

# Essays on Business Cycle Fluctuations

BY

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# Abstract

This thesis consists of three essays on business cycle fluctuations that are based on the market-clearing dynamic general equilibrium framework. The first two essays examine the ultimate source of economic fluctuations in Thailand and Australia, respectively. The tool of study is the Business Cycle Accounting (BCA) method developed by Chari et al. (2002; 2007a). The third essay investigates the relation between capital-labour substitution and sectoral externalities in self-fulfilling expectation equilibria. It employs a two-sector competitive model proposed by Benhabib and Farmer (1996).

The BCA method examines the transmission mechanisms of shocks within an economy. These transmission mechanisms are called wedges which are responsible for the deviation of aggregate variables from a competitive equilibrium. Four categories of wedges are defined in the BCA: 1) the efficiency wedge represents the input-financing frictions in production; 2) the labour wedge is the frictions between consumption-leisure trade-off and marginal product of labour; 3) the investment wedge is the frictions between the intertemporal marginal rate of substitution in consumption and the marginal product of capital; and 4) the government consumption wedge indicates the frictions in international borrowing and lending.

Chapter 2 applies the BCA method with deterministic wedges to examine the output variations in Thailand between 1971-2003. The efficiency wedge is found to be the most important driving force behind the output variations during episodes of boom and bust in Thailand over the studied period. In particular for the 1997 economic downturn, the evidence shows that the cost of credit intermediation for some firms was relatively high. This altered an acquisition of working capital and labour in these firms when compared to others, which likely caused inefficient reallocation of inputs across the economy. As such, the efficiency wedge appears to fall at aggregate level during the economic downturn.



Chapter 3 applies the BCA method with stochastic wedges to examine the variations in output and investment in Australia. Although the efficiency wedge alone can account for these variations, it predicts much more volatility in output than the actual data. Upon allowing for the combination of efficiency and labour wedges, the model can replicate the amplitude of output variations better. The negative cross correlation between these two wedges suggests their interference.

Chapter 4 examines the effect of capital-labour substitution on the existence of indeterminacy in two-sector models and check whether the corresponding returns to scale are still empirically plausible. The main finding is that a higher requirement of sectoral externalities for indeterminacy is needed when capital and labour are less substitutable.

Intuitively, the low substitutability implies that capital and labour are complementary factors of production. This retards the mobility of factors between the consumption and investment sectors. In the belief driven equilibria, the consumers' optimistic expectation on returns is fulfilled as long as the rate of returns is sufficiently high such that current consumption is given up for investment. The rate of returns hereby indicates sectoral externalities. In such a production environment, the minimum requirement of externalities for indeterminacy therefore becomes larger so that it can successfully break the tightly coupling factors within sector, and raises the production of investment goods effectively. As a result, the current relative price of investment goods falls. In the next period, consumers enjoy more consumption goods and the relative price of investment good rises. The ascending pricing sequence yields capital gains and the consumers' belief is finally fulfilled. Based on the logarithmic utility in consumption and the elasticity of substitution of 0.5 as suggested in Klump et al. (2007) and Chirinko (2008), the minimum requirement of returns to scale for indeterminacy is 1.1236, and it still lies within the range in most empirical studies.

# Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution to Noppawan Photphisutthiphong and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968. I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library catalogue, the Australasian Digital Theses Program (ADTP) and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

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# Chapter 1

## Introduction

Since the path-breaking “Time to build and aggregate fluctuations” by Kydland and Prescott was published in 1982<sup>1</sup>, the Real Business Cycle (RBC) approach is widely regarded as the mainstream of the study of economic fluctuations. It provides convincing understanding to researchers on how fluctuations in output, consumption, investment and employment arise. The RBC approach is based on the market-clearing dynamic general equilibrium. All economic agents are rational. Households maximize their expected life-time utility with respect to the budget constraint. Meanwhile, profit-maximizing firms produce outputs by hiring labour and capital from households. This economy has competitive equilibrium allocations.

This thesis consists of three essays on business cycle fluctuations based on the RBC approach. The first two core chapters apply the Business Cycle Accounting (BCA) method to examine the ultimate source of economic fluctuations in Thailand and Australia, respectively. The last core chapter examines how the capital-labour substitution affects the endogenous equilibrium fluctuations due to self-fulfilling expectations.

The BCA method is developed by Chari, Kehoe and McGrattan (2002; 2007a). It is founded in the RBC approach and provides the useful insight into the detailed

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<sup>1</sup>Finn E. Kydland and Edward C. Prescott were the Nobel Prize Laureates in 2004 for their contribution to the research in real business cycle models and time-consistent problems in implementing monetary policy. (Source: [http://nobelprize.org/nobel\\_prizes/economics/laureates/2004/public.html](http://nobelprize.org/nobel_prizes/economics/laureates/2004/public.html))

business cycle model that is relevant to the aggregate fluctuations. As a tool for exploring the economic fluctuations, it becomes more promising than the structural vector autoregression (SVAR) method. This is because the BCA method does not require large observations of data in the accounting procedure whereas the SVAR method, as discussed in Chari et al. (2008), does. The prototype economy in the BCA method incorporates wedges in the frictional detailed business cycle model. These wedges represents the transmission channels through which shocks propagate themselves in an economy. These wedges are measured by using the competitive equilibrium equations with time series data. The measured wedges are then fed into the model, either individually or in combinations, to assess the importance of each wedge to the business cycle fluctuations.

There are four wedges under the BCA method. They are the efficiency wedge, the labour wedge, the investment wedge, and the government consumption wedge. The efficiency wedge, or total factor productivity (TFP), represents input-financing frictions in production. A fall in the efficiency wedge during economic downturn is referred to an inefficient allocation of factors in production. The labour wedge is equivalent to the residual between the marginal product of labour and the marginal rate of substitution between consumption and labour. The presence of the labour wedge implies that labour demand and/or labour supply do not equate with the real wage in equilibrium. A fall in the labour wedge that is equivalent to a rise in artificial labour income taxes leads to and economic slowdown. The investment wedge is equivalent to the residual between the marginal product of capital and the intertemporal marginal rate of substitution in consumption. A decline in the investment wedge is equivalent to an increase in artificial taxes on investment. This tends to raise financial frictions in the credit market. It may cause an economic slowdown due to the shrinking investment. Lastly, the government spending wedge

is the sum of government spending and net exports in the resource constraint. It can represent the international borrowing and lending frictions in a detailed business cycle model.

Chapter 2 applies the BCA method with deterministic wedges to investigate the source of economic fluctuations in Thailand during 1971-2003. The main finding sheds light on the importance of the efficiency wedge which is largely responsible for the variations in the output of Thailand. In particular, the efficiency wedge alone accounted for the 1980s economic recession, the late 1980s economic boom, and the 1997 economic downturn in Thailand. The labour wedge may explain in part the fall in output in 1997 economic downturn. However, it plays no significant role in the rest of the sample period. This implies that the labour wedge is not the main force in driving the variations in output. The investment wedge is not important since it always drive the model output against the movement of actual output: the model output with investment rises whereas the actual output falls, and vice versa. The government consumption wedge is negligible.

The findings suggest that the Thai authorities should pay more attention on reducing input-financing frictions in order to alleviate the effect of economic downturn. According to Bernanke (1983), there exists significant real cost of intermediation for market making and information gathering services in the financial market; as such, credits are not attainable to all borrowers and relatively more expensive to some borrowers, like households and small firms. In addition, the cost of credit intermediation rises during a financial crisis largely due to higher debtor insolvency and increasing default loans. In the 1997 economic downturn, the evidence shows that the cost of credit intermediation for some firms was relatively higher when compared to others. This altered the acquisition of working capital and labour in these firms. Hence the inefficient reallocation of inputs across the economy was likely to have occurred. It

follows that the efficiency wedge appears to fall at aggregate level during the economic downturn.

Chapter 3 applies the BCA method with stochastic wedges to examine the propagation mechanism of economic fluctuations in Australia, using data covering 1980:Q3 - 2008:Q2. The result reveals the efficiency wedge is the major force driving the Australian business cycles, particularly the variations in output and investment. The efficiency wedge alone can account for the fall in output in the 1982/83 recession and the 1990/91 recession. The investment wedge plays a minor role in both recessions. The recovery in output after both recessions is well accounted for by the combination of efficiency and labour wedges. The model with just efficiency wedge predicts the amplitude of the recovery in output larger than what is actually observed in the actual data. On the other hand, the prediction produced by combination of these two wedges in the model resembles more closely with the actual data. There is a highly negative cross correlation between the measured efficiency and labour wedges. This suggests the interference between these two wedges. Intuitively, some increments in input-financing frictions in production are to be offset by the decreasing distortions in the labour market, and vice versa. This suggests that the frictional business cycle model for the Australian economy should incorporate shocks that propagate themselves through both the efficiency and the labour wedges. Otherwise, it may not be sufficient to explain the aggregate fluctuations. Further study on the Australian labour market should take into account the shocks that transmit themselves as the investment and the labour wedges. It is because the variations in hours worked is best explained by the model with both the investment and the labour wedges. Lastly, the efficiency wedge mostly accounts for the expansion of output in the late 1990s boom.

Chapter 4 focuses on business cycle fluctuations that are essentially driven by

animal spirits. Consumers' optimistic/pessimistic expectation on returns may cause fluctuations in consumption, investment, employment and output, regardless of any changes in fundamentals. The economic fluctuations due to self-fulfilling expectation arise in the model with indeterminate equilibrium. An indeterminate equilibrium refers to a stationary equilibrium with an infinite number of equilibrium paths. The steady state is unique. Market imperfections like increasing returns to scale can generate indeterminacy. Benhabib and Farmer (1996) develop a two-sector competitive model and show that consumers' belief becomes self-fulfilling with sufficiently high sector-specific externalities. Subsequent studies find that only externalities in investment sector matter for indeterminacy. All previous studies<sup>2</sup> rest on the Cobb-Douglas technology in production, which has the elasticity of substitution between capital and labour equal to one. However, empirical evidence argues that the elasticity of substitution is unlikely to be one (Klump, McAdam, and Willman 2007). It is worthwhile to investigate the effect of capital-labour substitution on the occurrence of indeterminate equilibrium.

