively in the literature, we will check the sensitivity of results to the alternative specification.

1.5 Estimation Results

1.5.1 U.S.

We begin with comparing impulse responses to a sector-neutral technology shock and an investment-specific technology shock estimated with U.S. data and each of three different systems. The sample period is 1948:1-2007:4.

The first, second, and third rows in Figure 1.3 show the impulse responses of hours worked per capita estimated from Galí's two-variable system, Fisher's three-variable system, and our four-variable system respectively. These summarize one key point of this paper: controlling for the nontechnology permanent shock has no effects on the results for U.S. All the three systems produce significant initial falls of hours in response to sector-neutral technology improvement and almost-zero initial responses to investment-specific technology improvement. The extent of declines in hours to sector-neutral technology improvement are around -0.3 percent across systems.

The message of variance decompositions is similar. Table 1.2 shows the contributions of technology shocks and nontechnology shocks to the variances of the forecast errors of labor productivity, hours, and output at different horizons. Those differ little across systems, regardless of variables and horizons. For example, at four quarter horizon, the portions of variances for which technology shocks account range 85 to 90 percent, 3 to 7 percent, and 11 to 19 percent for labor productivity, hours, and output respectively. The ranges are similar or narrower at other horizons. This finding means that adding nontechnology permanent shocks doesn't change the roles of technology shocks and just reduces the role of nontechnology temporary shocks.

These results are exactly consistent with what have been found in the literature for U.S., referred in the introduction: a near-zero correlation between an identified technology shocks series and a capital tax rate series. As shown in the equations (1.8) and (1.15), the capital tax rate affects the steady state level of labor productivity through that of factor intensity. Therefore it is theoretically a possible candidate of nontechnology permanent shocks. Our results suggest that the technology shocks identified as the sole source of permanent movement of labor productivity in the two-variable and three-variable systems don't seem to be contaminated by nontechnology factors much. The variance decomposition at the long horizon also supports this view. Nontechnology permanent shocks explain only two percent of variance of labor productivity at 50 quarter horizon. Therefore almost all sources affecting labor productivity in the long-run consist of technology shocks.

For a robustness check, we re-estimate impulse responses when hours worked per capita are assumed to be stationary and hence entered into the systems in the form of levels, since, as noted in the previous section, the specification of hours when using Galí's method is not necessarily conclusive in the literature.

Figure 1.4 shows the results. In the two-variable system, hours rise significantly when technology improves. This result is contrary to a significant negative response of hours to a positive technology shock under the difference specification and exactly reproduces CEV's result. However, what we focus on is not the sign of response, but the degree of dependence of response on systems. From such perspective, it is important to note that the impact response of hours to a positive sector-neutral technology shock is also positive when estimated with four-variable system. Furthermore the responses of hours to investment-specific technology improvement are negative when estimated with either three-variable system or four-variable system. Therefore, even when alternative specification of hours is adopted, our conclusion that nontechnology permanent shocks are not important in U.S. doesn't change.

1.5.2 Canada and European Countries

We proceed to the estimation results for Canada and the G-7 European countries. Galí (2005) shows that hours worked per capita fall in response to technology improvement in his two-variate system estimated for these countries. We can check the robustness of the result with our four-variable system. The sample periods are 1981:1-2007:4 for Canada, 1971:2-2007:4 for U.K., 1970-2006 for France, 1970-2005 for Italy, and 1960-2006 for Germany.

Figure 1.5-1.9 show the impulse responses of hours worked per capita to positive technology shocks. The first rows essentially replicate Galí's results. The all responses on impact are negative and, except for France, statistically significant. The responses to positive sector-neutral technology shocks from Fisher's three-variable system, shown in the second rows, basically preserve such features. In responses to positive investment-specific technology shocks, hours fall significantly in U.K. and Canada. As for the other countries, the responses are very weak and not statistically significant.

The third rows show the results from our four-variable system. The results are almost unchanged from those in three-variable system in quantitative aspects as well as in qualitative aspects. Therefore nontechnology permanent shocks seem unimportant in Canada and European countries

1.5.3 Japan

Impulse Response and Variance Decomposition

In Galí's (2005) results, Japan is the only G-7 country of which hours worked per capita rise significantly when technology improves. Although he doesn't consider any background behind this result, it is natural to ask whether Japan is an atypical country in the G-7 countries. Not only to study the importance of nontechnology permanent shocks, but to answer such question, it is worth applying our four-variable system to Japan's data.[6] The sample period is 1955:2-2007:4.

Figure 1.10 shows the results. The first row just reproduces Galí's result. The response of hours to a positive sector-neutral technology shock identified by Galí's two-variable system is positive and becomes statistically significant at the two quarters after the shock period. The second row shows that Fisher's three-variable system still produces the positive impact response of hours to a positive sector-neutral technology shock. On the other hand, hours fall significantly in response to a positive investment-specific technology shock.

The results from our four-variable system are displayed in the third row. It's a key result of this paper: under the four-variable system, the response of hours to a positive sector-neutral technology shock is negative on average. Although the response is not significant, it is very clear that strong positive response disappears. This result suggests that nontechnology permanent shocks are mislabeled as technology shocks in the two-variable and three-variable framework. Once such nontechnology factors are excluded in the four-variable system, a positive sector-neutral technology shock dampens hours as in

[6] Braun and Shioji (2004) also show that technology improvement is expansionary for Japan's hours worked per capita by applying SVAR with a sign restriction to Japan's data. However, it is problematic a lot that they use hours worked per capita as the ratio of hours worked data from establishment survey data to population. Such series follows an upward trend in the 1950s and 1960s since the sectoral shift from the self-employed and family workers to employed workers occurred in Japan during that period. Therefore it doesn't measure hours worked per capita correctly. Watanabe (2006) shows that using the incorrect measure significantly affects an impulse response estimated with Galí's method.

the results for the other G-7 countries.

The response of hours to technology improvement is important since the selection of model representing Japan's economy depends on it. Basu, Fernald, and Kimball's (2006) intensive argument shows that the negative response is in favor of the sticky price model and the positive one is in favor of the real business cycle model. From such perspective, our result suggests that Japan's economy corresponds to the sticky price model.

Basu, Fernald and Kimball emphasize that the response of nonresidential private investment to a positive technology shock is also interpreted in the way same as that of hours. Our four-variable system including real investment-output ratio naturally produces the response of investment. The fourth row in Figure 1.10 shows it. A positive sector-neutral technology shock dampens investment at the shock period and the subsequent period on average. This result is also in favor of interpreting Japan's economy in the framework of the sticky price model.

The result of variance decomposition is shown in Table 1.3. The nontechnology permanent shock accounts for 57 percent of forecast error variance of labor productivity at 50 quarter horizon. It means that the two- and three-variable systems, which identify technology shocks with the long-run restriction that the technology shock is the sole source of permanent movement of labor productivity, misidentify a lot of nontechnology shocks as technology shocks. Corresponding to the result for labor productivity, 69 percent of the forecast error variance of output at 50 quarter horizon is explained by the nontechnology permanent shock.

At horizons up to 20 quarters, the portion of the variances of output for which technology shocks account falls dramatically from 97-100 percent under the two- and three-variable systems to 28-55 percent under the four-variable system. The 22-38 percent of forecast error variance of hours worked per capita is explained by nontechnology permanent shocks at horizons from 2 to 20 quarters. These results show that the role of nontechnology permanent shocks is substantial in Japan's business cycle.

Historical Decomposition

We turn to decomposing historical movement of output into the components explained by technology shocks and nontechnology shocks respectively. Such historical decomposition is very effective in evaluating relative importance of each shock in historical episodes.

The procedure of decomposition follows CEV. We simulate estimated systems with each series of identified shocks in order to get each shock component. The resulting series are compared with series obtained by simulating estimated systems with all series of identified shocks. Drift components are excluded by suppressing constant terms in the equations.

The results are shown in Figure 1.11. The three-variable system attributes almost all the movements of output to technology shocks. On the other hand, under the four-variable system, the component explained by nontechnology permanent shocks gains much more importance. Specifically, the fluctuation of output until the 1970s is largely accounted for by nontechnology shocks and the surge in output around 1990, so called "bubble," and the persistent stagnation in the 1900s, so called, "Japan's lost decade," are due to nontechnology permanent shocks as well as technology shocks. These results suggest that studying historical economic fluctuations based on SVAR without nontechnology permanent shocks may be misleading a lot.

It is noteworthy that the role of nontechnology permanent shocks seems as important as that of technology shocks in explaining Japan's lost decade. Hayashi and Prescott (2002) replicate a large fall in output mainly by feeding the standard Solow residuals as technology into their growth model and argue that the main cause is technological regress. However our SVAR method clearly casts doubt on their argument. Table 1.4 displays the contribution of each shock to a decline in output in the 1991:1-2002:1 period, implied in the above historical decomposition. Under the three-variable system, almost all of 38 percent decline is explained by technology shocks. However, under the four-variable system, the contribution of technology shocks falls to 10 percent point. On the other hand, the contribution of nontechnology shocks goes up to 28 percent point. The contribution of nontechnology shocks is larger than that of technology shocks. Almost all the effect of nontechnology shocks is due to permanent one and 20 percent point in 28 percent point contribution of nontechnology shocks realizes through a decline in labor productivity. These calcuations make clear the importance of nontechnology permanent shocks.

Where does Hayashi and Prescott's result come? The plausible explanation is made by Kawamoto (2005). Based on Basu, Fernald, and Kimball's (2006) work, he calculates Solow residuals for Japan controlling for nontechnology factors such as utilization variation and shows that his measure of technology doesn't decelerate in Japan's 1990s. It is highly probable that Hayashi and Prescott use incorrect measure of technology.

Re-examining Nominal Investment-Output Ratio of Japan

Only Japan's data indicate that nontechnology permanent shocks work a lot in the business cycle. This result is consistent with the results of the ADF test and the KPSS test, which suggest that Japan's nominal investment-output ratio follows a unit root process. However it is worth re-examining time series property of Japan's nominal investment-output ratio, because of weakness of the standard diagnostic tests as already discussed.

One easy but effective way to check the robustness is to extend the sample period of nominal investment-output ratio data. Perron (1991) shows that the power of tests for a unit root is influenced by the span of the data. Figure 1.12 plots the Japan's nominal investment-output ratio from 1887. First of all, we can confirm that the series doesn't show the mean reversion behavior. Second, I performed the the ADF test and the KPSS test for the series. The null of unit root cannot be rejected at the 10% significance level and the null of stationarity is rejected at the 1% significance level.[7] These findings based on the long sample strongly suggest that Japan's nominal investment-output ratio is nonstationary and therefore the presence of nontechnology permanent shocks in Japan's economy.

1.6 What Is the Nontechnology Permanent Shock?

1.6.1 Effects of Nontechnology Permanent Shock

The nontechnology permanent shock is a linear combination of the nontechnology shocks that have permanent effects on labor productivity. The main purpose of this paper is to develop a method to identify the nontechnology permanent shocks and know how such shocks are important in the business cycles. Hence studying what shocks constitute the nontechnology permanent shock is basically beyond of the scope of this paper. This section, however, tries to give some insight into this issue. We examine Japan's data, since the nontechnology permanent shocks seem much more important in Japan's business cycle than in the other G-7 countries' business cycles.

In studying the nontechnology permanent shock, it is worth knowing the properties of nontechnology permanent shock with impulse responses. Figure 1.13 shows the responses

[7] The ADF test statistic is -1.28. The number of lags is four, chosen with BIC up to the maximum number of lags, four. The critical value at 10% significance level is -2.580. The KPSS test statistic is 3.528. The number of lags is set to two. The critical value at 1% significance level is 0.739.

of hours, investment, output, and labor productivity to a positive nontechnology permanent shock. The shock is significantly expansionary for all the variables. It suggests that nontechnology permanent shock is a driving force of Japan's business cycle.

1.6.2 Capital Tax Rate Shock

As already exlained, the shocks to captal tax rate have been studied as a representative candidate of nontechnology shocks affecting the steady state level of U.S. labor productivity. All of the studies conclude that such shocks are not misidentified as technology shocks with Galí's method. If shocks to capital tax rate are important as a determinant of labor productivity, our four-variable system identifies such shocks as nontechnology permanent shocks. We study the relationship between capital tax rate and nontechnology permanent shocks in Japan.

Figure 1.14 plots a series of Japan's capital tax rate. The calculation of the series follows Carey and Rabesona (2002). They improve Mendoza, Razin, and Tesar's (1994) tax ratio approach, which relates realized tax revenues directly to the relevant macroeconomic variables.

The series shows low frequency behavior and may be interpreted as a nonstationary series. However, we immediately note that it follows declining trend in the 1990s. It means that the movement of capital tax rate stimulated incentive to invest and hence worked in the way that it raised labor productivity during that period. Apparently it is not consistent with our finding that nontechnology permanent shocks are the important source of Japan's stagnation in the 1990s.

The exogeneity test makes clear the relationship between capital tax rate series and nontechnology permanent shocks statistically. The test is based on a regression of the capital tax rate series on a constant, two lags of the capital tax rate series, and the current and two lagged nontechnology permanent shocks identified with our four-variable system. The null is that all of the coefficients on nontechnology permanent shocks are jointly equal to zero. The resulting p-value was 0.35. Therefore we cannot reject the null and conclude that shocks to capital tax rate are not the main component of nontechnology permanent shocks in Japan, as in U.S.

1.6.3 Implications from Timing of Shocks during Japan's Lost Decade

Another approach to study what nontechnology permanent shocks represent is to correspond the timing of identified shocks to historical episodes.[8] Specifically we investigate shocks in Japan's 1990s, because Japan experienced various historically large economic shocks in that period and therefore it may be easy to imagine the source of identified shocks.

Figure 1.15 plots the series of identified shocks in the 1991:1-2002:1 period. Grid lines indicate the timings when negative shocks exceeding -1 percent occur and the shaded areas indicate the periods when negative shocks occur for at least four consecutive quarters. First, we can easily know that nontechnology permanent shocks play an important role relative to other shocks, as we've confirmed with historical decompositions before. Second, large negative nontechnology permanent shocks occur consecutively in 1991:2-1993:4, 1997:2-1998:4, and 2001:1-2001:4.

It is important to note that large revision of optimistic expectation occurred during these periods. As shown in the Figure 1.16, the period of 1991:2-1993:4 is the part of the collapse phase of the extremely bull stock market. Japan's stock price fell by 49.5 % from the end of 1989 to that of 1993. In the period of 1997:2-1998:4, Asian currency crisis occurred.[9] With the crisis, the expectation for Asian countries' high growth was upset. In the period of 2001:1-2002:4, as still fresh in our memory, the collapse of expectation of high growth driven by Information Technology occurred. The latter two episodes are also linked to significant falls in stock prices.

These consideration suggests that a kind of news shock may induce nontechnology permanent shocks. In our framework, an anticipation of technology movement that eventually materialized is identified as technology shocks.[10] On the other hand, news to force people to revise their anticipation and therefore change the future path of labor productivity may be identified as nontechnology permanent shocks, because such permanent change of the steady state level of labor productivity is led without technology shocks.

This interpretation is supported by the following three facts. First, revision to antici-

[8] Francis and Ramey (2006) study the pattern of shocks identified with Galí's method during prominent historical episodes in U.S.

[9] The crisis began with the depreciation of the Thai Baht in May 1997.

[10] Beaudry and Portier (2006) show that there is high correlation between innovations in stock prices, which are orthogonal to innovations in TFP, and innovations that drive long-run movement in TFP. It suggests that most of technology movement is anticipated.

pated technology may replicate impulse responses of macroeconomic variables to a nontechnology permanent shock shown in Figure 1.13. For example, Christiano, Illut, Motto, and Rostagno (2007) show that, in a version of monetary model, output, hours, and investment jointly fall when an anticipated positive technology shock doesn't realize. Second, Figure 1.11 shows that a dramatic surge in Japan's output in the second half of the 1980s is led by nontechnology permanent shocks. In this period, people had corrected the expectation of depressive effect of massive appreciation of the Yen after the Plaza Accord in 1985. Then so called the bubble economy surged around 1990, as shown in the stock price movement plotted in Figure 1.16.[11] Third, we've found that nontechnology permanent shocks work in Japan much more than in other G-7 countries. This may be because only Japan experienced the surge and collapse of the bubble economy in the post-World War II period.

1.7 Conclusion

Galí (1999) develops a sophisticated method to identify technology shocks with the long-run restriction SVAR. This paper has proposed modifying his method so as to deal with nontechnology permanent shocks, which affect labor productivity in the long-run together with technology shocks. Including real investment-output ratio in the SVAR system is a key to identify nontechnology permanent shocks. In addition, we've shown that studying nominal investment-output ratio is effective in diagnosing nontechnology permanent shocks. Applying our new SVAR system to G-7 countries' data shows that the role of nontechnology permanent shocks is important in Japan. Especially, our new system changes the response of hours worked to technology improvement from positive to negative and makes clear that negative nontechnology shocks as well as negative technology shocks induce Japan's stagnation in the 1990s.

The important future research is to study more what is behind the nontechnology permanent shocks. Our consideration points to the importance of a kind of news shock, specifically, revision to expectation of future productivity. It's desirable to identify such shock directly.

[11] Hayashi and Prescott (2002) note on the Japan's bubble period that "we think the unusual pickup in economic activities, particularly investment, was due to an anticipation of higher productivity growth that never materialized."

Data Appendix

U.S.

Business investment: Data are from BEA's homepage.

Business output, hours, and civilian noninstitutional population: Data are from BLS's homepage.

Japan

GDP and investment at the annual basis: 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.

GDP and investment at the quarterly basis: Data are available at the Cabinet Office's homepage, http://www.esri.cao.go.jp/index-e.html.

Hours and population: 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 available at the homepage are obtained from the monthly publications.

Canada

All data are from CANSIM.

U.K.

All data are from ONS's homepage.

France

All data are from OECD national accounts, OECD economic outlook database, and OECD.stat.

Italy

All data are from OECD national accounts and OECD.stat.

Germany

Data for Germany are linked to data for west Germany at 1991.

Population: OECD.stat and the Conference Board and Groningen Growth and Development Centre Total Economy Database.

Investment, hours, and GDP: OECD national accounts, OECD economic outlook database, and OECD.stat.

Table 1.1: Diagnostic Tests for Nominal Investment-Output Ratio

ADF Test
(Null: the variable follows a unit root process)

	Sample period	
U.S.	1947:3-2007:4	-1.892
Japan	1958:1-2007:4	-2.505
Canada	1961:3-2007:4	-2.614*
U.K.	1965:3-2007:4	-2.625*
France	1960-2007	-2.478
Italy	1955-2005	-3.125**
Germany	1960-2007	-0.922

Note: * indicates that null of unit root can be rejected at 10% significance level. Similarly ** at 5% and *** at 1%.

KPSS Test
(Null: the variable follows a stationary process)

	Sample period	
U.S.	1947:1-2007:4	2.617+++
Japan	1955:2-2007:4	0.967+++
Canada	1961:1-2007:4	0.470++
U.K.	1965:1-2007:4	0.853+++
France	1956-2007	0.353+
Italy	1951-2005	0.800+++
Germany	1956-2007	1.490+++

Note: + indicates that null of stationarity can be rejected at 10% significance level. Similarly ++ at 5% and +++ at 1%.

Table 1.2: Forecast Error Decompositions for U.S.

	Two-variable system	Three-variable system			Four-variable system				
		Technology			Technology			Nontechnology	
	N	All	I	N	All	I	N	All	P
					Labor productivity				
1	**78**	**79**	2	76	**86**	1	85	**14**	10
4	**85**	**86**	5	81	**90**	4	86	**10**	5
8	**92**	**92**	8	84	**93**	7	86	**7**	4
12	**94**	**94**	11	84	**95**	10	85	**5**	3
20	**96**	**97**	14	83	**97**	12	84	**3**	2
50	**98**	**99**	17	82	**98**	15	83	**2**	2
					Hours worked per capita				
1	**22**	**22**	0	21	**14**	0	13	**86**	58
4	**7**	**6**	0	6	**3**	0	3	**97**	63
8	**4**	**4**	1	3	**3**	2	1	**97**	55
12	**3**	**4**	2	2	**4**	3	1	**96**	53
20	**3**	**5**	3	1	**4**	4	0	**96**	52
50	**3**	**5**	4	1	**5**	4	0	**95**	51
					Output per capita				
1	**14**	**16**	2	14	**23**	1	22	**77**	23
4	**11**	**13**	1	12	**19**	1	18	**81**	32
8	**14**	**17**	1	16	**24**	0	23	**76**	36
12	**16**	**18**	1	18	**26**	0	26	**74**	36
20	**17**	**19**	0	19	**27**	0	27	**73**	36
50	**18**	**20**	0	19	**29**	0	29	**71**	37

Notes: Percent. I: Investment-specific technology shocks. N: Sector-neutral technology shocks. P: Nontechnology permanent shocks.

Table 1.3: Forecast Error Decompositions for Japan

	Two-variable system	Three-variable system			Four-variable system				
		Technology			Technology			Nontechnology	
	N	All	I	N	All	I	N	All	P
					Labor productivity				
1	**68**	**64**	1	63	**57**	5	52	**43**	18
4	**90**	**88**	1	87	**48**	5	43	**52**	44
8	**96**	**96**	2	93	**42**	8	34	**58**	55
12	**98**	**98**	4	93	**42**	12	30	**58**	57
20	**99**	**99**	7	92	**42**	16	26	**58**	57
50	**100**	**100**	10	90	**43**	19	24	**57**	57
					Hours worked per capita				
1	**1**	**16**	14	2	**11**	9	2	**89**	7
4	**8**	**26**	17	9	**13**	11	1	**87**	22
8	**16**	**32**	16	16	**11**	10	1	**89**	30
12	**20**	**35**	14	21	**9**	8	1	**91**	34
20	**25**	**38**	10	27	**6**	6	0	**94**	38
50	**30**	**40**	7	33	**4**	3	0	**96**	44
					Output per capita				
1	**100**	**100**	2	98	**55**	0	55	**45**	45
4	**97**	**98**	1	97	**33**	0	32	**67**	65
8	**97**	**98**	1	97	**28**	3	25	**72**	69
12	**97**	**97**	1	96	**29**	6	23	**71**	69
20	**97**	**97**	3	94	**30**	9	21	**70**	68
50	**97**	**97**	5	92	**31**	12	19	**69**	66

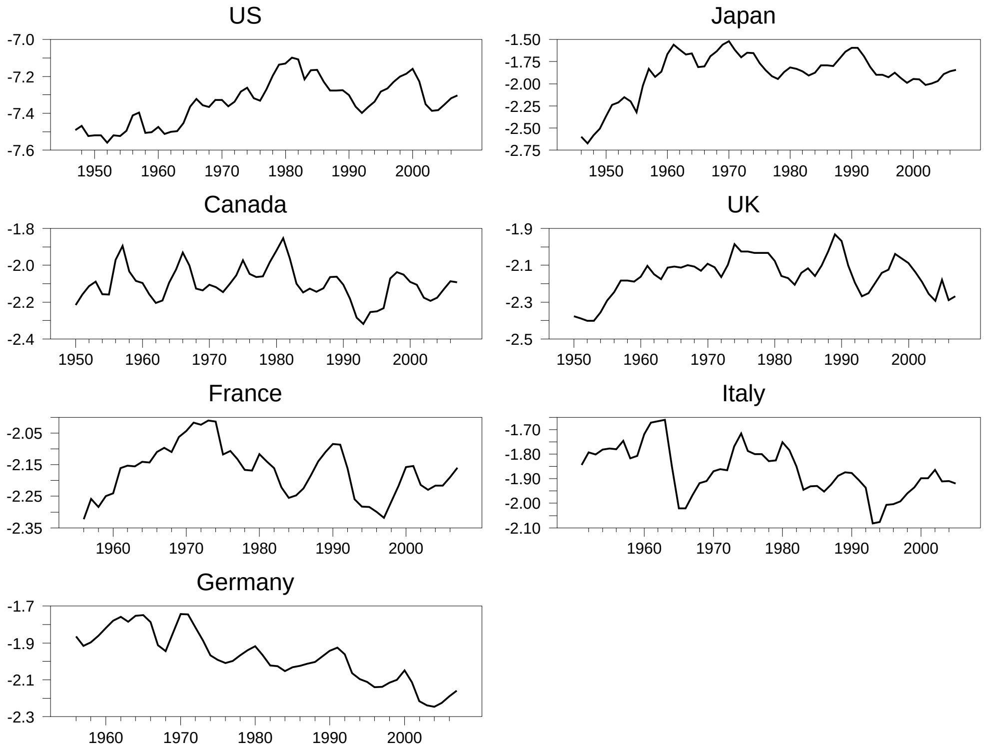
Notes: I: Investment-specific technology shocks. N: Sector-neutral technology shocks. P: Nontechnology permanent shocks.

