Investment Specific Technological Changes in Japan

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This paper studies the role of investment specific technological changes in economic fluctuations in Japan. Following Greenwood, Hercowitz, and Huffman (1998) and Fisher (2006), we model a consumption goods producing sector and an investment goods producing sector, and consider technological changes that are common to the two sectors as well as one that is specific to the latter sector. We evaluate each shock's role using two approaches. In the first approach, we extend the model of Hayashi and Prescott (2002) by incorporating investment specific technological changes. This model is calibrated to the Japanese economy. In the second approach, we estimate an SVAR model with sign restrictions (Uhlig 2005) in which the restrictions are derived from implications that are common to competing major dynamic general equilibrium models incorporating investment specific technology shocks. The first exercise suggests that investment specific technological improvements sustained the potential growth rate of the Japanese economy in its "lost decade." The second exercise shows that investment specific technology shocks are at least as important as neutral technology shocks in Japan's business cycles.

Keywords: Investment specific technology, Neoclassical growth model, VAR with sign restrictions, Japanese economy

JEL Classification: E10, E22, E32

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I. Introduction

This paper re-examines the role of investment specific technological changes in the Japanese economy. Unlike most of previous work on related topics that use one sector models, we model a consumer goods producing sector and an investment goods producing sector. We consider not only technological changes that are common to both sectors (called "neutral technological changes") but also those that are specific to the latter sector (called "investment specific technological changes"). Our results demonstrate the importance of the latter type of technological changes.

Two notable studies have demonstrated the potential importance of incorporating investment specific technological changes in analyzing the U.S. business cycles. In the theoretical literature, Greenwood, Hercowitz, and Huffman (1998) develop a Real Business Cycle Model with investment specific technology shocks, and show that this model can replicate important business cycle features of the U.S. economy. In the empirical literature, Fisher (2006) extends the structural VAR approach of Gali (1999), which has only technology shocks of a neutral nature, to incorporate investment specific technology shocks. His most preferred specification implies that the latter type of technology shock generates a positive response of work hours, in sharp contrast to Gali's result on the neutral technology shock (as well as that of Basu, Fernald, and Kimball (2004) who use a "purified TFP" approach) and that it can explain a substantial portion of fluctuations in hours.

Given those results, it is of interest to study the role played by investment specific technological changes in Japan. Hayashi and Prescott (2002) propose a view that the economic downturn of Japan during the 1990s can be explained by a relatively simple neoclassical growth model with no financial frictions or nominal rigidities. With such a model, a slowdown of TFP growth emerges as the main driving force behind the slow growth of the "lost decade." Their model, however, is a one sector model with neutral technological changes only. In the first part of our analysis, we extend their model and incorporate investment specific technological changes. It will be shown that our calibration results are quite different from those of Hayashi and Prescott.

In the second part of our analysis, we consider an approach that is less dependent on a specific type of economic model. For that purpose, we use a structural VAR approach. We use a structural VAR approach with sign restrictions developed by Uhlig (2005). We impose restrictions that are consistent with the two most influential models of business cycles today, namely Real Business Cycle Models and New Keynesian Models. These restrictions are robust to alternative specifications of adjustment costs on investment (investment goods producing technology) and capacity utilization, for wide ranges of plausible parameter values. Our results demonstrate the importance of investment specific technology shocks in Japanese business cycles.

The rest of the paper is organized as follows. In Section II, the extended version of the Hayashi-Prescott model is introduced and the calibration results are described. In Section III, the estimation procedure and the results for the structural VAR are explained. Section IV concludes.

II. Calibration Exercise

A. Model

The model in this section is an extension of Hayashi and Prescott (2002). As such, it inherits many of the characteristics of the original model, which is a version of the neoclassical growth model. Time is discrete. All the markets are perfectly competitive. All the prices are flexible. There is no externality or informational asymmetry. There is no money. The model is completely deterministic, and households and firms have perfect foresight. Our model differs from the original model in that investment goods are distinguished from consumer goods, and that there are consumer goods producing firms as well as investment goods producing firms. The former type of firms rent capital stock owned by households and employ labor to produce consumer goods. Those goods are sold to households, investment goods producing firms, and the government. Investment goods producing firms possess technology to convert consumer goods into investment goods. Those goods are also sold to households. They become a part of capital stock in the next period.

To be more concrete, the representative household is infinitely lived and derives utility from both consumption and leisure. Its lifetime utility function is specified as in the following Equation (1).

$$\sum_{t=0}^{\infty} \beta^t N_t(\ln \frac{C_t}{N_t} + \alpha \ln (1-h_t)) \tag{1}$$

In what follows, t denotes a period. The parameter β is the discount factor, N_t is the size of the household in period t, C_t is the total amount of consumer goods consumed by this household, h_t is work hours *per capita*, and α is a constant. In every period, this household faces the following budget constraint:

$$C_t + K_{t+1}/V_t = (1-\delta)K_t/V_t + (1-\tau)R_t K_t + w_t h_t N_t - T_t \tag{2}$$

Here, K_t denotes capital stock at the beginning of period t. V_t is the inverse of the price of investment goods (the consumer good is taken as the numeraire). Note that, in the original Hayashi-Prescott (2002) model, there was no distinction between the two types of goods, and this relative price was always equal to one. In our model, this needs not be the case. The parameter δ is the depreciation rate, while τ is the capital income tax rate, and both take values between 0 and 1. Variable R_t is the rental rate of capital, w_t is wage per hour, and T_t is lump sum tax.

The production function of the consumer goods producing firm is given by

$$Y_t = A_t K_t^{\theta}(h_t N_t)^{1-\theta} \tag{3}$$

Here, Y_t is the amount of output of consumer goods. A_t is the level of technology of consumer goods production, and θ is a constant that takes a value between 0 and 1. The equilibrium condition for consumer goods can be written as follows:

$$C_t + X_t + G_t = Y_t, \tag{4}$$

where X_t is the amount of consumer goods purchased by investment goods producing firms, and G_t denotes government purchases of consumer goods.

Investment goods producing firms convert consumer goods into investment goods, and the production technology is linear:

$$I_t = X_t V_t \tag{5}$$

Here, I_t is the amount of investment goods produced, and V_t is the level of technology for investment goods production. As the market is perfectly competitive, in equilibrium, the relative price of investment goods to consumer goods equals the inverse of this technology term, $1/V_t$. This is the same relative price that appears in the household budget constraint in Equation (2). The capital stock evolves over time according to the following equation:

$$K_{t+1}=(1-\delta)K_t+I_t \tag{6}$$

This completes the description of the model. The next sub-section explains details of the calibration exercise.

B. Calibration

To solve the model we have to specify sequences for the four exogenous variables in the model. For the level of technology of consumer goods production A_t, as well as that of investment goods production V_t, we estimate their values for every year between 1960 and 2000 from data. For A_t, we follow Hayashi and Prescott (2002) and use the estimated TFP (see Kawamoto (2004) for a criticism on their methodology for estimating TFP). However, we must note that "Y_t" in the model does not strictly correspond to real output in the GDP statistics. That is, as Y_t in the model is output measured in units of consumption goods, we deflate nominal output by the consumption deflator when calculating TFP. Likewise, the nominal capital stock is deflated by the investment deflator, rather than the GDP deflator, to be consistent with the model in the previous sub-section. Unlike Hayashi and Prescott (2002), *we exclude net foreign assets from the definition of capital*. This is because we do not have the relative price data for this variable (our relative price variable is computed for physical investment), and we find it unlikely that it declined at the same rate as physical capital. Given the importance of relative price movements in our study, we find it safe to leave this type of capital outside the analysis. Figure 1 plots the evolution of the relative price of investment goods, which corresponds to the inverse of the investment goods producing technology V_t in our model. Note that there is a clear and sustained downward trend in this variable, which continues all the way to the end of the 1990s (and beyond). In our model, this means that there