Chapter 4 aims to investigate the relationship between the capital-labour substitution and the sector-specific externalities in the model with indeterminate equilibrium. The corresponding rate of returns to scale is also examined whether it is consistent with the empirical evidence.

The main finding is that an economy with lower substitutability between capital and labour requires higher degree in externalities in order to produce indeterminate equilibria. Intuitively, the low substitutability implies the complementary nature between production factors in a sector. In the belief-driven equilibria, the consumers' optimistic belief is fulfilled as long as the rate of returns is sufficiently high such that current consumption is given up for investment. The rate of returns hereby

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<sup>2</sup>For example, Harrison and Weder (2000), Weder (2000) and Harrison (2001) are among others.



indicates the sectoral externalities. In such a production environment, the minimum requirement of externalities for indeterminacy therefore becomes larger in order to break the tightly coupled factors within a sector. Once it has been overcome, the production of investment goods is raised subsequently. As a result, the current relative price of investment goods falls. In the next period, consumers enjoy more consumption goods and the relative price of investment goods rises. The ascending pricing sequence yields capital gains.

Chapter 4 further checks whether the corresponding returns to scale for indeterminacy is plausible, and the results are summarized as follows. The benchmark case of utility function is the logarithmic consumption. In this case, the indeterminate equilibria are determined solely from the externalities in investment as concluded in previous literature. The larger requirement of externalities in investment is needed for indeterminacy when capital and labour become more complementary factors in production. Based on the elasticity of substitution of 0.5 suggested in Klump, McAdam, and Willman (2007) and Chirinko (2008), the minimum requirement of returns to scale for indeterminacy is 1.1236, a figure that lies within the range suggested in empirical studies. Comparatively, the minimum requirement of returns to scale in Cobb-Douglas technology is 1.0774.

Whenever consumers become more or less risk averse, the externalities in consumption play a role (Harrison 2001). The change in the intertemporal consumption of a more risk-averse consumer is less sensitive to the change in the interest rate. With the Cobb-Douglas production technology, the minimum degree of externalities in investment for indeterminacy is an increasing function of the externalities in consumption (Harrison 2001). This minimum requirement of externalities in investment increases further when capital and labour are complementary, or in other words, inputs are less substitutable. Given the elasticity of substitution of 0.5, the degree of

risk aversion of 2.0 and no externalities in consumption, the corresponding rate of returns to scale for indeterminacy is still as mild as 1.150.

In contrast, the change in intertemporal consumption of a less risk-averse consumer is proportionally more with respect to any changes in the interest rate. This increases the externalities in consumption. In the benchmark production function, the indeterminate equilibrium thus requires smaller externalities in investment as the externalities in consumption rise (Harrison 2001). However, the complementary nature of inputs has again raised the minimum requirement of externalities in both investment and consumption for indeterminacy. Given the elasticity of substitution of 0.5, the degree of risk aversion of 0.5 and no externalities in consumption, the corresponding minimum rate of returns to scale required is as low as 1.0880. Overall, the indeterminate equilibria arises with mild degree returns to scale, despite capital and labour are complementary factors.

# Chapter 2

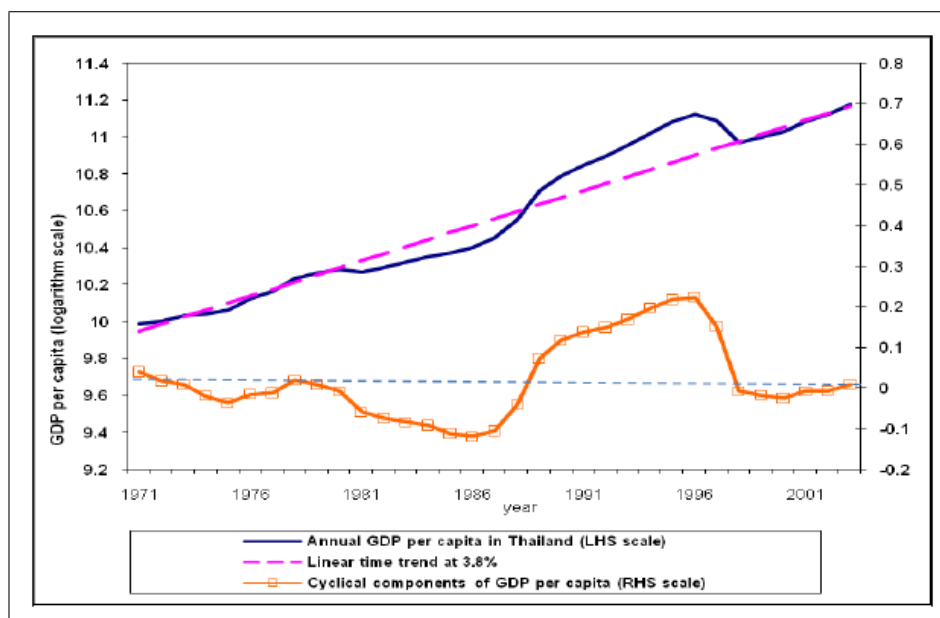
## Business Cycle Accounting for Thailand

### 2.1 Introduction

Thailand is amongst few countries that had remarkably high economic growth rate during the late 1980s to the early 1990s. It was particularly in 1988-1990 that the average growth rate of real Gross Domestic Product (GDP) per capita achieved 11.91% per annum. Further, the per capita output continued growing at 6.00% in 1991 amid the worldwide economic recession. However, the remarkable economic growth was terminated by the eruption of the 1997 financial crisis. The growth rate of per capita output dropped sharply from 4.35% per annum in 1996 to -3.33% and -11.39% per annum in 1997 and 1998 respectively. Figure 2-1 displays annual real GDP per capita in Thailand, its linear time trend and cyclical components during 1971-2003. All series are in logarithm scale. Recessions were in the periods of 1974-5, 1981, 1983-5 and 1998-2002. In this figure, the secondary value axis shows a drastic fall in real GDP per capita from its time trend in 1997-1998. What factors accounted for the economic boom in Thailand? How did the 1997 financial crisis put the spectacular growing economy into a deep recession?

This paper attempts to find the ultimate source of fluctuations that accounts for the variations in Thai output. I adopt the Business Cycle Accounting (BCA) method

Figure 2-1: Annual real GDP per capita in Thailand vs. its linear time trend at 3.8% and cyclical component during 1971-2003 (Logarithm scale).



developed by Chari, Kehoe, and McGrattan (2002; 2007a) as a tool of study. The key feature of this method is that it considers multiple time-varying distortions in the prototype model simultaneously. Having assessed these distortions simultaneously, the accounting procedure gives us the most important distortions that cause the fluctuations in aggregate variables. Based on the Neoclassical growth model, the BCA method introduces the distortions in investment and in labour market equilibrium in the form of time-varying taxes on investment and time-varying taxes on labour income. These distortions are hereby called the investment wedge and the labour wedge, respectively. The investment wedge is the distortion that drives the intertemporal marginal rate of substitution in consumption away from the marginal product of capital. This wedge represents financial frictions in credit market. The labour wedge is the residual between the marginal product of labour and the consumption-leisure trade-off. For example, it can be matched into the monetary economy with

wage rigidities or union power. The other two wedges in the BCA method are the efficiency wedge and the government consumption wedge. The efficiency wedge is essentially the total factor productivity in a production function. It refers to the change in output that is not explained by the production technology. Alternatively, it represents the input-financing frictions in production. The last wedge is the government consumption wedge which is obtained from the resource constraint. It represents the distortion in international borrowing and lending.

The main finding sheds light on the importance of the efficiency wedge which is largely responsible for the variations in the output of Thailand. In particular, the efficiency wedge alone accounted for the 1980s economic recession, the late 1980s economic boom and the 1997 economic downturn in Thailand. The labour wedge may explain in part the fall in output in the 1997 economic downturn. However, it plays no significant role in the rest of the sample period. This implies that the labour wedge is not the main force in driving the Thai output. The investment wedge is not important since it always drives the model output against the movement of actual output: the model output with investment rises whereas the actual output falls, and vice versa. The government consumption wedge can be ignored. The findings suggest that the Thai authorities should pay more attention on how to reduce input-financing frictions in order to alleviate the effect of economic downturn. There exists significant real cost of intermediation for market making and information gathering services in the financial market; as such, credits are not attainable to all borrowers and relatively more expensive to some borrowers, like households and small firms (Bernanke 1983). The cost of credit intermediation rises during a financial crisis largely due to higher debtor insolvency and increasing default loans (Bernanke 1983). In the 1997 economic downturn, the evidence shows that the cost of credit intermediation for some firms was relatively high. This altered an acquisition of working capital and labour in

these firms when compared to others and likely resulted in a reallocation of input across economy in an inefficient way. As such, the efficiency wedge appears to fall at aggregate level during the economic downturn.

In an open economy model, the efficiency wedge is often referred to the reciprocal of the terms of trade: the factors of production are comparable to exports while the output is seen as imports (Kehoe and Ruhl 2008). The terms of trade is defined by the index of export prices relative to that of import prices. In Thailand during 1979-2003, the correlation coefficient between the change in output and the change in the terms of trade is as low as 0.12 whereas the correlation coefficient between the change in output and the change in the efficiency wedge is 0.75. This suggests that in overall the terms of trade shocks is unlikely to influence the output fluctuations. However, the correlation coefficient between the change in output and the change in the terms of trade during 1996-1999 jumps up to 0.61 while the correlation coefficient between the change in output and the change in the efficiency wedge is 0.96. The deterioration in the terms of trade in the 1997 crisis coincides with the decline in output, indicating a large withdrawal of credit to a country. My finding of the 1997 economic downturn is similar to Otsu (2007). He finds that the improvement in the trade balance during the 1997 economic downturn increased the output and this offset part of the sharp fall in output due to the abrupt fall in the efficiency wedge. It must be noted, however, that my study applies the deterministic process of wedges and draws the same conclusion as Otsu (2007) in which the wedges follow the stochastic process. Moreover, my study covers the longer time horizon than Otsu (2007). This enables me to investigate the source of economic boom in Thailand as well.