Table 1.4: Contribution of Shocks to a Decline in Detrended Japan's Output in 1991Q1-2002Q1

Total	Contribution of									
	Technology					Nontechnology				
	All	Labor productivity	Hours	I	N	All	Labor productivity	Hours	P	T
					Three-variable system					
-38	**-37**	-33	-4	-3	-34	**-2**	2	-3		-2
					Four-variable system					
-38	**-10**	-10	0	-4	-6	**-28**	-20	-8	-27	-1

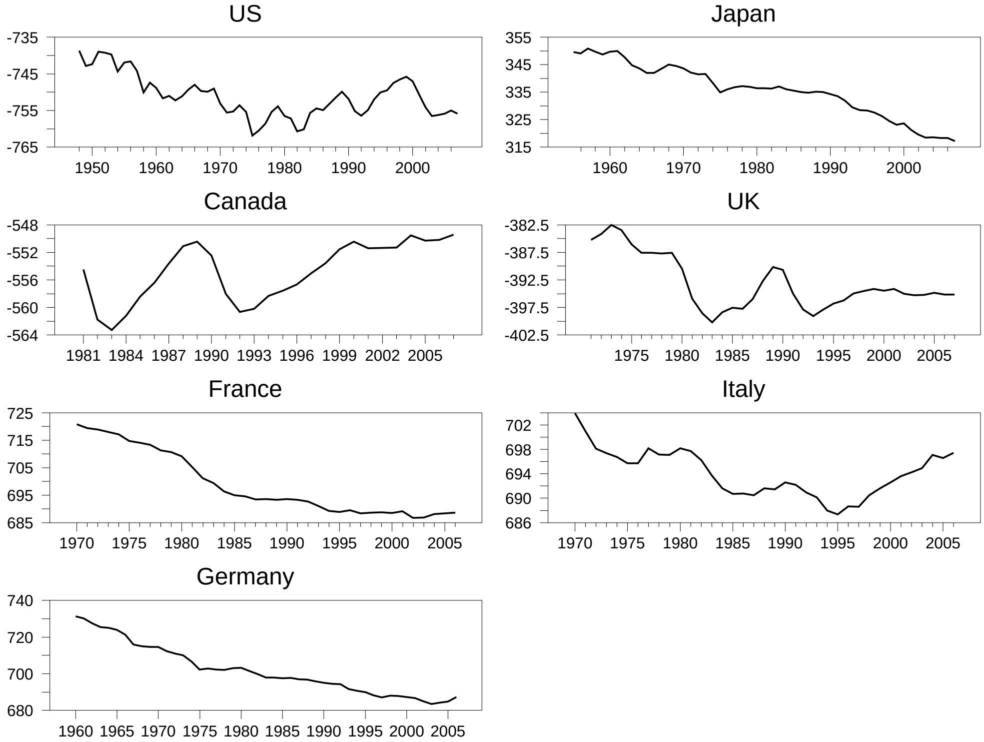
Note: Percent for total decline and percent points for contributions. I: Investment-specific technology shocks. N: Sector-neutral technology shocks. P: Nontechnology permanent shocks. T: Nontechnology temporary shocks.

Figure 1.1: Nominal Investment-Output Ratio



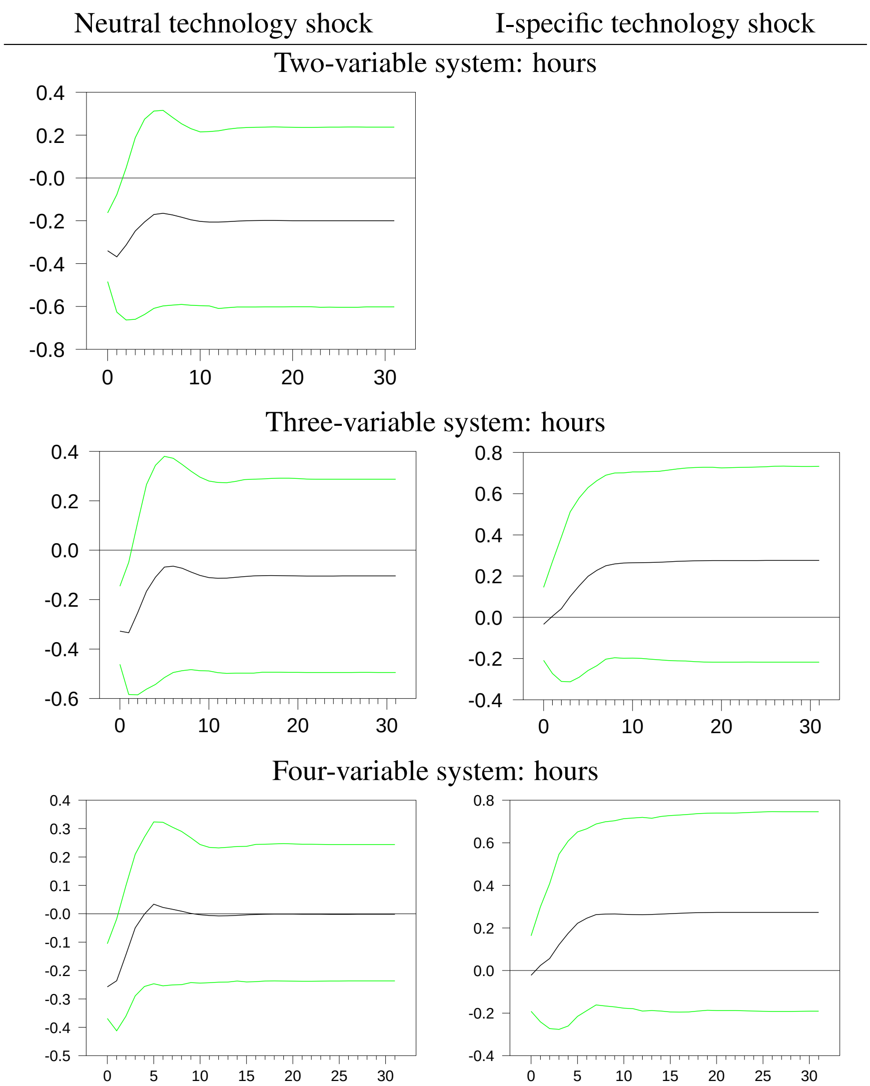
Note: The vertical axis shows log-levels.

Figure 1.2: Hours Worked Per Capita



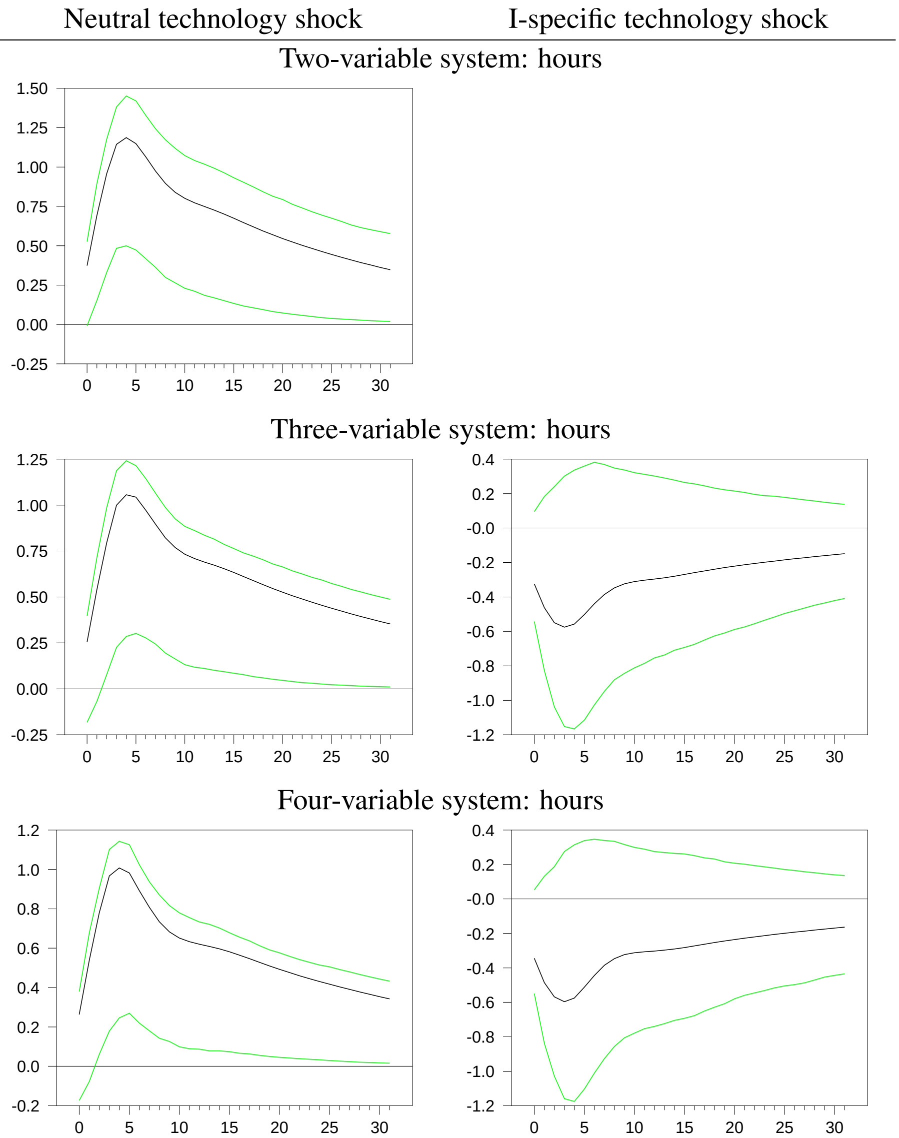
Note: The vertical axis shows log-levels.

Figure 1.3: Impulse Responses: U.S.



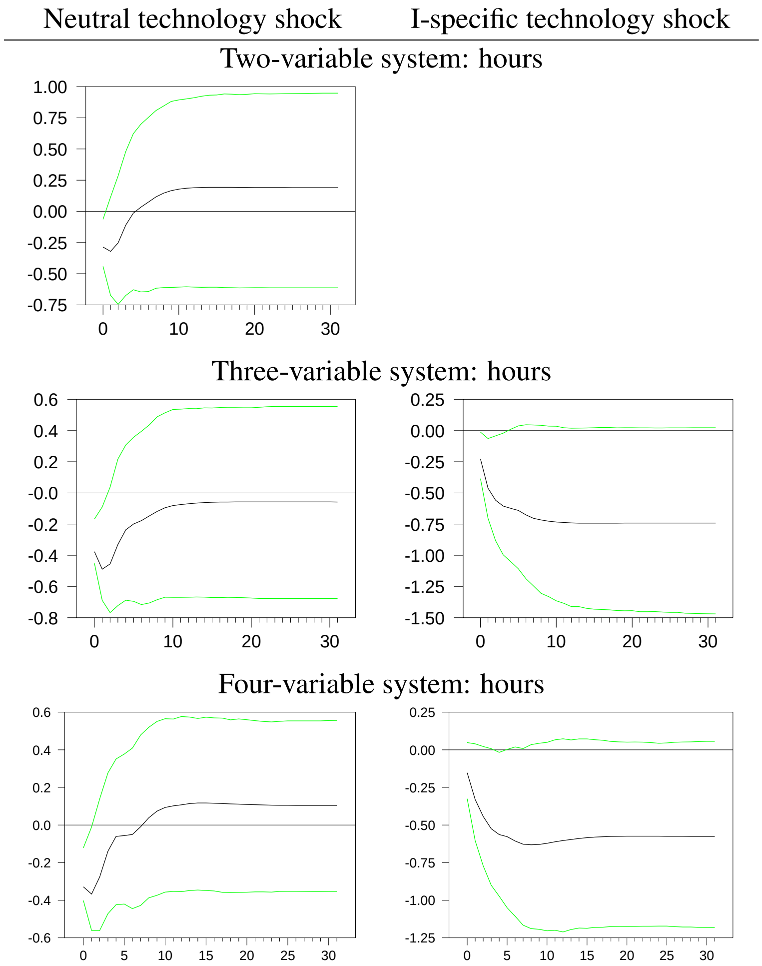
Notes: Vertical axes indicate log-levels multiplied by 100. Dashed lines indicate 90% confidence intervals.

Figure 1.4: Impulse Responses:U.S., Level Hours Specification



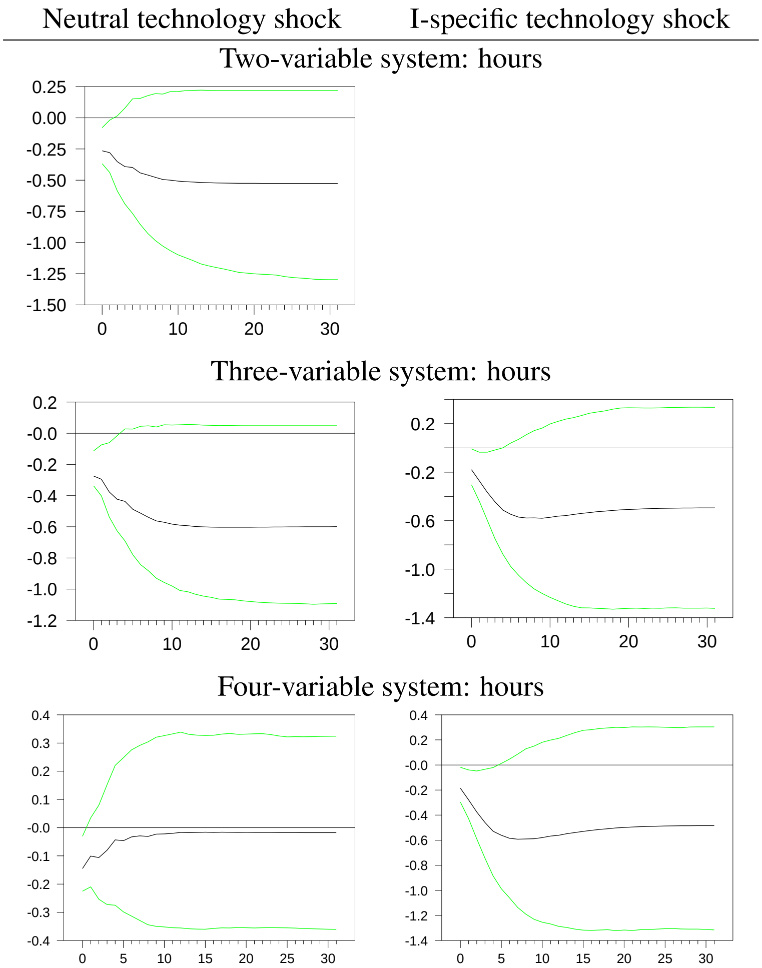
Notes: Vertical axes indicate log-levels multiplied by 100. Dashed lines indicate 90% confidence intervals.

Figure 1.5: Impulse Responses: Canada



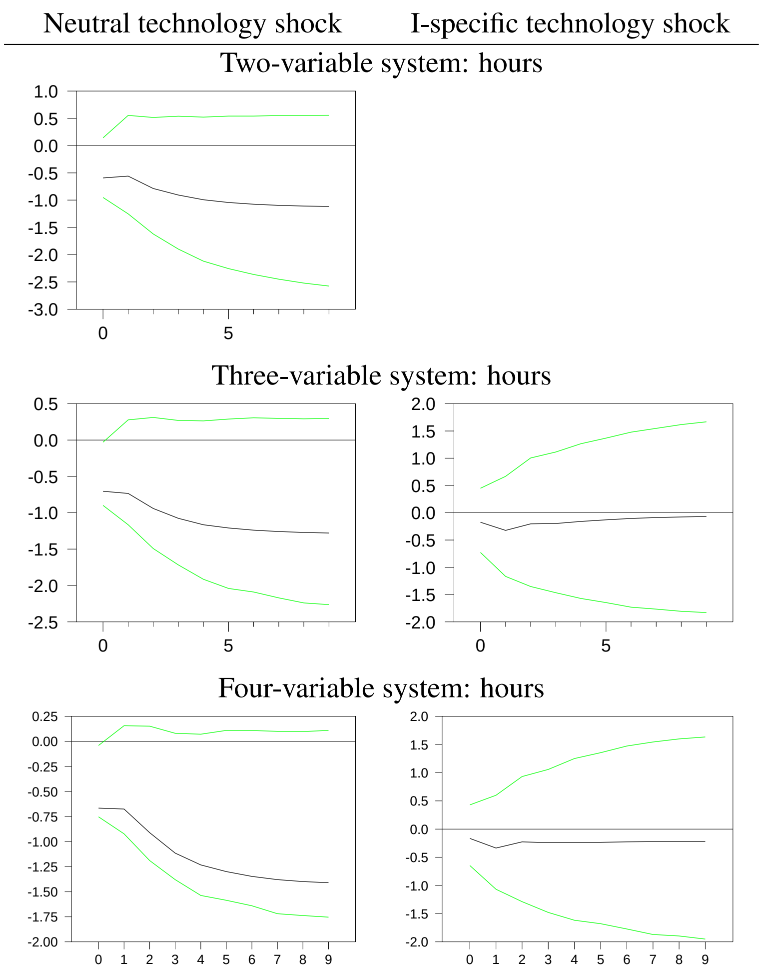
Notes: Vertical axes indicate log-levels multiplied by 100. Dashed lines indicate 90% confidence intervals.

Figure 1.6: Impulse Responses: U.K.



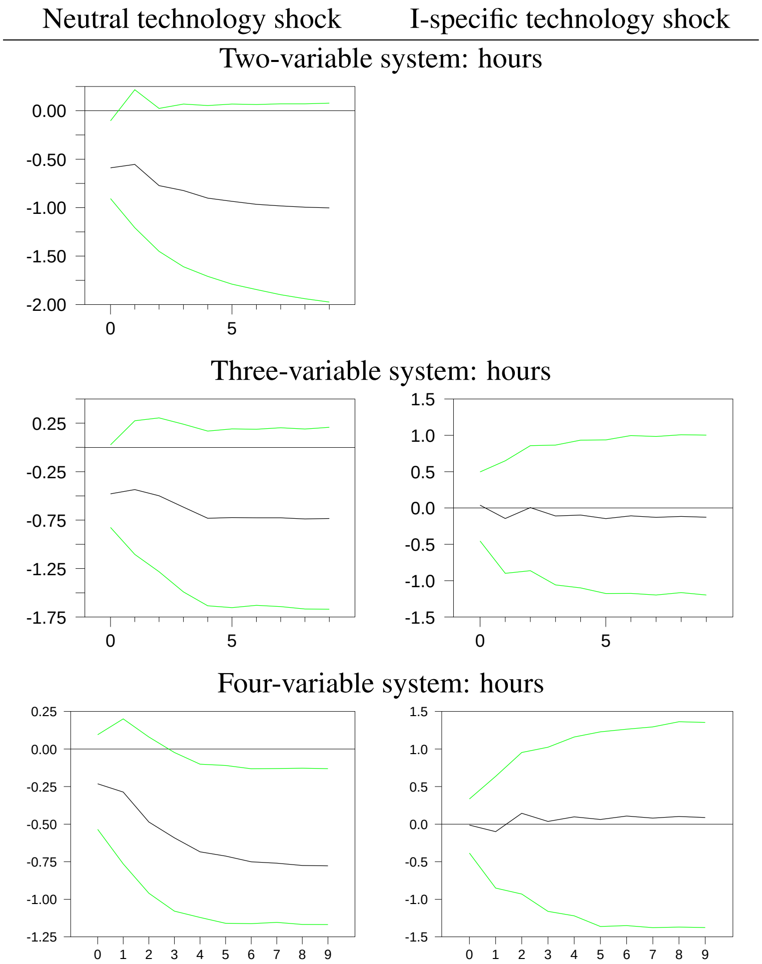
Notes: Vertical axes indicate log-levels multiplied by 100. Dashed lines indicate 90% confidence intervals.

Figure 1.7: Impulse Responses: France



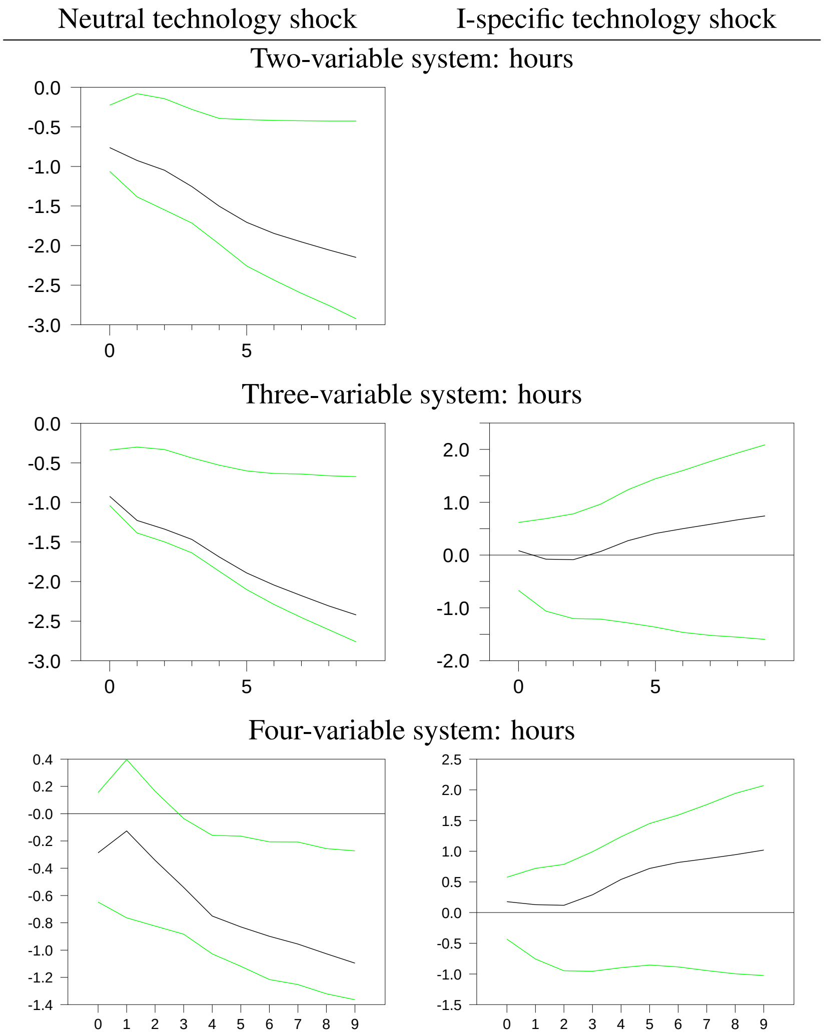
Notes: Vertical axes indicate log-levels multiplied by 100. Dashed lines indicate 90% confidence intervals.

Figure 1.8: Impulse Responses: Italy



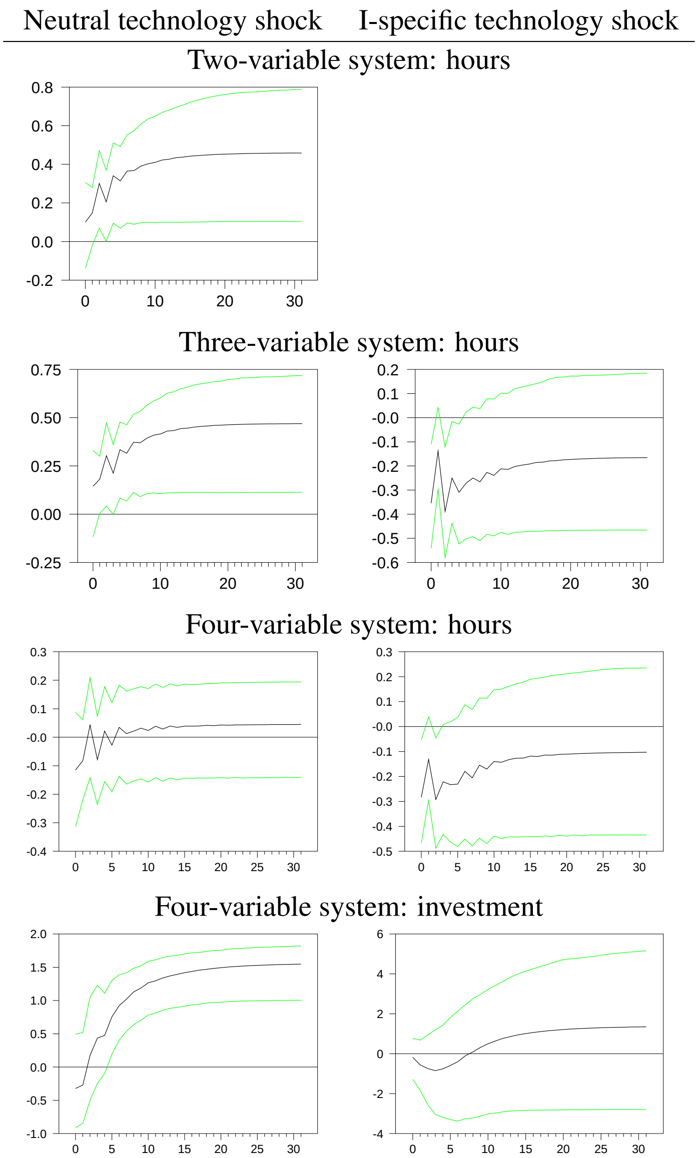
Notes: Vertical axes indicate log-levels multiplied by 100. Dashed lines indicate 90% confidence intervals.

