

## **Business Cycle in a Neoclassical Growth Model:**

### **How important are technology shocks as a propagation mechanism?**

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#### **Abstract**

This paper quantitatively investigates the role of technology shocks in propagating business cycles in a neoclassical growth model. I use the new technique of business cycle accounting (BCA) which enables me to maintain the basic framework of a standard growth model, but allows multiple propagation channels (referred to as wedges), technology fluctuations being one of them. My test case is Japan during the period 1980 to 2000. I find that though technology shocks play an important role in propagating market frictions, they are by no means enough to account for the observed economic fluctuations during this period. Shocks that propagate themselves as investment wedges play a major role. A standard RBC model fails to recognize this channel due to the paucity of propagation channels that it allows and consequently tends to overemphasize the role of technology shocks, often at the expense of other channels thus leading to erroneous conclusions.

Keywords: Technology shocks, business cycle accounting, wedges, neoclassical growth

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Since the pioneering works of Fynn E. Kydland and Edward C. Prescott (1982) and Prescott (1986), most quantitative studies of business cycles, modeling the economy like a neoclassical growth model with exogenous technology shocks (henceforth referred to as KP approach) often reaches a common conclusion: market frictions propagated as technology shocks can almost wholly account for observed economic fluctuations during business cycles<sup>1</sup>. In recent years this finding has generated a lot of controversy. Susanto Basu and John G. Fernald (1997) and Jordi Gali (1999) among others have questioned the use of RBC models as a good vehicle for studying business cycles and consequently questioned the result of most RBC models that highlight the importance of technology shocks as a propagation mechanism of market frictions that leads to business cycles. In this paper I revisit the question “How important are technology shocks as a propagation mechanism?” using a new approach and some new evidence from Japan.

My approach uses the technique of ‘Business cycle accounting’ developed by V.V. Chari, Patrick J. Kehoe and Ellen R. McGrattan (2002) where the economy is modeled as a neoclassical growth model with labor-leisure choice just like in KP approach. However, in contrast to the KP approach where the only way that market frictions propagate themselves are through technology shocks, in BCA approach market frictions are allowed to propagate through *three* different channels: as time-varying productivity or technology shocks (referred to as *efficiency wedge*), as a *labor wedge*, which resembles a tax on labor income and drives a wedge between the consumption-leisure marginal rate of substitution and marginal product of labor, and as an *investment wedge* which resemble taxes on investment expenditure that drives a wedge between intertemporal marginal rate of substitution and marginal product of capital. Using this procedure, the question I answer is “Under the BCA approach, are market frictions propagated as technology shocks *enough* to account for business cycle fluctuations as it is under KP technique

or can we identify *other* propagation channels that are also significant, and cannot be ignored?” My test case is Japan during the period 1980 to 2000, a period that has generated a lot of interest due to a sudden growth spurt in late eighties following liberalization, and an equally dramatic economic slump in the nineties.

A look at past literature on the importance of technology shocks leads us to identify one common channel of evaluation: that of questioning the RBC paradigm as a tool to study business cycles and therefore the empirical merits of such classes of models. For example, Basu and Fernald (1997) argues “calibrating dynamic general equilibrium models as if Solow residuals were technology shocks confuses impulses and propagation mechanisms” and in effect leads us to ignore other important propagation channels. Gali’s (1999) approach is to decompose productivity and hours into technology and non-technology components using VAR. He then shows that in an RBC model, responses of the economy to technology shocks are not very accurate to those observed in post war US data, non-technology shocks fare much better, thus leading him to question the empirical merits of the RBC models. Taking it a step further, he shows that a better fit to US like business cycles can be found if we instead consider a dynamic general equilibrium model with monopolistic competition, sticky prices and variable labor utilization with technology and non-technology shocks. A similar approach was undertaken by Peter N. Ireland (2004) who looks at technology shocks in the context of New Keynesian models and agrees with Gali that other shocks, namely preference shocks, monetary shocks etc are more important than technology shocks in explaining US post war data. In contrast to these earlier approaches, in my approach, I use the usual dynamic general equilibrium model with labor-leisure choice, but as mentioned before, I allow for not just the TFP channel, but also labor wedge and investment wedge channel, thus circumventing the problem of confusing propagation

channels that Basu and Fernald (1997) feared, but at the same time keeping the essential structure of RBC models intact.

The issue of the appropriateness of RBC models has as many supporters in literature as there are critics. Jonas Fischer (2003) introduces the concept of investment-specific technology shocks in the standard RBC model and shows that this type of technology shock can account for almost half of total fluctuations of hours worked in US. McGrattan (2004) uses Gali (1999) and Gali and Pau Rabanal (2004)'s model and allows for investment. She finds technology and monetary shocks do a poor job of generating US like business cycles and therefore need large shocks to preferences and to the degree of monopoly power for a better match to data. My approach is closest to that of McGrattan (2004), and Chari, Kehoe and MacGrattan (2005) who applies BCA technique to evaluate business cycles in United States. The authors use their result to argue two important points: one is that efficiency wedge and labor wedge play a central role in accounting for aggregate fluctuations in US during depression and post war period, and second and perhaps more significant, the propagation channel through investment wedges is not important. The advantage of the BCA approach is that it keeps the essence of the RBC models the same and extends its scope to allow for other propagation channels, thus allowing not only identification of other important channels but also testing for the appropriateness of RBC models in a more comprehensive setup, without introducing any complexity of identification of primitives behind the market forces.

To implement the BCA technique in Japan, I use a dynamic general equilibrium model with time varying productivity, labor wedge and investment wedge. Government consumption expenditure is also considered a wedge. Note that these wedges *do not* identify the primitive sources of frictions, but should be looked upon as different *transmission mechanisms*, through which

frictions affect the economy. I calibrate the model parameters to match the moments of Japanese data for the period 1980 to 1984 when the economy was relatively stable. Using the first order conditions and data, I then estimate the wedges and feed them one by one and in various combinations in the model to assess fractions of fluctuations in different economic variables like per capita output that can be attributed to these wedges.

The results show that efficiency wedges though important, are not *enough* to replicate the Japanese economic experience during the eighties and nineties. This result is quite different from that of Edward C. Prescott and Fumio Hayashi (2002) who studied Japan using KP technique and found that market frictions manifested as technology shocks can almost wholly account for business cycle fluctuations<sup>2</sup>. My results further indicate that *investment wedges* play a significant role in Japan and *labor wedges* hardly account for any of the business cycle fluctuations except for the period 1988 to 1993 to some extent. This finding has two implications: Firstly, this result shows that even though investment channel might not have been important in the context of US, we *cannot* ignore its role in the context of other business cycles, in this case Japan. Secondly, this result along with Chari, Kehoe, and McGrattan's result on US, clearly show that even though efficiency wedges are important, but they by themselves are not enough to replicate the business cycle experiences of Japan and US. Therefore while conceding the importance of technology shocks in contrast to some earlier studies, the studies that apply BCA technique also highlight the importance of other channels leading us to suspect that KP technique tends to overemphasize the importance of technology shocks as a propagation mechanism.

The results of this paper also help us on another dimension. Looking at the results, we can conclude that any model studying the business cycles in Japan during the eighties and nineties would not be successful if it concentrates on frictions that can only propagate themselves in an

RBC model as a labor wedge<sup>4</sup>. For example, many economists hold changes in labor market policies in Japan responsible for the economic debacle of 1990s. Given my findings, if the only way that these changes in labor market policies turn up in a standard growth model is as labor wedges that appear to be time-varying taxes on labor income, then the model will not be very successful in accounting for the economic experience during the lost decade.