The organization of this paper is as follows. The next section briefly overviews the related literature on the source of economic fluctuations in Thailand and the BCA method. Section 2.3 provides the theoretical framework of BCA method, including

model and accounting procedure, data and parameter values. Section 2.4 presents the main findings and discussions. Conclusions and suggestions for further study are given in section 2.5.

## 2.2 Literature Review

This section presents the related literature on the economic fluctuations in Thailand and the BCA method. It begins by summarizing the previous studies on the source of economic fluctuations in Thailand. Then, it overviews the shortcomings of the structural vector autoregression (SVAR) method and introduces the BCA method. Lastly, it summarizes the literature that applied the BCA method to study the aggregate fluctuations across different countries.

Very few quantitative studies on the source of economic fluctuations in Thailand are found, particularly those based on the microeconomics fundamentals. The study by Chuenchoksan and Nakornthab (2008) utilizes the growth accounting method and the econometric estimation methodologies to study the growth developments in Thailand. Their focus is particularly on the labour productivity denoted by the ratio of aggregate output to total hours worked and the labour market developments. The growth of labour productivity depends on the growth in capital intensity (the capital deepening), the change in labour quality and the TFP growth. Their econometric result suggests the aggregate production in Thailand is close to constant returns to scale. The economic boom during 1987-1996 was mainly accounted by the capital deepening. They note that the role of TFP growth is sensitive to the values of labour income share during the boom, but not after 1996. Notably, there is no explanation provided with regard to the sensitivity/insensitivity of TFP growth to the values of labour income. Unlike the capital deepening, the TFP growth played little role during the boom. However, the importance of the TFP growth is increasing during and after

the 1997 economic downturn. Particularly during the crisis period, the TFP growth rate of -6.7% is the main force that drives the growth of labour productivity down to -1.6%. Their explanation for the negative TFP growth is from the decline in capital utilization during the crisis.

Apparently, the growth accounting procedure in the above study mainly concentrates on the production side of the economy. It discards other distortions that can potentially cause the aggregate variations. These distortions may influence the economic agent's optimal decision. Therefore, a tool of study with microeconomics fundamentals is needed to pursue the dynamic general equilibrium analysis. Currently, there are two methods for the general equilibrium analysis of aggregate fluctuations: the SVAR method and the BCA method.

There have been a large number of studies of aggregate fluctuations that use the SVAR method. For instance, Ireland (2004) find that monetary policy is the main force driving output fluctuations in the US prior to 1980 whereas the productivity shocks play a minor role. Even after the period of 1980, the productivity shocks can account for less than half of output variations. He notes that the missing capital accumulation in his model may undermine the dominant role of productivity shocks. Later studies like Smets and Wouters (2005) incorporate the capital accumulation and find the major role of productivity shocks in explaining aggregate fluctuations. Smets and Wouters (2005) study the similarities and differences in the structural characteristics of the economy between the US and the Euro area. They include both nominal and real frictions in the model such as sticky nominal price and wage setting with partial backward indexation, habit formation in consumption, and variable capital utilization in production. They find that the fluctuations in output in both economies are largely driven by productivity and labour supply shocks. An advantage of the VARs method is that this method allows researchers to study the effects of several frictions



within the model.

The SVAR method is not the tool of study as two major concerns on this method have arisen. Firstly, an extremely long time series of data is strictly needed in order to obtain the theoretically correct SVAR impulse response irrespective of the specifications of non-technology shocks in the model (Chari et al. 2008). In the case of Thailand, it is impossible to use the very long time series in analysis as most of the aggregate data are on a yearly basis and available from 1971 onwards. Secondly, there are two specifications of SVAR: the level structural vector autoregression (LSVAR) and the differenced structural vector autoregression (DSVAR). The impulse responses of LSVAR is inconclusive in the literature and are likely sensitive to slightly different subsamples (Chari et al. 2008). The DSVAR is used when detecting the unit root process in data. However, it does not have the asymptotic properties when using with small samples as the autoregression becomes biased (Chari et al. 2008).

The BCA method is chosen in this study as it does not strictly require large observations of the data. Chari et al. (2002) propose the BCA method with deterministic distortions to study the cause of the Great depression in the U.S. Later, Chari et al. (2007a) modify the BCA method to allow for stochastic distortions to examine the source of aggregate variations during the Great depression and the 1982 recession in the U.S. The main findings in Chari et al. (2002) concur with Chari et al. (2007a) regardless of the assumption about deterministic distortions in the earlier version. The method is founded in the Neoclassical growth model with four time-varying wedges. These wedges represent various types of frictions that drive the economy from a perfect competitive equilibrium. The key feature of this method is that it considers multiple time-varying distortions simultaneously in the prototype model. Having assessed these distortions simultaneously, the accounting procedure gives the most important distortion that causes the fluctuations in aggregate variables.

There are two steps in the accounting procedure. The first step is to obtain the four measured wedges by using the data and the equilibrium conditions. The second step is to feed the measured wedges back into the model, either one wedge at a time or in combinations, in order to simulate the model. The assessment of the model is based on how well the model can replicate the actual data.

The four wedges in the BCA method are the following. This method introduces the distortions in investment and in labour market equilibrium in the form of time-varying taxes on investment and time-varying taxes on labour income. These distortions are hereby called the investment wedge and the labour wedge, respectively. The investment wedge is the distortion that drives the intertemporal marginal rate of substitution in consumption away from the marginal product of capital. This wedge represents financial frictions in credit market. The labour wedge is the residual between the marginal product of labour and the consumption-leisure trade-off. It can be matched into the monetary economy with rigidities. The other two wedges in the BCA method are the efficiency wedge and the government consumption wedge. The efficiency wedge is essentially the total factor productivity in a production function. It refers to the change in output that is not explained by the production technology. Alternatively, it represents the input-financing frictions in production. The last wedge is the government consumption wedge which is obtained from the resource constraint. It represents the distortion in international borrowing and lending. Chari et al. (2002, 2007a) conclude that the efficiency wedge and the labour wedge are the key distortions that accounted for the output fluctuations in the U.S. The investment wedge is not important to the study of business cycles in the U.S.<sup>1</sup>

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<sup>1</sup>Christiano and Davis (2006) argue that the result of accounting procedure is subject to small change in the specification of prototype model. More specifically for the intertemporal wedge, it is the choice between taxing the investment expenditure and taxing the capital revenue. They also argue that the BCA method cannot incorporate the spillover effect of the intertemporal wedges onto other wedges. However, Chari et al.

Recently, several studies have employed this method to study the propagation mechanism of shocks across economies. Ahearne et al. (2006) conclude that the efficiency wedge and the labour wedge greatly contribute to the decline in output and subsequent recovery in Ireland's 1980s economic downturn. This is similar to the finding in Chari et al. (2007a) for the U.S. economy.

Other studies also find the significant role of the efficiency wedge and the labour wedge while the investment wedge plays a trivial role. Kersting (2008) find that the labour wedge is the most important distortion that accounts for the U.K. recession and recovery in the 1980s. In particular, his finding is consistent with the new labour market policies under the Thatcher Government on reducing the union power and reforming social security as well as unemployment benefits. The implementation of the new policies appears to remove distortions in the labour market. Hence, it plays a substantial role in the economic recovery in the U.K. starting in 1984.

Cociuba and Ueberfeldt (2008) studied the economic fluctuations in Canada during 1961-2005. Their result confirms the importance of the efficiency wedge and the labour wedge to the variations in output, investment and labour supply in the Canadian economy. It further suggests that the relatively increasing effective labour income tax rate, which captures the change in the labour tax rate and consumption tax rate, particularly explains the growth slowdown period between 1980 and 2005 in Canada when compared to the growth rate in the U.S. The finding in Simonovska and Soderling (2008) also suggest that the efficiency wedge and the labour wedge are the main source of macro fluctuations in Chile from 1998 to 2007.

Kobayashi and Inaba (2006) find that the labour wedge is the crucial distortion

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(2007b) show that, theoretically, the two choices of representing the intertemporal wedge give the same results as long as they have the same probability distributions. In practice, even though the difference in probability distributions of these two choices is found, the underlying results of the two choices are not significantly different.

that accounts for the Japanese decade-long recession in the 1990s. This contrasts with the earlier finding in Chakraborty (2005). Unlike the conclusion of aforementioned studies, Chakraborty (2005) argues that the investment wedge is the most important distortion in explaining the lost decade in Japan. She also argues that the efficiency wedge alone cannot account for business cycle fluctuations in Japan and the role of total factor productivity in literature may have been overemphasized. Meanwhile, the labour wedge is not an important distortion in her study. Kobayashi and Inaba (2006) note that the different source of data, different data constructions and different simulation methods may lead to the disagreements over the explanation for the lost decade in Japan.

Otsu (2007) modifies the BCA method to examine the causes of output fall in the 1997 Asian financial crisis for four countries: Hong Kong, Indonesia, South Korea and Thailand. Using the small open economy model with the endogenous trade balance, the foreign debt wedge can be explicitly measured from the foreign debt Euler equation. This wedge is presumably equivalent to the shocks to the domestic effective real interest rates. The data in his study is from 1990 to 2003. In the case of Thailand, foreign debt wedges were large, suggesting the rise in the effective real interest rate. This decreased international borrowing and improved the trade balance. The rise in the effective real interest rate also leads to the fall in consumption and investment, explained by the intertemporal Euler conditions. Furthermore, the efficiency wedge during the crisis fell dramatically, suggesting the sharp drop in production efficiency. The model with efficiency wedge in Otsu (2007) dropped much deeper than the decline in actual output during 1996-1998. The discussion on the difference between my study and Otsu (2007) will be given in section 2.4.