Figure 1.9: Impulse Responses: Germany



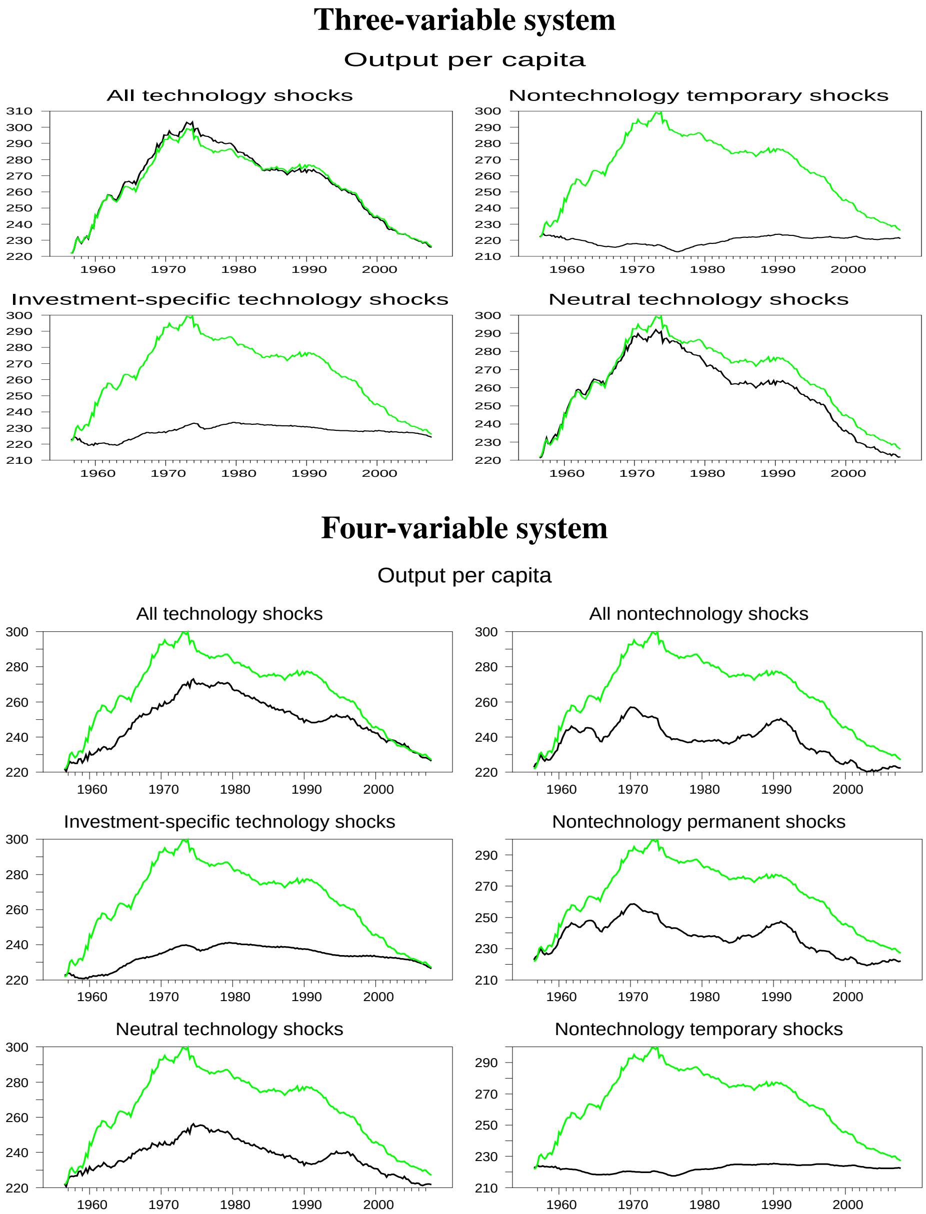
Notes: Vertical axes indicate log-levels multiplied by 100. Dashed lines indicate 90% confidence intervals.

Figure 1.10: Impulse Responses: Japan



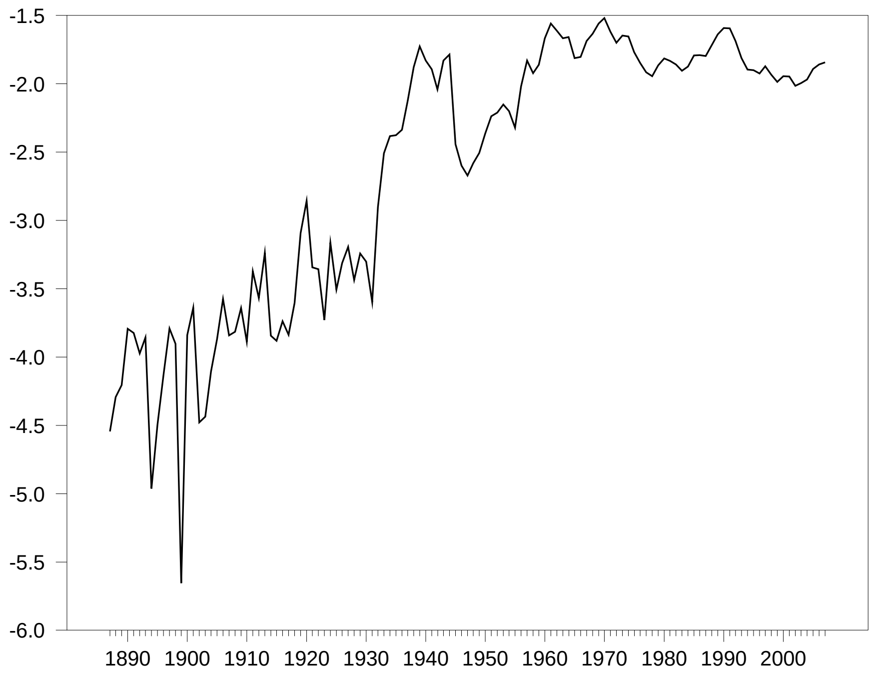
Notes: Vertical axes indicate log-levels multiplied by 100. Dashed lines indicate 90% confidence intervals.

Figure 1.11: Historical Decomposition for Japan



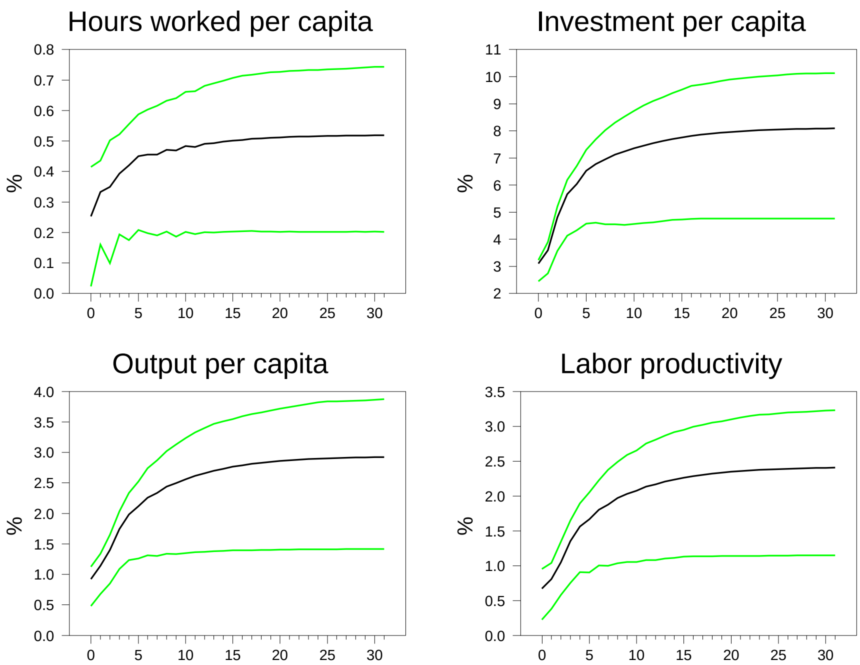
Notes: Dashed lines: decomposition using all shocks. Solid lines: decomposition using each type of shocks.

Figure 1.12: Nominal Investment-Output Ratio of Japan: 1887-2007



Note: Vertical axis indicates log-level.

Figure 1.13: Impulse Responses to a Nontechnology Permanent Shock: Japan



Notes: Vertical axes indicate log-levels multiplied by 100. Dashed lines indicate 90% confidence intervals.

Figure 1.14: Capital Tax Rate: Japan

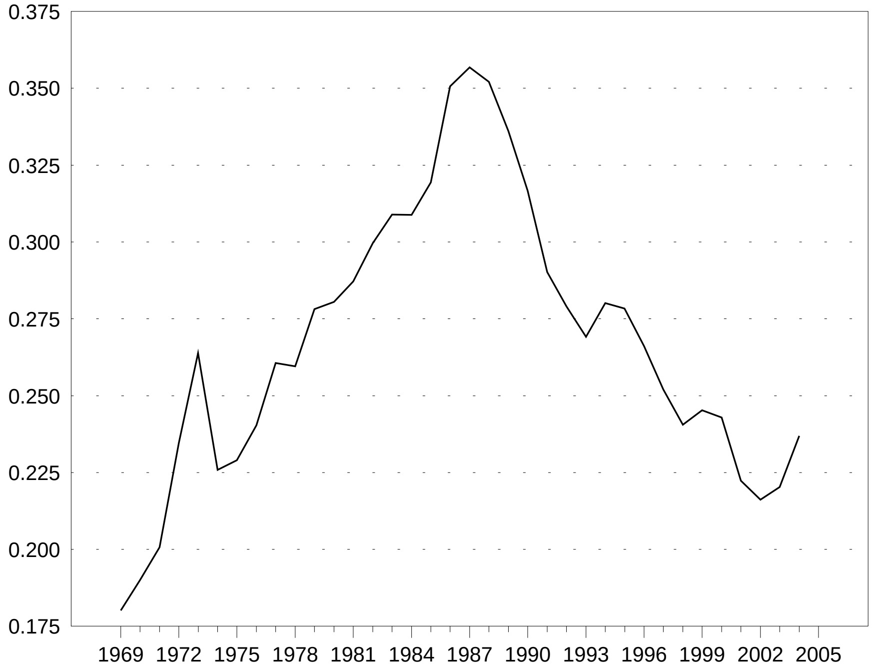
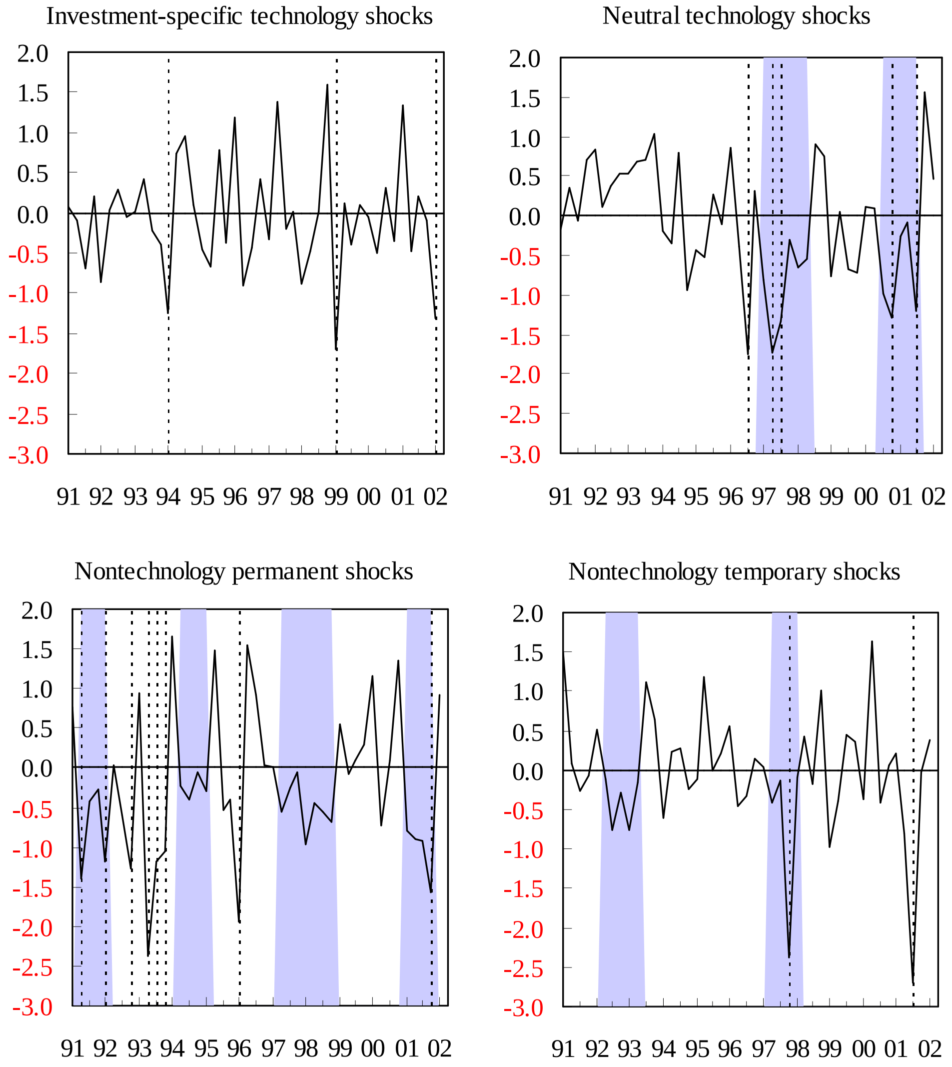


Figure 1.15: Shocks on Japan in 1991Q1-2002Q1



Note: Grid lines indicate the timings when negative shocks exceeding -1% occur and the shaded areas indicate the periods when negative shocks occur for at least four consecutive quarters.

Figure 1.16: Stock Price of Japan

Note: Nikkei 225. The unit is the Yen.

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Chapter 2

U.S. Technology Growth, 1891-2006

2.1 Introduction

The roles of technological change in the post-World War II U.S. business cycle have been argued extensively with a lot of empirical findings. On the other hand, the research on technological change going back to pre-W.W.II U.S. is relatively limited. We construct a series of Solow residuals for the private nonfarm economy beginning in 1891, which is purified from the effects of varying utilization of capital and labor, nonconstant scales, and imperfect competition, following Basu, Fernald and Kimball (2006, henceforth BFK). Their approach adopts first order conditions from cost minimization problem, which are free from the effects of nonconstant scales and imperfect competition, and relates unobserved utilization to observed inputs. Their assumption that the firm solves the cost minimization problem and is the price taker in the factor market is weak one because competitiveness in product market is not assumed at all.

By the *purified* Solow residuals, we address the following three issues regarding pre-W.W.II technological change in the literature. First, are the effects of technology shocks for macroeconomic variables in pre-W.W.II period different from those in post-W.W.II period? Second, what extent does technological regress explain a significant fall in output in the Great Depression period? Third, when was technological progress most rapid in the 20th century?

The first question is addressed by Francis and Ramey (2006). A lot of studies including BFK have empirically examined whether hours or investment falls in response to technological improvement in order to evaluate the plausibility of the standard real business cycle model, which cannot replicate such response. Francis and Ramey use truly long-run data for the total private economy extending back to 1889 and identify technology shocks by structural vector autoregression (SVAR). The identifying restriction follows Galí (1999), who assumes that the only source of permanent movement of labor productivity is the technology shock. Since Galí's method cannot produce reliable estimates when data have low-frequency movement, they construct a series of hour worked per capita that is free from the effects changes in the government employment, the school enrollment, and the population aged 0-4 and 65-. They find a structural break in the coefficients of their estimated model between 1948 and 1949 and hence estimate the model with pre- and post-W.W.II samples separately as well as the full sample. Their finding is that the hours worked per capita fall in response to a positive technology shock in the 1949-2002 period under all the specifications of the hours worked being stationary, being stationary around the quadratic trend, and following the unit root process. In the 1892-1940 period and the 1892-2002 period, however, the hours worked per capita fall under the former two specifications and rise significantly under the third specification.

The second question is addressed by Cole and Ohanian (2007) and Bernanke and Parkinson (1991). Cole and Ohanian feed in a series of traditional Solow residuals as their technology measure into the standard neoclassical model and compare the simulation results with data in the Great Depression period. The comparison shows that technological regress accounts for 61 percent of observed decline in detrended output from 1929 to 1933. On the other hand Bernanke and Parkinson *ab initio* exclude the possibility of technological regress being a cause of the Great Depression and think that a large decline in labor productivity in that period is due to increasing returns to scale or labor hoarding. They regress ten manufacturing industries' output on labor input with the interwar samples. The estimated coefficients of labor input are affected by adding cyclical indicators, e.g. real government spending, to estimated equations for some industries. Therefore they conclude that both of these factors may explain the observed decline in labor productivity.

The third question is addressed by Field (2003). He asserts that U.S. economy experienced the highest rate of technological progress in 1929-1941 in the 20th century, based on a series of total factor productivity by Kendrick (1961) and a lot of narrative evidences. For example, Kendrick's TFP rises by 48.8 percent from 1933 to 1941 after falls by 11.3 percent from 1929 to 1933. Since the 1929-1941 years include the Great Depression period, which led to a 27 percent fall in real GDP from 1929 to 1933, his assertion has attracted much attention with surprise.

All the papers' approach have weakness. First, Galí's long-run restriction used by Francis and Ramey has been intensively argued to accompany methodological problems.[1] The literature shows, for example, that the low-frequency movement unrelated to business cycles in labor productivity and hours worked potentially distort estimated impulse responses. Francis and Ramey carefully remove the low-frequency movement from the series of hours worked per capita. However, Fernald (2007) shows with the post-W.W.II data that changes in the trend productivity growth also distort impulse responses. Another methodological weakness is that nontechnological factors affecting labor productivity in the long-run are misidentified as technology. Especially, the movement in capital rax rate has been suspected as such factor by many researches.[2]

Second, Solow residuals series used by Field and Cole and Ohanian may be biased by variable utilization of input, imperfect competition, and nonconstant scales. Field carefully chooses the endpoint 1941. He argues that unemployment rate in 1941 is closer to the level in 1929 and therefore comparing productivity level in 1941 with in 1929 enables us to do a peacetime peak-to-peak comparison. However, unemployment rate is only one of utilization measures and he ignores capital utilization and working hours. Hence we are uncertain as to whether his comparison really removes the effect of utilization on Solow residuals. On the other hand, Cole and Ohanian (2007) argue that the role of utilization in a large fall in Solow residuals between 1929 and 1933 is small, following Ohanian's (2001) discussion. He asserts that the 15-20 percent of the aggregate capital stock became idled between 1929 and 1933 and such fall in capital utilization does not explain much of the decrease in aggregate Solow residuals because of capital's relatively small share. His assessment is also problematic. First, his number is based on Breshanan and Raff's report (1991) that the number of active manufacturing establishments fell one-third between 1929 and 1933. He makes a judgmental adjustment for this number, taking into account, for example, relatively large contraction in the manufacturing sector in the Great Depression period. But, apparently his adjustment lacks foundation. Furthermore, he doesn't adjust

[1]For example, see Christiano, Eichenbaum, and Vigfusson (2003), Chari, Kehoe, and McGrattan (2004), Erceg, Guerrieri, and Gust (2005), and Fernald (2007).

[2]See, for example, Galí and Rabanal (2004) and Francis and Ramey (2005).

the effects of labor utilization and labor efforts for Solow residuals. Therefore it is highly probable that the movement of Solow residuals in the Great Depression period is affected by varying utilization.

Third, Bernanke and Parkinson don't examine any measures of technology and hence their excluding the possibility of technological regresses in the Great Depression period is not based on any evidences. Also their results don't give any quantitative implications for the roles of increasing returns to scale and labor hoarding.

We examine their assertions with the purified Solow residuals. The purified Solow residuals are unrelated to the problems specific to Galí's long-run restriction. Also, as mentioned above, our technology series is free from the effects of any utilization variation and therefore more suitable for evaluating the technology growth. In addition, as explained in the next section, the degree of returns to scale is also estimated in the process of measuring technology and therefore we can check the importance of increasing returns to scale in the Great Depression period.

Our main results are the followings. First, estimated with the full sample and the pre-W.W.II sample, the responses of total hours worked of private nonfarm economy to a positive technology shock are around zero on impact and become positive an year later. Estimated with the post-W.W.II sample, the response is significantly negative on impact and remains negative on average in all the years that follow. In sum, although the responses after the shock period differ across sample periods, we can conclude that the initial response is weak or negative. Similarly, nonresidential fixed investment falls significantly on impact in response to a positive technology shock in the postwar period, while rises but insignificantly in the period including pre-W.W.II years. The result of insignificant response of inputs is robust to limiting the sample to the pre-Great Depression period, using per capita measure as hours series, and focusing on the manufacturing sector. Therefore, we don't support one of Francis and Ramey's findings that hours may rise in response to technology improvement in the pre-W.W.II period.

Second, technology regressed by 4.8 percent from 1929 to 1933 in the Great Depression period, which is less than one-third of 15.5 percent fall in the standard Solow residuals series. Jointly with the returns-to-scale estimate being 0.97, this result shows that a significant fall in labor productivity in the Great Depression period is due mainly to factor utilization and somewhat to technological regress. Increasing returns to scale don't play any role. Furthermore our regression result shows that technological regress explains only 13.5 percent of an observed fall in detrended private nonfarm output from 1929 to 1933. Therefore the role of technological regress in the Great Depression period is much less than thought in the literature.

Third, measured by the purified Solow residuals, U.S. technology growth was highest in the 1929-1941 years. This is consistent with Field's argument,

This paper is structured as follows. Next section briefly explains our estimation strategy. Third section introduces our data. Fourth section shows our estimates. In fifth section, we estimate the effects of purified Solow residuals on macroeconomic variables. In sixth section, we examine how the founding of the Federal Reserve affected macroeconomic responses to a technology shock. Seventh section examines technology behavior in the Great Depression period. Eighth section studies technology growth in a historical perspective. Final section concludes.

2.2 Estimating Strategy

This section explains briefly our estimation strategy. The method follows BFK, dropping some steps because of data availability.

First, we assume that the firm has a production function for value added:

$$Y = F(AK, EHN, Z) \tag{2.1}$$

where A is the capital utilization rate, K is the capital stock, E is the effort of each worker, H is hours worked per worker, N is the number of employees, and Z is the index of technology. We take logs of both sides of the equation and then differentiate with respect to time:

$$dy = \frac{F_1 AK}{Y}(da + dk) + \frac{F_2 EHN}{Y}(de + dh + dn) + dz, \tag{2.2}$$

We define dj as its logarithmic growth rate of any variable J, that is, $\ln(J_t/J_{t-1})$ and normalize the output elasticity with respect to technology equal to one.

As Hall (1990) shows, when the firm takes the price of all J inputs, P_j, as given in competitive markets, the first order conditions for the firm's cost-minimization imply that:

$$\frac{F_1 AK}{Y} = \gamma \frac{P_K K}{PY} \equiv \gamma s_K \text{ and } \frac{F_2 EHN}{Y} = \gamma \frac{P_N N}{PY} \equiv \gamma s_N,$$

where P is the price of firm's output. We assume that the firm makes zero profit and then we can interpret that γ is the degree of returns to scale. s_K and s_N are the ratios of payments to the capital stock and employees in total cost respectively. We can rewrite the equation (2.2) as follows:

$$dy = \gamma (dx + du) + dz,$$

where

$$dx = s_K dk + s_N (dh + dn) \text{ and } du = s_K da + s_N de.$$

dx is observed input growth and du is unobserved growth in utilization.

One of BFK's novel results is that, from the cost minimization conditions of firm, they derive the relationship that changes in hours worked per worker are proportional to unobserved changes in both the capital utilization rate and the effort of each worker.[3] The only assumption is that the firm minimizes cost and is the price taker in factor markets. Therefore they don't assume any firm's pricing behavior in the goods market. We follow BFK's result and therefore assume the following relationships:

$$da = \zeta dh \text{ and } de = \eta dh, \tag{2.3}$$

where $\zeta > 0$ and $\eta > 0$.

Then we have an estimating equation that controls variable utilization:

$$\begin{aligned} dy &= \gamma dx + \gamma (s_K \zeta + s_N \eta) dh + dz \\ &= \gamma dx + \beta dh + dz. \end{aligned} \tag{2.4}$$

Technology changes are identified as the residuals dz.

Note that BFK control for aggregation effect and materials intensity effect as well. The former effect arises from differences in marginal products of inputs across firms. If inputs growth is high in firms with above-average marginal products, aggregate output grows rapidly. The latter effect arises since value added growth partly depends on differences between gross output growth and materials growth under imperfect competition. We don't

[3] This idea is originally proposed by Basu and Kimball (1997).

control for these effects, since we don't have long-run sectoral input-output data.[4] However BFK note that the utilization correction brings most of the reduction in procyclicality in the standard Solow residuals. Therefore we can expect that our purified Solow residuals series is much superior to the standard one in measuring technology.

2.3 Data

We estimate annual technology series for the time period 1891-2006. The variables used for estimation are value added, capital stock, total hours worked, and employees for the private nonfarm sector. Data for the early part of the sample come from Kendrick (1961) and data for the later part of the sample come from the Bureau of Labor Statistics and the Bureau of Economic Analysis. The input aggregate, x, is constructed with factor shares averaged from 1900 to 2006. The hours worked per worker as proxy for utilization, h, are constructed by detrending log hours worked per worker with a Hodrick-Prescott filter.[5] As noted later, the parameters estimated by the full sample are not sensitive to the detrending method. The appendix explains the details of data and their sources.

The equation (2.4) is estimated by instrumental variables because there may be correlation between inputs growth and technology shocks. We use the oil price growth, the real military expenditure growth, and the average for the preceding year of quarterly VAR monetary shocks. The monetary shocks are measured as shocks to the three month interest rate, the ratio of M2 to monetary base, and the monetary base from VAR with GDP, the GDP deflator, and the three monetary variables. The sample period is 1885:1-2007:3 and the number of lags is four. The use of the ratio of M2 to monetary base, so called the money multiplier, is motivated by Bernanke and Parkinson (1991), who estimate the relationship between industrial production and labor input in U.S. interwar period using the currency/deposit ratio as one of instruments. The series of quarterly GDP and GDP de-

[4]In comment on Francis and Ramey's (2006) study referred in the introduction, Basu (2006) mentions this point.