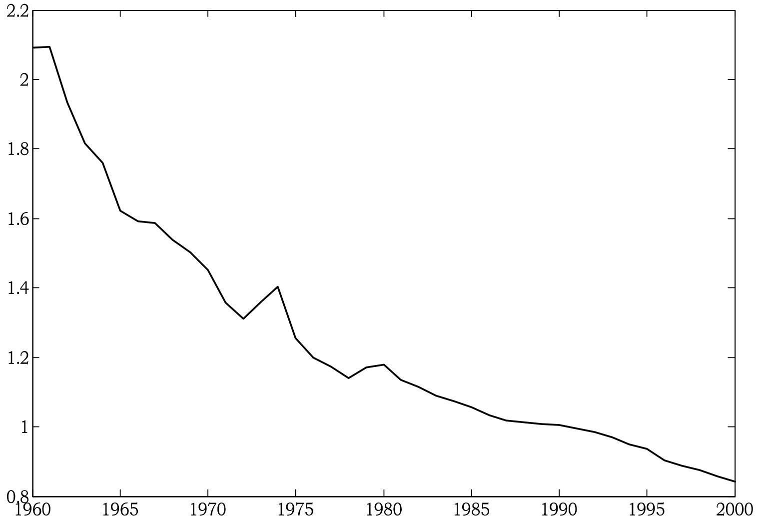


FIGURE 1
RELATIVE PRICE OF INVESTMENT GOODS IN JAPAN

was steady improvement in investment goods producing technology even during the "lost decade" in Japan. Figure 2 plots our TFP (the neutral technological term, A_t) estimate which is based on output computed using the consumption deflator. Note that there is a downward shift in the trend growth at the beginning of the 1990s. In our model, this means that neutral technological progresses stagnated. If we focus solely on this slowdown in the neutral technological component and do not take into account the continued improvement in investment specific technology, we may not be able to evaluate the overall role of technology correctly.

The other two exogenous variables needed for calibration, namely the year-by-year growth rate of the population aged 20-69, as well as the share of government expenditure in total output, are also computed from the data. Finally, as the model is deterministic and forward-looking, we have to make some assumptions on the evolution of those exogenous variables after the year 2000. We assume that they go back to their steady state values from the year 2001 onwards. Those steady state values for the growth rate of A_t, V_t, the population, and the share of government expenditure in GDP, are assumed to equal 0.0029, 0, 0, and 0.15, respectively.

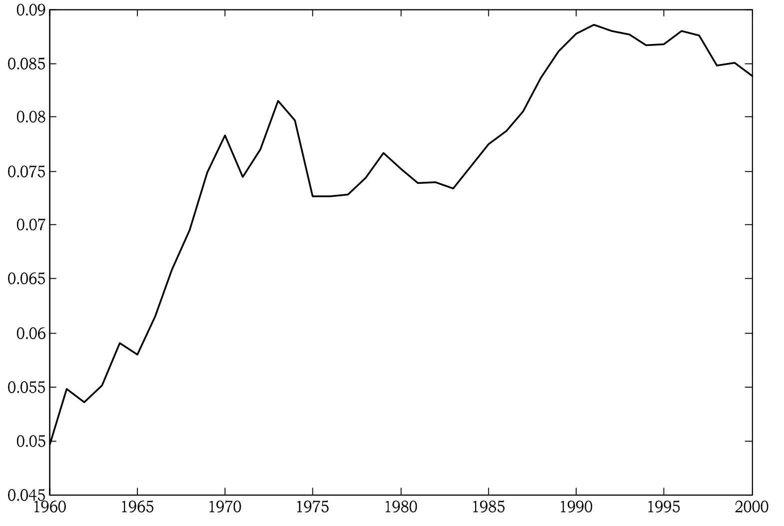


FIGURE 2
TFP (GDP IS DEFLATED BY CONSUMPTION DEFLATOR)

We set the structural parameters to the following values:

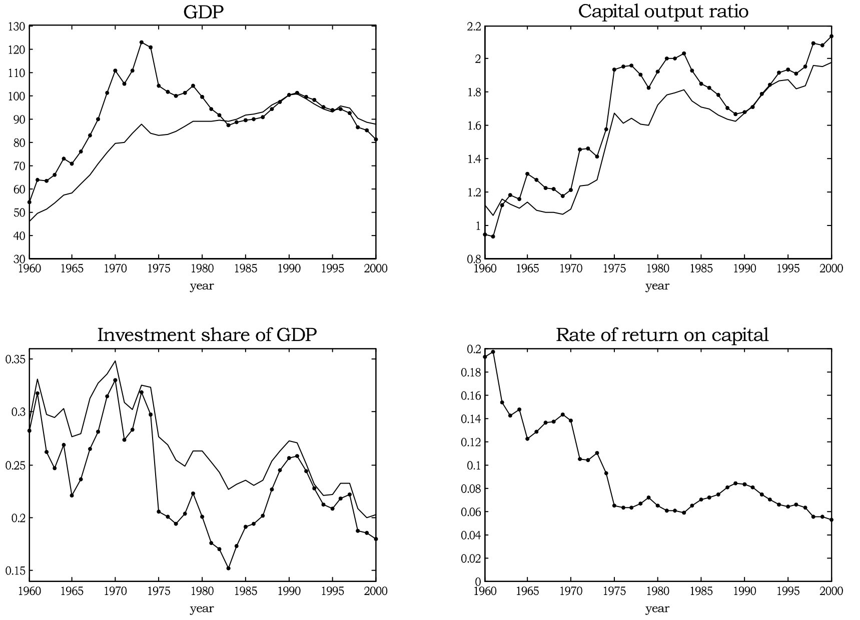
$$\delta = 0.089, \ \beta = 0.976, \ \theta = 0.362, \ \alpha = 2.9.$$

Note that one "period" in our calibration is one year. On the other hand, the value of τ is chosen to match closely to the observed capital-output ratio in 1990. The initial conditions are given by Japan's capital stock in 1961.

C. Results

Figures 3 and 4 present calibration results. In Figure 3, for the sake of comparison, we assume that the level of investment specific technology is held constant at 1 throughout the period. In Figure 4, we introduce time variations in the level of investment specific technology. By comparing the two results, we can evaluate the role of investment specific technological changes.[1] Each figure consists of

[1] As stated in the previous sub-section, τ is chosen to match the observed capita-output ratio in 1990. Because the assumed process for V_t is different, the two figures employ different values for τ. It is 0.265 for Figure 3 and



Note: In the upper-left, upper-right, and lower left panels, the lines with dots (.) are the calibration results, while the lines with no dots are the observations. The lower right panel shows the simulated (after-tax) real rate of return on capital.

FIGURE 3

CALIBRATION RESULTS WITH INVESTMENT SPECIFIC TECHNOLOGY CONSTANT

four panels. The upper-left panel shows GDP *per capita*, detrended by the 2% growth path. In all of the panels other than the lower right one, the solid lines with no markers represent the actual observations in the data,[2] while the lines with dots (.) are the simulated series from the model. The two lines in the upper left panel are normalized so that the value in 1990 is equal to 100.

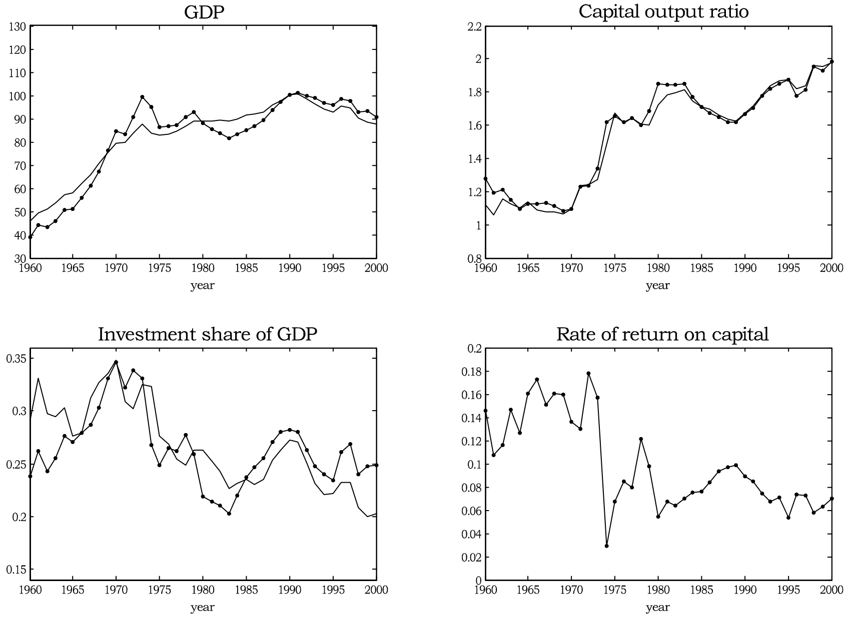
0.160 for Figure 4.