The study of international trade often refers to the efficiency wedge as the reciprocal of the terms of trade: the factors of production are comparable to exports while

the output is seen as imports (Kehoe and Ruhl 2008). The terms of trade is defined by the index of export prices relative to that of import prices. Kehoe and Ruhl (2008) argue that the terms of trade shocks influence a country's income through the reallocations across goods and sectors. The deteriorations in the terms of trade result in the inefficient use of working capital and accordingly lower the output. Therefore, the change in efficiency wedge that is conventionally measured by using real GDP is unlikely to be accounted for by the terms of trade shocks. In their study of Mexico during 1970-1990, Kehoe and Ruhl (2008), however, find that the correlation coefficient between the change in real GDP and the change in the terms of trade is 0.75 whereas the correlation coefficient between the change in the efficiency wedge and the change in the terms of trade is 0.73. Particularly in the 1982 and the 1994 crisis, they find that the deteriorations in the terms of trade clearly coincided with the dramatic fall in output and the efficiency wedge.

## 2.3 Model

This section provides the detail of the benchmark prototype model. Then, it explains the accounting procedure, the source of data and the parameter values accordingly.

### 2.3.1 Benchmark Prototype Model

I follow the benchmark prototype model in Chari et al. (2007a). The economy is comprised of identical infinitely-lived households and identical competitive firms. Note that all lowercase variables represent per capita values. Assume that the utility function is additively separable, continuously differentiable in its arguments and strictly concave. The household's preference mainly depends on consumption ( $c_t$ ) and leisure ( $l_t$ ). Time endowment is normalized to one. Hours worked ( $h_t$ ) is equal to  $1 - l_t$  since household's time endowment is devoted to leisure and work. In a frictionless econ-

omy, the household's expenditures on consumption and investment ( $x_t$ ) are financed by the income from supplying labour ( $w_t h_t$ ), the income from renting capital ( $r_t k_t$ ) and the transfers from government ( $tr_t$ ). Unlike the frictionless economy, the BCA method introduces two time-varying taxes into the budget constraint. They are taxes on labour income ( $\tau_{ht}$ ) and taxes on investment expenditure ( $\tau_{xt}$ ). In the household's optimal decision, the two taxes represent the labour wedge and the investment wedge, accordingly. The capital stock in the future ( $k_{t+1}$ ) is the sum of net capital stock and investment in the current period. To be consistent to the balanced growth path, the capital stock is thus adjusted by the growth rate of population ( $\eta$ ) and the rate of labour-augmenting technical progress ( $\lambda$ ). A large number of identical infinitely-lived households maximize their expected life-time utility

$$\begin{aligned} \max_{c_t, l_t, k_{t+1}} E_0 \left[ \sum_{t=0}^{\infty} \beta^t (1 + \eta)^t U(c_t, l_t) \right], \quad 0 < \beta < 1, \\ \lim_{c \rightarrow 0} u_c(\cdot, \cdot) = \infty \text{ and } \lim_{c \rightarrow \infty} u_c(\cdot, \cdot) = 0, \\ \lim_{h \rightarrow 0} u_h(\cdot, \cdot) = \infty \text{ and } \lim_{h \rightarrow \infty} u_h(\cdot, \cdot) = 0 \end{aligned}$$

with respect to the budget constraint

$$c_t + (1 + \tau_{xt}) x_t = (1 - \tau_{ht}) w_t h_t + r_t k_t + tr_t$$

and the capital accumulation law

$$k_{t+1} = \frac{(1 - \delta) k_t + x_t}{(1 + \eta)(1 + \lambda)}$$

where  $w_t$  is the real wage at period  $t$ ,  $r_t$  is the rental of physical capital at period  $t$ ,  $\beta$  is the discount factor and  $\delta$  is the depreciation rate of capital.

A large number of firms maximize their profit with respect to the technology used in production. Factors of production are capital and labour. The firm's output is

denoted by  $y_t$ . The firm's production cost is the sum of labour cost ( $w_t h_t$ ) and capital cost ( $r_t k_t$ ). In the competitive equilibrium, firms can earn normal profit only. Assume that all firms use the labour-augmenting technology in their production in order to be consistent to the balanced growth path, profit-maximizing firms will

$$\max_{k_t, h_t} y_t - w_t h_t - r_t k_t$$

subject to

$$y_t = A_t F(k_t, (1 + \lambda)^t h_t)$$

where  $A_t$  is total factor productivity at period  $t$ .

The government is assumed to maintain a balanced-budget in every period. The government receives revenue from taxing investment expenditure and labour income, and spends the revenue on consumption and transfers.

$$g_t + tr_t = \tau_{xt} x_t + \tau_{ht} w_t h_t$$

Lastly, this economy is summarized by the resource constraint

$$y_t = c_t + x_t + g_t$$

where  $g_t$  is the government consumption plus net exports.

Equation 2.1 to 2.4 are the equilibrium conditions of the model.

$$-\frac{U_{ht}}{U_{ct}} = (1 - \tau_{ht}) w_t \tag{2.1}$$

$$(1 + \tau_{xt}) U_{ct} = \beta E_t U_{ct+1} [A_{t+1} F_{kt+1} + (1 - \delta)(1 + \tau_{xt+1})] \tag{2.2}$$

$$A_t (1 + \lambda)^t F_{ht} = w_t \tag{2.3}$$

$$A_t F_{kt} = r_t \tag{2.4}$$

In the BCA method, the four wedges are derived from the equilibrium equations and the resource constraint in the benchmark prototype economy. They are equivalent to the distortions that drives an economy from a perfectly competitive equilibrium. The four wedges are:

- Efficiency wedge:  $A_t$

$$A_t = \frac{y_t}{F(k_t, (1 + \lambda)^t h_t)} \quad (2.5)$$

The efficiency wedge is equivalent to the Total Factor Productivity (TFP). It captures the segment of output which cannot be explained by the production technology. The efficiency wedge can represent input-financing frictions like that in Bernanke (1983). A fall in the efficiency wedge implies an increasingly inefficient allocation of resource in production.

- Labour wedge:  $(1 - \tau_{ht})$

$$1 - \tau_{ht} = -\frac{U_{ht}}{U_{ct}} \times \frac{1}{A_t(1 + \lambda)^t F_{ht}} \quad (2.6)$$

The labour wedge is the residual between the marginal product of labour and the marginal rate of substitution between consumption and leisure. In this case, labour demand and/or labour supply are not equal to the real wage in market equilibrium. This represents frictions in the detailed model with union power as in Cole and Ohanian (2004). A fall in the labour wedge that is equivalent to a rise in artificial taxes on labour income leads to an economic slowdown.

- Investment wedge:  $\frac{1}{1 + \tau_{xt}}$

$$(1 + \tau_{xt}) U_{ct} = \beta E_t U_{ct+1} [A_{t+1} F_{kt+1} + (1 - \delta)(1 + \tau_{xt+1})] \quad (2.7)$$



The investment wedge is equivalent to the residual between the marginal product of capital and the intertemporal marginal rate of substitution in consumption. A decline in investment wedge is equivalent to an increase in artificial taxes on investment. This tends to raise frictions in the credit market as can be found in the model of Bernanke et al. (1999). It may cause an economic slowdown due to the shrinking investment.

- Government consumption wedge:  $g_t$

$$g_t = y_t - c_t - x_t \tag{2.8}$$

The government spending wedge is the sum of government consumption spending and net exports in the resource constraint. It can be thought of the international borrowing and lending frictions in a detailed model.

### 2.3.2 Accounting Procedure

Assume that the utility function exhibits constant relative risk aversion (CRRA)

$$U(c_t, l_t) = \frac{\left[ c_t^{1-\phi} (1-l_t)^\phi \right]^{1-\varphi} - 1}{1-\varphi}$$

where  $1/\varphi$  is the intertemporal elasticity of substitution and  $\phi$  is the leisure preference.  $\varphi$  also represents the coefficient of risk aversion.

To be consistent to the balanced growth path,  $\varphi$  is set to one. With regard to the change in the interest rates, the income effect completely offsets the substitution effect in the intertemporal consumption. As a result, the change in consumption is in the same proportion to the change in the interest rates. Accordingly, the utility function is reduced to

$$U(c_t, l_t) = (1 - \phi) \ln c_t + \phi \ln(1 - l_t)$$

Furthermore, it is assumed that firms have an identical production function which is characterized by a Constant Return to Scale (CRS) Cobb-Douglas function as below:

$$y_t = A_t k_t^\alpha (1 + \lambda)^{(1-\alpha)t} h_t^{1-\alpha}$$

where  $\alpha$  is the share of capital in output.

The four measured wedges in this study are displayed in equations 2.9 to 2.12. Note that the variable with tilde represents the detrended actual per capita series.