[5]BFK use frequency components between two and eight years of hours per worker, which are isolated by Christiano and Fitzgerald's (2003) band pass filter. However, the level of hours worked per worker detrended by the band pass filter in 1933, when private nonfarm output recorded the bottom in that period, is *higher* than that in 1929. The utilization in 1933 is hardly believed to have been higher than that in 1929 and therefore I don't use the band pass filter. The result appears to come from the inability of the frequency components to capture the variable's persistent movement.

flator in 1884:1-1946:1 are estimated by interpolating annual GDP and GDP deflator with the industrial production index and the wholesale price index respectively.[6] Gordon and Veitch (1986) recommend to use the information available in pre-W.W.II annual GNP data rather than use other raw quarterly data in analyzing the interwar economy.

For identification, we assume that monetary shocks don't have an effect on output within a quarter, following Galí (1992). Because of a possibility that it is better to treat the founding of the Federal Reserve in 1914 as a structural break in the system, we estimate monetary policy shocks series for the time periods 1885:1-1914:4 and 1915:1-2007:3 separately and check correlations with the shocks series estimated for the full sample.[7] The correlations are significantly positive and therefore we use monetary shocks originating from the VAR system estimated for the full sample.[8]

The F statistic from the first-stage regression of observed input dx is 9.5 and that of hours per worker dh is 8.4. These are high enough to be statistically significant. In addition, Staiger and Stock (1997) suggest that, when the statistic is above 10, the estimation result is ensured against a weak instruments problem. In their standard, our instruments seem nearly satisfactory.

[6]The quarterly GDP and GDP deflator series in 1884:1-1946:4 are constructed as follows. For preparation, we make the annual GDP and GDP deflator series from 1884 to 2006 by splicing data from the Bureau of Economic Analysis beginning in 1929 to data from Balke and Gordon (1989). In addition we make the quarterly industrial production index over the same period by splicing data from the Board of Governors of the Federal Reserve System beginning in 1919:1 to data from Miron and Romer (1990) and similarly we make the quarterly wholesale price index by splicing data from the Bureau of Labor Statistics beginning in 1921:1 to data from Warren and Pearson (1933). Then we interpolate the annual GDP and deflator series by the quarterly industrial production and wholesale price series respectively with Chow and Lin's (1971) method, assuming that the residual series follow AR1. Finally the quarterly GDP and GDP deflator series published by the BEA beginning in 1947:1 are spliced to the interpolated series.

[7]Our identifying assumption is consistent with the popular recursiveness assumption in the empirical research of monetary policy shocks such as Christiano, Eichenbaum and Evans (1999). But, since the sample includes pre-FED period, our monetary shocks are not limited to monetary *policy* shocks.

[8]The correlations of the series of shocks to interest rate estimated for the time periods 1885:1-1914:4 and 1915:1-2007:3 with that estimated for the full sample are 0.78 and 0.96. As for the shocks to the ratio of M2 to monetary base, the correlations are 0.72 and 0.96 and, as for the shocks to the monetary base, the correlations are 0.84 and 0.97.

2.4 Estimates

Table 2.1 reports parameter estimates from the equation (2.4). The returns-to-scale estimate is 0.97, which is almost same as BFK's median estimate 1.00. Omitting hours-per-worker growth raises the estimate to 1.76 (not shown). Thus, correcting for variable utilization, we find little evidence for increasing returns in the entire private nonfarm economy.

The coefficient on hours per worker is 2.95 and strongly significant. The estimate is much higher than BFK's estimates, 1.34, 2.13, and 0.64 for durables manufacturing, nondurables manufacturing, and nonmanufacturing respectively. This result would come from the data availability preventing us from measuring the industries' purified Solow residuals and aggregating those. Output as a dependent variable and hours per worker as an independent variable both reflect positive covariance across industries in utilization. Therefore the extent that hours-per-worker explain output movement rises.

Table 2.2 reports summary statistics for the standard Solow residuals and the purified Solow residuals. The standard deviation of the latter, 4.61 percent per year, is higher than that of the former, 3.92 percent per year. BFK find the same relationships between the standard Solow residuals and the purified Solow residuals for durable and nondurable manufacturing. Also, they find that the standard deviation of their aggregate purified Solow residuals, 1.50 percent per year, is lower than that of the aggregate standard Solow residuals, 2.04 percent. They argue that it comes primarily because the aggregate purified Solow residuals are not affected by positive covariance across industries in utilization. This argument is still valid for our case, although, as argued above, a part of large volatility in output due to the positive covariance is partly reduced by a high coefficient on hours-per-worker term in our estimation.

Table 2.2 also reports correlations between BFK technology, the standard Solow residuals, the purified Solow residuals. The correlation of the purified Solow residuals with BFK technology is 0.42 and statistically significant, while that of the standard Solow residuals is 0.19 and not statistically significant. As explained in the section 2.2, we control for varying utilization of capital and labor, nonconstant scales, and imperfect competition, but not for aggregation effects and materials intensity effects on technology series due to the absence of long-run sectoral input-output data. However, these correlations appear to show that our purified Solow residuals series measure technology correctly to a respectable degree.[9]

The parameter estimates are almost same in the case that the band-pass-filtered hours per worker are used for estimation. That is, the returns-to-scale estimate is 1.05 and the coefficient on hours per worker is 2.97 (not shown). The correlation with the baseline purified Solow residuals is 0.95. These results suggest that how to detrend hours-per-worker doesn't matter so much when enough long samples are used.

Figure 2.1 plots our purified Solow residuals series and the difference from the standard Solow residuals series. In most recession periods, the demeaned growth rates of the purified Solow residuals are higher than those of the standard Solow residuals. It means that the adjustment for utilization substantially reduce procyclicality in the standard Solow residuals. Another feature is that the volatility of technology in the post-W.W.II period appears to be far less than in the prewar period. This finding will be argued later.

2.5 Effects of Technology Improvement

2.5.1 Baseline Results

Using the purified Solow residuals, we study the macroeconomic effects of technology. Especially, we are interested in differences in the effects across pre- and post-W.W.II periods.

Table 2.3 shows the results from regressing total hours worked, the private nonfarm sector output, and private nonresidential fixed investment on current and four lags of the purified Solow residuals. All the variables are in the form of growth rates. For the post-W.W.II sample, 1949-2006, total hours worked and investment fall significantly and output changes little on impact. All of the responses are consistent with BFK's results. For the samples including pre-W.W.II period, 1894-2006 and 1894-1940, the impact responses of total hours worked are still very weak, although not significantly negative. On the other hand, for the same samples, output significantly rises on impact. Investment rises on

[9]I estimated the purified Solow residuals using the 1949-1996 data and hours per worker series detrended by the band pass filter. Then the resulting series was different from BFK technology series only in that I didn't control for the aggregation effects and the materials intensity effects. Correlation between the two technology series was 0.35 and statistically significant. Therefore it seems that we are still able to get much purified technology series even if we don't control for these effects.

impact but not significantly for the 1920-2006 period.[10]

We examine the possibly more complex dynamics with bivariate VAR. We estimate a near-VAR, in which the first equation regresses the purified Solow residuals series on a constant term and the second regresses a variable on two lags of itself and the current and two lags of the purified Solow residuals. That is, the system is formed by the following two equations:

$$dz = c_z + \varepsilon_z \text{ and} \tag{2.5}$$

$$ds = c_s + \alpha_1 ds_{-1} + \alpha_2 ds_{-2} + \beta_0 dz + \beta_1 dz_{-1} + \beta_2 dz_{-2} + \varepsilon_s \tag{2.6}$$

where dz is technology growth and ds is the growth of a macroeconomic variable.

Figure 2.2 shows VAR impulse responses of variables to a 1-percent technology improvement. The responses of the variables on impact are very similar with the above regression results. The responses at longer horizons are as follows: the responses of total hours worked and investment remain negative for the post-W.W.II sample; for the samples including the prewar periods, the responses of total hours worked are positive, although not significantly, and those of investment are significantly positive; the response of output is not significant for the postwar sample while significantly positive for the samples including the prewar periods. These results indicate that technology improvement was, at longer horizon, more expansionary in the prewar period than in the postwar period. However, even in the prewar period, the impact responses of hours and investment are weak.

As noted in the introduction, the negative impact response of hours to technology improvement in the post-W.W.II period is also found by Francis and Ramey (2006), who use hour worked per capita adjusted for the effects changes in the government employment, the school enrollment, the population aged 0-4 and 65-, with the Galí's (1999) SVAR method. On the other hand, Francis and Ramey find that hours worked per capita sharply increase to a positive technology shock for the samples including pre-W.W.II years under the assumption that hours worked per capita follow the unit root process. In order to examine the possibility that the difference in the response of hours comes from the specification of hours, we estimate the bivariate VARs with Francis and Ramey's hours worked per capita

[10] I haven't been able to find the data of investment for the total private economy in pre-1919 period.

series instead of total hours worked series.[11]

Figure 2.3 shows VAR impulse responses of hours worked per capita to a 1-percent technology improvement. We try both specifications of hours series being stationary and following unit root process. Across specifications and sample periods, the impact responses are negative on average. When we use the full sample 1893-2002, hours fall significantly in response to a positive technology shock regardless of the specification of hours.

The bottom line is that, in our framework using the purified Solow residuals, the responses of hours to technology improvement are significantly negative or very weak regardless of sample periods and specifications of hours. This result shows a stark contrast with Francis and Ramey's result mentioned above. However we have four reasons to believe that our findings are more in line with true data generating process.

The first two points are related to methodological problem in Galí's SVAR method adopted by Francis and Ramey, which is noted in the introduction. First, Galí's SVAR misidentifies nontechnology shocks having permanent effects for labor productivity as technology shocks. Basu (2006) points out, in his comment on Francis and Ramey's study, the possibility that the permanent shift of workers from agriculture to manufacturing up to W.W.II raised measured labor productivity in the total *private* sector because of output in agriculture sector, which is often home-consumed, being under-measured. Our purified Solow residuals are measured for the *private nonfarm* sector and therefore not disturbed by such labor shift. Second, as Fernald (2007) emphasizes, SVAR with the long-run restriction is so much sensitive to low-frequency correlation between variables, even if it is not causal. Figure 2.4 shows the growth rates of labor productivity in the private sector and Francis-Ramey hours worked per capita with HP-filtered trend series in the period 1890-1940. The trend series are positively correlated especially due to the Great Depression being so large and persistent. The correlation coefficient between the two series is 0.33 and significant.[12] It is possible that such positive correlation produces the positive impact response of hours to technology improvement even if the Great Depression was not caused by technological regress. Third, the negative impact responses of hours and investment to a positive technology shock that we have found for the postwar samples are consistent with

[11] I gratefully thank Valerie Ramey for providing data.

[12] The significance level based on the Ljung-Box Q statistics is 0.02.

the findings by BFK, who make a fully purified Solow residuals series in the postwar period and estimate the macroeconomic responses to a technology shock. Recall that we have estimated technology series with the full sample, 1891-2006. The fact that the postwar part of the technology series generates plausible responses supports the prewar part being also reliable. Fourth, investment responds to a positive technology shock insignificantly for the 1922-2006 sample. Kimball (2003) shows that, at least in the standard real business cycle model with the capital adjustment cost, the response of investment to technology is qualitatively same as that of hours. These considerations seem enough to support our result that the response of hours to technology improvement in the pre-W.W.II period is not positive.

2.5.2 Robustness Checks

Alternative VAR Specification

Technology series have been implicitly assumed to follow a unit root process so far. BFK try other specifications of VAR. For a robustness check, we estimate the system specified most differently from the baseline specification within systems tried by BFK: allowing the series to be autoregressive and affected by shocks to another variable in the bivariate VAR. That is, the equation (2.5) is replaced by the following:

$$dz = c_z + \acute{\alpha}_1 ds_{-1} + \acute{\alpha}_2 ds_{-2} + \acute{\beta}_1 dz_{-1} + \acute{\beta}_2 dz_{-2} + \varepsilon_z. \tag{2.7}$$

Figure 2.5 shows the responses of total hours worked and investment to a positive technology shock. These are almost same as the baseline results in all sample periods. Therefore the baseline results seem robust to VAR specifications.

The Timing of a Structural Change

The sample has been split at the W.W.II so far, following Francis and Ramey, who note that structural break tests suggest breaks in the late 1940s for their SVAR model. On the other hand, they consider that there may be breaks at the Great Depression and the W.W.I. They estimate their SVAR model with the 1892-1929 sample and with the prewar sample except for the W.W.I years 1917-1920. These result in finding no significant changes from their baseline results.

We also examine the plausibility that the sample is split at timings other than W.W.II by exploring structural breaks. Specifically, we do the recursive estimation of equations regressing hours and output respectively on the current and four lags of purified Solow residuals and check one-step ahead prediction errors. Figure 2.6 shows recursive residuals with two-standard error bands. The residuals lying outside the standard error bands is equivalent to a t statistic being greater than two and suggestive of parameter inconstancy. This criterion indicates breaks in the hours equation in 1919, 1930, 1931, 1932, and 1938 and breaks in the output equation in 1919, 1930, 1932, and 1938.

According to the result that most of possible break dates are in the Great Depression period, we regress total hours worked on the current and four lags of purified Solow residuals for the pre-Great Depression sample, 1885-1929. The estimated coefficient on the current purified Solow residual is 0.01 with the standard error 0.24.[13] The initial response of total hours is still very weak. This result suggests that the baseline result is robust to another possible break date.

Manufacturing Sector

As noted above, we don't have the input-output data for enough number of sectors in the pre-W.W.II period and therefore cannot control for the aggregation effects. A promising way to reduce the aggregation effects is to focus only on the sector for which the input-output data are available. Fortunately, Kendrick (1961) tables the series of output, employment, and total hours worked for the manufacturing sector in that period. Furthermore he tables the data of capital stock in the manufacturing sector in 1889, 1899, 1909, 1919, 1929, 1937, 1948, and 1953. Therefore interpolating the capital stock data by investment data from other sources produce enough set of data for estimating purified Solow residuals and hence we can estimate the effects of a technology shock for the manufacturing sector.[14]

Table 2.4 reports parameter estimates. We use the bandpass filtered hours per employees for correcting for the effect of variable utilization, because using HP-filtered series produces implausibly low estimate of returns-to-scale parameter. The resulting estimate of returns-to-scale parameter is 0.84, which is less than the estimate for the total economy,

[13]Heteroskedasticity and autocorrelation robust standard error with Newey-West window (calculated with RATS's ROBUSTERRORS command with LAGS=3).

[14]Interpolating procedure is described in the appendix.

0.97. In BFK's estimates, the median of returns-to-scale parameters for nonmanufacturing sectors, 1.10, is larger than for the durable and the nondurable manufacturing sectors, 1.07 and 0.89. Such relationship is implicitly preserved in our estimates.

The coefficient on hours-per-worker is 2.70 and strongly significant. This estimate is higher than BFK's estimates for the durable and nondurable manufacturing sectors, 1.34 and 2.13. As in the case of estimate for the private nonfarm economy, it would be due to the data availability preventing us from measuring the manufacturing industries' purified Solow residuals and aggregating those. As a result, since both of output and hours per worker reflect positive covariance across manufacturing industries in utilization, the extent that hours-per-worker explain output movement rises.

Table 2.5 reports summary statistics for the standard Solow residuals and the purified Solow residuals of the manufacturing sector. Similar with a result for the private nonfarm economy, the standard deviation of the latter, 6.23 percent per year, is higher than that of the former, 5.59 percent per year. The correlation of the purified Solow residuals with BFK technology is 0.29 and statistically significant, while that of the standard Solow residual is -0.38.[15] This result indicates that utilization variation makes the standard Solow residuals of the manufacturing sector strongly procyclical.

Estimating with the sample period of 1949-1996, which is same as BFK's, enables us to know the bias arising from not controlling for aggregation effects and material intensity effects. The correlation between resulting purified Solow residuals series and the BFK technology is 0.54 (not shown), which is higher than in the case of the private nonfarm economy, 0.42. It suggests that the bias is smaller than in the estimate for the private nonfarm economy.

The effects of technology on total hours worked and investment are estimated with bivariate VAR consisting of equations (2.5) and (2.6), as in the case of the private nonfarm economy. Focusing on the manufacturing sector enables us to use the investment data since 1889, while the investment data for the private nonfarm economy begin in 1919. Figure 2.7 shows the impulse responses of these variables to one percent positive technology shock. Across sample periods and dependent variables, it is common that the impact effects of technology improvement are very small and insignificant. When we restrict the sample

[15] BFK didn't calculate the series of technology for total manufacturing sector. Therefore I calculated a weighted sum of the manufacturing sectors' technology using the weights used by BFK.

to the pre-Great Depression period, 1895-1929, and regress the growth rates of total hours worked and investment respectively on the current and four lags of purified Solow residuals, the estimated coefficients on the current purified Solow residuals are -0.52 with the standard error 0.34 and -0.90 with the standard error 0.47 (not shown).[16] The bottom line is that the data for manufacturing sector confirm that a positive technology shock doesn't raise inputs significantly.

2.6 Technology Shocks and Monetary Policy

As BFK argue intensively in their conclusion, our estimates may reflect not only the direct effect of technology improvement, but also the reactions of monetary policy. Without the Federal Reserve's intervention to stabilize inflation, the effect of technology improvement may be more contractionary than the results we've found so far. Our technology series since 1891 can potentially address this possibility, because it covers the period prior to 1915, when the Federal Reserve was founded.[17]

We estimate the effects of one percent technology improvement for the sample periods after the Federal Reserve was founded and compare those with the results based on the sample periods including pre-Federal Reserve period. Figure 2.8 shows the impulses responses of total hours worked for the sample periods 1915-2006 and 1915-1940. For both samples, hours fall on impact on average to technology improvement. Comparing with the results based on 1893-2006 and 1893-1940 samples, shown in Figure 2.2, these responses seem to suggest that technology improvement is *more* contractionary in the post-1915 period. If the Federal Reserve offset deflation as a result of technology improvement more or less, we should observe the opposite results.

One possibility to bring this result is that the Federal Reserve responded to changes in growth resulting from technology movement more than to changes in inflation. The bottom line is that it may not be necessary to suppose that the monetary policy responses mitigate the contractionary effect of technology improvement.

[16]Again, heteroskedasticity and autocorrelation robust standard errors with Newey-West window (calculated with RATS's ROBUSTERRORS command with LAGS=3).

[17]Strictly speaking, the Federal Reserve opened for business on November, 1914.

2.7 Technology Movement in the Great Depression Period

As mentioned in the introduction, some argue that technological regress explains the part of a large decline in output during the Great Depression period, but others assert that the Great Depression cannot be caused by technological regress intrinsically and should be attributed to increasing returns to scale or a large fall in utilization. Such opponent views arise partly from a reliable measure of technology in the pre-W.W.II period having not been developed. Our purified Solow residuals series is a promising measure to examine a cause of the Great Depression.

Figure 2.9 shows the behavior of three measures of technology in the Great Depression period. All measures suggest a decline in technology from 1929 to 1933, followed by a dramatic surge that will be argued later. Technology measured by the purified Solow residuals regressed by 4.8 percent from 1929 to 1933. This number is much smaller than 15.5 percent fall in the standard Solow residuals series and 11.3 percent fall in the Kendrick's (1961) total factor productivity series, which is adjusted for changes in the quality of labor.[18] Since our returns-to-scale estimate is 0.97, such difference comes almost from adjustment for utilization.

It is clear that Cole and Ohanian's (2007) use of the standard Solow residuals for measuring the behavior of technology in the Great Depression period is inappropriate. Their focusing only on a fall in capital utilization makes them under-evaluate the contribution of a fall in utilization in that period. On the other hand, Bernanke and Parkinson's (1991) assumption that technological regress was not a cause of the Great Depression is also incorrect. Technology seems to have fallen in the Great Depression period. However a significant fall in labor productivity in that period is mostly due to factor utilization, not technological regress.

The purified Solow residuals are used to assess how technology dampened output during the Great Depression period. While Cole and Ohanian measure the contribution of technology by feeding the Solow residuals series into their neoclassical model, we try to directly estimate it. Specifically, the bivariate VAR system consisting of the equations (2.5) and (2.6), in which the second variable is private nonfarm output, is simulated with the purified Solow residuals. Constant terms are set to zero in order to exclude a deterministic

[18] Kendrick adjusts for the quality of labor by aggregating sectoral hours with fixed sectoral wage.

trend from the resulting series.

The resulting series of output is shown with the solid line in Figure 2.10 and falls only by 7.6 percent from 1929 to 1933. For comparison, the detrended output series, which is derived from the simulation with both the purified Solow residuals and errors from the second equation, is plotted with the lower dashed line. It declines by 56.1 percent during the same period. Therefore technological regress explains only 13.5 percent of the fall in output. This number is much smaller than Cole and Ohanian's result, 61 percent.

It is interesting to assess to what extent using the incorrect measure of technology induces the downward bias in the simulation. We feed the standard Solow residuals series, instead of purified Solow residuals series, into the estimated VAR system. The resulting series is shown with the upper dashed line and falls by 17.4 percent from 1929 to 1933. It means that, in the case of using the standard Solow residuals, technological regress explains 31.0 percent of decline in output during that period, which is far above the number we've gotten using the purified Solow residuals. This calculation suggests that using appropriate measure of technology is important in evaluating the role of technology in the Great Depression period.

Overall, the technological regress contributed to the Great Depression, but inconsiderably. In this sense, Cole and Ohanian exaggerate the role of technology in that period, while Bernanke and Parkinson's ignoring it is incorrect.

2.8 Technology Fluctuations in Historical Perspective

2.8.1 Historical Comparison of Technology Growth

As mentioned in the introduction, Field (2003) shows that some measures of productivity growth such as Kendrick's (1961) productivity series record the highest in the period 1929-1941 and, with a lot of narrative evidences, asserts that the Great Depression is highly innovative period. However, it is not clear whether his peak-to-peak comparison, which expects that utilization rate in the economy in 1929 was same as in 1941, excludes the effects of utilization variation on the standard productivity measures. We assess his assertion with the purified Solow residuals.

Table 2.6 shows the average technology growth rates. Technology grew by 2.78 percent on average from 1929 to 1941. The number is the highest since 1890 and hence our technology series supports Field's finding. As shown in the previous section, technology began to grow dramatically since 1934 after a decline during the Great Depression period.

The other periods of high innovative activity are 1941-1948 and 1997-2006 and the technology growth rates in these periods are above 2 percent. The former may be linked to wartime innovations in some industries such as airframes.[19] The latter period has been studied much in the literature for its high productivity growth in the postwar period. The purified Solow residuals show that that period is characterized by high technology growth even if compared with pre-W.W.II periods.[20]

The purified Solow residuals also give new facts on historical movement of technology growth. Technology growth in the period 1919-1929 is much lower than in the other periods, while technology measured with the standard Solow residuals grows in that period by a rate comparable to the other periods. On the other hand, the purified Solow residuals indicate that technology grew relatively fast in the period 1941-1948, but the standard Solow residuals don't.

2.8.2 Changes in Volatility of Output and Technology

Figure 2.1 shows that the volatility of technology in the postwar period seems much lower than in the prewar period. The standard deviation in the 1891-1940 period is 6.65, while that in the 1949-2006 period is 1.51. The low volatility in output in the postwar period relative to in the prewar period has been intensively argued in the literature.[21] Our finding indicates the possibility that the reduction in the volatility of technology is the source of it.[22]

In order to study the role of technology in the historical fluctuations in output, again we do the same experiment as in studying the contribution of technological regress to the Great Depression. The variance of output due to technology shocks is calculated by the variance

[19]Field (2003) study the possibility that wartime experience raised U.S. productivity in details.

[20]Basu, Fernald and Shapiro (2001) estimate technology growth in the second half of 1990s based on the BFK method and confirm that it accelerated.

[21]See, for example, papers in Gordon (1986).

[22]Francis and Ramey (2006) also find the low volatility of both identified technology and nontechnology shocks in the postwar period relative to in the prewar period. Since the decline in variance of technology shocks is larger than that of nontechnology shocks, they argue that the former is a potential source leading to the postwar reduction in the variance of output. However their argument is not enough, since they don't take account for propagation mechanisms of shocks.

of output series resulting from the simulation of the bivariate VAR system consisting of equations (2.5) and (2.6) only with the purified Solow residuals. It is compared with the variance of detrended output, which is calculated by the variance of output series resulting from the the simulation of the same bivariate VAR with the purified Solow residuals and the errors from the second equation. Constant terms are set to zero in both cases.

The variances of resulting series are as follows (not shown). The variances of output fluctuations due to all shocks are 217 in the 1893-1940 period and 18 in the 1949-2006 period. On the other hand, those due to technology shocks are 33 in the 1893-1940 period and 15 in the 1949-2006 period. These results suggest that a decline in volatility of technology shocks do minor role in stabilizing economic fluctuations in the post-W.W.II economy. At the same time, it is worth noting that the decline in variance of output due to technology shocks being less than that that of the detrended output indicates that the role of technology in the business cycle is more important in the postwar period than in the prewar period.