[2] "Actual" GDP is obtained by deflating nominal GNP (computed as in Hayashi and Prescott (2002)) by the consumption deflator (a weighted average of private consumption, public consumption, and public investment deflators). Capital-GDP ratio and investment-GDP ratios are computed in the same way as in Hayashi and Prescott (2002), except that net foreign asset is excluded from capital.

Hence, the two lines necessarily intersect in that year. The upper-right panel shows capital-GDP ratio. Again, note that, as we choose τ in our calibration so that the calibrated value for this ratio will be close to the observed one in 1990, the two lines (almost) coincide in that year. The lower-left panel shows investment-GDP ratio. In the lower-right panel, we show the time paths of the simulated after-tax real rate of return on capital.

Let us start with Figure 3, in which investment specific technological changes are deliberately ignored. The calibrated model does a good job in fitting the observed patterns of GDP during the 1990s. From those panels, we could not detect any evidence that growth was too slow or that capital accumulation was hampered by factors not captured by the model during this period. The model also does reasonably well in fitting changes in the investment-GDP ratio during the 1990s, though the level of the simulated series is slightly lower than the observed one. Thus, the model yields no evidence that investment was constrained in the 1990s: If anything, it should have been slightly lower. The model, however, does not do well in the pre-1990 period. Predicted growth is too slow compared to the data. According to the model, the capital-output ratio should have been higher for much of this period. The model also underpredicts investment, especially during the 1980s. Finally, as the lower right panel shows, the model predicts a steady decline in the rate of return on capital throughout the 1990s: This is due to the sustained accumulation of capital shown in the upper right panel, which causes the marginal product of capital to decrease.

In Figure 4, fluctuations in the investment specific technology are introduced. Note that the overall fit for the capital-output ratio is much improved. This suggests the importance of introducing technological changes specific to this sector. On the other hand, the new calibration over-predicts GDP after 1990, which is quite different from the result in Figure 3. That is, according to our model, GDP should have been higher than was observed. Also, the calibrated investment-GDP ratio is higher than the data. That is, according to our model, investment should have been larger. Finally, as the lower right panel shows, the model predicts that the decline in the rate of return on capital ends after 1995. This is because the cost of investment continued to decline in this period, due to reductions in the relative price of investment. This effect offsets the decline in the marginal product of capital, which occurs due to capital



Note: In the upper-left, upper-right, and lower left panels, the lines with dots (.) are the calibration results, while the lines with no dots are the observations. The lower right panel shows the simulated (after-tax) real rate of return on capital.

FIGURE 4

CALIBRATION RESULTS WITH TIME-VARYING INVESTMENT SPECIFIC TECHNOLOGY

accumulation. This explains why, in the lower left panel, the model predicts a high level of investment in the post 1995 period.

To summarize, once investment specific technological changes are taken into account, the neoclassical growth model cannot explain observed patterns in GDP and investment during the 1990s very well. As indicated in Figure 1, the relative price of investment goods continued to decline during this period, which, according to our model, indicates that investment specific technological progress did not decelerate. This should continue to boost investment and GDP growth. But, in reality, GDP growth stagnated, and investment-output ratio fell slightly. Those gaps between the model's predictions and the data indicate the possibility that some factors that were ignored in our (augmented) neoclassical growth model may have played important roles during the 1990s in Japan. Possible candidates include market frictions such as financial market imperfections and demand deficiencies due to nominal price rigidities. But this issue needs to be investigated further on another occasion.

Thus, by incorporating investment specific technological changes in the neoclassical growth model, we have shown the importance of those types of technological changes. Our model results also suggests that investment was surprisingly low in Japanese data from 1985 on. There is a possibility that non-technological factors might have acted to limit investment after 1985.

III. VAR Analysis

In the previous section, we used a fully specified theoretical model to analyze the role of investment specific technological changes. Investment goods producing technology was restricted to take a linear form. In this section, we try to estimate the effects of both neutral and investment specific technological changes directly from data, using an econometric methodology, without imposing strong a priori restrictions based on a particular type of model or a specific set of parameter values. The method we employ is a structural VAR. We utilize a relatively new approach based on sign restrictions on impulse responses.

A. VAR with Sign Restrictions

Since Sims (1980), the VAR methodology has been applied to many important macroeconomic issues. Among studies that utilize the VAR to identify structural sources of macroeconomic fluctuations, two alternative approaches for achieving such identification have been most popular. One approach imposes restrictions on the short run relationships between economic variables. On the other hand, Blanchard and Quah (1989), Gali (1999), and Fisher (2006), among others, impose restrictions on long run relationships between the variables.

In this paper, we utilize an alternative approach developed by Uhlig (2005) which imposes sign restrictions on impulse responses. Here, we explain the essence of the methodology briefly. Let x_t denote an $(N\times 1)$ vector of economics variables in period t. Then a VAR model can be expressed in the following way:

$$x_{t+1}=C_0+C(L)x_t+u_{t+1}, \quad u_t \sim IID(0, \Sigma) \tag{7}$$

Here, L is the lag operator and $C(L)$ is the lag polynomial. The vector u_{t+1} is the vector of innovations ($N\times 1$). Let us denote the ($N\times 1$) vector of structural shocks as ε_t, and assume that there is the following linear relationship between the innovations and the shocks: $\varepsilon_t=Pu_t$, where P is a ($N\times N$) matrix. "Identification" in the VAR model means how to choose a matrix P that satisfies the following:

$$Px_{t+1}=PC_0+PC(L)x_t+Pu_{t+1}, \quad \mathrm{E}(Pu_t u_t' P')=I \tag{8}$$

As already mentioned, there are several ways to achieve identification. The short run restriction approach typically imposes sufficient numbers of zero restrictions on the elements of matrix P to achieve identification of non-zero elements of P. The long run restriction approach typically imposes zero restrictions on the matrix of long run relationships, P-$PC(1)$.

On the other hand, the sign restriction approach by Uhlig (2005) utilizes the Monte Carlo approach and starts from randomly generating model parameter values. This process consists of two stages. In the "first stage," we estimate the reduced form VAR, and this yields posterior distributions for the reduced form coefficients and the variance covariance matrix Σ.[3] Then we generate those parameter values randomly from their posterior distributions. For each of the realizations of those random experiments, we make the "second stage" randomizations for the matrix P^{-1}.[4] Based on those

[3] Uhlig (2005) shows that, when diffuse prior is used, the posterior distribution for the former becomes normal, while that for the inverse of the latter becomes a Wishart distribution.

[4] For the purpose of illustration, let us explain how this works for the case with just two variables. Let us denote the random draw for the variance covariance matrix Σ as $\hat{\Sigma}$. And let its eigenvalues denoted by μ_1 and μ_2, and the corresponding eivgenvectors by ν_1 and ν_2. Uhlig (2005) shows that the first column of the matrix P^{-1}, which will be denoted as a, satisfies the following relationship: $a=\sum_{m=1}^{2}\alpha_m \cdot \sqrt{\mu_m} \cdot \nu_m$, where α_m denotes a weight attached to each of the eigenvectors. The weights are assumed to satisfy the following normalization condition: $\sum_{m=1}^{2}\alpha_m^2=1$. This leaves us with one degree of freedom. We first generate the α_m's from a uniform distribution, and then modify them to satisfy the above normalization condition.

randomly chosen parameters, we can compute impulse response functions. If the set of impulse responses satisfies all the sign restrictions, this set of randomly drawn parameters is kept for further analysis. If not, it is discarded. Repeating this a number of times, we derive a range of parameter values and a set of impulse responses that are consistent with the sign restrictions. In this paper, we will report medians of impulse responses that were "kept," as well as percentile bands. In a series of studies (Braun and Shioji 2003, 2004, 2006a, 2006b), we have utilized this method to investigate the U.S., Korean, and Japanese economies.

Francis, Owyang, and Theodorou (2003) use this methodology for identification of technology shocks. They impose a sign restriction that a technology shock has a positive effect on labor productivity "in the long run" (say 10 years later). They find that the response of work hours to a technology shock is not significantly different from zero. To get clearer result, they later restrict the size of the response of work hours to a technology shock becomes very small in the long run.