- Efficiency wedge:  $A_t$

$$A_t = \frac{\tilde{y}_t}{\tilde{k}_t^\alpha \tilde{h}_t^{1-\alpha}} \quad (2.9)$$

- Labour wedge:  $(1 - \tau_{ht})$

$$(1 - \tau_{ht}) = \frac{\phi}{1 - \phi} \times \frac{\tilde{c}_t}{\tilde{h}_t} \times \frac{h_t^\alpha}{A_t (1 + \lambda)^t (1 - \alpha) \tilde{k}_t^\alpha} \quad (2.10)$$

- Investment wedge:  $\frac{1}{1 + \tau_{xt}}$

$$(1 + \tau_{xt}) \times \frac{1}{\tilde{c}_t} = \beta E_t \left\{ \frac{1}{\tilde{c}_{t+1}} \left[ A_{t+1} \times \alpha \left( \frac{h_{t+1}}{\tilde{k}_{t+1}} \right)^{1-\alpha} + (1 - \delta) (1 + \tau_{xt+1}) \right] \right\} \quad (2.11)$$

- Government consumption wedge:  $g_t$

$$\tilde{g}_t = \tilde{y}_t - \tilde{c}_t - \tilde{x}_t \quad (2.12)$$

It is straightforward that the efficiency wedge, the labour wedge and the government consumption wedge can be measured directly by using the data and the equilibrium conditions. Obtaining the investment wedge is, by contrast, not as simple as the other three wedges since it involves the rational expectation in computation. For the sake of simplicity, the economic agents are assumed to have perfect foresight. Equation 2.11 which governs the measured investment wedge thereby becomes deterministic and the steady-state Euler condition can be rewritten as

$$(1 + \tau_{xt}) \times \frac{1}{\tilde{c}_t} = \beta \frac{1}{\tilde{c}_{t+1}} \left[ A_{t+1} \times \alpha \left( \frac{h_{t+1}}{\tilde{k}_{t+1}} \right)^{1-\alpha} + (1 - \delta)(1 + \tau_{xt+1}) \right]$$

As shown in Chari et al. (2002; 2007a), the main finding from the deterministic measured wedges and from the stochastic measured wedges are identical. Kobayashi and Inaba (2006) also adopt the assumption of perfect foresight agents in their computing on the measured investment wedge. I follow Kobayashi and Inaba to have the steady-state starting right after the last period of the time horizon. This allows me to compute the measured investment wedge along with other measured wedges in the steady-state. Once all measured wedges are obtained, the series of measured investment wedge during the study period are also obtained by solving the deterministic Euler condition backwards. The details of the backward solution are as follows. Let  $t = \{0, 1, 2, 3, \dots, T\}$  denote the period of study and  $A^*$ ,  $(g/y)^*$  and  $\tau_h^*$  denote the steady-state value of efficiency wedge, government consumption wedge and labour wedge. I assume that the period after 2004 ( $t \geq 2004$ ) in the steady-state. With perfect foresight assumption, I have  $A_{T+1} = A^*$ ,  $(g/y)_{T+1} = (g/y)^*$  and  $\tau_{lT+1} = \tau_l^*$ . Therefore,  $\tau_{xT+1}$  will be equal to  $\tau_x^*$  as well. Since the capital stock is constructed from the actual investment series, I will definitely find the steady-state investment wedge ( $\tau_x^*$ ) associated with the equilibrium path of consumption and output. Lastly, I can obtain measured investment wedge by solving equation 2.11 backward with the

steady-state investment wedge ( $\tau_x^*$ ).<sup>2</sup>

### 2.3.3 Data

The data are on yearly basis and cover the period from 1971 to 2003. This is because the employment data are available starting from 1971. They are obtained from various sources as follows. Gross domestic product, private consumption expenditure, gross fixed capital, change in inventories, public expenditure and net exports are downloaded from the United Nations Statistics Division website. (<http://unstats.un.org>). All values are at constant prices. Numbers of actual working hours and the total number of non-institutional civilian population are collected from various issues of the Labour Force Yearbook, the National Statistical Office, Thailand. Actual gross capital stock and depreciation rate are obtained from the Office of the National Economic and Social Development Board website. (<http://nesdb.go.th>).

The definitions of data are the following. Output ( $y_t$ ) is represented by the real gross domestic product. Household consumption ( $c_t$ ) is represented by the real private consumption expenditure. Investment ( $x_t$ ) is the sum of real private and real public gross fixed capital and the change in inventories. Government consumption ( $g_t$ ) is the sum of the real government consumption expenditure and net exports. Non-institutional civilian population are the population aged of 11 years old and over for the period of 1971-1988, 13 years old and over for the period of 1989-2000, and 15 years old and over for the period of 2001-2003.

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<sup>2</sup>See Inaba (2007) for further details.

### 2.3.4 Parameter Values

The parameter values in this study are as follows. The share of capital income in total output<sup>3</sup> ( $\alpha$ ) is equal to 0.47 as suggested in Chuenchoksan and Nakornthab (2008). Following the Cooley-Prescott approach, the ambiguous income from GDP at factor cost when computing the labour income share is eliminated (Chuenchoksan and Nakornthab 2008). The annual discount factor ( $\beta$ ) is 0.96 which is widely used in the RBC literature. The annual depreciation rate of capital ( $\delta$ ) is 5.58% which is an average depreciation of physical capital in Thailand over 1971-2003. The average productivity growth over the sample period ( $\lambda$ ) is 3.80% per annum. The baseline period for other wedge values when simulating output series with either one wedge only or in combinations is from 1989 to 1994. In the following table, I compare parameter values used in other BCA studies with my study.

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<sup>3</sup>The main finding is not sensitive to small change in the labor income share. For instance, the result from  $\alpha = 0.35$ , of which value is widely used in the literature, is almost the same as that from  $\alpha = 0.47$  and  $\alpha = 0.60$ .

Table 2.1: Summary of parameter values used in BCA studies

Author (Alphabetical Order)	Country: Period	Parameter Value					
		$\alpha$	$\beta$	$\delta$	$\phi$	$\eta$	$\lambda$
Ahearne, Kydland and Wynne (2005)	Ireland: 1973-2002	0.35	0.97	0.08	1.50	0.006	0.036
Chakraborty (2005)	Japan: 1980-2000	0.36	0.972	0.089	1.13	n.a.	0.0215
CKM (2007)	U.S.: 1900-2005	0.35	0.97	0.0464	2.24	0.015	0.016
Cociuba and Ueberfeldt (2008)	Canada: 1950-2005	0.33	0.976	0.042	1.770	0.016	0.0102
Inaba and Kobayashi (2006)	Japan: 1981-2003	0.372	0.98	0.0846	n.a.	n.a.	0.0206
Kersting (2008)	U.K.: 1979-1989	0.35	0.97	0.05	1.50	0.015	0.020
My study	Thailand: 1971-2003	0.47	0.96	0.0558	n.a.	n.a.	0.038
Otsu (2007)	Hong Kong: 1990-2002	0.33	0.942	0.023	n.a.	0.024	0.038
	Korea: 1990-2002	0.33	0.889	0.018	n.a.	0.021	0.029
	Singapore: 1990-2002	0.33	0.911	0.018	n.a.	0.028	0.023
	Thailand: 1990-2002	0.33	0.94	0.026	n.a.	0.027	0.030
Simonovska and Soderling (2008)	Chile: 1998-2007	0.30	0.9758	0.049	3.3631	0.016	0.020

## 2.4 Findings

This section presents the main findings of the accounting procedure for Thailand. Note that the efficiency wedge is defined by  $A_t$ . The labour wedge is defined by  $(1 - \tau_{ht}) \times \left(\frac{1-\phi}{\phi}\right)$ , where  $\phi$  is the leisure preference. Since the leisure preference is assumed to be constant, it does not affect the variations in the measured labour wedge. The investment wedge is defined by  $1/(1 + \tau_{xt})$ . The government wedge is defined by  $g_t$ . There are two steps in the BCA exercise. Firstly, I calculate the four measured wedges. Secondly, I feed these measured wedges back into the model, either one wedge at a time or in combination. I then obtain a series of simulated outputs which are influenced by either different individual wedges or a combination of wedges. In order to control the influence of other wedges from an underlying wedge, I use the baseline values for controlled wedges. The baseline period is from 1989 to 1994 in which is excluded from the economic downturn. I take the average value of wedges during the baseline period to represent the controlled wedges. The results in figures 2-2 to 2-6 are normalized to equal 100 in 1979 whereas those in figures 2-7 and 2-8 are normalized to equal 100 in 1994.

To verify the accounting procedure, all of the realized wedges are fed back into the model and the model successfully retrieves the actual output as shown in figure 2-2. To see the importance of each wedge in the accounting procedure, the measured wedges are plotted along with the Thai output. In figure 2-3, it is very clear that the efficiency wedge is the most important distortion that explains the fluctuations in output. The investment wedge is obviously irrelevant to the output fluctuations since its variations are against the variations in output. The government consumption wedge is not presented as its variations is very high and do not coincide with the output fluctuations.

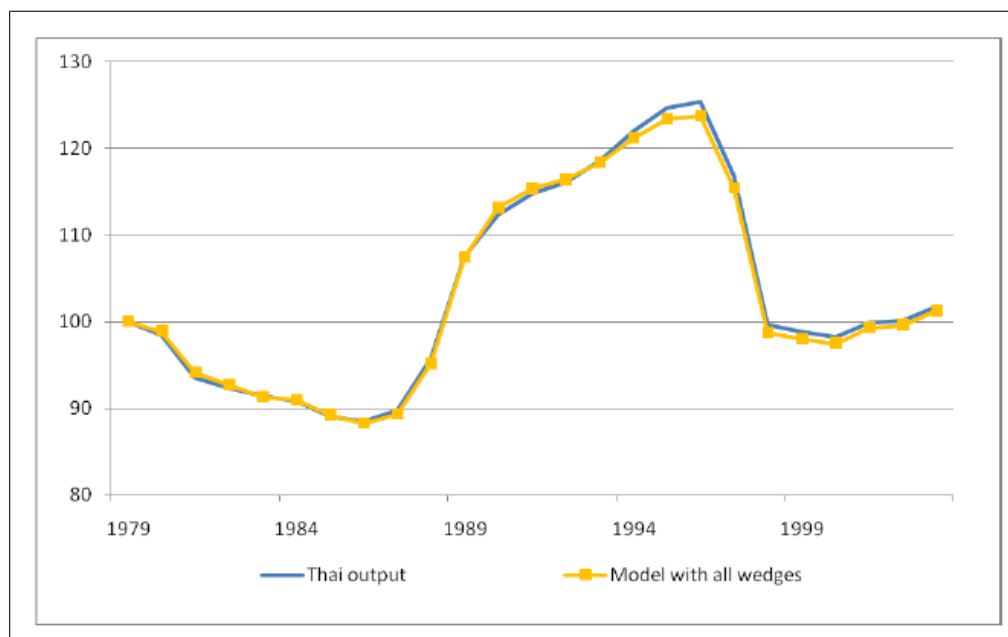
In the next step, the measured wedges are fed back into the model, either individ-

ually or in combinations as displayed in figure 2-4 to 2-6. In figure 2-4, it is obvious that the model with efficiency wedge largely explain the variations in output. This is consistent with the result shown in figure 2-3. Notably, there was an upward spike in the model with the efficiency wedge and there was a downward spike in the model with the labour wedge in 1983. This captures the unexplained change in the model. One plausible explanation for the unexplained change may come from the labour market in which both the resource allocation in production and the equilibrium in labour market are radically altered. In their study on Thailand's labour market, Chuenchoksan and Nakornthab (2008) note that there was a major change in the labour force survey question during 1982-1983. As a result, the unemployment rate fell drastically from 14% in 1982 to 8.7% in 1983. On the one hand, a sudden jump in employment may be equivalent to a dramatic rise in production efficiency. On the other hand, the sudden jump in employment may imply a drastic fall in real wage that is equivalent to a sharp rise in the labour wedge. It should therefore be kept in mind that the definition of employment figures prior to 1983 and post 1983 are fairly different. The last two panels in this figure affirm that the investment wedge and the government consumption wedge are irrelevant to the output fluctuations. The predictions of models with these two wedges fail to capture the variations in output.