2.9 Conclusion

We construct a series of U.S. technology growth from 1891 to 2006, following BFK. The series is purified from the effects of varying utilization of capital and labor, nonconstant scales, and imperfect competition. With the purified Solow residuals, first, we find that, when technology improves, hours worked change little or significantly fall on impact, regardless of periods and the specification of hours. Francis and Ramey's (2006) finding that the impact responses of hours to a positive technology shock, which is identified by Galí's method, substantially differ across pre- and post-W.W.II periods is not valid in our study. Second, technology regressed by 4.8 percent from 1929 to 1933 in the Great Depression period, which is less than one-third of 15.5 percent fall in the standard Solow residuals series. The VAR analysis shows that technology regressed explains only 13.5 percent of a decline in output between 1929 and 1933. Both of the extent of technological regress and its effect of output are much smaller than assessed by Cole and Ohanian (2007). Third, the average growth rate of technology in 1929-1941 was highest in U.S. economic history. It supports Field's (2003) argument, which is partly based on the standard Solow residuals series.

We cannot exclude the effects of sectoral differences in marginal product and material intensity in production from our purified Solow residuals series, because of data availability. The development of sectoral input-output data in the pre-W.W.II period is expected for constructing more complete measure of technology.

Data Appendix

GDP and GDP deflator

Quarterly series beginning in 1947:1 is from the BEA. Annual series from the BEA beginning in 1929 is spliced to series from Balke and Gordon (1989).

Hours and employment in manufacturing sector

The series from the BEA beginning in 1948 is spliced to those from Kendrick (1961). The series from the BEA is for full-time and part-time employees.

Hours and employment in private nonfarm business

The series from the BLS beginning in 1947 is spliced to those from Kendrick (1961).

Industrial production index

The series from the Board of Governors of the Federal Reserve System beginning in 1919:1 is spliced to that from Miron and Romer (1990). Seasonality in Miron and Romer's series is not identified by the Census X-12-ARIMA program. So we use the original series.

Interest rate

The series of three-month Treasury bill secondary market rate beginning in 1934:1 from the Board of Governors of the Federal Reserve System is spliced to the series of yields on three-nine month Treasury notes, certificates, and bills beginning in 1920:1 and the series of 60-90 day commercial paper rates in New York City, both of which are from NBER Macrohistory database (m13002 and m13029). The level of second series is adjusted by the average difference from the first series in 1931 and that of third series is adjusted by the average difference from the adjusted second series in 1920.

Labor share

The Bureau of Economic Analysis publishes the data of national income and the components for the time period 1929-2006. The labor share is the ratio of compensation of employees to the sum of compensation of employees, net interest, consumption of private fixed capital, corporate profits, and rental income of persons. The shares of compensation of employees and enterpreneurial labor income for the time periods 1900-1909, 1910-1919, 1920-1929, and 1930-1939 are calculated by Johnson (1954). Therefore we adjust the level of later series by the difference in 1930-1939 shares of the two series and calculate the 1900-2006 average weighted by the number of years. The resulting number is 68.0 percent.

M2

The series from the Board of Governors of the Federal Reserve System beginning in 1959:1 is spliced to that from Balke and Gordon (1986).

Military expenditure

The national defense expenditure series from the BEA beginning in 1929 is spliced to the national security outlays series from Kendrick (1961).

Monetary base

The series from the Federal Reserve Bank of St. Louis beginning in 1918:1 is spliced to that from Friedman and Schwartz (1963) beginning in 1907:3 (1963, Table B-3, Column 3) and the series of total currency outside the Treasury from NBER Macrohistory database (m14135), which is seasonally adjusted by the Census X-12-ARIMA program.

Nonresidential capital stock in manufacturing sector

The series from the BEA begins in 1929. Kendrick's (1961) data of capital stock in manufacturing sector in 1889, 1899, 1909, 1919, and 1929 are extended by the BEA data to 1939, 1949, 1959, 1969, 1979, 1989, and 1999. Then, in order to make the series in pre-1929 period, the capital stock data are interpolated by the series of investment in the manufacturing sector from Historical statistics of the United States Millennial Edition Online spliced in 1910 to that from U.S. Department of Commerce (1989). The interpolation follows Chow and Lin's (1971) method. The resulting series is spliced to the BEA series in 1929.

Nonresidential capital stock in private nonfarm business

The series from the BEA beginning in 1929 is spliced to that from Kendrick (1961). The BEA series is the sum of manufacturing and nonfarm nonmanufacturing. The summation follows the aggregation example in the BEA's file of detailed data of nonresidential net stocks quantity index (detailnonres_stk2.xls).

Nonresidential fixed investment in manufacturing sector

The series from Historical Statistics of the United States Millennial Edition Online beginning in 1910 is spliced to that from U.S. Department of Commerce (1989).

Nonresidential fixed investment in private nonfarm business

The private nonresidential fixed investment series from the BEA beginning in 1929 is spliced to the series of investment to producer's durable equipment and nonresidential structures from Balke and Gordon (1986).

Oil price

The series of crude petroleum average value at well from Historical Statistics of the United States Millennial Edition Online is spliced to the same series from Energy Information Administration.

Output in manufacturing sector

The series from the BEA beginning in 1947 is spliced to the series from Kendrick (1961).

Output in private nonfarm business

The series from the BLS beginning in 1947 is spliced to the series of difference between private domestic output and farm product from Kendrick (1961).

Producer price index

The series from the Bureau of Labor Statistics beginning in 1921:1 is spliced to that from Warren and Pearson (1933).

Table 2.1: Parameter Estimates

Constant	1.54	Returns-	0.97	Coefficient on hours	2.95
	(0.57)	to-scale	(0.25)	per worker	(1.18)

Note: Heteroskedasticity and autocorrelation robust standard errors with Newey-West window in parentheses (calculated with RATS's ROBUSTERRORS command with LAGS=3).

Table 2.2: Summary Statistics of Productivity and Technology

	Mean	Standard Deviation	Correlation with BFK Technology
Solow Residual	1.58	3.92	0.19 (0.18)
Purified Solow Residual	0.10	4.61	0.42 (0.00)

Note: The Solow residuals are from 1891 to 2006. Annual percent change. BFK technology series is from 1949 to 1996. Significance level for null of no correlation based on Ljung-Box Q-Statistics are shown in parentheses.

Table 2.3: Regression on Current and Lagged Technology: Private Nonfarm Sector

Dependent variable	Sample period	Regressor dz	dz(-1)	dz(-2)	dz(-3)	dz(-4)	R^2	DW stat.
(1) Total	1895-	−0.07	0.13	0.22	0.11	0.06	0.06	1.57
hours	2006	(0.15)	(0.09)	(0.17)	(0.10)	(0.18)		
worked	1895-	0.01	0.16	0.22	0.08	0.07	0.05	1.64
	1940	(0.17)	(0.11)	(0.20)	(0.11)	(0.22)		
	1949-	−0.54	−0.23	0.23	−0.09	−0.27	0.18	1.80
	2006	(0.21)	(0.20)	(0.20)	(0.15)	(0.12)		
(2) Non-	1920-	0.68	0.88	0.69	0.28	−0.11	0.08	1.41
residential	2006	(0.65)	(0.26)	(0.62)	(0.36)	(0.70)		
fixed	1949-	−1.09	−1.06	0.46	0.07	−0.42	0.14	1.64
investment	2006	(0.49)	(0.60)	(0.47)	(0.46)	(0.35)		
(3) Output	1895-	0.49	0.13	0.30	0.13	0.07	0.15	1.76
	2006	(0.17)	(0.18)	(0.19)	(0.11)	(0.22)		
	1895-	0.63	0.25	0.35	0.08	0.02	0.24	1.85
	1940	(0.20)	(0.17)	(0.23)	(0.13)	(0.25)		
	1949-	−0.02	−0.08	0.36	−0.12	−0.17	0.05	1.95
	2006	(0.26)	(0.23)	(0.25)	(0.20)	(0.19)		

Note: Heteroskedasticity and autocorrelation robust standard errors with Newey-West window in parentheses (calculated with RATS's ROBUSTERRORS command with LAGS=3). Dependent variables are the growth rates of variables shown.

Table 2.4: Parameter Estimates for Manufacturing Sector

Constant	1.96	Returns-	0.84	Coefficient on hours	2.70
	(0.70)	to-scale	(0.30)	per worker	(0.78)

Note: Heteroskedasticity and autocorrelation robust standard errors with Newey-West window in parentheses (calculated with RATS's ROBUSTERRORS command with LAGS=3).

Table 2.5: Summary Statistics of Technology of Manufacturing Sector

	Mean	Standard Deviation	Correlation with BFK Technology
Solow Residual	1.93	5.59	−0.38 (0.01)
Purified Solow Residual	0.14	6.23	0.29 (0.04)

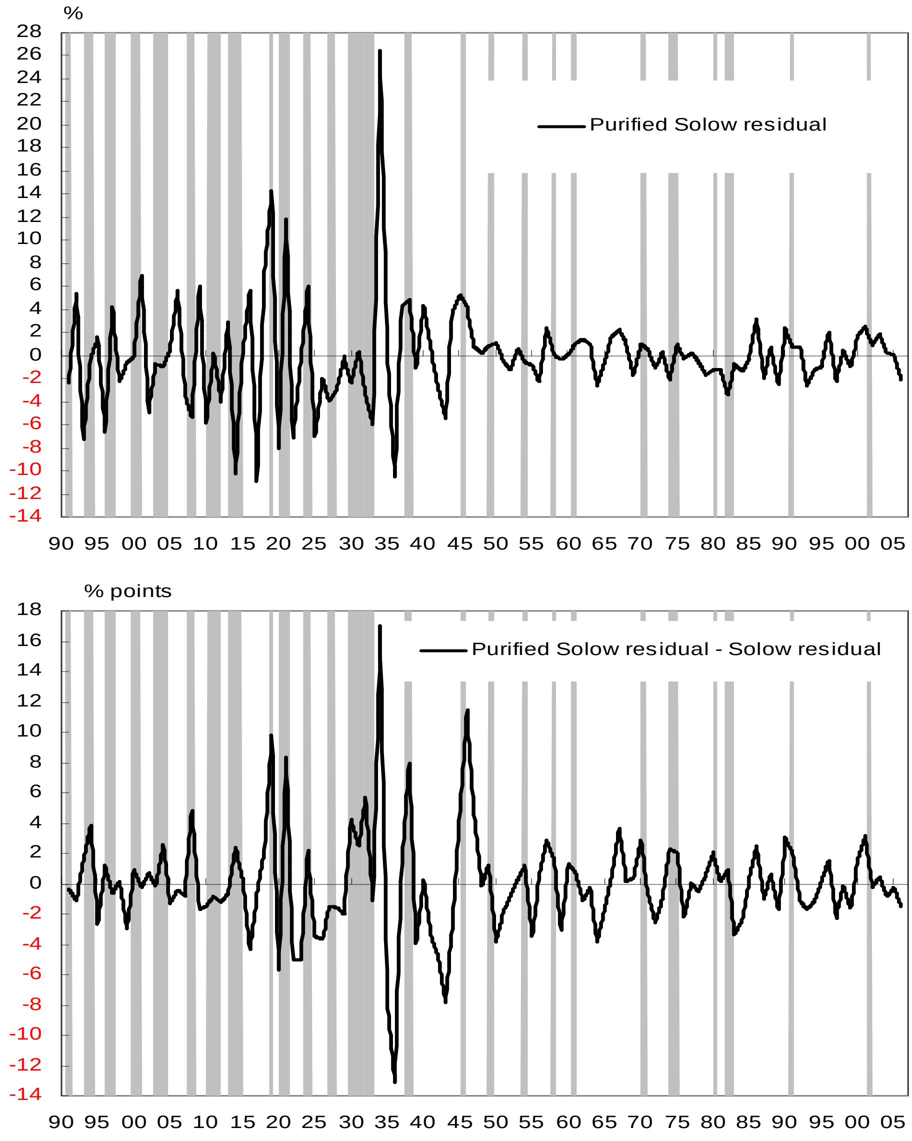
Note: The Solow residuals are from 1891 to 2006. Annual percent change. BFK technology series is the weighted average of BFK industry technology and from 1949 to 1996. Significance level for null of no correlation based on Ljung-Box Q-Statistics are shown in parentheses.

Table 2.6: Annual Average Growth Rates of Technology

	Purified Solow Residual	Solow Residual	Kendrick (1961)
1890-1900	0.75	0.67	1.09
1900-1919	1.63	1.09	1.51
1919-1929	0.08	1.89	2.04
1929-1941	2.78	2.11	2.34
1941-1948	2.45	1.63	1.30
1948-1973	1.78	1.99	
1973-1997	1.06	0.98	
1997-2006	2.14	2.04	

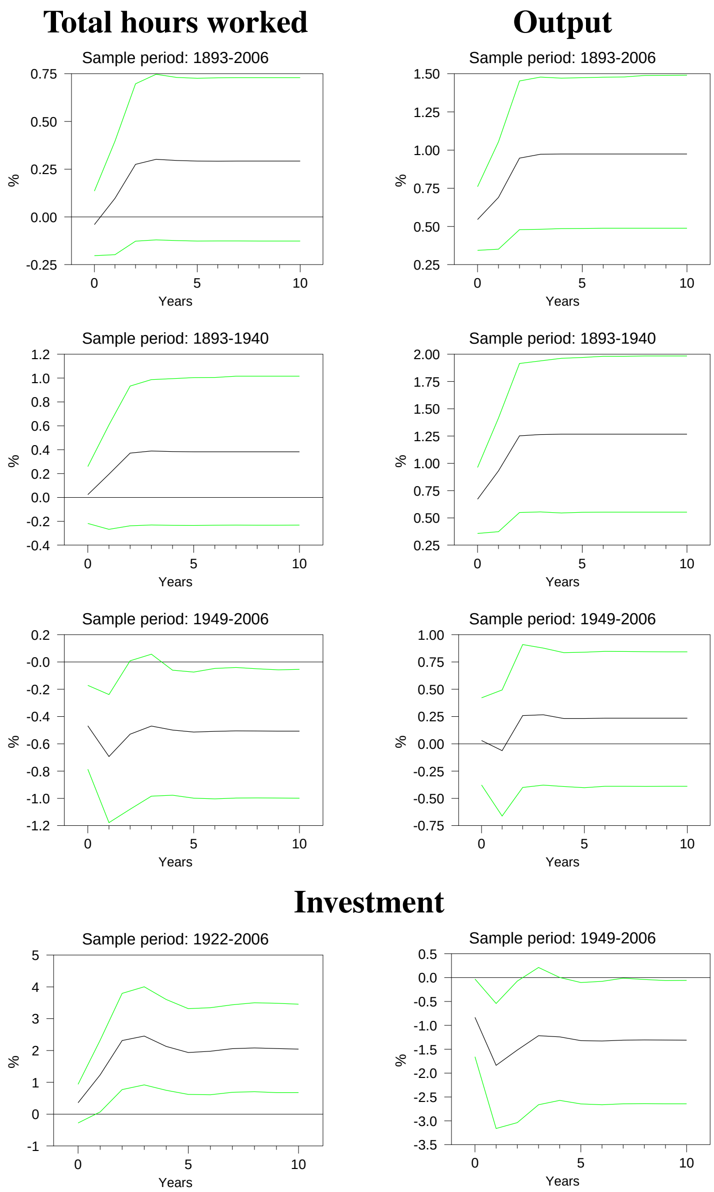
Note: Geometric mean. The deterministic trend growth component is added to purified Solow residuals.

Figure 2.1: Purified Solow Residual and Solow Residual



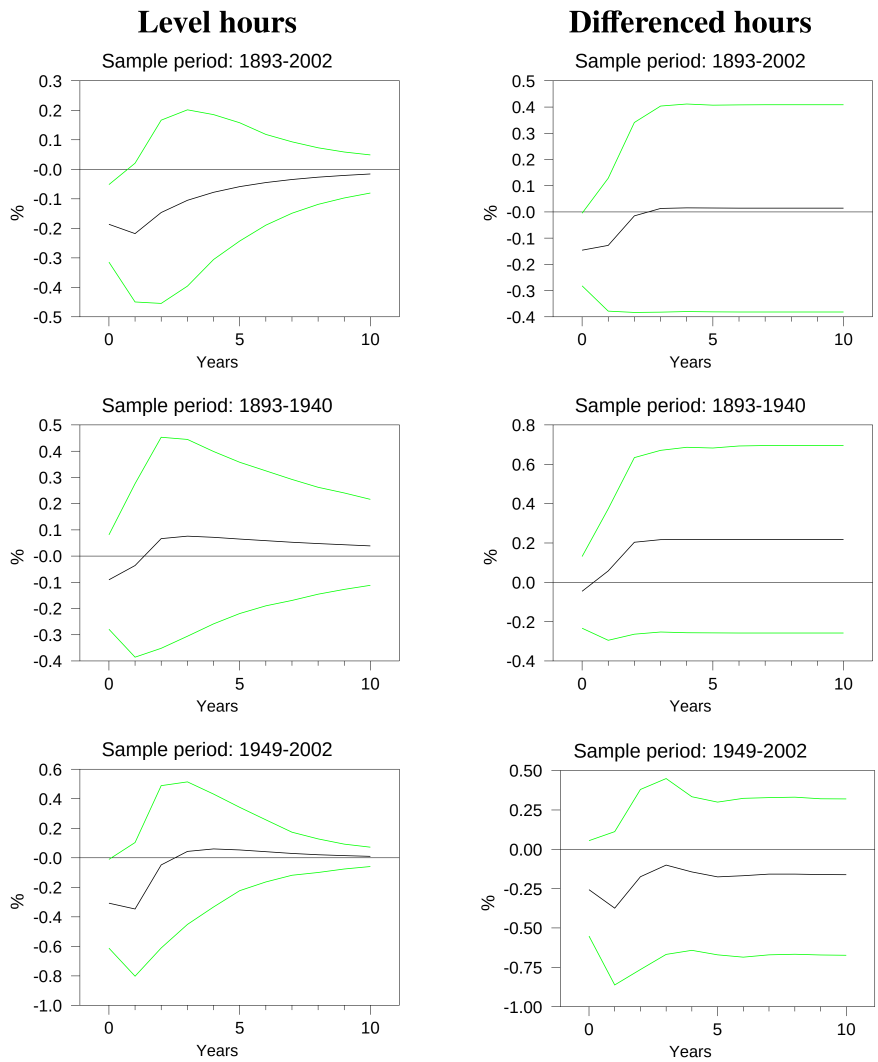
Note: Shaded regions show NBER recession dates. Both series are demeaned.

Figure 2.2: Impulse Responses to Technology Improvement



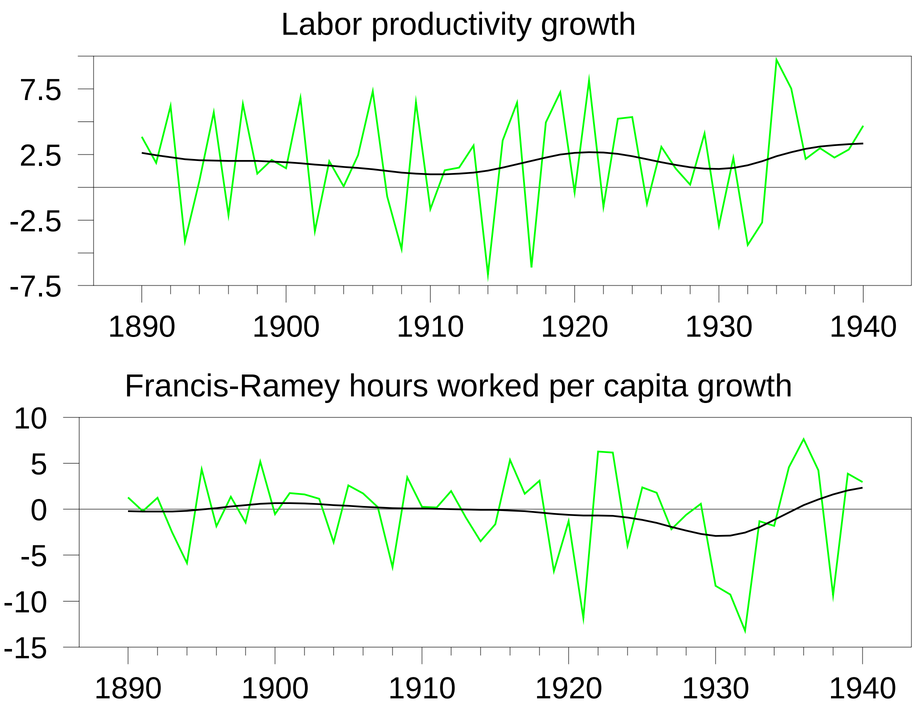
Note: Dashed upper and lower lines show 90% confidence intervals calculated by a bootstrap Monte Carlo procedure with 1000 replications.

Figure 2.3: Impulse Responses of Hours Worked per Capita



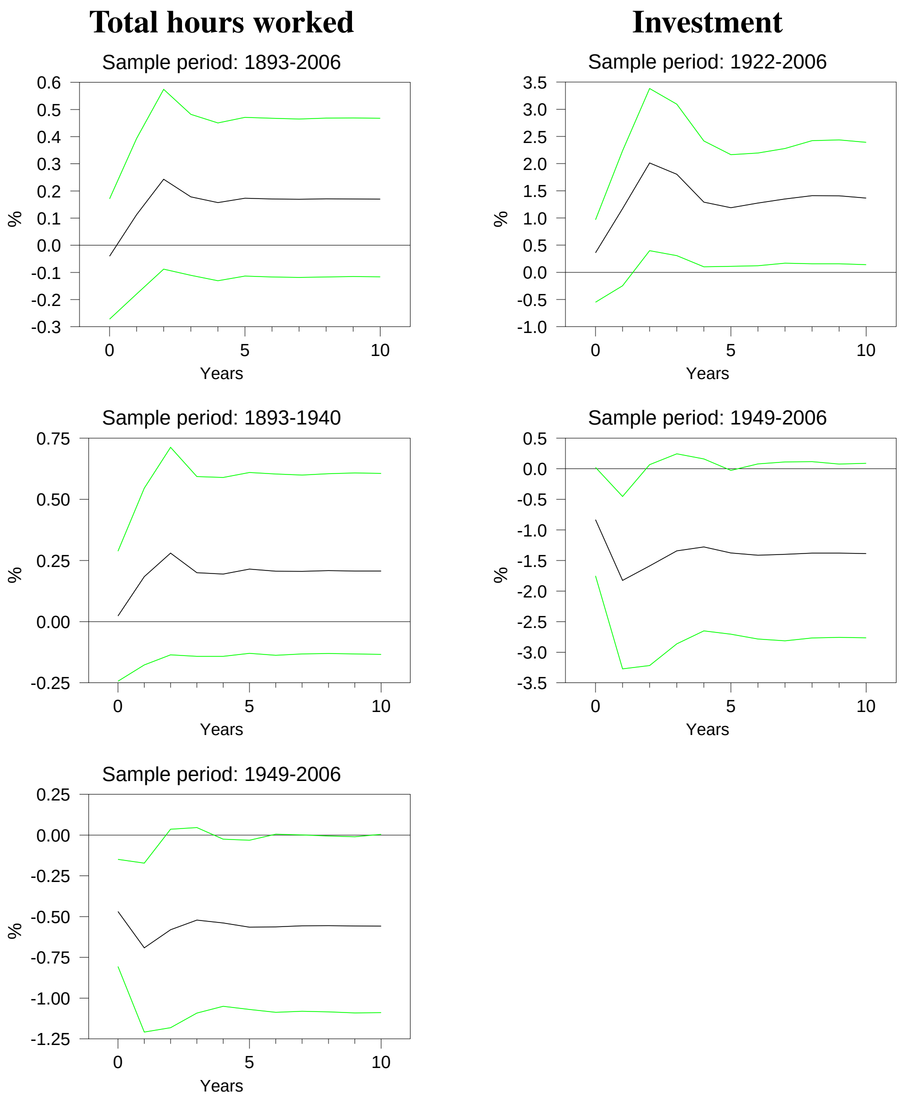
Note: Dashed upper and lower lines show 90% confidence intervals calculated by a bootstrap Monte Carlo procedure with 1000 replications.

Figure 2.4: Lower Frequency Movement of Labor Productivity Growth and Hours Growth



Note: Dashed lines show original series. Solid lines show HP-filtered trend.

Figure 2.5: Impulse Responses: Alternative VAR Specification



Note: Dashed upper and lower lines show 90% confidence intervals calculated by a bootstrap Monte Carlo procedure with 1000 replications.