B. On the Choice of Sign Restrictions

In this paper, we use the VAR approach with sign restrictions to achieve identification of both neutral technology shocks and investment specific technology shocks. The reason is the following. First, we found it extremely difficult to come up with plausible short run restrictions to identify either type of technology shock, as most economic variables are expected to respond endogenously to those shocks within a short period of time. On the other hand, the literature on technology shocks has utilized long run restrictions frequently. For example, Gali (1999) assumed that, in the long run, a technology shock has a permanent impact on labor productivity, but not a non-technology shock. This kind of restriction, however, is justified only when the shocks themselves are permanent in their nature. Even a very persistent technology shock, as long as it is not completely permanent, would not satisfy a long run restriction of the above kind. The sign restriction approach is not subject to this kind of problem.

A major advantage of the VAR approach is that we do not need to commit ourselves to a particular model to analyze the effects of certain shocks on macroeconomic variables. To take full advantage of such a characteristic, it would be ideal to come up with a set of restrictions that are consistent with a broad class of models. In our previous study, Braun and Shioji (2003), we base our restrictions on a literature survey. But this approach is more difficult to adopt here because there are relatively few studies that have taken up the issue of investment specific technology shocks. Hence, in this paper, we adopt an approach close to that of Gambetti, Pappa, and Canova (2005). As in their analysis, we construct standard dynamic general equilibrium models. We derive our sign restrictions by producing a large number of impulse responses under different parameter settings and looking for common features between those responses. Unlike Gambetti, Pappa, and Canova (2005), who used only one type of the New Keynesian Model (which includes a flexible price model as a special case with measure zero), we use both the Real Business Cycle Models and the New Keynesian Models, the two most popular models of the business cycle. We build standard versions of both types of models that incorporate an investment goods producing sector, which produces investment goods from consumer goods. In the model of the previous section the investment goods producing technology was restricted to be linear. Here we introduce concavity in this technology in the form of adjustment costs of investment. In this case, the relative price of investment depends not only on the level of the investment goods producing technology but also on the demand for investment goods. We consider two forms of adjustment costs, namely the traditional type of adjustment costs that accrues to changing the stock of capital, as well as quadratic costs to changes in the flow of investment. We consider models with and without endogenous capacity utilization in the form of Greenwood, Hercowitz, and Huffman (1998). All together, we will be considering eight (=2*2*2) types of models as opposed to just one. The models contain seven types of shocks, namely neutral technology shocks, investment specific technology shocks, time preference shocks, labor supply shocks, government spending shocks, money demand shocks, and monetary policy shocks. As for the set of parameter values, unlike Gambetti, Pappa, and Canova (2005), who draw them randomly from prior distributions, we will limit ourselves to just two or three values per parameter, to cut down on the computation time. Still, we end up producing exactly 24,000 different impulse responses per variable per shock.

As indicated above, we follow Gambetti, Pappa, and Canova (2005) and look for sign conditions that are satisfied by most (or, preferably, all) of the impulse responses to neutral technology and investment specific technology shocks in the model. But this, in our view, is not sufficient. To be useful as identifying restrictions, we also require that the same set of sign conditions be *not* satisfied by any of the 24,000 impulse responses to *any of the other types of shocks*.

To save space, we leave the detailed description of our background theoretical models to the appendix. Here, we simply state that the models are standard ones, with the exception of the introduction of investment specific technology shocks. In the Real Business Cycles version of the model, prices are perfectly flexible. In the New Keynesian version, there is a convex adjustment cost of changing prices, in a form similar to that of Rotemberg (1982). In the Real Business Cycles version, the monetary authority simply sets money supply. In the New Keynesian version, the monetary authority follows a Taylor rule, in which the nominal interest rate is a function of both the deviation of inflation rate from the target as well as GDP gap.

C. Sign Restrictions

Here we summarize the sign restrictions on the impulse responses that we impose in our VAR analysis. These are *robust* restrictions that are selected by conducting an extensive analysis of theoretical impulse responses, in which both the structural model and the structural parameters are varied. This process is detailed in the appendix. In what follows, a "positive" shock is defined as a shock that increases GDP in the 4*th* period.[5] Also, the size of a shock is normalized so that the 4*th* period response of GDP to a unit shock is equal to one.

***Restriction 1*:** Out of seven structural shocks included in the VAR model, there should be either two or three shocks that increase labor productivity in all of the 4*th*, 20*th*, and 40*th* periods after a positive

[5] In our analysis of the model impulse responses, we have found that the same shock (in the theoretical sense) could often move GDP in opposite directions at the impact, depending on the parameter set. This suggests that it is not wise to use impact responses for the sign normalization. In the same analysis, we have found that the fourth period response of GDP to an improvement in either the neutral technology term or the investment specific technology term is virtually always positive.

shock.[6] When this restriction is satisfied they are considered as candidates for both a neutral technology shock and the investment specific technology shock.

That is, a technology shock is a shock that increases labor productivity persistently (though not necessarily permanently). This restriction alone does not fully distinguish technology shocks from non-technology ones. A monetary policy shock can also produce a persistent increase in labor productivity, depending on the parameter values. This can happen, for example, when nominal rigidity is sufficiently strong and firms do not face a very steeply increasing marginal cost of changing capacity utilization. In such a case, a monetary loosening stimulates the aggregate demand, and firms meet this demand increase mainly by adjusting capacity utilization. This results in a short run increase in labor productivity. In the medium to long run, the capital stock accumulates, and this increases output per labor.

***Restriction 2*:** Out of these two or three candidate shocks there has to be exactly one shock that lowers the relative price of investment goods in all of the 4*th*, 20*th*, and 40*th* periods after there was a positive shock. This is our investment specific technology shock.

Neither a positive neutral technology shock nor a positive monetary policy shock reduces the relative price of investment goods. Both of those shocks increase the demand for investment goods, and thus increase their relative prices (if investment is subject to some form of adjustment cost). On the other hand, a positive investment specific technology shock lowers the relative price because investment goods can be produced more efficiently.

***Restriction 3*:** If there is only one shock that increases both labor productivity and the relative price of investment goods persisntently, that is our neutral technology shock. If there are two, and if one of them increases labor productivity more strongly than the other in all

[6] In the conference version of the paper, we were imposing restrictions only on the 4*th* period response. By imposing additional restrictions on the medium to long run responses, we can attain much sharper identification. We thank Yongsung Chang for suggesting us to put additional restrictions on periods other than the 4*th* period.

TABLE 1
SIGN RESTRICTIONS FOR THE VAR ANALYSIS

	Neutral technology shock	Investment specific technology shock
GDP	+	+
Labor productivity	+	+
Relative price of investment goods	+	−

of the 4*th*, 20*th*, and 40*th* periods, that is our neutral technology shock. If neither of the two satisfies this restriction, such a draw will be discarded.

Our analysis of model impulse responses indicates that even in cases where a monetary loosening increases labor productivity, its effects are weaker than those of an improvement in the neutral technology term. Table 1 summarizes these three restrictions.

Although Restrictions 1-3 are, in principle, sufficient for identifying both types of technology shocks, we also impose additional restrictions on the size of the responses to obtain sharper identification. Our size restrictions are also derived from an analysis of the model impulse responses.

Additional Restrictions: (1) The 4*th* period response of labor productivity to a neutral technology shock has to be greater than 0.15. (2) The 4*th* period response of investment to an investment specific technology shock has to be greater than 3.