The rest of the paper is organized as follows. In Section 2, I provide a model for business cycle accounting. Section 3 outlines the actual process of estimation. In section 4, I provide the results generated by applying the business cycle accounting procedure to the Japanese case. Section 5 summarizes the paper.

## **2 Underlying model for business cycle accounting**

BCA procedure uses a standard growth model with four stochastic variables or wedges: *efficiency wedge*  $A_t$  which appears like time varying productivity; the *labor wedge*  $\tau_{nt}$  which acts like a time varying tax on labor income, and the *investment wedge*  $\tau_{xt}$  which acts like a tax on investment expenditure. Further, per capita government expenditure  $g_t$  is also considered as ‘*government wedge*’, which can have a significant impact on the economy. It should be emphasized that each of the wedges represents the overall distortion to relevant first order conditions and do *not* identify the primitives driving these wedges.

## 2.1 Representative consumer's problem

The representative consumer in the economy has one unit of time endowment every period and chooses per period consumption  $c_t$  and labor  $l_t$  to maximize present discounted value of lifetime utility:

$$E_0 \sum_{t=0}^{\infty} \beta^t N_t u(c_t, 1-l_t)$$

subject to the budget constraint:

$$c_t + x_t(1 + \tau_{xt}) \leq w_t l_t (1 - \tau_{nt}) + r_t k_t + Tr_t \quad \forall t$$

and law of capital accumulation:

$$N_{t+1} k_{t+1} \leq N_t x_t + (1 - \delta) N_t k_t \quad \forall t$$

where  $k_t$  denotes per capita capital stock,  $x_t$  denotes per capita investment, after-tax labor income is  $(1 - \tau_{nt}) w_t l_t$  and after-tax rental income is  $(1 - \tau_{xt}) r_t k_t$  where  $w_t$  is the wage rate and  $r_t$  is the rental rate on capital stock,  $\beta$  is the discount factor,  $\delta$  is the depreciation rate on capital stock.  $Tr_t$  denotes transfers from the government at period  $t$ . I further assume that  $N_t$  denotes period  $t$  population that grows every period at the rate  $(1 + g_n)$ .

## 2.2 Representative firm's problem

Every period, the representative firm produces a single output using labor and capital to maximize profits  $y_t - w_t l_t - r_t k_t$ , where  $y_t$  denotes per capita output. I assume that the production technology is labor augmenting, represented by  $A_t F(k_t, (1+g_z)^t l_t)$ . The constant rate of technical progress is given by  $(1+g_z)$ .

## 2.3 Equilibrium

The equilibrium of this economy is given by the resource constraint

$$(1) \quad c_t + x_t + g_t \leq y_t$$

where we assume that per capita government expenditure  $g_t$  fluctuates around a trend

rate  $(1+g_z)^t$

and the set of equations:

$$(2) \quad y_t = A_t F(k_t, (1+g_z)^t l_t)$$

$$(3) \quad \frac{u_{ml}(c_t, (1-l_t))}{u_{cl}(c_t, (1-l_t))} = (1-\tau_m) A_t F_{lt}(k_t, (1+g_z)^t l_t)$$

$$(4) \quad \beta E_t u_{ct}(c_{t+1}, (1-l_{t+1})) \{A_{t+1} F_{kt+1}(k_{t+1}, (1+g_z)^{t+1} l_{t+1}) + (1+\tau_{xt+1})(1-\delta)\} = (1+g_z)^t (1+\tau_{xt}) u_{ct}(c_t, (1-l_t))$$

where notations like  $u_{ct}$ ,  $u_{lt}$ ,  $F_{lt}$  etc. denote the derivatives of the utility function and production function with respect to their arguments. Equation (2) directly follows from the production function. Equation (3) equates the marginal rate of substitution between consumption and leisure

to the after tax marginal return to labor, where in equilibrium, the marginal return to labor or the wage rate  $w_t$  is equal to the marginal product of labor. Equation (4) is the inter-temporal equation taking into account the fact that in equilibrium, rental rate on capital  $r_t$  is equal to the marginal product of capital.

It is interesting to note that the BCA technique in a way can be considered a ‘dual’ to the KP technique<sup>3</sup>. In KP technique, the economy is modeled as a dynamic general equilibrium, which is affected by exogenous frictions and shocks. The procedure involves identifying predetermined frictions and using them to simulate the model outcome. The model is evaluated on how close the simulated results match the actual data. In contrast, in BCA approach the wedges are measured using data and the first order conditions of the model so that the model replicates the data exactly when all the wedges are jointly fed. The evaluation of the model takes the form of feeding in the calculated value of the wedges one by one and in various combinations in the model and identifying the ones that are needed to best replicate the data, keeping in mind that by construction, feeding in all the wedges jointly will exactly replicate the data.

### **3 Technical details of the accounting procedure**

To apply the accounting procedure<sup>4</sup>, we first choose our benchmark prototype model’s parameters of preferences and technology, and then use the equilibrium conditions of our prototype economy to estimate the parameters of a stochastic process for the wedges. This collection of parameters implies decision rules for output, labor, and investment, which can be used with the data to uncover both a stochastic process for the wedges and the realized values of the wedges in the data. Contributions of these wedges are measured by feeding in the realized sequence of wedges in the model in various combinations, and comparing the realizations of variables like output, labor, and investment from the model to the data on these variables.

For my analysis, I assume a Cobb-Douglas production function where  $F(k, l) = (k)^\theta (l)^{1-\theta}$ ; the utility function has the form  $u(c, 1-l) = \log c + \psi \log(1-l)$ .

To identify the parameters, we however cannot use the usual calibration technique as for that we would need to know the steady state values of the wedges, which can only be determined by solving the model, for which we need the parameter values! Therefore, I need to choose my parameters from literature. I choose capital share  $\theta = .36$ ; discount factor  $\beta = .972$ ; depreciation rate  $\delta = .089$  and time allocation parameter  $\psi = 1.13$  (the parameters are from Prescott and Hayashi (2002)). The time endowment is taken as 5000 hours annually, similar to Chari et. al (2005). I further assume that long-term growth rate of the per capita output is 2.15%, the average over the period 1960 to 2000, which is slightly higher than the long-term growth rate of 2% in United States. This gives the value of  $g_z$  which is 2.15%.