Figure 2.6: Recursive Residuals and Standard Error Bands

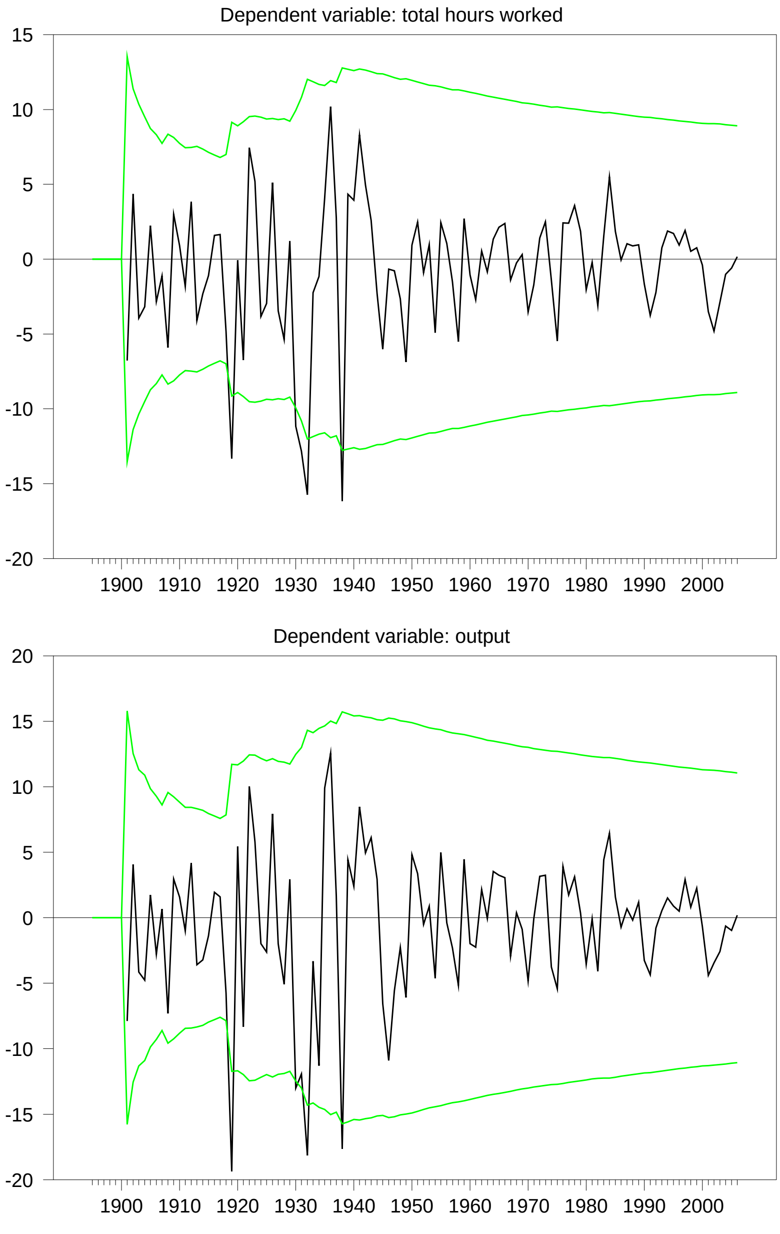
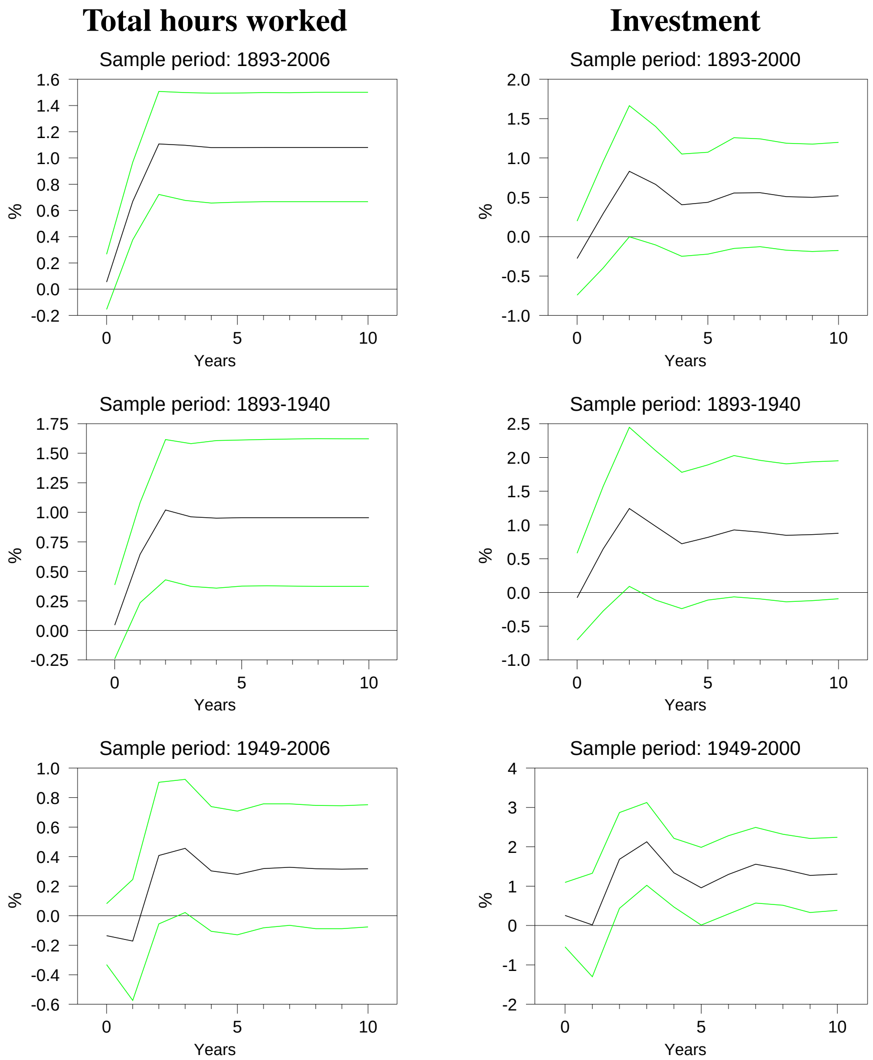
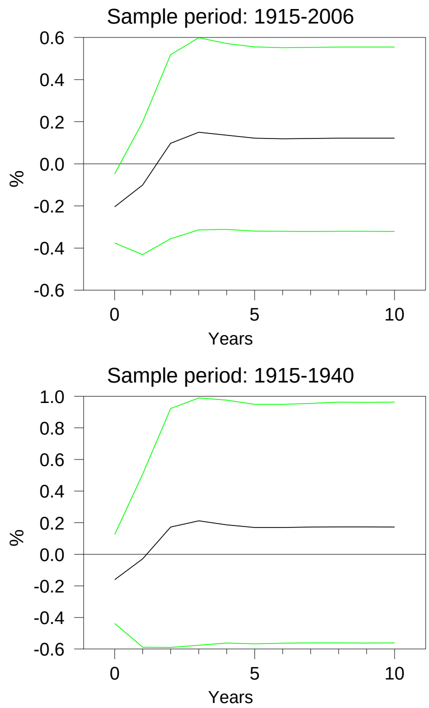


Figure 2.7: Impulse Responses: Manufacturing Sector



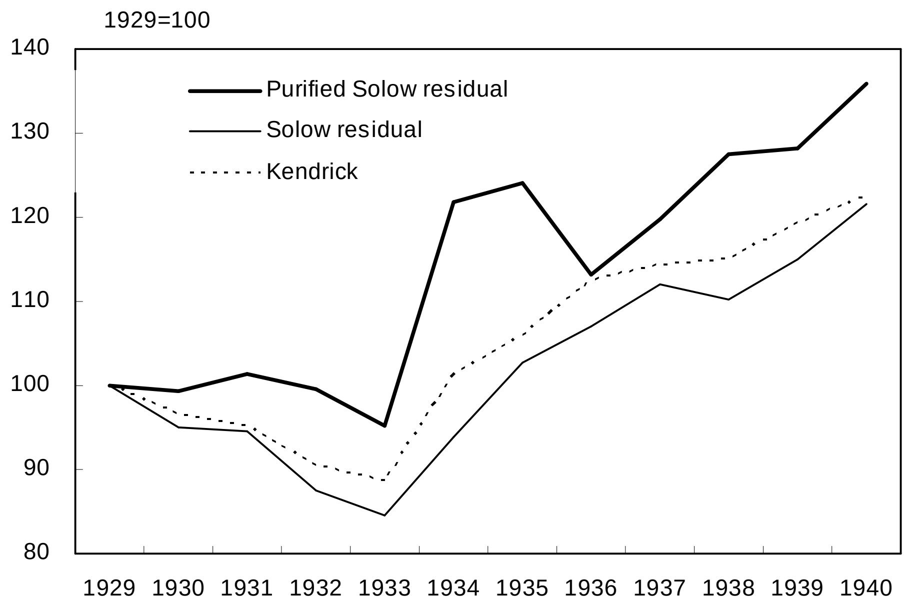
Note: Dashed upper and lower lines show 90% confidence intervals calculated by a bootstrap Monte Carlo procedure with 1000 replications.

Figure 2.8: Impulse Responses of Hours: Post-Federal Reserve Establishment Period



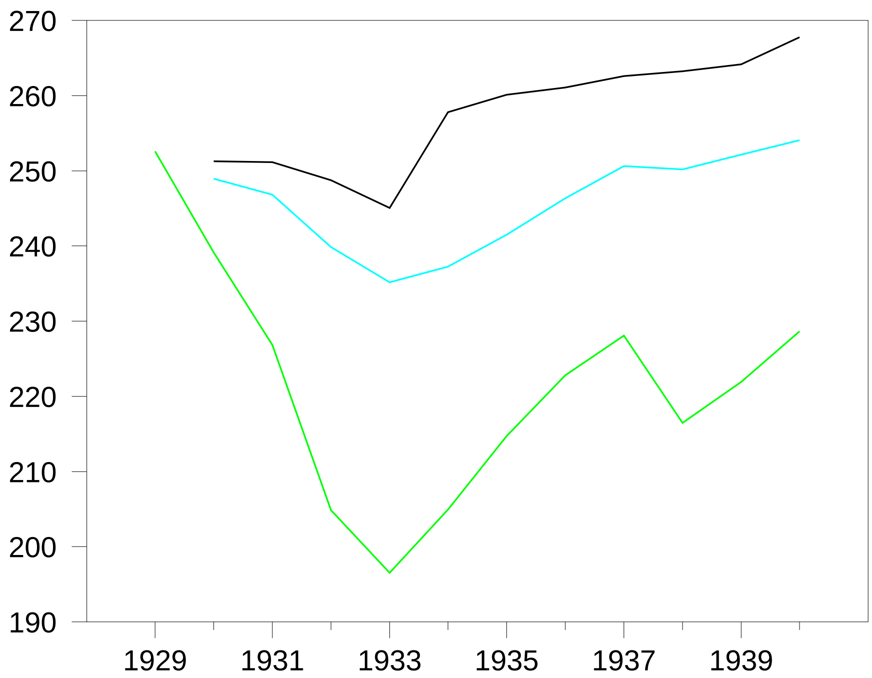
Note: Total hours worked. Dashed upper and lower lines show 90% confidence intervals calculated by a bootstrap Monte Carlo procedure with 1000 replications.

Figure 2.9: Technology Measures during the Great Depression



Note: The deterministic trend growth component is added to purified Solow residuals.

Figure 2.10: Output Forecasted by Technology Shocks



Solid line: output due to purified solow residuals as technology shocks
Upper dashed line: output due to the standard Solow residuals as technology shocks
Lower dashed line: actual detrended level of private nonfarm output

Note: Log-levels multiplied by 100.

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Chapter 3

Re-examining U.K. Wartime Economy in the Pre-World War I Period

3.1 Introduction

The war is a natural experiment of big and temporary fiscal shocks, since it induces an unexpected large increase in military spending, accompanied by the government's fund-raising. A seminal study is by Barro (1987), who interprets wars in which pre-World War I United Kingdom participated as large positive shocks to government *goods* purchases and argues that observed wartime rises in the interest rate support a prediction of the standard neoclassical model on the effects of a government goods purchases shock.[1] Theoretically, resource drain due to such shock, which means that goods become more valuable, makes the household raise labor supply and hence the marginal product of capital and, as a result, the real interest rate rises. His argument is so persuasive that it has been explained in prominent textbooks by Romer (2005) and Mankiw (2003).

This paper revisits the pre-W.W.I U.K. economy and asserts that his argument is not robust. While Barro studies only the behavior of the interest rate, we study that of the industrial production as well and find that the industrial production fell during wars in which pre-W.W.I U.K. participated. This finding casts doubt on Barro's argument, because, as we will show, the standard neoclassical model produces only one of the two phenomenons

[1]With a similar spirit, Braun and McGrattan (1993), Ohanian (1997), and McGrattan and Ohanian (2006) try to replicate macroeconomic behavior in U.S. or U.K. during W.W.I, W.W.II, or Korean War with a version of real business cycle models.

on impact, a rise in the interest rate or a fall in the industrial production, in response to any fiscal shocks other than tax shocks on the firm. The theory behind this result is that any fiscal shocks other than tax shocks on the firm cannot directly affect the marginal products of labor and capital. Therefore, on impact, labor demand is unchanged and hence a change in equilibrium hours is driven only by labor supply. As a result, for example, a rise in labor supply in response to fiscal shocks, which directly leads to a rise in equilibrium hours and a rise in output, raises the marginal product of capital and hence the interest rate.

Empirically, we not only look at data of the interest rate and the industrial production during wars but also take a narrative approach developed by Ramey and Shapiro (1998) in order to accurately grasp the impact responses of those variables to war starts. Ramey and Shapiro read *Business Week* and specify three dates when people appeared to initially expect the starts of three large military buildups in the post-World War II United States, that is, Korean War, Vietnam War, and Carter-Reagan military buildup. They estimate impulse responses of macroeconomic variables to the dummy variable which takes unity at the three dates and regard them as the effects of a positive government goods purchases shock. Following their procedure, we also identify twelve event dates associated with pre-W.W.I U.K.'s participation in wars and estimate the macroeconomic effects of war starts. It results in confirming a rise in the interest rate and a fall in the industrial production at the timing of war starts for U.K.

How can we understand a rise in the interest rate and a fall in the industrial production observed simultaneously during wars? We propose the hypothesis that the observed fall in the industrial production is consistent with the prediction of the standard neoclassical model and the rise in the interest rate arose outside the mechanism of the model. The key is that the wartime increase in military spending, all of which Barro regards as having been directed to goods, was also directed to *employment*. The effects of a government goods purchases shock and those of a government employment shock show a stark contrast in the standard neoclassical model and both effects are taken into account in some recent model-based studies on fiscal shocks (see, for example, Braun and McGrattan (1993), Finn (1998), Cavallo (2005), and McGrattan and Ohanian (2006)).[2] We reconfirm with the

[2]Braun and McGrattan (1993) try to replicate U.K. and U.S. macroeconomy during the W.W.II with their neoclassical model incorporating conscription as an exogenous variable. McGrattan and Ohanian (2006) do similar experiments focusing only on U.S. economy during W.W.II. Finn (1998) shows that government purchases lose a driving role for replicating U.S. business cycles in her neoclassical model when govern-

model simulation that the former raises labor supply, the interest rate, and output, while the latter dampens private hours, the interest rate, and private output. This distinction matters much in understanding macroeconomic effects of wars in the pre-W.W.I period, because military spending was much more labor intensive than in the later period, as will be shown later. When we give the model the shocks corresponding to average behavior of military spending and military employment across U.K. war episodes in pre-W.W.I period, the model generates falls in the private output and the interest rate. Therefore we understand that the wartime falls in the industrial production were due to military employment.

On the other hand, the wartime rises in the interest rate may be explained by rises in risk premium due to the possibility of defeat, as Mankiw (2003) and Barro suggest. We study yield spreads between the consol and foreign government bond in the nineteenth century and find a sign supporting it.

The reminder of this paper is as follows. Next section highlights some facts on U.K. wartime economy in the pre-W.W.I period. Section 3.3 analyzes U.K. wartime economy more formally with the narrative approach. Section 3.4 shows that the standard neoclassical model cannot explain at least one of our findings. Also, we focus on the role of military employment in that period and reinterpret the wartime economy. Section 3.5 gives an evidence that suggests that a driving force behind the rises in the wartime interest rate is risk premium. Section 3.6 contains concluding remarks.

3.2 A Look at Data for Pre-W.W.I U.K.

We begin with looking at data for pre-W.W.I U.K. in order to know wartime economy's characteristics. Figure 3.1.A plots the series of military spending as the share of the nominal GDP. Vertical lines show the event dates associated with U.K.'s participation in wars, which will be described later. The figure makes clear the fact that pre-W.W.I U.K. participated in many wars and the wars induced abrupt large increases in military spending. At the maximum, the ratio of military spending to nominal GDP rose to about 16 percent. The war is an event which is not only with such large military expenditure but also unantic-

ment goods purchases and compensation are distinguished. Cavallo (2005) estimates exogenous variations of government goods purchases and compensation in response to Ramey-Shapiro dates and simulates his neoclassical model with those. He shows that the distinction raises the model ability to replicate estimated macroeconomic responses to the dummy variable, especially a tiny decline of consumption.

ipated in general. Hence the wartime economy is a nice laboratory in studying the effects of fiscal shocks. Pre-W.W.I U.K., which participated in many wars, gives us an unmatched opportunity to study those.

For the later discussion, it should be noted here that the military spending data, which are taken from Mitchell (1988), include compensation, although Barro doesn't care the distinction between goods and compensation. Figure 3.1.B plots the series of military employment per capita. The military persons data are taken from Clode (1869) and the National Material Capabilities Data Set version 3.02. The former source describes the legal and administrative aspects of the British army. The latter source, which is described by Singer, Bremer, and Stuckey (1972), is the data set of national capability indicators.[3] The graph shows that military employment also surged during wars. At the maximum, it rose to near-two percent of the population.

Figure 3.2.A plots the series of the interest rate. One is the series of the consol rate over 18th and 19th centuries, taken from Homer (1977), and another is that of the short-term interest rate in 18th century, taken from Weiller and Mirowski (1990). The latter is a rate of return on East India bonds, which they choose, based on a document written in 1761, as the best index of the short-term interest rate because of the enough liquidity, the stable maturity, and the enough transferability. The figure shows that the interest rate seems to have risen during many wars, as Barro emphasizes. He focuses on the positive correlation between the consol rate and the military spending and, regarding all of the spending having been directed to goods purchases, asserts that it is consistent with the theoretical relationship between the real interest rate and government goods purchases.[4]

These interest rate series are not deflated. Barro tells that he cannot make a series of inflation expectation in the pre-W.W.II U.K. period in a reliable way and assumes that the expected inflation in 18th and 19th centuries was close to zero. This assumption is supported by Barsky (1987), who argues that U.K. WPI inflation during prewar years is autocorrelated but negatively and therefore seems to have been non-forecastable. Further-

[3]The data set includes data of military expenditure, military personnel, energy consumption, iron and steel production, urban population, and total population in 1816-2001.

[4]As Barro explains, we don't have a long-term series of the unregulated short-term interest rate and hence use the consol rate as a proxy for the short-term interest rate over the 18th and 19th centuries. The correlation between the consol rate and a rate of return on East India bonds, plotted in the Figure 3.2.A, being 0.69. supports this treatment.

more, Barro finds that military spending explains almost none of the variations in inflation in the Gold standard periods 1705-1796 and 1822-1913. Therefore this assumption seems appropriate in studying the relationship between the interest rate and military spending in the most part of the pre-W.W.I period.

Figure 3.2.B plots the series of the industrial production, which was recently developed by Crafts and Harley (1992), in the form of the deviation from the linear trend. It shows that, in contrast with the interest rate, industrial production seems to have been dampened during most wars. As shown later, a fall in output cannot be produced by a positive government goods purchases shock in the standard neoclassical model. Therefore the wartime behavior of output doesn't support Barro's assertion that pre-W.W.I U.K. wartime economy is consistent with the response of the standard neoclassical model to a positive government goods purchases shock.

3.3 Narrative Approach

3.3.1 Econometric Strategy

The previous section looked at U.K. data in order to study the behavior of wartime economy. This section examines macroeconomic responses to war starts more formally with the narrative approach developed by Ramey and Shapiro (1998).

Ramey and Shapiro's narrative approach regresses a log variable of interest x on own lags and the dummy series e that takes unity at the event dates when surges in military spending were expected:

$$x_t = F(L)\, x_{t-1} + G(L)\, e_t + \varepsilon_t \tag{3.1}$$

where $F(L)$ and $G(L)$ are lag operators. Then the impulse response of x to a unit shock on e is calculated. Ramey and Shapiro determine the dates when military buildups in U.S. post-W.W.II period were expected by reading *Business Week*.

Following them, we examine historical episodes about pre-W.W.I wars involving U.K. and determine event dates associated with U.K.'s participation in wars. We specify tentative shock dates first using dictionaries of history such as Howat (1973), Kenyon (1981), and Wetterau (1983), and then statistically test the exogeneity of dates using the series of military spending, military employment, the consol rate, and the industrial production. This procedure can avoid a large cost associated with identifying the dates based on articles published in the pre-W.W.I U.K. period. Although this strategy is a short-cut relative to the original narrative approach, it is still worth pursuing because of the following reasons. First, as shown below, the dictionaries will allow us to specify the timings of political events that resulted in U.K.'s participation in wars with acceptable accuracy, given that our data are annual basis. Such descriptive information is very useful in specifying the timings of unanticipated fiscal shocks. Second, as also shown later, a battery of Granger-causality tests will result in ensuring to much extent the exogeneity of specified dates and showing the dates leading to surges in military spending. Third, the intuition that wartime event dates can be specified with acceptable accuracy in annual basis seems to be common among other studies. Braun and McGrattan (1993) and McGrattan and Ohanian (2006) try to replicate wartime economy during W.W.II with their neoclassical model, determining the start year of wartime economy without referring the articles of those days.

3.3.2 War Episodes

We study historical episodes on wars involving U.K. by the historical dictionaries and pick up the wars of which we can specify the event dates associated with U.K.'s participation. In the procedure, if an event leading to U.K.'s participating in a war occurred between September and December but the actual participation realized in the first half of the next year, we think that the latter year is the first candidate of the shock date. This is because it is highly probable that the behavior of data in the former year was determined mainly by shocks prior to the event associated with U.K.'s participation in a war. Furthermore, if the specified dates were later than when people actually expected U.K.'s participation, the statistical test in the next section would reject the exogeneity of the dates.

Our study results in allowing us to use the following 12 war episodes as positive shocks to military spending.

War of Jenkin's Ear (1739-1743). The war was one between Britain and Spain, induced by the exclusion of British traders from Spain's American colonies. Under increasing British desire to break the Spanish monopoly, Captain Robert Jenkins's showing the remains of his ear in Parliament in 1738, which he claimed Spanish had cut off, stimulated the British national resentment against the Spanish. The war was declared in October 1739.

This timing of declaration suggests that military spending for the war was anticipated during the year. Therefore we specify *1739* as a shock date. This war merged into the War of Austrian Succession.

War of the Austrian Succession (1740-1748). In 1740 Maria Theresa's succession to the Hapsburg lands following the death of her father, Holy Roman Emperor Charles VI, was disputed by rival countries such as Bavaria, Prussia, and France and the war broke out. Britain sided with Austria in 1741 in order to prevent French dominance in Europe under the assumption that Austria collapsed. The British army was formed in 1742.

We tentatively assume that military spending for the war was anticipated during the year and specify *1742* as a shock date. But robustness is checked under the assumption that the shock date is 1741.

French and Indian War (1754-1763). Under rivalry over the upper Ohio Valley region between Britain and France, George Washington with colonial troops were sent to warn the French to leave the Ohio lands in 1754 but the French refused. Defense plans were coordinated at Albany in the same year and campaign against the French began under British Gen. Braddock in 1755.

We assume that military spending for the war was anticipated in the year of planning. Therefore we specify *1754* as a shock date. This war became part of the Seven Years' War.

Seven Years' War (1756-1763). The war evolved from the rivalry between Prussia and Austria. The immediate cause was the invasion of Saxony by Frederick, the Great of Prussia in 1756. George II of England allied with Fredrick in 1756 before the war start and British involvement was provoked by the French capture of British Minorca in the same year. Therefore we specify *1756* as a shock date.[5]

War of Independence (1775-1783). The military conflict that resulted in American independence began with battles of Lexington and Concord in April 1775. Before the battle starts, Boston Tea Party happened in December 1773 and Intolerable Acts were passed by British Parliament to punish Boston in 1774. The acts increased resentment among colonials and led to convening of First Continental Congress in September 1774.

[5]In 1756, a dispute between the ruler of Bengal in India and the East India Co. also occurred. It led to the Battle of Plassey in 1757.

It seems plausible to assume that the war was anticipated in the period between the dates of the Congress and the battles. Taking into account that the date of Congress is September 1774, we assume that the data in 1775 reflect the effects of the war start more than those in 1774. Therefore we specify *1775* as a shock date. But robustness is checked under the assumption that the shock date is 1774.

French Revolutionary Wars (1792-1802). The wars were provoked by the European monarchs' disapproval of the new revolutionary government. British involvement was brought about by the French invasion of the Austrian Netherlands in November 1792 and France declared war on Britain in February 1793.

Taking into account that the date of French invasion is November 1792, we assume that the data in 1793 reflect information on the war start more than those in 1792. Therefore we specify *1793* as a shock date. But robustness is checked under the assumption that the shock date is 1792.

Napoleonic Wars (1803-1815). The wars were ones between Napoleon I and various European states. Under rivalry between him and the British in the European continent, British refusal to evacuate Malta led to war in May 1803. Therefore we specify *1803* as a shock date.

War of 1812 (1812-1815). The war was one between U.S. and Britain stimulated by British harassment of U.S. shipping. Americans doubted that the British had provoked Indians to attack them at the Battle of Tippecanoe in November 1811 and, subsequently, "war hawks," who were U.S. Congressmen of the 12th Congress (1811-1813), promoted war with Britain vigorously. Then the war was declared by US in June 1812.