Figure 2-5 plots the Thai output along with the model with two wedges. Apparently, the model with the efficiency wedge and labour wedge appears to be very similar to the model with just the efficiency wedge. The only difference between the two models is that the spike in 1983 disappears when the efficiency wedge and the labour wedge are in the model. The unexplanatory change in the efficiency wedge offsets the unexplanatory change in the labour wedge. The model with both the investment and labour wedges does not seem to capture the variations in output. In figure 2-6, it is clear that the investment wedge is not important to the fluctuations



Figure 2-2: Detrended Thai output vs. Model with all wedges during 1979-2003.



in Thai output. The model without the efficiency wedge is clearly not correlated to the actual output. Meanwhile, the model with the efficiency, labour and investment wedges is very similar to the model with just the efficiency wedge.

Figure 2-3: Detrended Thai output vs. Three measured wedges during 1979-2003.

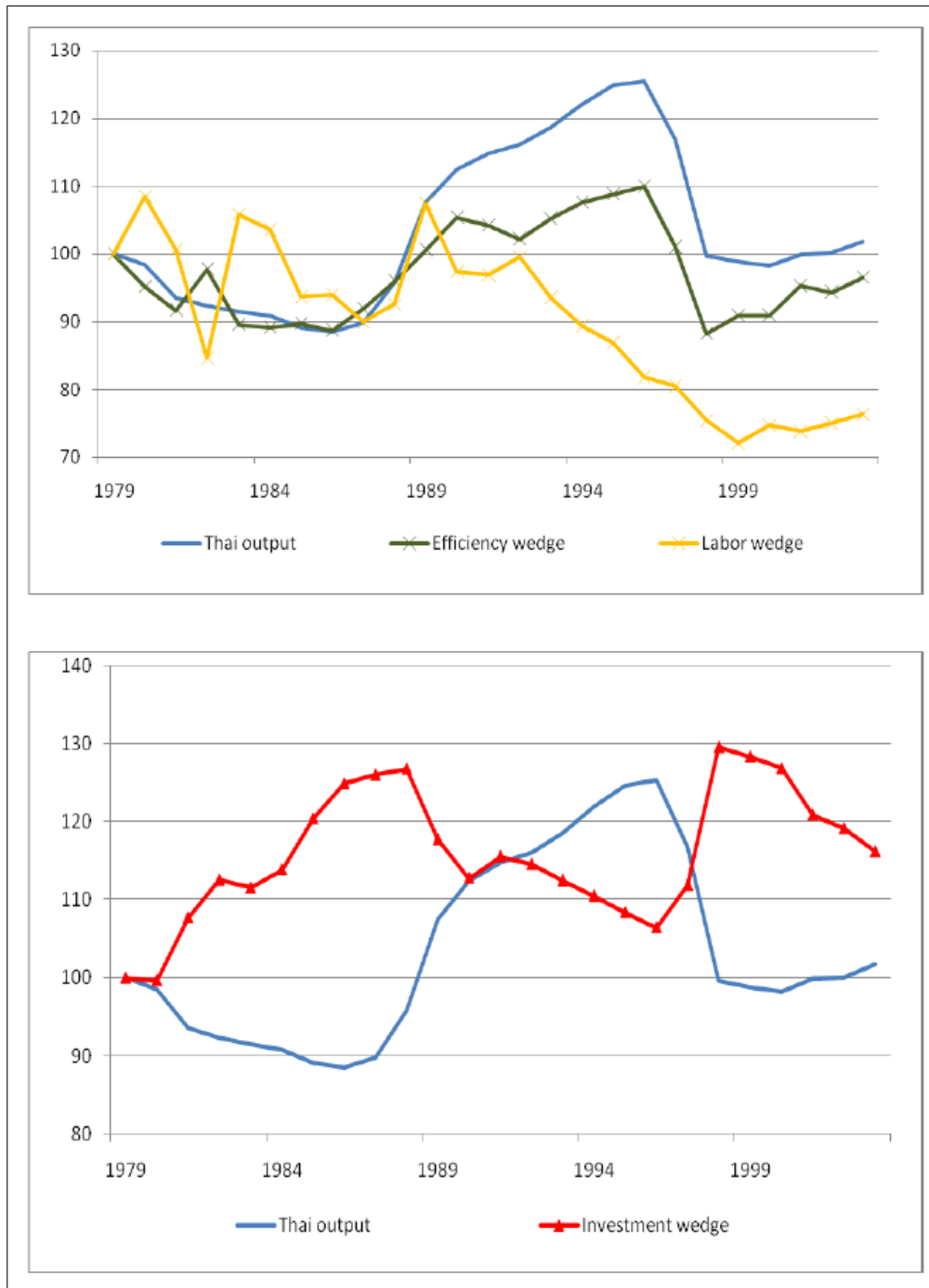


Figure 2-4: Detrended Thai output vs. Predictions of models with just one wedge during 1979-2003.

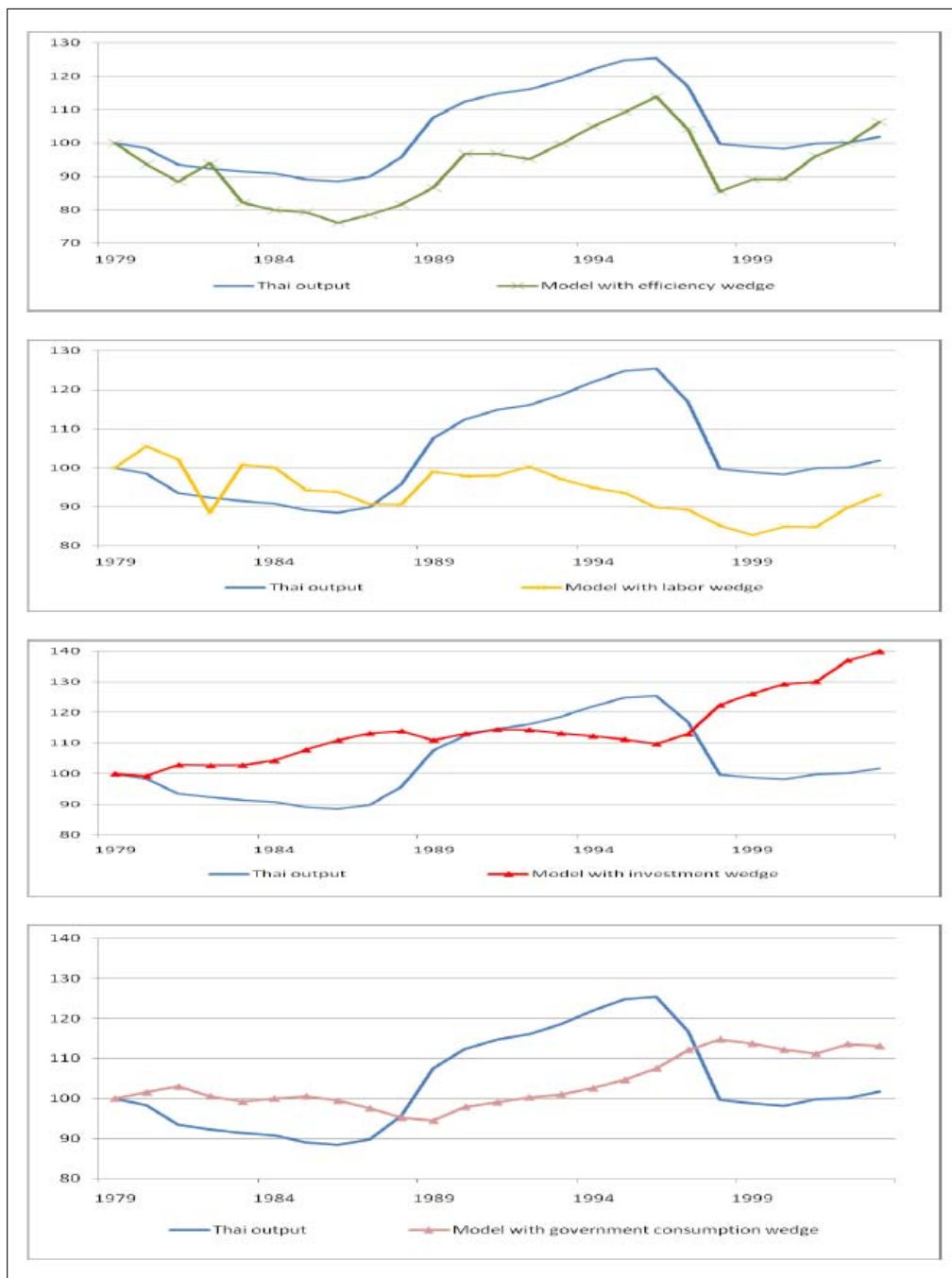


Figure 2-5: Detrended Thai output vs. Predictions of models with two wedges during 1979-2003.