### 3.1 Measuring the wedges

The method of measuring the wedges has two parts. First, I need to estimate the stochastic process driving the wedges, and then I use the estimated stochastic process and data to estimate the value of the realized wedges. I substitute the value of consumption  $c_t$  from equation (1) into equations (2) and (3) and detrend the relevant variables by the rate of technical progress to get:

$$(5) \quad A_t = \frac{\hat{y}_t}{F(\hat{k}_t, (1+g_z)^t l_t)}$$

$$(6) \quad \frac{u_{n_t}((\hat{c}_t(\hat{y}_t, \hat{g}_t, \hat{x}_t))(1-l_t))}{u_{c_t}((\hat{c}_t(\hat{y}_t, \hat{g}_t, \hat{x}_t))(1-l_t))} = (1-\tau_{n_t}) A_t F_{l_t}(\hat{k}_t, (1+g_z)^t l_t)$$

$$(7) \quad \beta E_t u_{ct+1}(((\hat{c}_{t+1}(\hat{y}_{t+1}, \hat{g}_{t+1}, \hat{x}_{t+1})), (1-l_{t+1}))) \{A_{t+1} F_{kt+1}(\hat{k}_{t+1}, (1+g_z)^{t+1} l_{t+1}) + (1+\tau_{xt+1})(1-\delta)\} = (1+g_z)^t (1+\tau_{xt}) u_{ct}((\hat{y}_t, \hat{g}_t, \hat{x}_t))(1-l_t)$$

where I denote a variable  $z_t$  detrended by the long-term growth rate of technological development as:

$$\hat{z}_t = \frac{z_t}{(1+g_z)^t}$$

Note that we could have directly measured productivity and labor wedge from the first order conditions of the model. Given time series data on per capita output  $y_t$ , capital stock  $k_t$ , labor  $l_t$  and per capita government expenditure  $g_t$ , Equation (5) would give me the efficiency wedge series  $A_t$  and Equation (6) would give me the labor wedge series  $\tau_{nt}$ . However, investment wedge cannot be directly calculated from the given equations because we need to specify expectations over future values of consumption, the capital stock, and wedges and so on. The decision rules from my model implicitly depend on these expectations and therefore on the stochastic process driving the wedges. Thus, the estimated stochastic process is important only for measuring the investment wedge.

Let us denote the vector of log deviations of the wedges from the steady state values as

$$\tilde{\mathbf{s}}_t = \{\tilde{A}_t, \tilde{\tau}_{n,t}, \tilde{\tau}_{x,t}, \tilde{g}_t\}, \text{ where } \tilde{\mathbf{s}}_t = \{\tilde{A}_t, \tilde{\tau}_{n,t}, \tilde{\tau}_{x,t}, \tilde{g}_t\} \text{ follows a vector autoregressive AR1 process,}$$

such that

$$\tilde{\mathbf{s}}_{t+1} = \mathbf{P}_0 + \mathbf{P}\tilde{\mathbf{s}}_t + \mathbf{Q}\tilde{\boldsymbol{\epsilon}}_{t+1}$$

where we denote the log deviation of variable  $z_t$  from the steady state value as  $\tilde{z}_t$ . I assume that the errors follow a lognormal distribution, where the errors are contemporaneously correlated across equations but identically and independently distributed across time. Now we use the log-linearized form of equations 5, 6, and 7 along with the four equations underlying the vector autoregressive AR1 process for log-linearized wedges to estimate the parameters  $\mathbf{P}_0, \mathbf{P}$  and  $\mathbf{Q}$ . Given 7 equations and 7 unknown parameters underlying the vector autoregressive AR1 process, the parameters can be uniquely determined. We are going to solve the model using standard log-linearization techniques of Robert King, Charles Plosser and Sergio Rebelo (1988) and data on output, labor, investment and government consumption to solve for the parameter values underlying the stochastic process. Once we know the stochastic process, we can derive the values of the realized wedges.

The government consumption is taken directly from the national income accounts. I calculate the capital stock series using the initial capital stock and by the perpetual inventory method. Let us denote the log deviation of data variable  $z_t$  from the steady state value as  $\tilde{z}_t^{dat}$ . Now given the state of the economy at time  $t$  is summarized by the vector  $\tilde{\mathbf{s}}_t = \{\tilde{A}_t, \tilde{\tau}_{n,t}, \tilde{\tau}_{x,t}, \tilde{g}_t\}$  and  $\tilde{k}_t$ , we can get solutions to the decision variables as function of  $\tilde{\mathbf{s}}_t = \{\tilde{A}_t, \tilde{\tau}_{n,t}, \tilde{\tau}_{x,t}, \tilde{g}_t\}$  and  $\tilde{k}_t$ . Since we mentioned before that this is an accounting procedure, so we know that if we insert all the wedges jointly in the model we will be able to exactly replicate the data. In other words we know that:

$$(8) \quad \tilde{y}_t^{dat} = \tilde{y}_t(\tilde{\mathbf{s}}_t, \tilde{k}_t)$$

$$(9) \quad \tilde{x}_t^{dat} = \tilde{x}_t(\tilde{\mathbf{s}}_t, \tilde{k}_t)$$

$$(10) \quad \tilde{l}_t^{dat} = \tilde{l}_t(\tilde{\mathbf{s}}_t, \tilde{k}_t)$$

We then determine efficiency, labor and investment wedges every period from the above set of equations. Once we have a numerical measure of the wedges, we can feed them into the model separately and in various combinations to assess what fraction of fluctuations in output, investment and labor can be accounted for by various combinations of wedges, thus letting us assess the importance of various wedges in accounting for the lost decade. This exercise is referred to as *decomposition*.

### 3.2 Decomposition

Our accounting procedure decomposes movements in variables from an initial date with an initial capital stock into four components consisting of movements driven by each of the four wedges away from their values at the initial date. We construct these components as follows.

Define the efficiency component of the wedges by setting  $\tilde{\mathbf{s}}_{1t} = \{\tilde{A}_{1t}, \tilde{\tau}_{n0}, \tilde{\tau}_{x0}, \tilde{g}_0\}$  where  $\tilde{\mathbf{s}}_{1t}$  is the vector of log deviation of wedges in period  $t$ , where the efficiency wedge takes on its period  $t$  value while the other wedges stay at their initial i.e. steady state value. Thus, using  $\tilde{\mathbf{s}}_{1t} = \{\tilde{A}_{1t}, \tilde{\tau}_{n0}, \tilde{\tau}_{x0}, \tilde{g}_0\}$  and the initial period capital stock  $\tilde{k}_0$ , we can generate the capital stock series by  $\tilde{k}_{t+1} = \tilde{k}_{t+1}(\tilde{\mathbf{s}}_{1t}, \tilde{k}_t)$  where  $\tilde{k}_{t+1}(\tilde{\mathbf{s}}_{1t}, \tilde{k}_t)$  is the estimated decision rule of the capital stock next period. Then, using the vector of wedges  $\tilde{\mathbf{s}}_{1t} = \{\tilde{A}_{1t}, \tilde{\tau}_{n0}, \tilde{\tau}_{x0}, \tilde{g}_0\}$ , the estimated capital stock series and the decision rules estimated, we could get the movements in the decision variables due to the efficiency component only. Thus, we can get

$$(11) \quad \tilde{y}_{1t} = \tilde{y}_t(\tilde{\mathbf{s}}_{1t}, \tilde{k}_t)$$

$$(12) \quad \tilde{x}_{1t} = \tilde{x}_t(\tilde{\mathbf{s}}_{1t}, \tilde{k}_t)$$

$$(13) \quad \tilde{l}_{1t} = \tilde{l}_t(\tilde{\mathbf{s}}_{1t}, \tilde{k}_t)$$

We can analogously get movements in decision variables due to other components like labor or investment wedge, also in different combinations of the wedges. For example, we can define efficiency and labor component as  $\tilde{\mathbf{s}}_{12t} = \{\tilde{A}_{1t}, \tilde{\tau}_{nt}, \tilde{\tau}_{x0}, \tilde{g}_0\}$  and proceed with decomposition where efficiency and labor wedges take on their period  $t$  value respectively, while investment and government wedges remain at their initial date value. For our results that we subsequently illustrate we perform such decompositions for all possible combinations of wedges.