It seems plausible to assume that the war was anticipated in the period between the Battle and the declaration. Taking into account that the date of Battle is November 1811, we assume that the data in 1812 reflect effects of the war start more than those in 1811. Therefore we specify *1812* as a shock date. But robustness is checked under the assumption that the shock date is 1811.

Opium War (1839-1842). The war began because China attempted to enforce its ban on the import of opium and seized British-owned opium in Canton in 1839. British expeditionary force arrived in June 1840.

Although both 1839 and 1840 are the candidates of event date, we tentatively assume that the data in 1840 reflect the effect of war start more than the data in 1839 and specify

1840 as a shock date. But robustness is checked under the assumption that the shock date is 1839.

Crimean War (1853-1856). The war was one between Russia and France, Britain, Turkey, and Piedmont. Russia's occupying the part of Turkey in July 1853 and Turkey's declaration of war on Russia in October led to British participation to war in March 1854.

Taking into account that the date of Turkey's declaration of the war is October 1853, we assume that the data in 1854 reflect the effect of war start more than those in 1853. Therefore we specify *1854* as a shock date. But robustness is checked under the assumption that the shock date is 1853.

Arrow Incident (1856-1860). The cause of war was that the British ship *Arrow* anchored at Canton was boarded by Chinese officers in October 1856. British force arrived at Canton in December 1857.

Although it seems plausible to assume that military spending for the war was anticipated in 1857, the timing of a clear rise in military spending data is 1858. One reason might be that military spending decreased temporarily after the end of the Crimean War. Another reason might be that China's opposition to the Treaty of Tientsin in 1858 led to a new conflict. We focus on the event in 1858 and specify *1858* as a shock date. But robustness is checked under the assumption that the shock date is 1857.

Boer War (1899-1902). The war was one between the Boers and Great Britain under tension caused by conflicts of territorial claims between them in South Africa. British troop reinforcements were sent to South Africa in 1899 and the war broke out in October. Therefore we specify *1899* as a shock date.

In summary, we specify 12 shock dates consisting of 1739, 1742 (1741), 1754, 1756, 1775 (1774), 1793 (1792), 1803, 1812 (1811), 1840 (1839), 1854 (1853), 1858 (1857), and 1899. The second candidates are in parenthesis. Figure 3.1 indicates the dates by the vertical lines and shows that military spending and military employment rise after the dates.

Note that I excluded from our sample the wars in which we cannot specify the dates of political episodes associated with U.K.'s participation. Those include Maratha Wars (1775-1782, 1803-1805, and 1817-1818), Burma Wars (1824-1826, 1852, and 1885-1886), and Afghan Wars (1838-1842 and 1878-1880). King George's War (1744-1748) was also excluded since the Encyclopædia Britanica tells that there were little military aid from mother countries in the war.

3.3.3 Exogeneity Test for the Identified Dates

In order to ensure that unanticipated fiscal shocks occur at these dates, we follow the procedure of Ramey (2008) and Perotti (2008), which examines the Granger-causality relationships between the Ramey-Shapiro dates and VAR shocks.

We test whether the series which takes unity at the dates is Granger-caused by VAR shocks identified with the bivariate systems consisting of military spending and military employment and those consisting of the consol rate and the industrial production. The VAR shocks should include the fiscal shocks associated with wars and the other structural shocks. If the specified dates are exogenously determined and not later than when people expected wars, the dates series shouldn't be Grange-caused by the VAR shocks. At the same time, we test whether the dates series Granger-causes the VAR shocks arising from the bivariate systems of military spending and military employment. This test can confirm whether the events that occurred at those dates really led to surges in military spending and military employment.

We estimate the VAR shocks by the Choleski decomposition to the errors from the bivariate systems consisting of military spending and military employment and those consisting of the consol rate and industrial production. The systems include two lags of variables and time trend. The bivariate system consisting of military spending and military employment is similar with that used by Rotemberg and Woodford (1992), who study macroeconomic responses to fiscal shocks in U.S. post-W.W.II period with military goods purchases and military employment data.

Table 3.1 shows the results. First, it is impossible to reject the null hypothesis that the VAR shocks don't Granger-cause the dates series, regardless of included variables, the ordering of equations, and the number of shocks included in the tests. Second, we can safely reject the null hypothesis that the dates series doesn't Granger-cause the VAR shocks arising from the systems of military variables. These results suggest that unanticipated fiscal shocks occurred at the specified dates.

3.3.4 Estimation Results

We estimate the equation (3.1), using the dummy series that takes unity at the event dates. Dependent variables are military spending, military employment, the consol rate, and the industrial production. We include the linear trend in the equation. The effect of a fiscal shock is evaluated by the impulse responses obtained by giving a unit shock to the dummy series. Those correspond to the average wartime behavior of the variables across the war episodes.

Figure 3.3 shows mean responses with 90 percent confidence intervals calculated by a bootstrap Monte Carlo procedure with 1000 replications. Military variables rise sharply in response to a war start. The consol rate also significantly rises. On the other hand, the industrial production significantly falls. Note that these results not only confirm the findings in the section 3.2, but also show that the significant rise in the interest rate and the significant fall in the industrial production happen on impact. This finding is important when we interpret the results with the standard neoclassical model later.

We do some robustness checks. First, instead of using the linear trend, we detrend the consol rate and the industrial production by the Hodrick-Prescott filter. Estimated impulse responses are shown in the first row in Figure 3.4. Although not significant, the mean responses on impact are same as the baseline results: a rise in the consol rate and a fall in the industrial production.

Second, in the search of event dates associated with U.K.'s participation in wars, we were not able to uniquely identify the event dates for War of the Austrian Succession, War of Independence, French Revolutionary Wars, War of 1812, Opium War, Crimean War, and Arrow Incident. As a robustness check, we use alternative dates, that is, 1741, 1774, 1792, 1811, 1839, 1853, and 1857, instead of 1742, 1775, 1793, 1812, 1840, 1854, and 1858. Estimated impulse responses are shown in the second row in Figure 3.4. Although not significant, the consol rate rises on impact. The response of the industrial production is almost zero on impact but significantly negative in most periods that follow.

Third, the assumption of zero expected inflation rate may not be appropriate in the period when the gold standard was suspended. Barro shows that military spending in the suspension period 1797-1821 has a significantly positive effect on inflation. If the expected inflation also had risen in response to war starts in that period, including such war starts into our sample may have upward bias in the estimated responses of the consol rate. The behavior of the industrial production also may have been different between the Gold standard periods and the non-Gold standard period. Hence we remove the dummy variables representing the event dates for Napoleonic Wars and War of 1812, both of which occurred in the suspension period, and re-estimate the impulse responses. The results are shown in the third row in Figure 3.4. Those are almost same as the baseline results.

Fourth, the number of war episodes may not be enough, although the number of our episodes, 12, is much more than in Ramey and Shapiro's (1998) study, which uses U.S. three military buildup episodes in the post-W.W.II period. If it were the case, our results would represent extreme macroeconomic behavior in a limited number of war episodes. In order to evaluate the importance of each episode for the baseline results, we redo the above estimation replacing each of dummies for the 12 event dates with zero. The results shown in the fourth row in Figure 3.4 are qualitatively same as the baseline results, regardless of which episode is excluded. Hence the number of episodes seems enough.

In sum, the impact rise in the consol rate is robust to a detrending method, alternative event dates, the currency system, and the number of episodes. So is the impact fall in the industrial production in responses to the events, except for the case of alternative event dates. Even in the case of alternative dates, war starts are very contractionary to the industrial production.

3.4 Model-based Investigation on Observed Wartime Economic Behavior

3.4.1 Standard Neoclassical Model

Barro interprets the observed wartime rises in the consol rate as consistent with the prediction of the standard neoclassical model on an effect of a positive government goods purchases shock. On the other hand, he doesn't care the wartime behavior of output. We construct the standard neoclassical model including fiscal variables in order to study whether these two phenomenons can be interpreted simultaneously as the model response to a fiscal shock.

Firm sector. We construct the firm sector following the standard neoclassical setting. Any taxes on the firm or any subsidies for the firm are not assumed. Then we can prove that the interest rate and the private output move in the same direction on impact in response to any fiscal shocks.

The firm solves the following profit maximization problem:

$$\max \sum_{t=0}^{\infty} \prod_{s=0}^{t} \frac{1}{1+r_s} \left(f\left(k_t, n_t^P\right) - w_t n_t^P - i_t \right) \tag{3.2}$$

$$\text{s.t. } k_{t+1} = i_t + (1-\delta) k_t$$

where f is the production function, r is the real interest rate, k is the capital stock, n^P is the private hours, w is the real wage, i is the investment, and δ is the depreciation rate. We assume the standard properties of the production function: $f_k > 0$, $f_{kk} < 0$, $f_{n^P} > 0$, $f_{n^P n^P} < 0$, and $f_{kn^P} > 0$. The first order conditions are the followings:

$$-q_t + \frac{1}{1+r_{t+1}} \left(f_{k_{t+1}} + q_{t+1} (1-\delta) \right)) = 0, \tag{3.3}$$

$$f_{n^P} = w_t, \tag{3.4}$$

$$\text{and } q_t = 1, \tag{3.5}$$

where q is the Lagrangian. Note that the private output y^P is defined as

$$y_t^P \equiv f\left(k_t, n_t^P\right). \tag{3.6}$$

The first order conditions (3.3) and (3.5) imply

$$f_{k_t} = r_t + \delta. \tag{3.7}$$

Under this setting, we can assert the following proposition:

Proposition 1 *If the firm solves the profit maximization problem (3.2), the real interest rate and the private output move in the same direction on impact in response to all types of shocks.*

Proof. *Totally differenciate the equation (3.7) with respect to time and evaluate it at the shock period, noting that the capital stock k_t is the state variable. Then we get*

$$f_{kn^P}\Delta n_t^P = \Delta r_t.$$

Totally differenciate (3.6) with respect to time and evaluate it at the shock period. Then we get

$$\Delta y_t^P = f_{n^P}\Delta n_t^P.$$

From these two equations, we get

$$\Delta y_t^P = \frac{f_{n^P}}{f_{kn^P}}\Delta r_t.$$

Since $f_{n^P} > 0$ and $f_{kn^P} > 0$ by assumption, the sign of Δy_t^P and the sign of Δr_t are same. ■

As asserted in the proposition, the real interest rate and the private output moves in the same direction on impact in response to all types of shocks but shocks that can be added to the firm's profit maximization problem. Note that this property holds regardless of settings of the household. Intuitively speaking, since the capital stock is fixed at the shock period, the response of output is only due to hours. A rise in output requires a rise in hours, which raises the marginal product of capital stock and hence the interest rate. Importantly, Kimball (2003) shows in an analytical way that this property holds as for a government goods purchases shock in the standard neoclassical model with the capital adjustment cost. These results suggest that one of a rise in the interest rate or a fall in the industrial production observed in the wartime U.K. economy in the pre-W.W.I period should arise outside the mechanism of the standard neoclassical model.

Household sector. The household solves the following utility maximization problem:

$$\max \sum_{t=0}^{\infty}\beta^t u\left(c_t, n_t\right)$$

$$\text{s.t. } a_{t+1} = \left(1 + r_t\right) a_t + w_t n_t - c_t$$

where β is the discout factor, c is the consumption, n is the labor supply, and a is the asset. u is the utility function, which has the standard properties: $u_c > 0$, $u_n < 0$, $u_{cc} < 0$, and $u_{nn} < 0$.

The first order conditions are as follows.

$$u_c = \lambda_t,$$

$$u_n = -\lambda_t w_t$$

$$\text{and } \lambda_t = \beta\lambda_{t+1}\left(1 + r_{t+1}\right).$$

Equilibrium conditions. We assume that the government buys goods (and services) and hours from the markets. Then the goods market equilibrium condition and the labor market equilibrium condition are

$$f\left(k_t, n_t^P\right) = c_t + i_t + g_t$$

$$\text{and } n_t = n_t^P + n_t^G,$$

where g is the government goods purchases and n^G is the government hours. The gross domestic product y is defined as

$$y_t \equiv y_t^P + w_t n_t^G.$$

Note that we don't make any special mechanism specific to the wartime economy. Barro explains that U.K. economy during wars before W.W.I was not of the command economy. Hence we can simply compare the behavior of this standard model with that of wartime data.

3.4.2 Government Goods Purchases Shock

First, we reconfirm theoretical effects of a government goods purchases shock. For this purpose, the utility function and the production function need to be specified and the model parameter values also need to be calibrated. We set the parameter values as replicating the pre-W.W.I U.K. economy as possible.

The utility function follows one of functional forms used by Burnside, Eichenbaum, and Fisher (2004), who compare estimated impulse responses of macroeconomic variables to Ramey-Shapiro dates with model responses. Specifically we use

$$u(c_t, n_t) = \ln c_t + \frac{1}{1-\mu}(1-n_t)^{1-\mu}$$

where $\mu = 10$ and $n_* = 0.24$, where asterisk represents the steady state.[6] Then implied labor supply elasticity is 0.32.[7] We set $\beta = 0.98$.

The production function is the standard Cobb-Douglous with the capital share α being 0.3:

$$f\left(k_t, n_t^P\right) = k_t^{\alpha}\left(n_t^P\right)^{1-\alpha}.$$

We set the other parameters replicating U.K. economy in 1921, which is regarded as at the steady state. The 1920 economy is the oldest U.K. economy that we can replicate with enough data corresponding to our model. The data are from Feinstein (1976). We choose the 1921 economy, instead of the 1920 economy, since the effects of W.W.I still seem to remain much in the data of military spending and military employment for 1920. As a result, the steady state shares of consumption, investment, and government goods purchases in the private output are 0.88, 0.07, and 0.05 respectively and the steady state share of private output in GDP is 0.95. We assume that hours-per-worker are same across sectors at the steady state because I didn't find sectoral hours data. Then the steady state shares of private hours and government hours in total hours are same as those of private employment and government employment in total employment: 0.94 and 0.06.

Figure 3.5 shows the effects of one-percent positive shock to government goods purchases, which follows AR(1) process with the coefficient 0.90. The shock makes output more valuable and hence the household increases labor supply and reduces consumption. As a result, GDP increases and, with the marginal product of capital increasing, the interest rate rises. Therefore, when we regard all of the military spending as directed to goods,

[6]Ramey and Francis (2008) find that, in the case of U.S., hours of work for prime age individuals are essentially unchanged for 106 years. Therefore using the steady state hours of Burnside, Eichenbaum, and Fisher, 0.24, for replicating pre-W.W.I U.K. economy is not necessarily inappropriate.

[7]Alogoskoufis (1987) shows that the labor supply elasticity estimate based on post-W.W.II U.K. data is 0.37 when the labor supply is evaluated by the number of employees.

we can replicate wartime rises in the interest rate with the model, but not replicate wartime falls in output.

3.4.3 Government Employment Shock

We can replicate a fall in private output, instead of a rise in the interest rate, with a government employment shock. This is because a rise in government employment reduces hours available for the private sector. Figure 3.6 shows the effects of one-percent positive shock to government hours. Those are dramatically different from the effects of a government goods purchases shock. Private output falls corresponding to a fall in private hours. Since the marginal product of capital falls, the interest rate also falls. We still observe that the household raises labor supply and reduces consumption because the resource in the economy becomes more scarce, but such rise in labor supply cannot offset the outflow of hours to the government sector. GDP, which is the sum of private output and the compensation in the government sector, rises.

We emphasize the role of government employment shock in the wartime economy in the pre-W.W.I period, since the following evidences suggest that the military spending in that period was much more labor intensive than in the later period.

First, as shown in Figure 3.7.A, the level of real military spending per military employment in U.K. was much lower in the pre-W.W.II period than in the post-W.W.II period. For example, the 1725-1938 average was 189 pounds while the 1946-1979 average was 480 pounds. Note that the effect of a rise in military employment depends on the share of the compensation in military spending, which is the inverse of military spending per military employment multiplied by wage. Although I didn't find the time series data of military compensation share in the pre-W.W.I period, our finding strongly suggests that the military compensation share was higher in the pre-W.W.II period.

Second, the share of compensation in military spending was very large in the national budget for a specific year in the pre-W.W.I period. Table 3.2 shows the detailed votes granted by the parliament for Navy and Army services in the financial year commencing from 31st March 1869. The data are taken from an official report written by Hunt and Ayrton (1869) for the House of Commons, which collects the data for U.K. public income and expenditure. We present the data as some aggregated items, each of which is the sum of original items whose main components seem common. The important feature is that the share of wages amounts to almost 50 percent of military spending. If we compose the labor intensive item by adding the items of "salaries and contingent expenses" and "services and supplies" to "wages," it consists of 65 percent.

Third, the share of compensation in U.K. military spending began to follow a declining trend in the post-W.W.I period. Figure 3.7.B shows the time series data of military compensation share in military spending after W.W.I, which is calculated with data taken from Feinstein (1976) and U.K. National Statistics Online. It had been above 60 percent until 1925, but fell rapidly into near-20 percent between mid-1930s and W.W.II, and recently remains below 40 percent. This fact also suggests that the share of compensation in the military spending was much higher in the pre-W.W.I period than in the post-W.W.I period.

Fourth, the behavior of U.S. series is surprisingly similar with that of U.K. series. If the composition of military spending didn't differ so much across major countries, U.S. data in the pre-W.W.II period should be useful in evaluating the factor intensity of U.K. military spending. Figure 3.7.C plots the series of U.S. military spending per military employment and U.S. compensation share in military spending. U.S. series of military spending per military employment has also followed a rising trend in the post-W.W.II period. Furthermore, the military compensation share in the beginning of 1930s was well above 60 percent, which is almost same level as the U.K. share in that period, and fell dramatically toward W.W.II. It would be an internationally common feature of military spending that the military compensation share was higher in the pre-W.W.I period.

3.4.4 Government Goods Purchases Shock vs. Government Employment Shock in the Pre-W.W.I Wartime Economy

These evidences suggest that the effect of an increase in military employment for the wartime economy was much larger in the pre-W.W.I period than in the post-W.W.I period. If the effect of an increase in military employment dominates that of an increase in military goods purchases in the standard neoclassical model, the observed wartime falls in industrial production, which is a proxy of the private output, are consistent with the prediction of the model but the rises in the interest rate are not.

In order to evaluate which effect is larger, it is necessary to give shocks corresponding to average wartime scales to both of government goods purchases and government employment in the model and see the model response. We log-linearize the model and feed the average paths of military spending and military employment over 50 years in response to war starts, of which 10 years paths are shown in Figure 3.3, into the model.[8] Since military spending includes both of goods purchases and compensation, we add the following equation to the model:

$$s_t = g_t + w_t n_t^G$$

where s is government spending. Shocks are given to government spending s and government hours n^G and government goods purchases g is endogenously determined in the level consistent with the levels of exogenously given s and n^G.[9]

The parameter of compensation share in military spending in the steady state is set to 0.60. This value corresponds to the compensation share in military spending in 1921, which is shown in Figure 3.7.B. The steady state shares of government hours and government goods purchases in labor market and goods market are scaled down to 0.03 and 0.01 respectively, corresponding to those of military hours and military goods purchases.

The result is shown in Figure 3.8. In response to the shocks, private output and the interest rate fall. At the bottom, private output and the interest rate deviate from the steady states by more than one percent and ten percent point respectively. These responses show that the effects of wartime rises in military employment in pre-W.W.I U.K. dominate those of wartime rises in military goods purchases in the standard neoclassical model on average. Therefore the fact that is consistent with the prediction of the model about pre-W.W.I wartime U.K. economy is the falls in industrial production, not the rises in the interest rate.

Is it possible that other shocks explain the wartime behavior of the industrial production and the interest rate? The representative candidate of shocks potentially occurring during wars is the tax shock, because the government needs to finance military spending.[10] However, Barro shows that 96 percent of U.K. pre-W.W.II temporary military spending would

[8] The responses converge to almost zero in 40-50 years after the shock period.

[9] We assume that total population and military hours per military employment are unchanged in response to war starts. Then the wartime percent change of n^G, military hours per capita in the case of this simulation, is same as that of military employment.

[10] Burnside, Eichenbaum, and Fisher (2004) study the behavior of their model in response to shocks to tax rates on capital and labor income as well as to government purchases during post-W.W.II U.S. three military buildup episodes. Cooley and Ohanian (1997) assert that the higher capital income tax during W.W.II made the postwar growth performance of Britain poorer than that of U.S. Ohanian (1997) attributes differences in U.S. wartime economic behavior across W.W.II and Korean War to the way of financing wartime expenditure.

have been financed by debt issues. Although, as explained by Bordo and White (1994), French Revolutionary Wars led England to institute an income tax, the data of standard rate of income tax, which are seen in Mitchell (1988), don't show any responses to the starts of wars. Hence it seems that we don't have to care such shocks in studying the U.K. wartime economy in the pre-W.W.I period.

3.5 Reinterepreting the Behavior of Interest Rate

The remaining task is to explain the source of the wartime rises in the interest rate. Mankiw (2003) and Barro suggest that those may be explained by rises in risk premium due to the possibility of defeat, but they don't show any evidences.

We focus on yield spreads between U.K. consols and the other government bonds, which rose if such rises in risk premium occurred. Homer (1987) explains that foreign bonds were made in London in volume soon after the Napoleonic wars and tables some of spreads of foreign bonds from consols. Since he notes that spreads of bonds issued by colonial governments from consols declined over 19th century because of improving popularity of such bonds among British investors, we guess that the spreads of foreign bonds also had declining trend. Hence, if wartime spreads of foreign bonds were lower than in the postwar peacetime periods, it is a sign indicating that war-specific factors such as rises in risk premium on consols shrunk the spreads.

Homer's table includes four cases that enable us to compare wartime spreads with postwar peacetime spreads of same countries' bonds. As shown in Table 3.3, the wartime spreads were lower than the peacetime spreads in all the cases. It supports the hypothesis that the consol rate rose due to risk premium.

3.6 Conclusion

We find that not only rises in the interest rate but also falls in industrial production were significant in U.K. during wars in the pre-W.W.I period. Although Barro focuses only on the the former and asserts that it is consistent with the response of the standard neoclassical model to a government goods purchases shock, we prove that the standard neoclassical model cannot generate both phenomena simultaneously in response to fiscal shocks. When we give the model the shocks corresponding to average behavior of military spending and military employment across U.K. war episodes in the pre-W.W.I period, the model generates falls in the private output and the interest rate. This is because the effect of wartime rises in military employment, which reduce labor available for private sector, private output, and the marginal product of capital, dominates that of military goods purchases. According to this result, we understand that the wartime falls in the industrial production were due to military employment. On the other hand, the rises in consol rates may be explained by rises in risk premium, since the data of yield spreads of foreign issues in London from consols declined during wars.

Empirically studying the effects of government goods purchases and government employment is in the important future research agenda. In the literature, the number of empirical studies on the effect of changes in government employment is very limited. The studies use post-W.W.II U.S. data and find evidences contrary to inferred from ours: private hours increase in response to government employment shocks. Perotti (2008) adopts a structural vector autoregression approach (SVAR) using external information on the elasticity of fiscal variables to other macroeconomic variables. Pappa (2005) also adopts an SVAR approach using sign restrictions. On the other hand, Rotemberg and Woodford (1992) estimate a bivariate system which orders military goods purchases first and military employment second and identify two structural shocks by the Choleski decomposition. Then they estimate another multivariate system including those series as exogenous shocks and calculate impulse responses of variables of interest to the shocks. A problem of this approach is that they don't distinguish the two types of fiscal shocks in reality, since both of the first and the second structural shocks affect military employment at the shock period.

Appendix A. Data Sources

U.K.

Interest Rate: The consol rate series, of which data are taken from Homer (1977), is constructed following Barro (1987).

Military Spending: U.K. Data after 1802 are taken from Mitchell (1988). Data up to 1801 are the sum of Great Britain's data taken from Mitchell (1988) and Ireland's data taken from Hunt and Ayrton (1869). Other data-constructing procedures follow Barro (1987): the data combine the items of army, navy and ordnance, special expeditions, and votes of credit. The fiscal year data ended September 29 in 1729-51 and those ended October 10 in 1752-99 are treated as the calender year data. The fiscal year data ended January 5 in 1801-54 and those ended March 31 in 1855-1919 are treated as the prior calender year data. The constructed series is deflated by the price series explained below.

Data from 1920 to 1938 in Figure 3.7.B are taken from Feinstein (1976). Data from 1998 to 2003 in the same figure are taken from U.K. National Statistics Online.

Military Persons: Data up to 1815 are taken from Clode (1869). Data after 1816 are taken from the National Material Capabilities data set version 3.02. The former is linked to the latter in 1815 by the ratio of the two data in 1816. The National Material Capabilities data set is available in http://www.correlatesofwar.org/ and explained by Singer, Bremer, and Stuckey (1972).

Nominal GDP: Data since 1830 are taken from Mitchell (1988). The data are extrapolated by data for Great Britain up to 1801. The data for G.B. are also taken from Mitchell (1988) and linearly interpolated. Furthermore the connected data are extrapolated by data for England and Wales, which are taken from Mitchell (1988) and linearly interpolated.

Population: Data up to 1800 are the sum of Griffith's series for England and Wales, Connel's series for Ireland, and Sir Sinclair's series for Scotland, the former two series of which are from Mitchell (1988) and the last of which is from Deane and Cole (1962). Each series is linearly interpolated. Data from 1801 is from Mitchell (1988).