D. Results from the VAR Analysis

We estimate the VAR model imposing the restrictions listed above, using Japanese data. The model includes the following seven variables: GDP, Consumption, Investment, The Relative Price of Investment Goods, Work Hours, the Price Level (Consumption Deflator), and the Interest Rate (the Call Rate).[7] The data is

[7] Data for GDP, Consumption, Investment, Consumption Deflator and Investment Deflator are taken from the Japanese National Accounts (Economic and Social Research Institute, Cabinet Office). For the years between 1960 and 1979, for which only the data based on 1968SNA (with the base year being 1990) was available, we use this data. For the year 1980

quarterly. All the series are seasonally adjusted except for the Interest Rate. The sample period is from 1960QI to 2005QII. The number of lags is set at 4. With the exception of the Interest Rate, all the variables are in logs. The Interest Rate is divided by 100. We use the levels of all the series.[8]

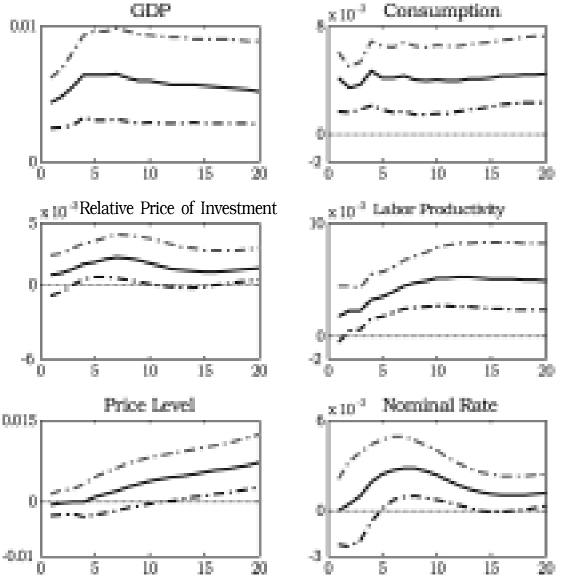
As explained in sub-section III-*A*, the VAR approach with sign restrictions involves randomly generating the parameters of the reduced form VAR (we call this the "outer-loop" draws) and, for each of those random draws, randomly generating the elements of the matrix of contemporaneous relationships, P^{-1} (we call them the "inner-loop" draws). In our estimation, we made 500 outer-loop draws, and, for each of those, made 500 inner-loop draws. We found 4125 draws that satisfy all of our restrictions.

Figure 5 shows the estimated impulse responses to a neutral technology shock, while Figure 6 shows those for an investment specific technology shock. The solid lines correspond to the medians of the impulse responses from those random draws that were deemed valid (that is, those that satisfy the sign restrictions). The dashed lines indicate 68 percentiles from those valid random draws. The horizontal axes show the number of periods after a shock arrives, where a period corresponds to a quarter.

As indicated in Figure 5, a neutral technology shock has persistent effects on GDP, consumption, and investment. The shape of the response of investment is hump-shaped. The effect on the relative price of investment goods is positive, though insignificant on impact. The effect on labor productivity is positive and persistent, which is consistent with our restriction. The response of work hours is

onwards, we use the data based on 1993SNA (with the base year being 1995). They are connected at the first quarter of 1980 using growth rates. The relative price of investment goods is the ratio of the Investment Goods price deflator to the Consumption goods Price deflator. Work Hours is derived by multiplying the number of Employed Persons (Non-Agricultural) from *Labor Force Survey* by the Labor Hours Index (Total Hours, establishments with 30 workers or more, manufacturing) from *Monthly Labor Statistics*. The Call Rate is the quarterly average of "with collateral, monthly averages" statistics (Bank of Japan).

[8] We do not take their first differences. As Sims, Stock, and Watson (1990) emphasize, taking differences may result in a loss of important information contained in the original series. Sims, Stock, and Watson (1990) also observe that impulse responses based on VARs that are estimated in levels are consistent even when the data is integrated.

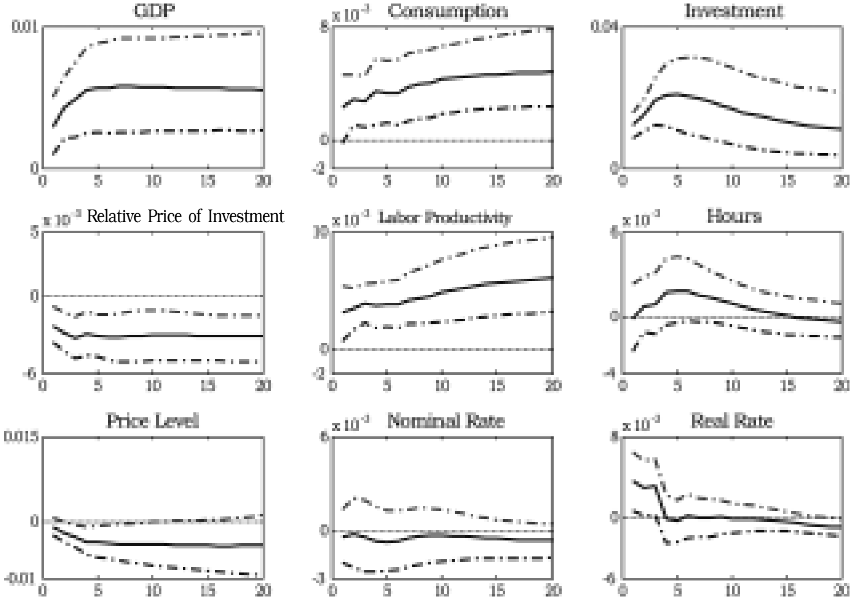


Note: Impulse responses to a one standard deviation shock. Horizontal axes correspond to periods (quarters). Solid lines are the medians of all the valid draws. Dashed lines are the 68 percentiles. Number of valid draws = 4125. Estimation period = 1960QI - 2005QII. Number of Lags = 4.

FIGURE 5
VAR RESULTS: ESTIMATED IMPULSE RESPONSES TO NEUTRAL TECHNOLOGY SHOCK

positive and significant in the short run. This is an interesting result in view of the recent debate on whether a technological improvement raises or lowers hours (Gali 1999; Christiano, Eichenbaum, and Vigfusson 2003, Miyagawa, Sakuragawa, and Takizawa 2006, Nutahara 2006, among many others). The response of the price level is insignificant in the short run and turns positive afterwards. The response of the nominal interest rate is significantly positive in the medium run, but the real interest rate response is insignificantly different from zero.

The Investment specific technology shock in Figure 6 has significant effects on GDP, consumption, and investment. The hump-shapedness of the investment response is less pronounced for this type of shock. The response of the relative price of investment



Note: Impulse responses to a one standard deviation shock. Horizontal axes correspond to periods (quarters). Solid lines are the medians of all the valid draws. Dashed lines are the 68 percentiles. Number of valid draws = 4125. Estimation period = 1960 QI - 2005 QII. Number of Lags = 4.

FIGURE 6

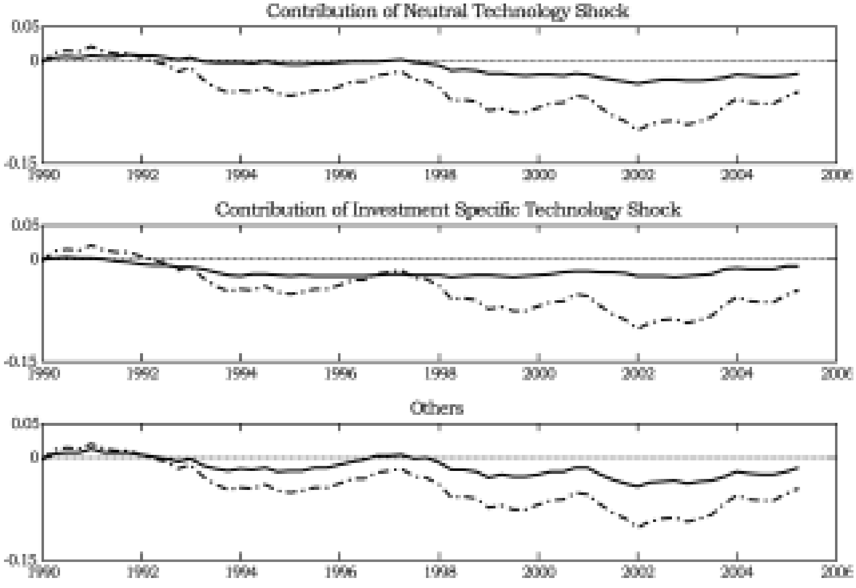
VAR RESULTS: ESTIMATED IMPULSE RESPONSES TO INVESTMENT SPECIFIC TECHNOLOGY SHOCK

goods is significantly negative and persistent, while that labor productivity is significantly positive and very persistent, as is consistent with our restrictions. Work hours increase in the medium run, though insignificantly. The price level goes down, but only in the short run. The response of the nominal rate is insignificant but the real interest rate goes up significantly from period 1, and then turns insignificant quickly. This increase in the real rate could be considered as evidence that this investment specific technology shock acts more like a demand shock in the very short run. On the other hand, the eventual fall of the price level can be considered as evidence that the same shock acts more like a supply shock in the long run.