#### 4 Data and account findings

To highlight the economic experiences of Japan, we turn to the National income accounts of Japan and remove the net indirect business taxes from the output and consumption expenditure. Given we are dealing with closed economy, we add net exports to private consumption (Chari et al. (2002) adds it to government expenditure). We remove a trend of 2.15% (the average growth rate of per capita output during 1960 to 2000) from per capita output, investment and government consumption (since our objective is to see how far did the economy *move away* from the trend during the period of investigation). We take 1980 to be the base period of our analysis (a period when the economy was relatively stable and poised on a balanced growth path) and normalize both output and labor hours to equal 100 in the base period. In Figure 1 and 2, we depict the per capita output discounted for the long-term trend and capital-output ratio. The average growth rate of per capita GDP during late eighties was 1.39% above trend but during the nineties, it fell to 1% below trend level. Capital-output ratio, however, increased from 1.74 in

1980 to 2.53 in 2000, which has led economists to conclude that there was significant capital deepening during the eighties and nineties. Even labor market saw some big changes. During 1988 to 1993 due to huge support amongst the Japanese population, the Labor Standards Law was modified. The new legislation reduced workweek from 6 to 5 days a week, it added one day to paid vacation and increased the number of national holidays by three. The impact was a huge drop in labor hours, which between 1988 and 2000, fell by 7.5% as depicted in figure 3. What stands out from these numbers is an obvious and decade-long slowing down of the economy during the nineties, following a surprisingly short-lived economic boom of late eighties. The next subsection discusses some possible mechanisms that allowed market frictions to result in such a dramatic fluctuation.

#### **4.1 Observed wedges and some comments on possible market frictions underlying them**

We begin with an analysis of wedges estimated using the procedure outlined in section 3. Table 1 summarizes the stochastic process for the wedges. The idea that taxes of various kinds distort the relation between various marginal rates is the cornerstone of public finance. Many studies have relied on analysis of such wedges to explain various business cycle phenomenons. The efficiency wedge has been extensively studied, both in the context of Japan (Kehoe and Prescott (2002)), and otherwise (Pedro S. Amaral and Jim MacGee (2002); Timothy J. Kehoe and Kim J. Ruhl (2003)). Interpretations of other wedges have occupied an equally important role in literature. Michael Parkin (1988) shows how monetary shocks might drive the labor wedge. For Robert Hall (1997), wedges that drive macroeconomic fluctuations, particularly movements in employment represent preference shocks. In Japan, the wedge dynamics is also open to many interesting interpretations.

Figure 4 graphically depicts the realized wedges in Japan and Table 2 summarizes the cross-correlation of output with respect to wedges over the two sub periods: 1980 to 1991 and 1991 to 2000. Over both sub periods, output is positively correlated with efficiency wedges and negatively with investment wedges. No surprises there as the eighties saw a boom in productivity and an easing of the investment market due to liberalization measures, both of which are conducive to an economic boom. The trend reversal of nineties has generated much more of a debate as to the primitives dictating them. For Prescott and Hayashi (2002), the action is a downturn of productivity. Others look into investment frictions. Dekle and Kletzer (2003) highlights the role played by deposit insurance in generating a banking crisis and Caballero, Hoshi and Kashyap (2004) argue that “essentially Japan has reached the situation of having bankrupt banks lend to bankrupt firms, and in this scenario the private sector struggles”. Kenneth Kasa (1998) has also looked at the impact of borrowing constraints and asset market dynamics in an attempt to investigate effect of investment market frictions on asset prices. The role of labor wedges, however, has not generated much of literature. In Japan, labor wedge was falling slightly during the first sub period, but the trend reversed since 1988. One can conjecture that this was due to the changing labor laws that essentially made labor costlier than before. It could well be an important transmission channel in the nineties. Government consumption, on the other hand, has always been on the rise since the eighties, and could not have been responsible for the depression of the nineties. If it played any role at all, it might have acted as a brake in the downfall, which explains its negative cross-correlation with output since 1991. We can therefore ignore government consumption as a transmission channel that might have affected the economy adversely.

## 4.2 Findings

We begin by feeding the wedges one by one in the model and observing to what extent these wedges generate the data. As depicted in figure 5, with respect to 2.15% trend, per capita output increases by 12.2% from 1980 to 1991 and falls by 6.6% by 2000. Feeding efficiency wedge alone shows an increase in output per capita by 3.8% and fall by 4.5%, and feeding investment wedge alone shows an increase by 8.5% and fall by 1.2%. Both wedges also perform well in generating capital-output ratio that closely matches data<sup>6</sup>. In fact, investment wedge alone predicts a capital-output ratio of 2 by 2000 as compared to 2.53 in data (figure 6). This is quite in contrast to the findings of Prescott and Hayashi (2002) who shows that in a standard RBC model, exogenous technology shocks account for almost the entire fluctuations in output and the observed capital-output ratio. Model prediction about role of labor wedges is better observed for labor hours (figure 7). Data shows a unilateral fall in labor hours, particularly during 1988 to 1993 when new labor laws were enacted. Labor wedge can account for a quarter of the total fall in labor hours, and investment wedges also perform well and accounts for about half of the observed changes. However, our wedges do not perform well in accounting for labor hours in the latter half of nineties. One can conjecture that in our model once the efficiency and investment market frictions became strong in the nineties causing an economic downturn, consumers responded by working more to smooth consumption, something that probably did not happen in Japanese economy due to stringent labor laws that prevented consumers from working over-time. It would be interesting to introduce a regime-switching model to incorporate such restrictions explicitly and observe model predictions about Japanese labor markets.

The results show that though efficiency wedges are an important transmission mechanism, but one *cannot* ignore the role played by investment wedges, particularly in the latter half of eighties.

Considering both wedges jointly the model can account for almost the entire fluctuations in output per capita and accounts for a significant portion of the observed capital-output ratio (figures 8 and 9). The wedges jointly account for about 55% of the observed fluctuations in labor hours during 1988 to 1993 (figure 10) but the performance is not as good for latter years.

This section highlights two results: on the one hand, efficiency wedges are important for transmitting the impact of market frictions on the economy, especially during the depression era of the nineties but on the other hand, in contrast to the assertions of Prescott and Hayashi (2002), they are definitely *not* the only channel that we need consider. In fact, investment wedges emerge as an important transmission channel, not only during the late eighties when it played a more important role than efficiency wedges, but also during the nineties, when it played a significant role. This result has another important implication. It tells us that researchers who look for primitives behind these wedges to explain the happenings in Japan should concentrate not only on productivity fluctuations and market frictions that directly caused technological upheavals, but also concentrate on market frictions like the ones outlined by credit-constrained models of Nobuhiro Kiyotaki and John Moore (1997) and Ben Bernanke and Mark Gertler (1989), in which market frictions play a major role in causing business cycles by affecting credit flows. One channel that seems not to have played any significant role except during 1988 to 1993 is the labor wedge channel, which probably reflects changes in labor policy during that period.

## **5 Conclusion**

Since the inception of RBC models as a way of accounting for business cycles, researchers have debated as to the effectiveness of RBC paradigm by pointing out that it fails to reproduce many observed features of business cycles. Such questions about its empirical merits have also led to questions about the effectiveness of productivity fluctuations as a propagation channel for market frictions, something that RBC models stress on. This paper looks at that question using the new approach of BCA, which allows us to keep the essence of the RBC architecture, but extends it to embrace other important propagation channels.