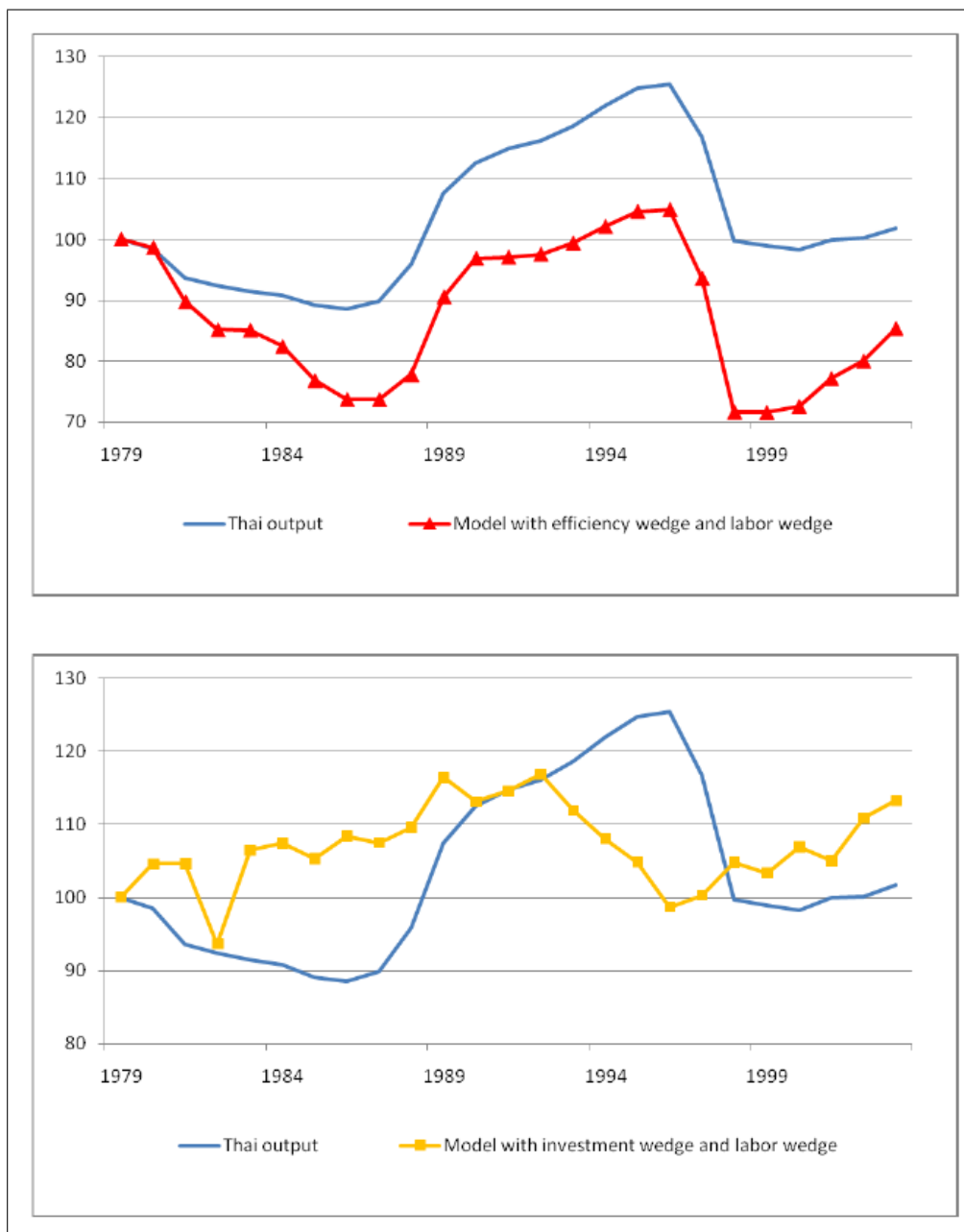
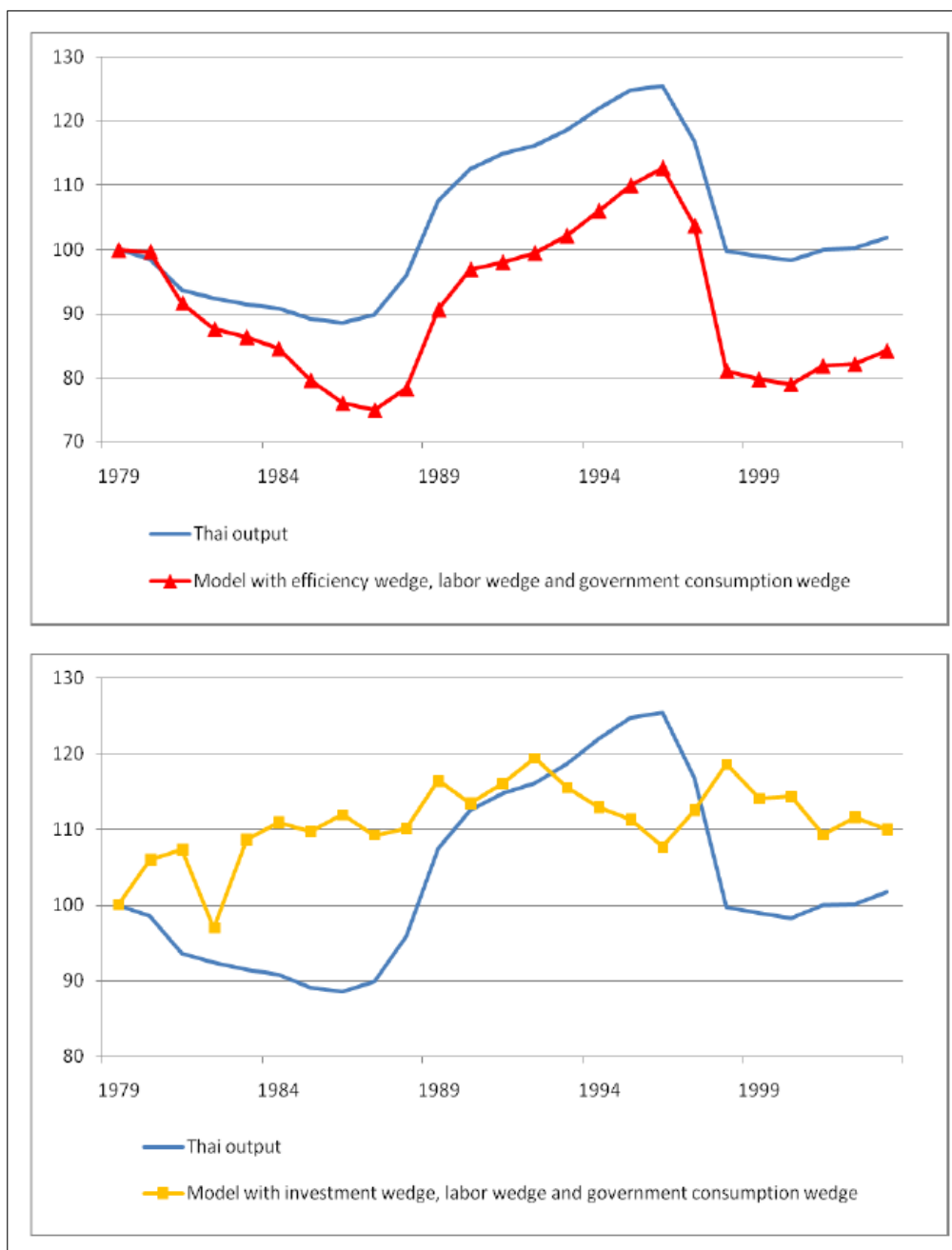


Figure 2-6: Detrended Thai output vs. Predictions of model with three wedges during 1979-2003.



From figure 2-4 to 2-6, it can be concluded that the efficiency wedge is the major driving force behind both the early 1980s economic recession and the late 1980s economic boom. In figure 2-7, the BCA result for the 1997 economic slump reveals that the efficiency wedge alone can be responsible for the sharp fall in output between 1996 and 1998. Figure 2-8 strongly supports the dominant role of the efficiency wedge and the insignificant role of the investment wedge in the 1997 crisis.

The above findings suggest that the Thai authorities should pay more attention on how to reduce input-financing frictions in order to alleviate the effect of economic downturn. One of the candidates of the input-financing frictions is the cost of intermediation. There exists significant real cost of intermediation for market making and information gathering services in the financial market; as such, credits are not attainable to all borrowers, or otherwise, more expensive for some borrowers, typically small firms (Bernanke 1983). Moreover, the cost of credit intermediation rises during a financial crisis largely because of higher debtor insolvency; under such circumstances, financial institutes intensively screen and evaluate potential loans at larger expenses (Bernanke 1983).

During the 1997 financial crisis, the cost of credit intermediation has gone up. Furthermore, the cost for the small borrowers was higher than for the large borrowers. This can be seen in figure 2-9, which shows the commercial bank and the finance company lending rates across industry between October 1993 and December 2004<sup>4</sup>. Commercial banks charge different rates for borrowers of different sizes in Thailand. The minimum lending rate for small borrowers and large borrowers are the minimum retail rate (MRR) and the minimum loan rate (MLR), respectively. Whereas the

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<sup>4</sup>The series of lending rate are from the Bank of Thailand database. However, it does not provide the data of the share of loans to small borrowers and to large borrowers by commercial banks nor by finance companies. These data will essentially demonstrate how much the availability of loans is changing across different size of borrowers during and after the crisis.

prime rate is what the finance companies charge their customers<sup>5</sup>. During the underlying period, the MRR charged a premium of 0.25% - 0.50% over the MLR on average. From the top and middle panels of this figure, it is noted that the spread between the minimum and maximum of the MRR across commercial banks increased markedly during the crisis and persisted until 2004. Meanwhile, the spread of the MLR is relatively smaller than that of MRR. The marked spread of MRR remained although the trend of lending rate has since moved downward after the crisis. Apparently, the large spread of the MRR implies the high variations on loan acquisition among small borrowers. Furthermore, the cost of loan among those who borrow from finance companies is even more massively different in the crisis as shown in the bottom panel of figure 2-9<sup>6</sup>. This evidence points to the difficulties in obtaining funding for production to some firms when compared to others. Hence, the reallocation of input across economy is most likely inefficient. As such, the efficiency wedge tends to fall at aggregate level during the economic downturn.