We also performed forecast error variance decomposition based on the estimation results.[9] We found that the relative contribution to GDP in period 4 was 29% for the neutral technology shock and 24% for the investment specific technology shock. At the 20*th* period horizon, the contribution of the neutral technology shock was 24% while that of the investment specific technology shock was 30%. Thus, among the seven types of shocks in the model, the two technology shocks combined explain over 50% of the variance of GDP. This indicates that technology shocks are important driving forces of business cycles in Japan. On the other hand, non-technology shocks as a whole also explain more than 40% of the variance in GDP. This is against the extreme view that non-technology shocks are unimportant.

Using this estimation result (to be concrete, the medians over all valid draws of the VAR coefficients and that for the matrix of contemporaneous relationships, P^{-1}), we performed a historical decomposition of the forecast variance of Japan's GDP during the 1990s. The results are shown in Figure 7. In each panel in the figure, the dashed line is the forecast error we would have obtained if we had used our VAR estimates in 1990 to make future forecasts. The solid line in Panel A is the contribution of the neutral technology shock to this forecast error. That in Panel B is the contribution of the investment specific technology shock. That in Panel C is the part of forecast errors that cannot be attributed to either of the technology shocks. It is useful to divide the entire period shown in the figure into two, namely the period before 1997 and the period afterwards. The magnitude of the decline in the observed series between 1990 and 1997 almost coincides with that of the contribution of investment specific technology shock. On the other hand, neutral technology shocks are not very important. Observed swings around the downward trend is mainly due to non-technology shocks. After 1997, the observed series experiences a further decline until 2002, but investment specific technology shock does not play an important role here. Instead, neutral technology shocks and non-technology shocks contribute to the decline. Thus, the overall picture is consistent with the view that negative technology shocks were important driving forces behind the

[9] To obtain the estimates, we perform the variance decomposition for each of the valid draws, and then take averages across those draws of the relative contributions of each types of shocks.



Note: Decomposition of errors in GDP forecasts made as of 1990 using our VAR estimates (median VAR coefficients of all the valid draws). Solid line represents contribution of each factor. Dashed line represents the sum of contributions of all the factors.

FIGURE 7
HISTORICAL DECOMPOSITION OF FORECAST ERRORS IN GDP

stagnation, but it also suggests that neutral technology shocks became important only toward the end of the 1990s. And, most importantly, evolution of GDP during this period was most closely correlated with the part driven by non-technology shocks. Thus, our results indicate important roles played by non-technological factors during Japan's "lost decade."

IV. Conclusions

In this paper we have analyzed the roles of neutral and investment specific shocks to technology in accounting for economic fluctuations in Japan. In the calibration analysis in Section II, we assumed that the investment goods producing technology was linear, and used the inverse of the relative price of investment goods to measure the level of technology in the investment goods producing sector. We found that investment specific technology experienced steady improvements during the low growth period of the 1990s, while technology in the consumer goods producing sector stagnated. The fact that investment from the model lies about investment in Japanese data from 1985 through the end of our sample in 2000 suggests that there may have been other un-modeled factors that were acting to depress investment during this period.

While Section II focused mainly on the *secular* effects of technological change for the Japanese economy, Section III analyzed how shocks to technology affect the Japanese *business cycle*. For that purpose, we identified investment specific technology shocks (as well as neutral shocks) using a time series technique, without committing ourselves to a specific model and parameter settings. We imposed a set of sign and size restrictions on a VAR that are common to some of the leading models of the business cycle. The particular set of sign restrictions was chosen after conducting an extensive analysis of theoretical impulse responses from both flexible and sticky price models of the business cycle. Using this relatively new methodology, we found that investment specific technology shocks are at least as important as neutral technology shocks in the Japanese economy.

In our future research, we intend to expand the set of models considered in our theoretical impulse response analysis, to study the robustness of our sign restrictions to variations in model specifications. One of the candidates for such a model would be a model with financial market imperfections.

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Appendix: Neutral and Investment Specific Technology Shocks in Dynamic General Equilibrium Models

In this appendix, we present models that are behind our identifying restrictions in Section III.[10] The models are based on those of Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2003).[11] We consider two classes of models, namely the

[10] This appendix is a much improved and far more thorough version of a similar exercise conducted in Braun and Shioji (2006c).

[11] Unlike those authors, we do not incorporate nominal wage rigidity, which

Real Business Cycle Models or RBCM (in which prices are perfectly flexible) and the New Keynesian Models or NKM (in which it is costly to change prices). Within each class, the models are differentiated by their treatment of adjustment cost of investment and capacity utilization.

Firms

Firms produce consumer goods. There are infinitely many firms with homogeneous technology, whose number is normalized to equal 1. In the RBCM, the consumer goods market is perfectly competitive. In the NKM, those firms are monopolistically competitive. The production function for firm *i* takes the following form:

$$y_{it}=\varepsilon_t^A\cdot(z_t\cdot k_{it-1})^{\alpha}(\Gamma_t\cdot l_{it})^{1-\alpha} \tag{A.1}$$

where y_{it} denotes output of this firm in period t, ε_t^A is the "neutral technology" or TFP term, z_t is the capacity utilization rate (which is determined by the representative household in cases where this variable is endogenous), k_{it-1} is the amount of capital stock rented by this firm in period t, Γ_t is the term that represents exogenous labor augmenting technology which grows at the rate g, and l_{it} denotes this firm's labor demand. The parameter α takes a value between 0 and 1. Note that output is measured in the units of investment goods. The firm's objective is to maximize the following discounted sum of profits:

$$V_{it}=E_t\sum_{j=0}^{\infty}\beta^j\left(\prod_{k=0}^{j}\frac{\lambda_{t+k}}{\lambda_{t+k-1}}\right)v_{it+j}. \tag{A.2}$$

In the above, β is the representative household's discount factor, v_{it} is this firm's real profit in period t, and λ is the Lagrange multiplier associated with the periodic budget constraint in the representative household's optimization problem ($\lambda_{t-1}\equiv 1$). The real profit can be written as follows:

$$v_{it}=\frac{1}{P_t}[p_{it}y_{it}-r_t^k\cdot z_t k_{it-1}-w_t l_{it}]-ADJP_{it} \tag{A.3}$$

is left for future research.

where P_t is the general price level, p_{it} is the price of goods sold by this firm, r_t^k is the rental rate of capital, w_t is the nominal wage, and $ADJP_{it}$ denotes the adjustment cost of changing prices. The treatment of this adjustment cost term distinguishes the RBCM and the NKM.

$$\text{(RBCM)}\ ADJP_{it}=0 \tag{A.4}$$

$$\text{(NKM)}\ ADJP_{it}=\frac{\gamma}{\theta+1}(\pi_{it}-\pi^*)^{\theta+1}\ \text{where}\ \pi_{it}\equiv\frac{p_{it}-p_{it-1}}{p_{it-1}} \tag{A.5}$$

In (A.5), both θ and γ are positive constants. The term π^* denotes the "target" or "normal" inflation rate. Also, in the NKM case, this firm faces a downward sloping demand curve of the form:

$$y_{it}=\left(\frac{p_{it}}{P_t}\right)^{-\xi} Y_t$$

where ξ is a constant greater than 1.

Representative Household

The objective function of the representative household (which is assumed to be infinitely lived) takes the following form:

$$U_t=E_t\sum_{j=0}^{\infty}\beta^j N_{t+j}\cdot u_{t+j}, \tag{A.6}$$

where N_t denotes the size of the household which grows at the constant rate n each period, the periodic *per capita* utility, u_t, is given by:

$$u_t=\varepsilon_t^B\cdot[u_t^{cm}-u_t^l] \tag{A.7-1}$$

where

$$u_t^{cm}=\frac{1}{1-\sigma}\cdot[u_t^c+u_t^m], \tag{A.7-2}$$

and

$$u_t^c = (c_t - h \cdot c_{t-1})^{1-\sigma},\ u_t^m = \psi \cdot \varepsilon_t^{MD} \cdot (\frac{m_t}{P_t})^{1-\sigma},$$

$$u_t^l = (1+g)^{(1-\sigma)t} \frac{\chi \varepsilon_t^L}{1+\sigma_l} \cdot l_t^{1+\sigma_l} \tag{A.7-3}$$

Here, c_t is consumption, m_t is money holding, l_t is labor supply, ε_t^B is "shock to time preference," ε_t^{MD} is "money demand shock," ε_t^L is "labor supply shock." The parameters h, σ, ψ, σ_l, and χ are all positive. We multiply the utility from leisure by the term $(1+g)^{(1-\sigma)t}$ so that the balanced growth path exists. The periodic budget constraint is given as follows:

$$\frac{m_t}{P_t} + \frac{b_t}{P_t} = \frac{m_{t-1}}{P_t} + (1+r_t)\frac{b_{t-1}}{P_t} + y_t - c_t - x_t \tag{A.8}$$

Here, b_t is the bond holding at the end of period t and r_t is the nominal interest rate. Variable x_t is the amount of consumer goods spent for production of investment goods (note this is measured in the units of consumer goods). Real income y_t is defined in the following manner:

$$y_t = \frac{1}{P_t}[w_t l_t + r_t^k \cdot z_t k_{t-1} + div_t - T_t], \tag{A.9}$$

where div_t is dividend payment from firms to the household, and T_t is lump sum tax.