Applying this new technique to study the interesting happenings in Japan during the last two decades of the twentieth century, we find that though productivity or efficiency fluctuation is an important propagation channel, but it is by no means, the only important channel. Investment channel emerges as a strong propagation mechanism, something that traditional RBC model with exogenous TFP shocks would fail to recognize, thus erroneously overemphasize the role played by technology. The paper also helps researchers looking for primitives to recognize that at least in the context of Japan, they need not restrict themselves to market frictions that can only influence the economy through their impact on productivity. It is definitely desired and perhaps necessary to also realize that any market friction that manifested itself in a way that directly affected the investment financing in Japan played an equally important role in generating the business cycle fluctuations that have so puzzled the economists.

## **Bibliography:**

**Amaral, Pedro & Macgee, James** (2002), “The Great Depression in Canada and the United States: A Neoclassical Perspective”, *Review of Economic Dynamics* 5(1), pp. 45-72

**Backus, David K; Kehoe, Patrick J. and Kydland, Finn E** (1992), “International Real Business Cycle”, *Journal of Political Economy* 100(4), pp. 745-775

**Basu, Susanto & Fernald, John G** (2002), "Aggregate Productivity and Aggregate Technology" *European Economic Review*, 2002, 46(6), pp. 963-91

.....“Aggregate productivity and aggregate technology”, *International finance discussion papers no. 593*; Washington, D.C.: Board of Governors of the Federal Reserve System, 1997

**Bergoing, Raphael; Kehoe, Patrick J; Kehoe, Timothy J and Soto, Raimundo** (2002), “A Decade Lost and Found: Mexico and Chile in the 1980s”, *Review of Economic Dynamics* 5(1), pp. 45-72

**Caballero Ricardo, Hoshi Takeo and Kashyap Anil** (2004), “Zombie lending and depressed restructuring in Japan” *NBER Working Paper*, 2004

**Chari, V V; Kehoe, Patrick J and Macgrattan, Ellen R** (2002), “Accounting for the Great Depression”, *Federal Reserve Bank of Minneapolis Quarterly Review*, Volume 27, Number 2

..... ‘Business Cycle Accounting’ Revision (2005), *Federal Reserve Bank of Minneapolis Staff Report*

..... Accounting for the Great Depression”, *American Economic Review Papers and Proceedings*, Vol. 92, No. 2, May 2002

**Cole, Harold L. & Ohanian, Lee E** (1999), “The Great Depression in the United States from a Neoclassical Perspective”, *Federal Reserve Bank of Minneapolis Quarterly Review*, Volume 23, pp. 2-24

**Dekle, Robert & Kletzer, Kenneth** (2003), “The Japanese Banking Crisis and Economic Growth: Theoretical and Empirical Implications of Deposit Guarantees and Weak Financial Regulation”, *Journal of Japanese and International Economies*, (17) pp. 305-335.

**Fischer, Jonas** (2004), "Technology Shocks Matter," Working Paper Series WP-02-14, Federal Reserve Bank of Chicago

**Gali, Jordi** (1999), “Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?”, *American Economic Review*, March 1999, pp. 249-271

**Gali, Jordi & Rabanal, Pau** (2004), “Technology Shocks and Aggregate Fluctuations: How Well Does the RBC Model Fit Postwar U.S. Data?”, *NBER Macroeconomics Annual*, Forthcoming

**Hall, Robert E** (1997) “Macroeconomic Fluctuations and the Allocation of Time”, *Journal of Labor Economics*, University of Chicago Press, vol. 15(1), pp. S223-50

**Ireland, Peter N** (2004) “Technology Shocks in the New Keynesian Model,” *Review of Economics and Statistics*, November 2004.

**Kenneth Kasa** (1998), “Borrowing constraints and asset market dynamics: evidence from Pacific Basin”, *Pacific Basin Working Paper Series 98-04*, Federal Reserve Bank of San Francisco

**Kehoe, Timothy J & Ruhl, Kim J** (2003), “Recent Great Depressions: Aggregate growth in New Zealand and Switzerland 1973-2000” *New Zealand Economic Papers*, 37, pp. 5-40

**King, Robert; Plosser, Charles and Rebelo Sergio** (1988), “Production, growth, and business cycles: The basic neoclassical model”, *Journal of Monetary Economics* 21(2), pp. 195-232.

**Kydland, Finn E. and Prescott, Edward C** (1982), “Time to Build and Aggregate Fluctuations.” *Econometrica*, November 1982, 50(6), pp. 1345–70.

**McGrattan, Ellen R** (2004), “Comment on Gali and Rabanal’s “Technology Shocks and Aggregate Fluctuations: How Well Does the RBC Model Fit Postwar U.S. Data?”” *Federal Reserve Bank of Minneapolis Staff Report 338*, Revised December 2004

**Parkin, Michael** (1988), “A Method for Determining Whether Parameters in Aggregative Models are Structural,” *Carnegie-Rochester Conference Series on Public Policy*, 29, 215—252.

**Prescott, Edward C** (1999), “Theory Ahead of Business Cycle Measurement”, *Federal Reserve Bank of Minneapolis Quarterly Review*, 10(Fall) , 9-22

**Prescott, Edward C & Hayashi, Fumio** (2002), “The 1990s in Japan: A Lost Decade”, *Review of Economic Dynamics* 5(1), pp. 206

**Footnote:**

<sup>1</sup> Fumio Hayashi and Edward C. Prescott (2002) were the first ones applying it to Japan during the nineties. Pedro S. Amaral and Jim MacGee (2002) apply the same technique to Canada during Great Depression and found market frictions manifested as technology shocks to be the determining factor behind the Great Depression. There are also similar studies done by Timothy J. Kehoe and Kim J. Ruhl (2003) on New Zealand and Switzerland that finds technology shocks responsible for the economic fluctuations. The common thread of all these studies as already evident is the significant role played by technology fluctuations.

<sup>2</sup> Hayashi and Prescott (2002) who studied Japan during the nineties using the standard accounting conclude, “The problem then and still today, is a low productivity growth rate. Growth theory, treating TFP as exogenous, accounts well for the Japanese lost decade of growth”.

<sup>3</sup> This result follows from the key idea underlying BCA accounting that large classes of models, including models of market frictions, are *equivalent* to a prototype growth model, where the market frictions manifest themselves as wedges that, at least at the face value, look like time varying efficiency, taxes on labor income and taxes on investment expenditure.

<sup>4</sup> I thank Keiichiro Kobayashi of RIETI, Tokyo, Japan who first pointed out this fact to me.

<sup>5</sup> The technical details are available in the Appendix available upon request

<sup>6</sup> I could have graphed investment instead of capital-output ratio. I provide model results on capital-output ratio for an easy comparison with Prescott and Hayashi’s (2002) model results using the KP technique, where they graphically depict capital-output ratio.