Price: The data after 1870 are taken from Feinstein's (1976) deflator of public authorities' current expenditure on goods and services. The data series is linked with Sauerbeck index of commodities in 1870, Gayer, Rostow and Schwartz index of domestic and imported commodities in 1850, and Schumpeter-Gilboy index of consumer goods in 1790. The latter three index are taken from Mitchell (1988).

U.S.

Military Spending: Data up to 1929 are for the spending of the department of army and the department of navy taken from U.S. Department of Commerce (1989). Data after 1929 are taken from the Bureau of Economic Analysis homepage. Real military spending series up to 1929 is constructed using price data described below.

Military Persons: Data are taken from the National Material Capabilities data set version 3.02.

Price: Price series up to 1929 is GNP deflator series calculated with nominal GNP series and real GNP series taken from U.S. Department of Commerce (1989). The series is spliced to the BEA GDP deflator series in 1929.

Appendix B. Aggregation in Table 3.2

The details of items in Table 3.2 are as follows:

Wages

Wages to seamen and marines; half pay, reserved, and retired pay to officers of the navy and royal marines; general staff and regimental pay, allowances, and charges at home and abroad exclusive of India; reserve force; rewards for distinguished services; pay of general officers; full pay of reduced and retired officers, and half pay; non-effective services of militalia, yeomanry cavalry and volunteer corps.

Salaries and contingent expenses

Salaries and contingent expenses of admiralty office; salaries and expenses of coast guard service, royal naval coast volunteers, and royal naval reserve; salaries of officers and contingent expenses of the several scientific department of the navy; salaries of the officers and contingent expenses of her majesty's dockyards and naval yards, at home and abroad; salaries of the officers and contingent expenses of her majesty's victualling yards and transport establishments, at home and abroad.

Transfers

Military and civil pensions and allowances; widow's pensions and compassionate allowances; pensions and allowances to wounded officers; Chelesa and Kilmainham hospitals, and in-pensions; out-pensioners of Chelsea hospital &e.; superannuation allowances.

Services and supplies

Naval medical establishments at home and abroad; royal marine divisions; martial law and law charges; various naval miscellaneous services; commissariat establishment, services, and movement of troops; clothing establishments, services and supplies; barrack establishments, services and supplies; divine service; administration of martial law; hospital establishment, services and supplies; establishments for military education; surveys of the United Kingdom; miscellaneous services of the army; administration of the army.

Freight

Freight of Ships for the Victualling and Conveyance of Troops.

Victuals, clothing, stores, works, and buildings

Victuals and clothing for ditto; naval stores for building, repair, and outfit of the fleet and coast guard; steam machinery, and ships built by contract; new works, buildings, machinery, and repairs in the naval establishments; medicines, medical stores, &.e.; military store departments, for supply and repair of warlike and other stores, for land and sea service, including manufacturing departments; superintending establishment of, and expenditure for, works, buildings, and repairs, at home and abroad.

Table 3.1: Granger Causality Tests

Null hypothesis: VAR shocks don't Granger cause war starts dates	P-value
Ordering: military spending first and military employment second	
VAR shocks-1: first structural shocks	0.378
VAR shocks-2: second structural shocks	0.931
Ordering: military spending first and military employment second	
VAR shocks-3: first structural shocks	0.993
VAR shocks-4: second structural shocks	0.360
VAR shocks-1 and -2 or -3 and -4	0.730
Ordering: consol rate first and industrial production second	
VAR shocks-5: first structural shocks	0.247
VAR shocks-6: second structural shocks	0.749
Ordering: industrial production first and consol rate second	
VAR shocks-7: first structural shocks	0.718
VAR shocks-8: second structural shocks	0.258
VAR shocks-5 and -6 or -7 and -8	0.497
Null hypothesis: War starts dates don't Granger cause VAR shocks	**P-value**
VAR shocks-1	0.001
VAR shocks-2	0.000
VAR shocks-3	0.000
VAR shocks-4	0.000

Table 3.2: Composition of Votes Granted by the Parliament for Navy and Army Services in 1869-70

Item, main component of which is:	%
Wages	45.1
Salaries and contingent expenses	6.7
Transfers	9.8
Services and supplies	13.9
Freight	1.3
Victuals, clothing, stores, works, and buildings	23.1

Notes: The data is for a fiscal year commencing March 31. See an appendix on aggregation.

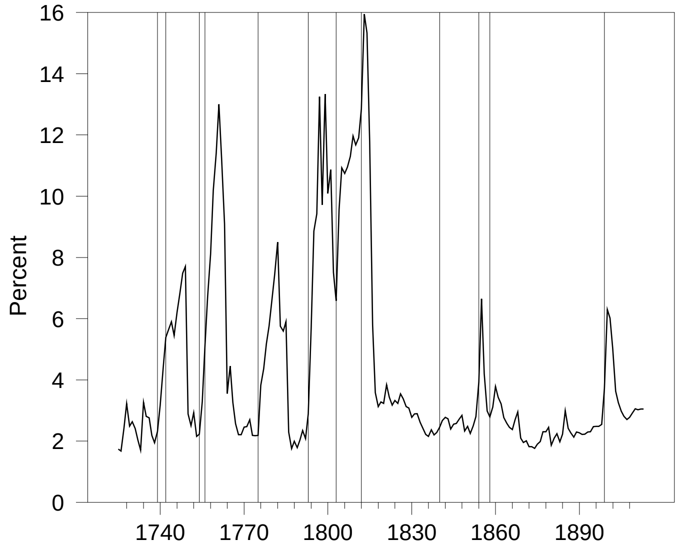
Table 3.3: Spread of Stering Bond Issued by Foreign Governments

	Wartime Spread	Peacetime Spread
Russia	136 (1859)	343 (1867)
Brazil	336 (1824), 235 (1825)	546 (1829)
Brazil	313 (1839), 172 (1852)	340 (1865)
Argentina	375 (1824, issued by Buenos Aires)	459 (1866)

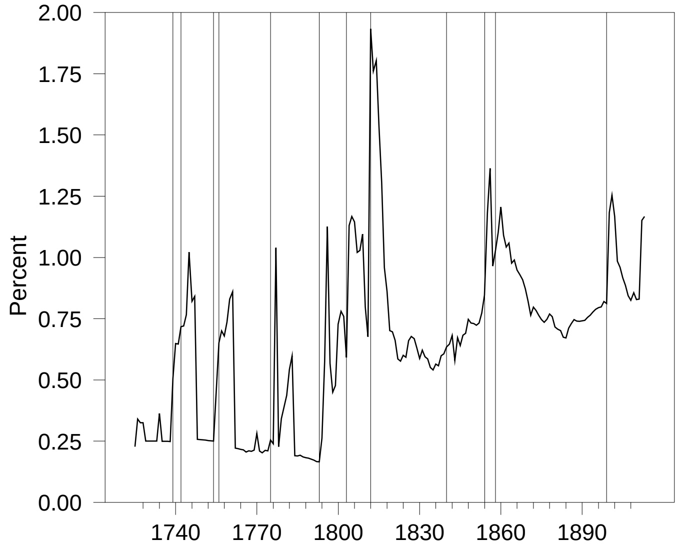
Note: Yield difference from annual average of Consols. Basis points. Issuance years are indicated in parentheses.

Figure 3.1: Military Spending and Military Employment for Pre-W.W.I U.K.

A. Ratio of Military Spending to GDP



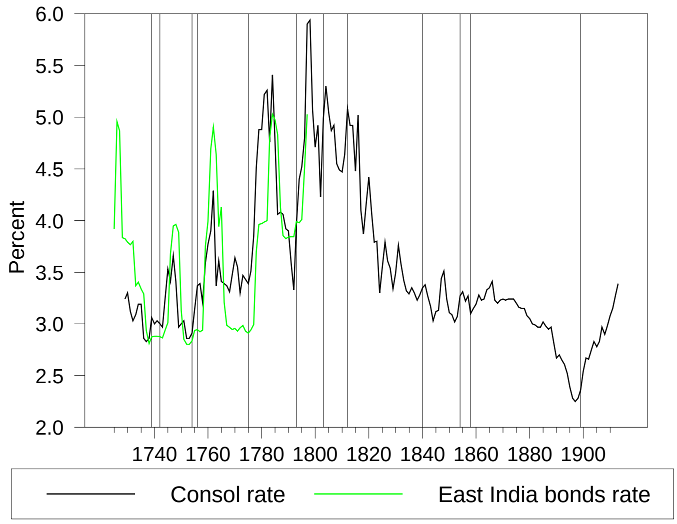
B. Military Employment per Capita



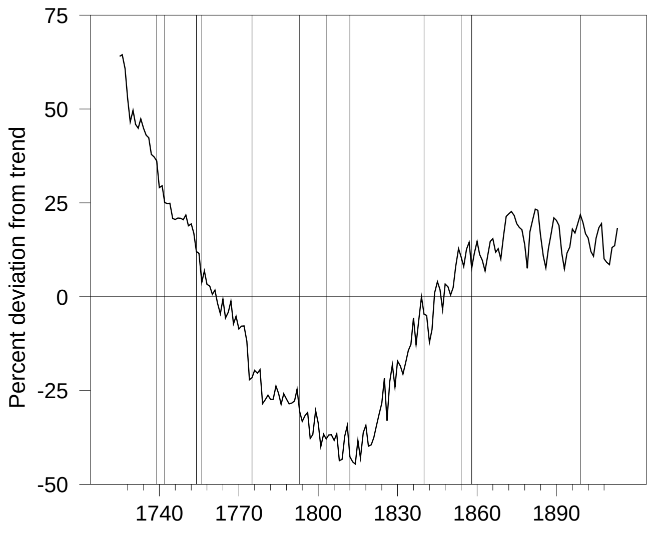
Note: Vertical lines show war start dates.

Figure 3.2: Interest Rate and Industrial Production for Pre-W.W.I U.K.

A. Interest Rate

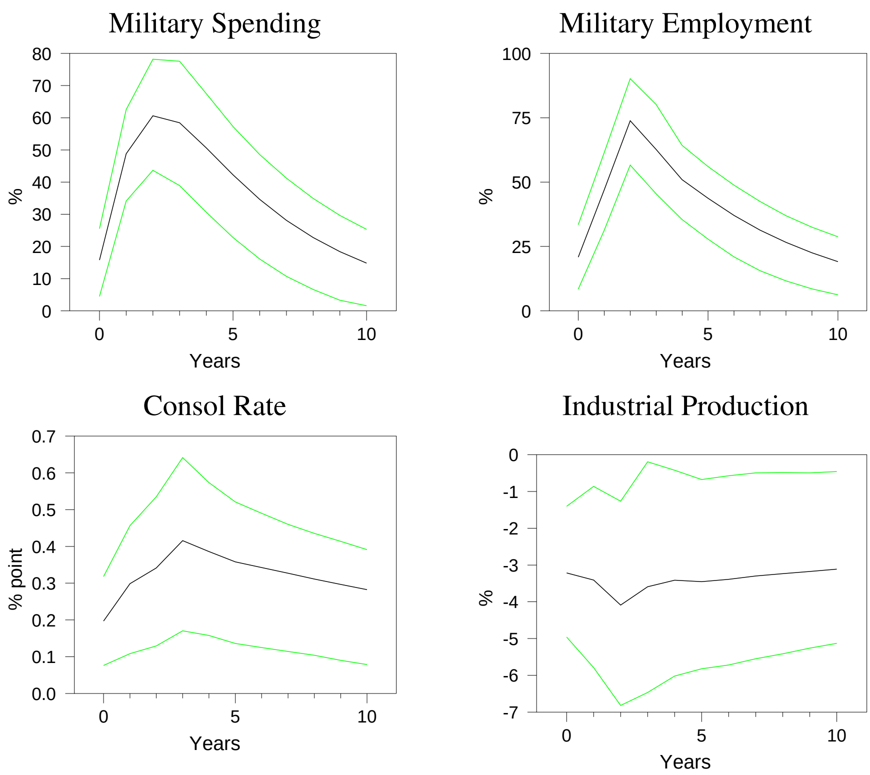


B. Industrial Production



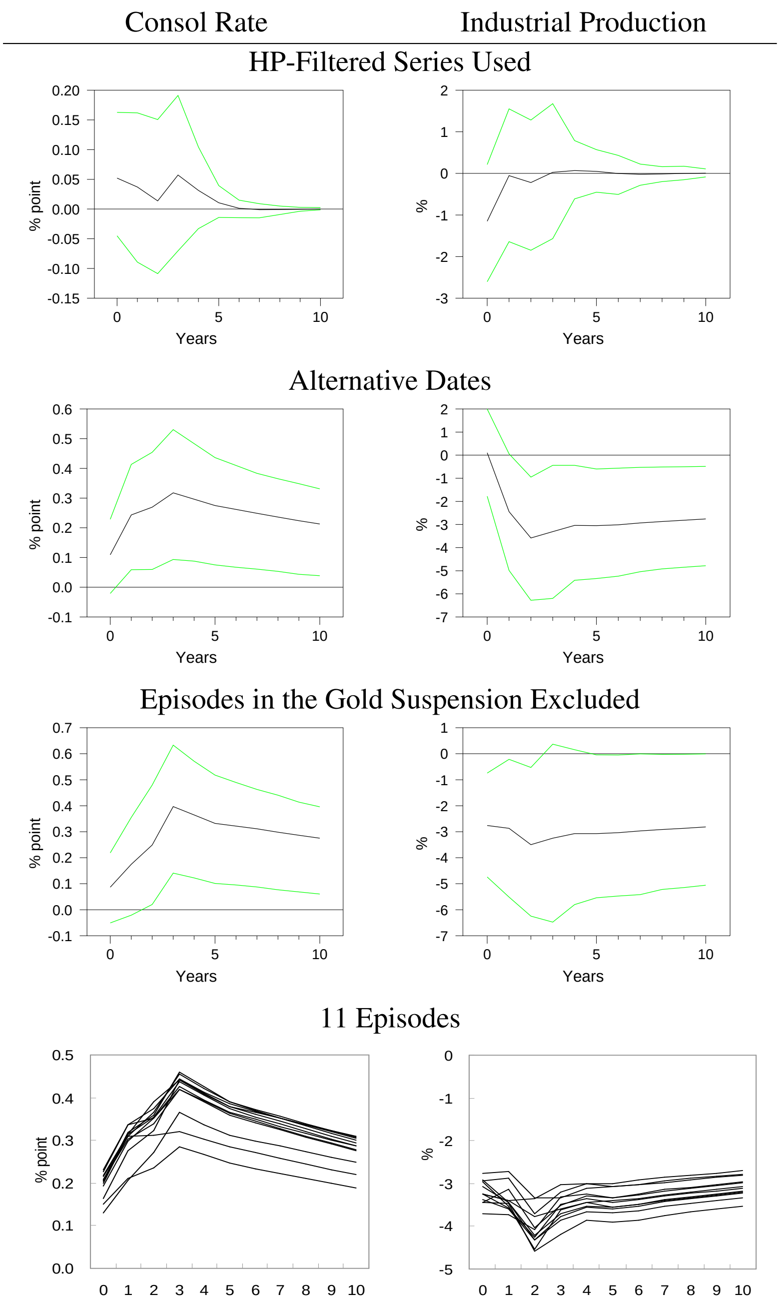
Note: Vertical lines show war start dates.

Figure 3.3: Impulse Responses to the Dummy Series



Note: Upper and lower lines show 90% confidence intervals.

Figure 3.4: Robustness Checks



Note: Upper and lower lines show 90% confidence intervals.

Figure 3.5: Government Goods Purchases Shock

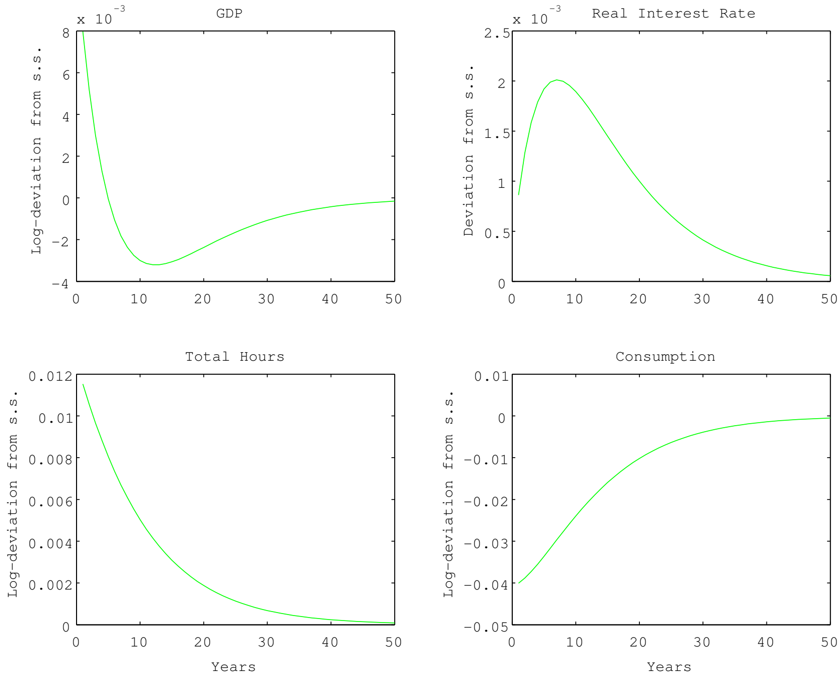


Figure 3.6: Government Employment Shock

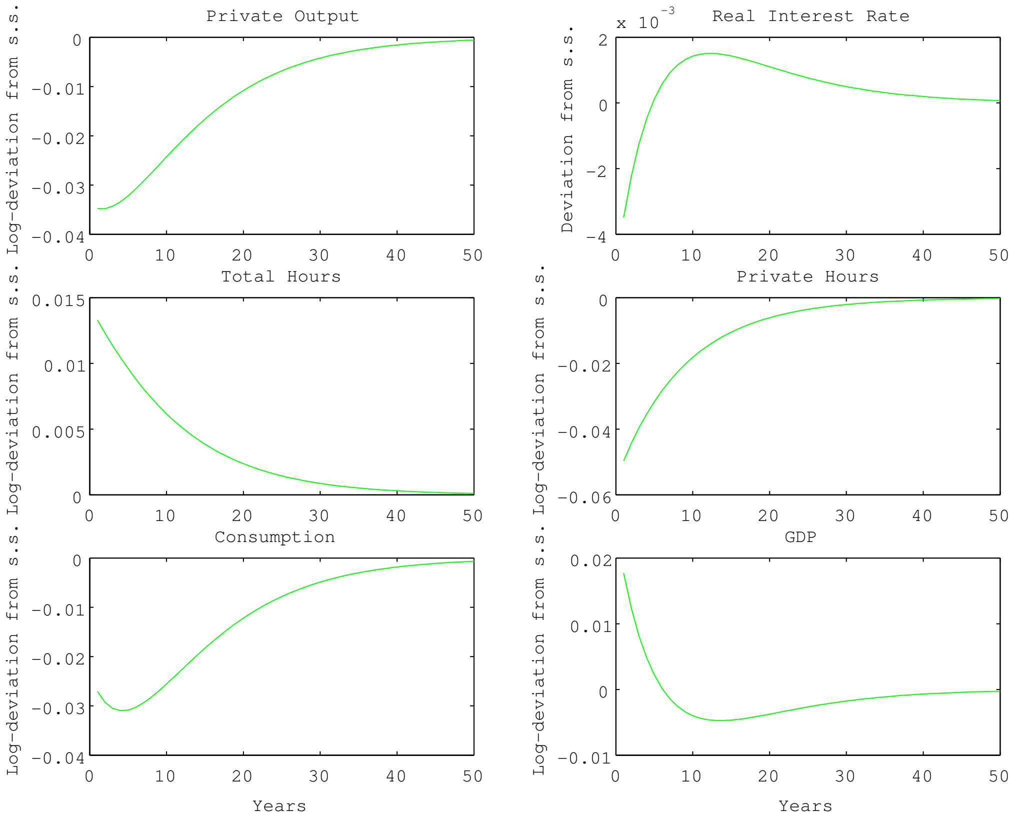
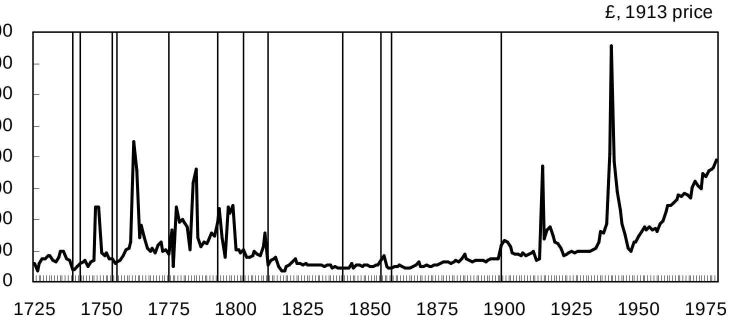
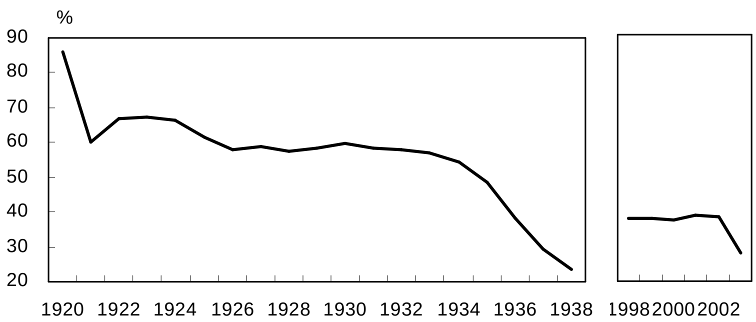


Figure 3.7: Military Employment

A. U.K. Military Spending per Military Employment



B. U.K. Military Compensation Share in Military Spending



C. U.S. Labor Intensity of Military Spending

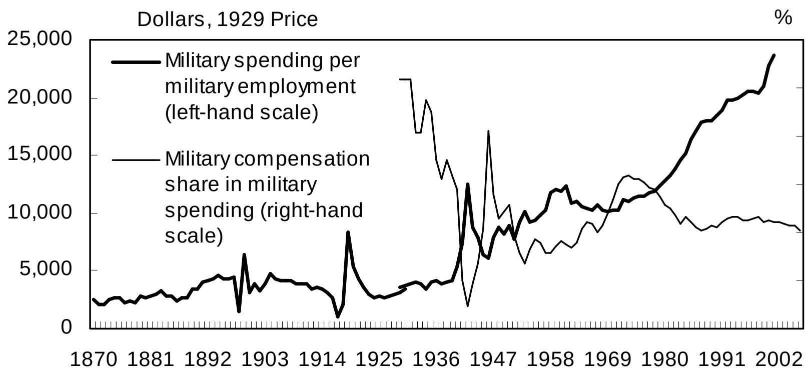
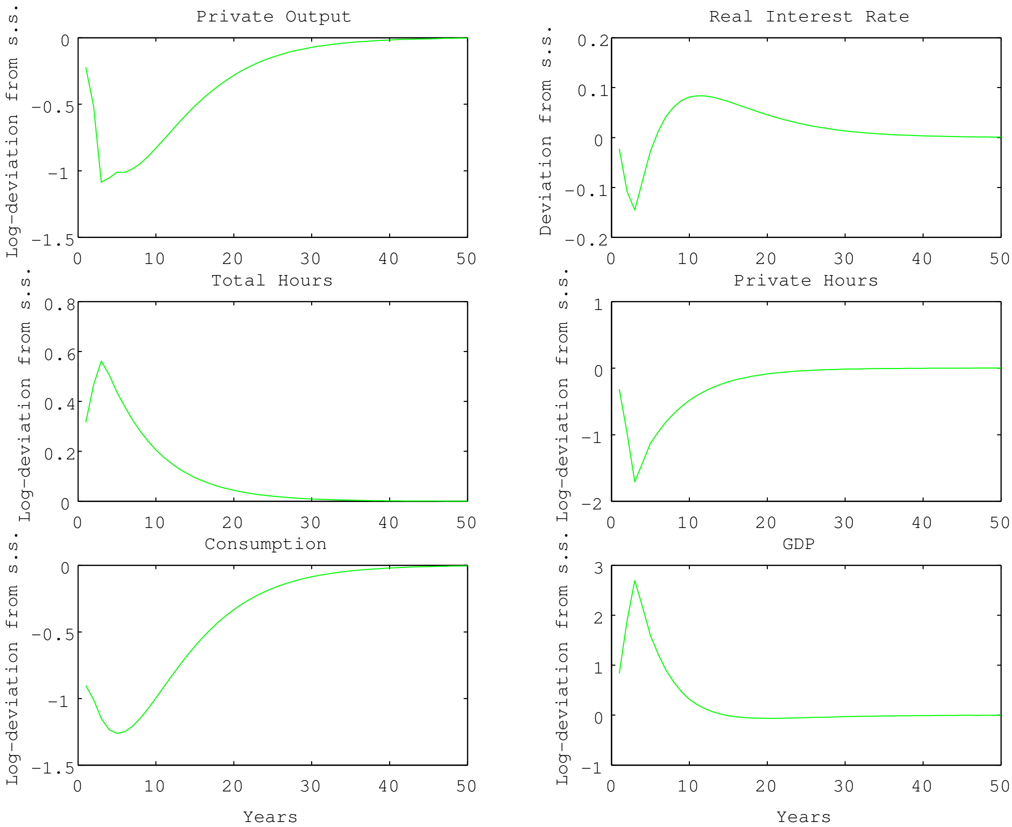


Figure 3.8: Replicating Wartime U.K. Economy



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