The household, being the sole owner of capital, determines how much capital to accumulate. Investment expenditure x_t is transformed into aggregate investment i_t, *via* investment goods producing technology, which is subject to adjustment costs. The capital accumulation equation is the following:

$$k_t = (1 - \delta - DEP_t)k_{t-1} + (1 - ADJ_t)i_t \tag{A.10}$$

$$i_t = \varepsilon_t^I \cdot x_t \tag{A.11}$$

where δ is the exogenous part of the depreciation rate, and ε_t^I is the technology shock that is specific to investment goods production, or "investment specific technology shock." The term ADJ_t denotes adjustment cost which will be specified below. The term DEP_t is the endogenous component of the depreciation rate which varies with the rate of capacity utilization, in the endogenous capacity utilization case. This term will also be specified below.

Adjustment Cost of Capital Formation

We consider the following two specifications.

(K-1) The adjustment cost accrues to the rate of increase of capital stock, or, more concretely, the ratio between investment expenditure and capital stock outstanding:

$$ADJ_t = ADJK_t = \frac{b}{\nu}\left[\frac{k_t - k_{t-1}}{k_{t-1}}\right]^{\nu}. \tag{A.12}$$

(K-2) The unit adjustment cost depends on the growth rate of investment expenditure:

$$ADJ_t = ADJI_t = \frac{b}{\nu}\left[\frac{x_t - x_{t-1}}{x_{t-1}}\right]^{\nu} \tag{A.13}$$

In either of the (K-1) or (K-2) cases, b and ν are positive constants.

Capacity Utilization

We consider two cases.

(U-1) Capacity utilization rate is an exogenous constant: $z_t = 1$, and $DEP_t = 0$.

(U-2) Capacity utilization is endogenous:

$$DEP_t = \phi \cdot z_t^{\eta} \tag{A.14}$$

where ϕ is a positive constant and η is a constant greater than 1.

Monetary Authority

In the RBCM case, we assume that the central bank simply sets the stock of money, subject to stochastic disturbances.

$$\ln(M_t) = \bar{M} + \varepsilon_t^{MP} \tag{A.15}$$

where $\bar{M}$ is a positive constant, and ε_t^{MP} is the "monetary policy shock" in this case. In the NKM case, the central bank follows a Taylor-style rule:

$$i_t - i^* = (1 - \omega_{lag})[\omega_\pi \cdot (\pi_t - \pi^*) + \omega_{GAP} \cdot GAP_t] + \omega_{lag}[i_{t-1} - i^*] - \varepsilon_t^{MP}. \tag{A.16}$$

The term i^* denotes the long run target nominal interest rate for the central bank. The parameter ω_{lag}, which is greater than or equal to zero and is strictly smaller than one, represents the central bank's desire to smooth fluctuations in the interest rate. The usual Taylor rule corresponds to the case where $\omega_{lag} = 0$. Inside the large brackets on the righ hand side, the constant ω_π denotes the central bank's response to inflation and is assumed to be greater than 1. The term π^* is the central bank's "target" or "normal" inflation rate, and is assumed to be the same as the one in firms' price adjustment cost function, (A.5). The parameter ω_{GAP} represents the central bank's response to GDP gap, denoted as GAP_t, which is defined as

$$GAP_t = \alpha \cdot [\ln(z_t) - \ln(z^*)] + (1 - \alpha) \cdot [\ln(l_t) - \ln(l^*)] \tag{A.17}$$

where l^* and z^* are steady state values of z_t and l_t, respectively.

Fiscal Authority

The government purchases follow a purely stochastic process, and are financed by lump sum taxes.

$$\ln(G_t / G^*) = \varepsilon_t^G \tag{A.18}$$

where G^* is a constant and ε_t^G is the "government spending shock."

Equilibrium

$$Y_t = C_t + X_t + G_t, \quad M_t = m_t \tag{A.19}$$

Stochastic Processes

All the shock terms are assumed to follow AR(1) processes, with the coefficient on the lagged shock term, ρ, satisfying $0 \leq \rho < 1$.

Definition of the Relative Price

The relative price of investment goods is defined in the following manner:

$$PINV_t = \mu_t / \lambda_t$$

where λ_t is the Lagrange multiplier associated with the representative household's budget constraint (the marginal utility of consumer goods), and μ_t is the Lagrange multiplier associated with the equation for capital accumulation.

Choice of Parameter Values

In our exercise, there are two sets of parameters depending on how their values are chosen. For some of the parameters, we pick their values from standard ranges of values used in the literature. For the others, their values are chosen so that certain steady state relationships match what we observe in data. Note that, when parameters of the former set are changed, those in the latter set might also change to keep certain steady state values constant. Appendix Table 1 shows the parameter values used for the former type of parameters. Appendix Table 2 shows how each of the parameters of the latter type is chosen: that is, which variable it is chosen to match, and the steady state value of such variable.

Some Results

To give examples, in Appendix Figures 1 and 2, results are reported for the NKM case in which adjustment cost occurs to a change in investment expenditure (the (K-2) case) and capacity utilization is endogenous (the (U-2) case). Each of the figures reports responses to a neutral technology shock and an investment specific technology shock, respectively. One period is a quarter. For each of the shocks, we produce 6912 different responses per variable. Rather than showing every one of them, we plot the upper and lower bounds of all the responses (dashed lines), together with upper and lower 10 percentiles (solid lines).

Several characteristics are noteworthy, in relation to the sign restrictions imposed in the main text. (1) In response to both types of technology shocks, labor productivity increases persistently in virtually all the cases. (2) However, in the very short run, there are

APPENDIX TABLE 1
CHOICE OF PARAMETER VALUES (1),
PARAMETERS WHOSE VALUES ARE SET EXOGENOUSLY

Population growth rate	n	$1.01^{1/4}$-1
Rate of growth of technology	g	$1.017^{1/4}$-1
Capital share	α	0.36
Inverse of the elasticity of intertemporal substitution, consumption, and money demand	σ	1.01, 2
Inverse of the elasticity of intertemporal substitution, leisure	σ_l	0.1, 1.01
Strength of habit formation, consumption	h	0, 0.5
Degree of convexity of adjustment cost of capital (or investment)	ν	1, 2
Degree of convexity of the endogenous depreciation function	η	1.2, 2
Persistence of disturbances	ρ	0.8, 0.95
Importance of price adjustment cost (NKM case only)	γ	1, 10, 100
Degree of convexity of price adjustment cost (NKM case only)	θ	1
Price elasticity of demand for consumer goods (NKM case only)	ξ	6
Taylor rule coefficient, inflation (NKM case only)	ω_π	1.5, 2
Taylor rule coefficient, GDP gap (NKM case only)	ω_{GAP}	0, 0.5
Taylor rule coefficient, lagged interest rate (NKM case only)	ω_{lag}	0, 0.5
"Normal" inflation rate (NKM case only)	π^*	$1.02^{1/4}$-1
"Normal" nominal interest rate (NKM case only)	i^*	$1.05^{1/4}$-1

cases in which labor productivity *declines* in response to a positive investment specific technology shock. It is therefore better not to use responses within a very short run for sign restrictions. (3) Responses of the relative price of investment take the opposite signs between the two types of technology shocks. It is thus reasonable to use those responses for the sign restriction to distinguish the two.