**TABLE 1****Parameters of Vector AR (1) Stochastic Process; Standard errors in ( ) & t-statistics in [ ]**

Table 1-a	Coefficient matrix on constants ( $P_0$ )			
	-0.004793 (0.00374) [-1.28205]	-0.001628 (0.00280) [-0.58068]	-0.016830 (0.01295) [-1.29946]	0.014503 (0.00262) [ 5.53271]
Table 1-b	Coefficient matrix on lagged states ( $P_1$ )			
	0.572370 (0.36885) [ 1.55177]	-0.786184 (0.27658) [-2.84251]	-0.694558 (1.27779) [-0.54356]	-0.209597 (0.25861) [-0.81046]
	-0.200652 (0.16885) [-1.18833]	1.054868 (0.12661) [ 8.33139]	0.169310 (0.58495) [ 0.28944]	0.634573 (0.11839) [ 5.36009]
	-0.096127 (0.07336) [-1.31034]	-0.166658 (0.05501) [-3.02963]	0.756134 (0.25414) [ 2.97526]	0.076329 (0.05144) [ 1.48397]
	-0.151049 (0.28267) [-0.53436]	-0.487030 (0.21196) [-2.29771]	-0.342762 (0.97926) [-0.35002]	0.524405 (0.19819) [ 2.64593]
Table 1-c	Covariance matrix on shocks ( $Q$ )			
	-0.410255 (0.52950) [-0.77480]	0.104454 (0.44766) [ 0.23333]	1.605405 (1.87843) [ 0.85465]	0.407362 (0.39600) [ 1.02869]
	0.670436 (0.43022) [ 1.55837]	-0.058617 (0.36372) [-0.16116]	-.213772 (1.52622) [-1.40066]	-0.436363 (0.32175) [-1.35622]
	-0.150869 (0.13267) [-1.13717]	-0.006141 (0.11216) [-0.05475]	0.716424 (0.47066) [ 1.52218]	0.091274 (0.09922) [ 0.91991]
	0.170627 (0.37263) [ 0.45790]	0.106834 (0.31504) [ 0.33911]	0.424041 (1.32193) [ 0.32077]	-0.085824 (0.27868) [-0.30796]

**TABLE 2****Properties of the wedges**

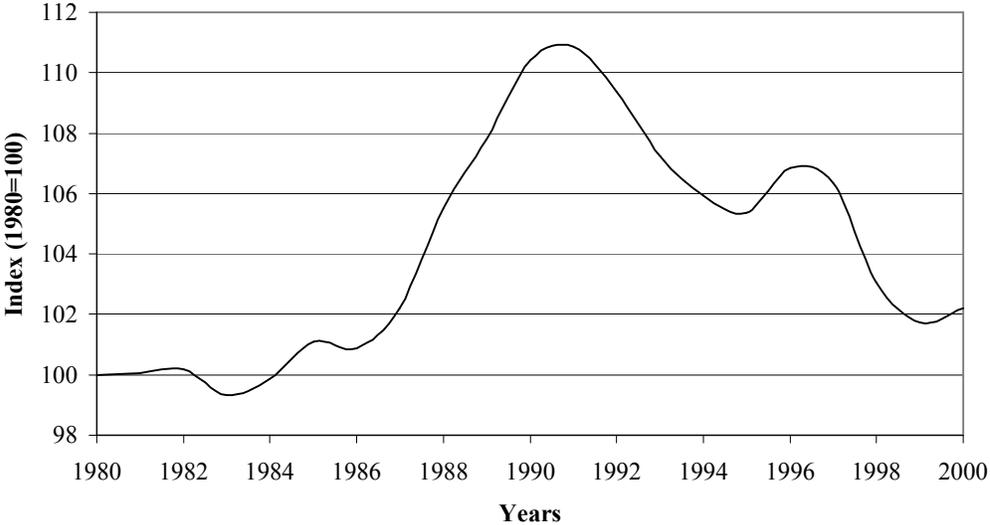
Summary statistics during the period 1980:1991

Wedges	Standard deviation relative to output	Cross correlation of wedge with output at lag k		
		-1	0	1
Efficiency	.2	.64	.9	.84
Labor	.21	.8	.91	.93
Investment	1.04	-.98	-.99	-.93
Govt. Consumption	.19	.51	.48	.58

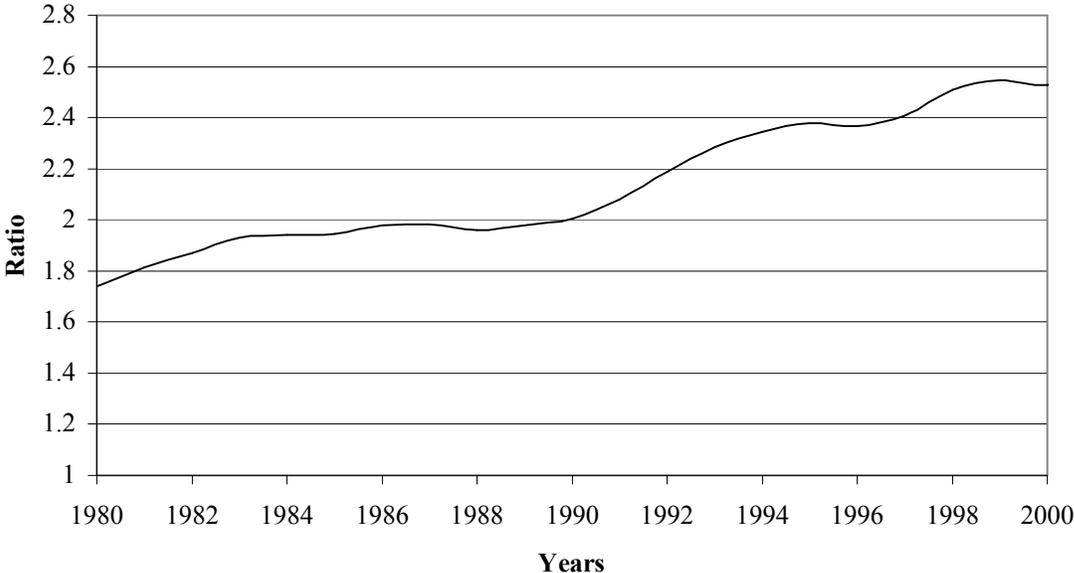
Summary statistics during the period 1991:2001

Wedges	Standard deviation relative to output	Cross correlation of wedge with output at lag k		
		-1	0	1
Efficiency	.43	.91	.95	.84
Labor	.29	-.76	-.91	-.93
Investment	.86	-.8	-.93	-.64
Govt. Consumption	.58	-.75	-.83	-.95

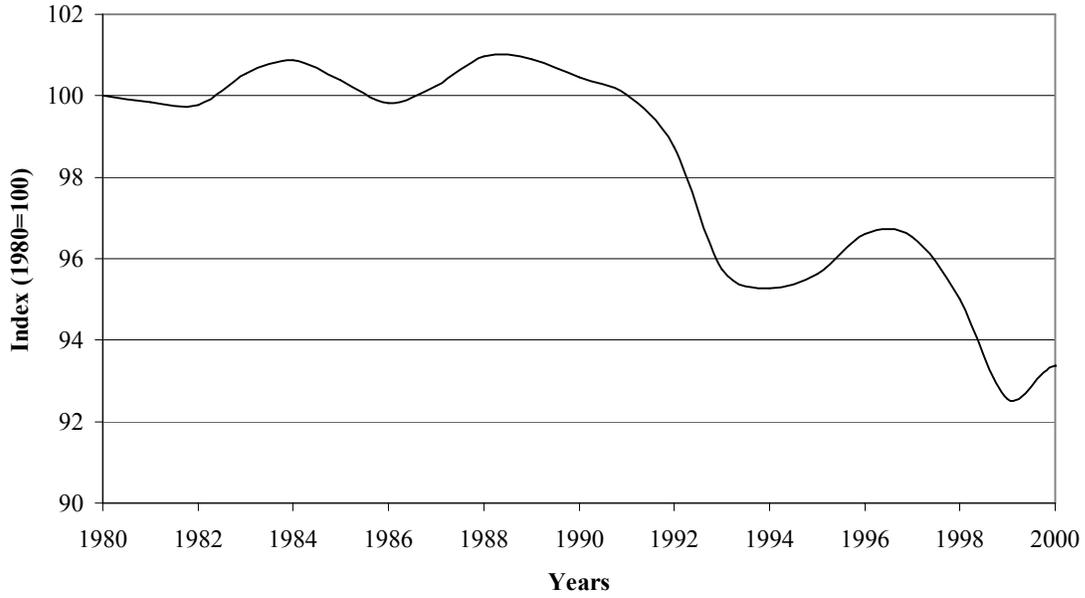
**Figure 1: Data on per capita output with respect to a long- term trend during 1980 to 2000**



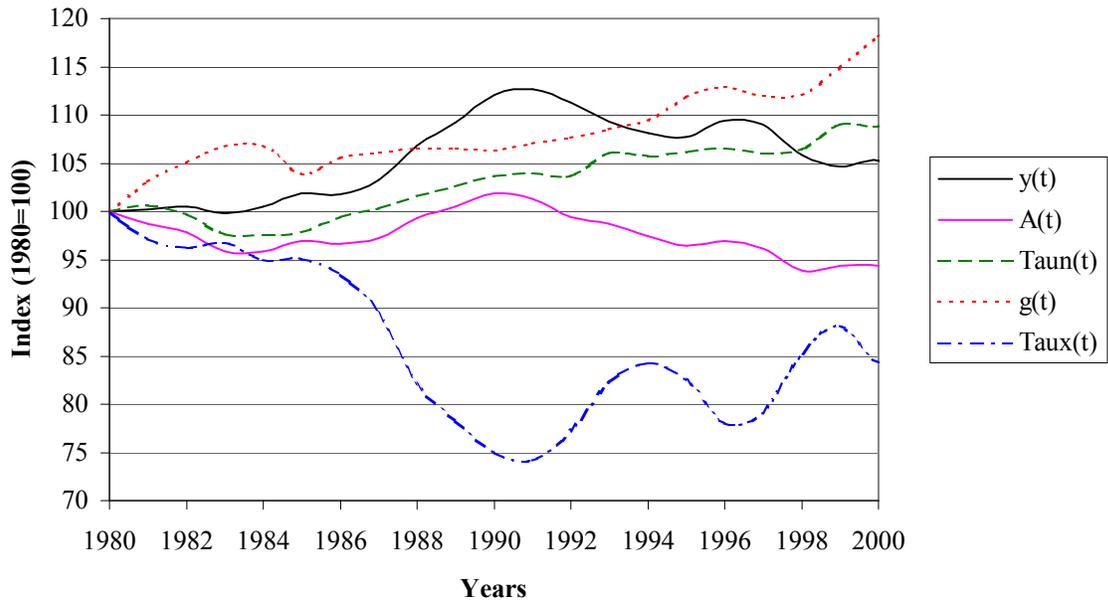
**Figure 2: Data on capital-output ratio during 1980 to 2000**



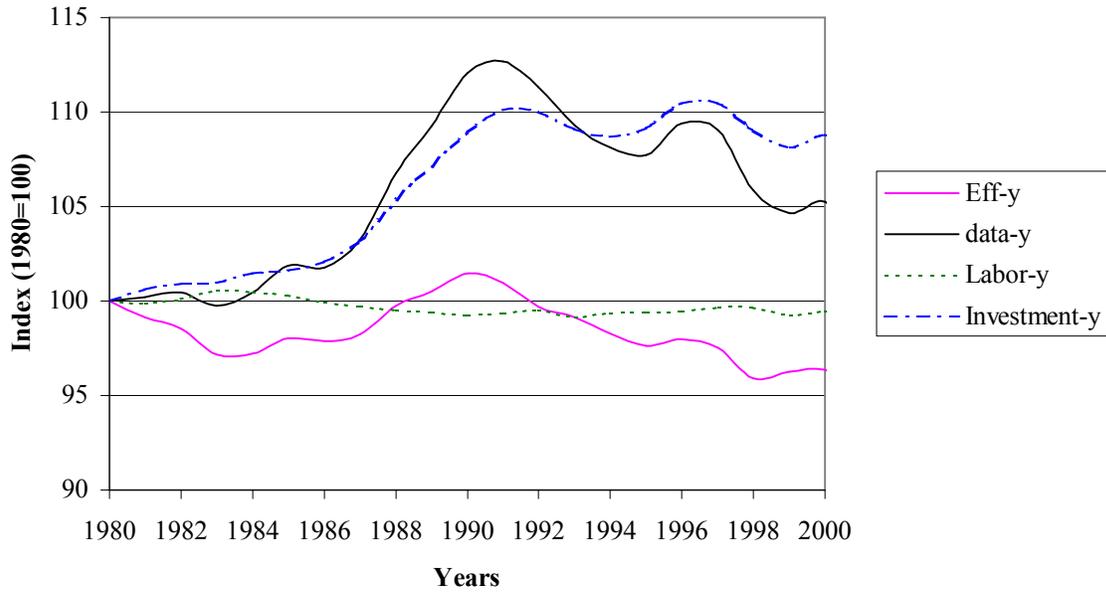
**Figure 3: Data on labor hours during 1980 to 2000**



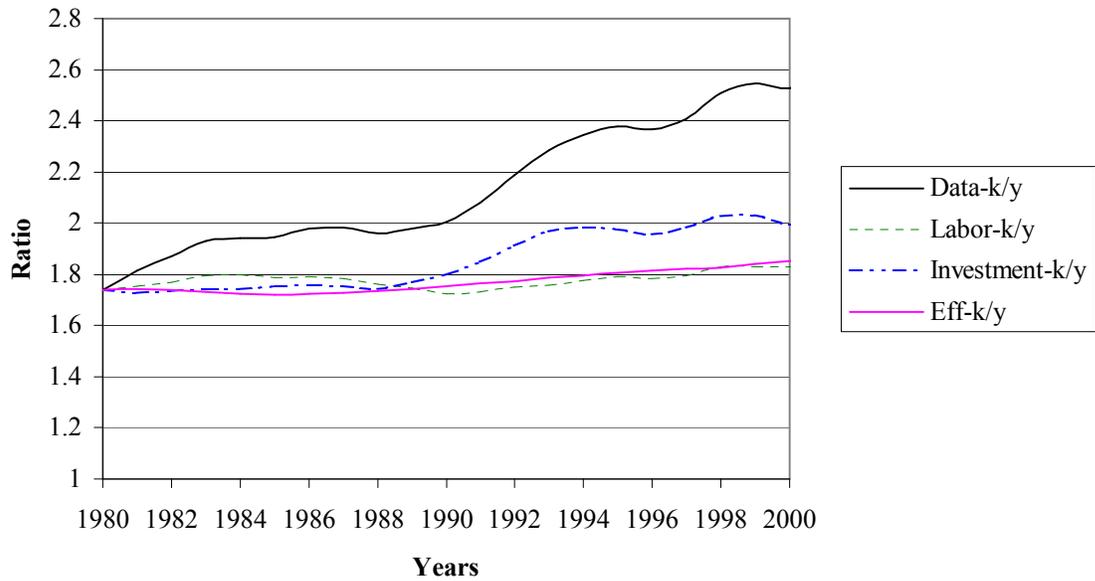
**Figure 4: Per capita output and wedges as calculated from the model and data**