Appendix Figure 3 shows why the persistent positive response of labor productivity mentioned above does not fully discriminate between technology shocks and non-technology shocks. The figure demonstrates the response of labor productivity to an expansionary monetary policy shock. It is often believed that this type of shock necessarily reduces labor productivity, because it increases output through stimulating employment, and the elasticity of output with respect to employment is less than 1. The two lines in the figure

APPENDIX TABLE 2

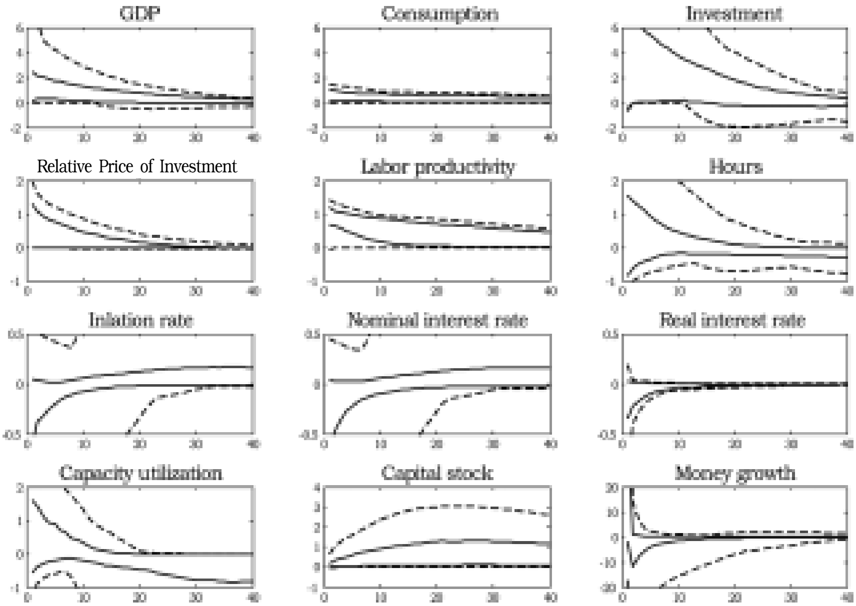
CHOICE OF PARAMETER VALUES (2), PARAMETERS WHOSE VALUES ARE CHOSEN TO MATCH CERTAIN STEADY STATE RELATIONSHIPS

Parameter		Variable whose steady state value is matched by this parameter	Its steady state value
Discount factor	β	Real interest rate	$(1.05/1.02)^{1/4}$-1
Importance of utility from money	ψ	Ratio of real money to consumption	1
Importance of utility from leisure	χ	Time share of leisure	1/3
Exogenous part of the depreciation rate	δ	Capital-output ratio	12
Importance of endogenous part of the depreciation rate	ϕ	Capacity utilization rate, z	1
Importance of adjustment cost of capital (or investment)	b	Ratio of adjustment cost to investment expenditure, x_t	0, 0.001, 0.01
Steady state gov. expenditure	G^*	Steady state ratio, G/Y	0.2

correspond to different parameter settings. In both figures, the model is the New Keynesian Model with adjustment cost of investment flows and endogenous capacity utilization. The following parameter values are assumed:

$$\sigma=\sigma_l=1.01,\ h=0,\ \nu=2,\ \rho=0.95,\ \gamma=100,\ \omega_\pi=1.5,\ \omega_{GAP}=0.5,\ \omega_{lag}=0,$$

and the steady state share of the adjustment cost in investment expenditure is 0.01. The two lines in the figure differ in the underlying value of η, the inverse of the elasticity of the depreciation cost with respect to capacity utilization. The line with dots (.) corresponds to the "elastic capacity utilization case" in which $\eta=1.2$. The solid line with no dots corresponds to the "inelastic capacity utilization case" in which η is set at 2. The two cases differ in the signs of the response of labor supply. In the "inelastic case," labor productivity declines at the outset, as is usually believed. However, in the "elastic case," labor productivity increases even in the short run. This is because, in the latter case, monetary policy increases capacity utilization more strongly. Note that the effect is fairly persistent, reflecting the assumption of a gradual adjustment of



Note: Dashed lines are the maximum and minimum of theoretical impulse responses. Solid lines are the upper and lower 10 percentiles.

Appendix Figure 1

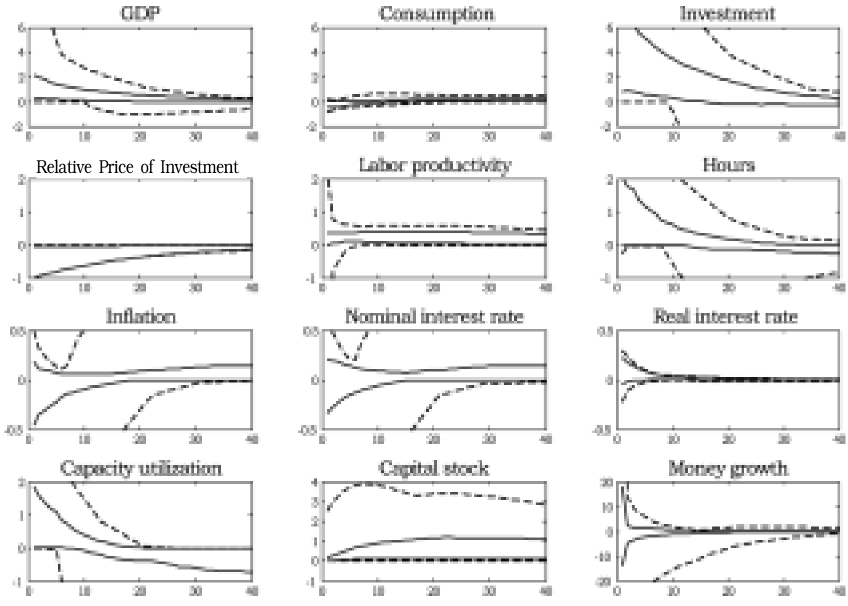
Theoretical Impulse Responses to Neutral Technology Shock, New Keynesian Model with Adjustment Cost of Investment Flows and Endogenous Capacity Utilization

capital. Thus, the sign of this response cannot be used to effectively distinguish technology shocks and monetary policy shocks.

On the other hand, a positive monetary policy shock always increases the relative price of investment goods. This property distinguishes this type of shocks from investment specific technology shocks. But we still need a restriction to distinguish monetary policy shocks from neutral technology shocks.

Some might argue that we could use the response of inflation to distinguish the two. But Appendix Figure 1 shows that this may not always work. It shows that the response of inflation to a neutral technology shock is mostly negative *but not always*.

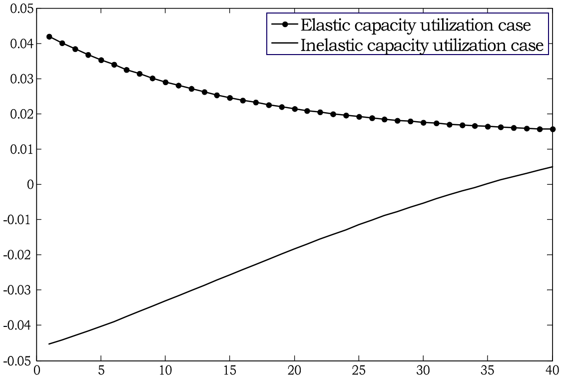
It turns out that, whenever a positive monetary policy shock increases labor productivity, a positive neutral technology shock causes a greater increase in the same variable. In the main text, we



Note: Dashed lines are the maximum and minimum of theoretical impulse responses. Solid lines are the upper and lower 10 percentiles.

APPENDIX FIGURE 2

THEORETICAL IMPULSE RESPONSES TO INVESTMENT SPECIFIC TECHNOLOGY SHOCK, NEW KEYNESIAN MODEL WITH ADJUSTMENT COST OF INVESTMENT FLOWS AND ENDOGENOUS CAPACITY UTILIZATION



APPENDIX FIGURE 3

THEORETICAL IMPULSE RESPONSES OF LABOR PRODUCTIVITY TO MONETARY POLICY SHOCK, NEW KEYNESIAN MODEL WITH ADJUSTMENT COST OF INVESTMENT FLOWS AND ENDOGENOUS CAPACITY UTILIZATION use this property to separately identify those two types of variables.

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