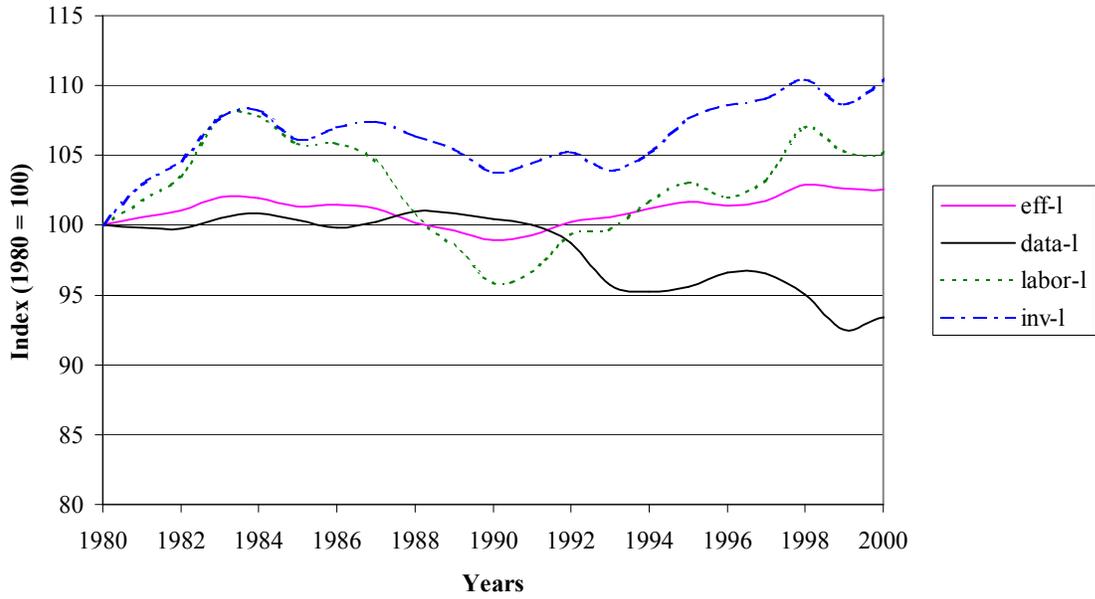
**Figure 5: Per capita output inserting wedges one at a time in the model**



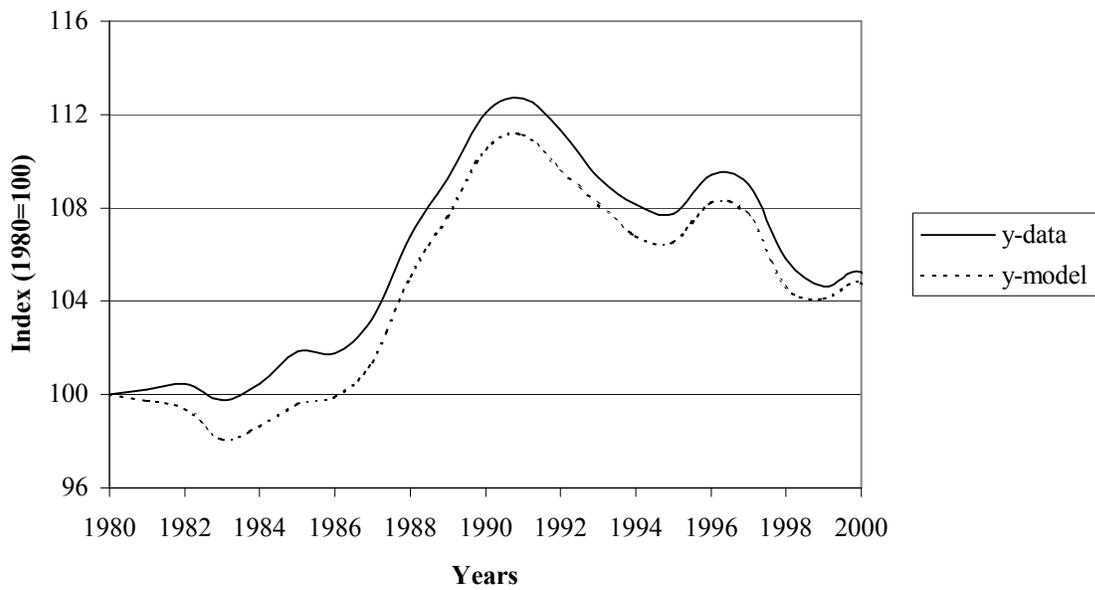
**Figure 6: Capital-output ratio inserting wedges one at a time in the model**



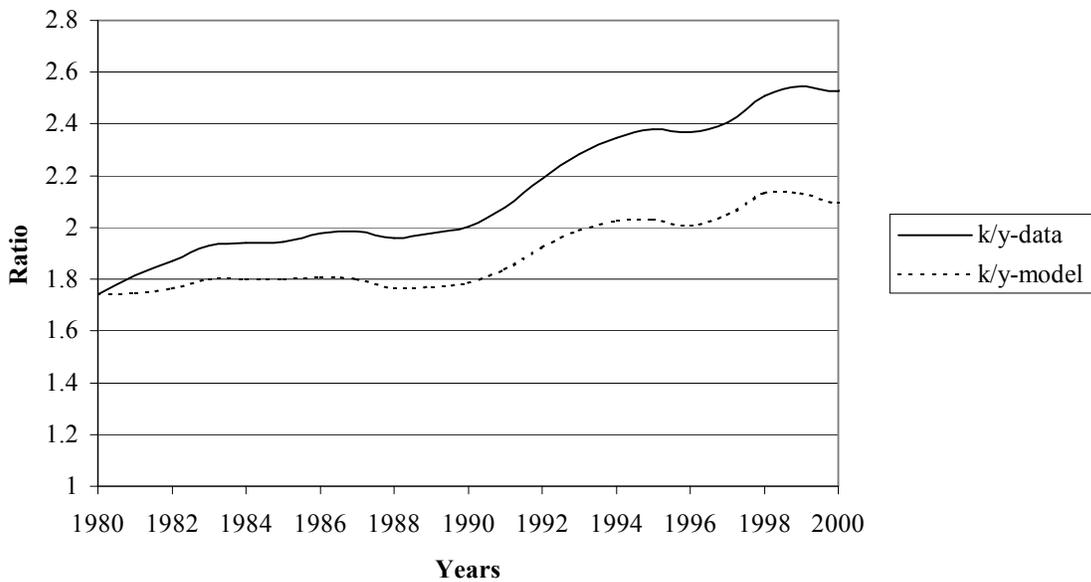
**Figure 7: Labor hours inserting wedges one at a time in the model**



**Figure 8: Per capita output inserting efficiency and investment wedge jointly**



**Figure 9: Capital-output ratio inserting efficiency and investment wedge jointly**



**Figure 10: Labor hours inserting efficiency and investment wedge jointly**