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<sup>5</sup>From the Bank of Thailand database, the ratio of loan from finance companies to that from commercial banks varies between 2% and 12% over 1989-2002.

<sup>6</sup>According to the Bank of Thailand annual report, there were 56 out of 92 finance companies that were shut down in 1997. This led to the decrease in overall loans from finance companies by 11% in the same year.

Figure 2-7: Detrended Thai output vs. Predictions of models with just one wedge during 1994-2003.

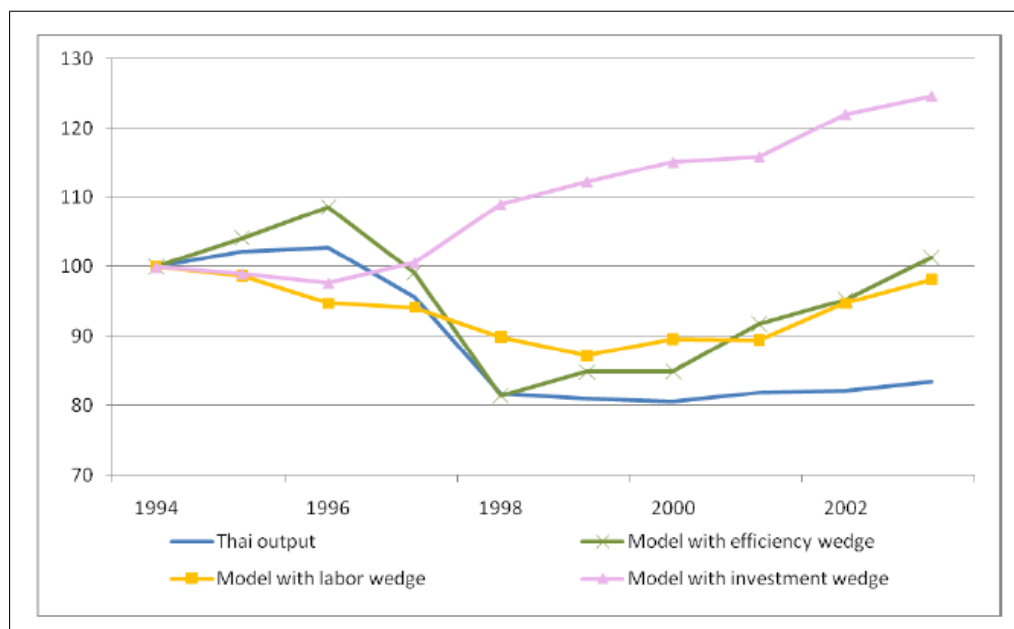


Figure 2-8: Detrended Thai output vs. Predictions of models with two wedges during 1994-2003.

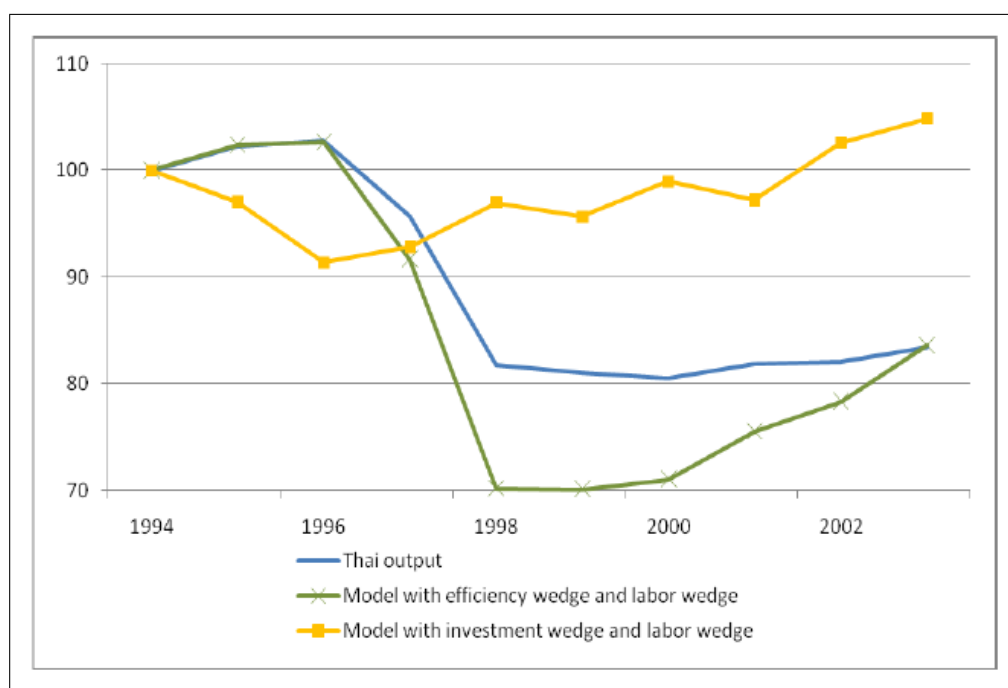
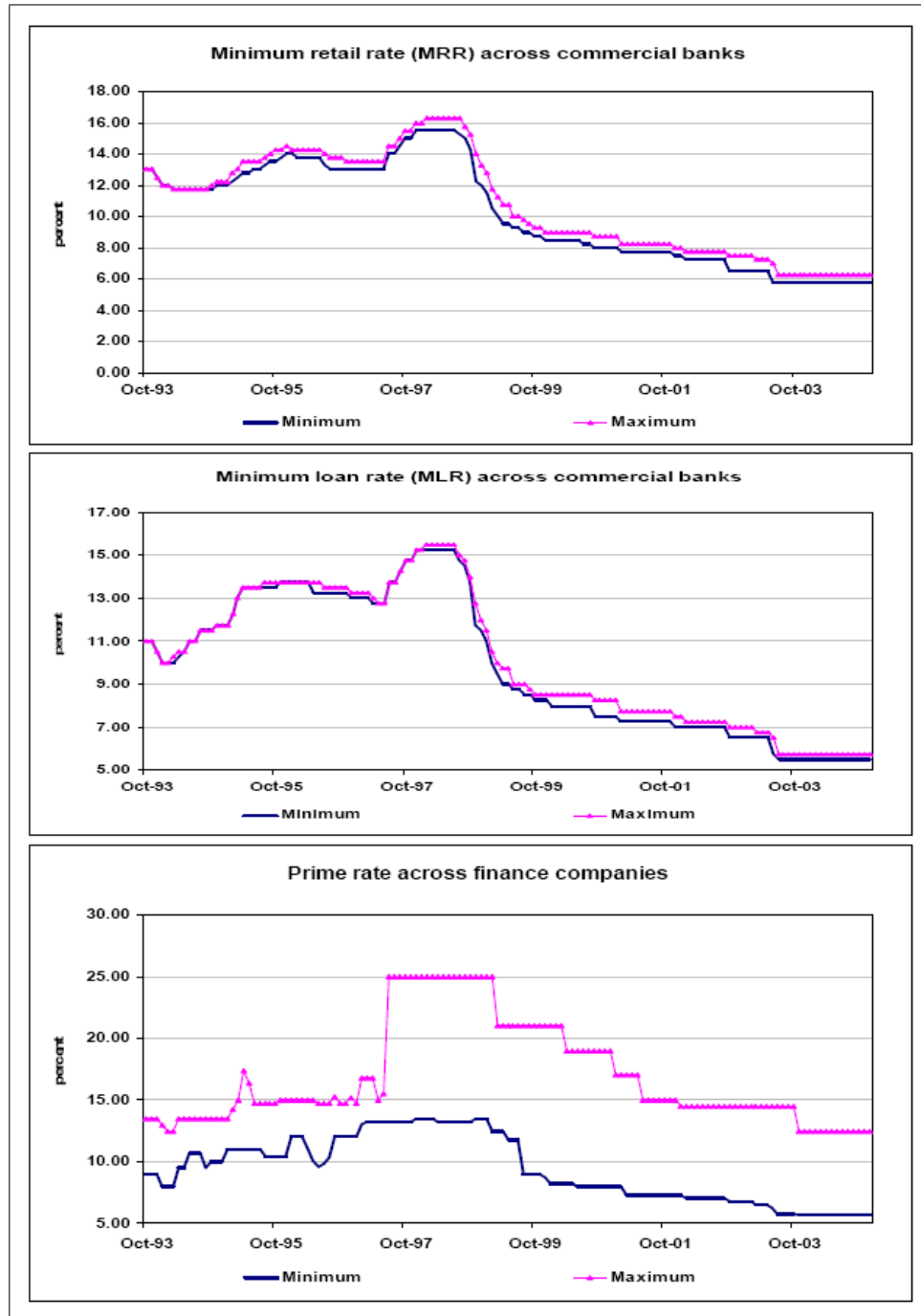




Figure 2-9: Commercial bank and finance company lending rate across industry



From all of the above discussions, it is very clear that the variations in Thai output is principally explained by the efficiency wedge: in the early 1980s economic recession, in the late 1980s economic boom and in the 1997 economic downturn. Thus, it is worthwhile to further explore what the efficiency wedge can refer to besides the input-financing frictions in production. In an open economy model, the efficiency wedge is often referred to as the reciprocal of the terms of trade: the factors of production are comparable to exports while the output is seen as imports (Kehoe and Ruhl 2008). The terms of trade is defined by the index of export prices relative to that of import prices. Kehoe and Ruhl (2008) argue that the terms of trade shocks influence national income rather than real GDP; therefore, the change in efficiency wedge measured in the conventional way is unlikely to be accounted for by the terms of trade shocks. However, I follow the conventional measurement of output by using real GDP in this study.

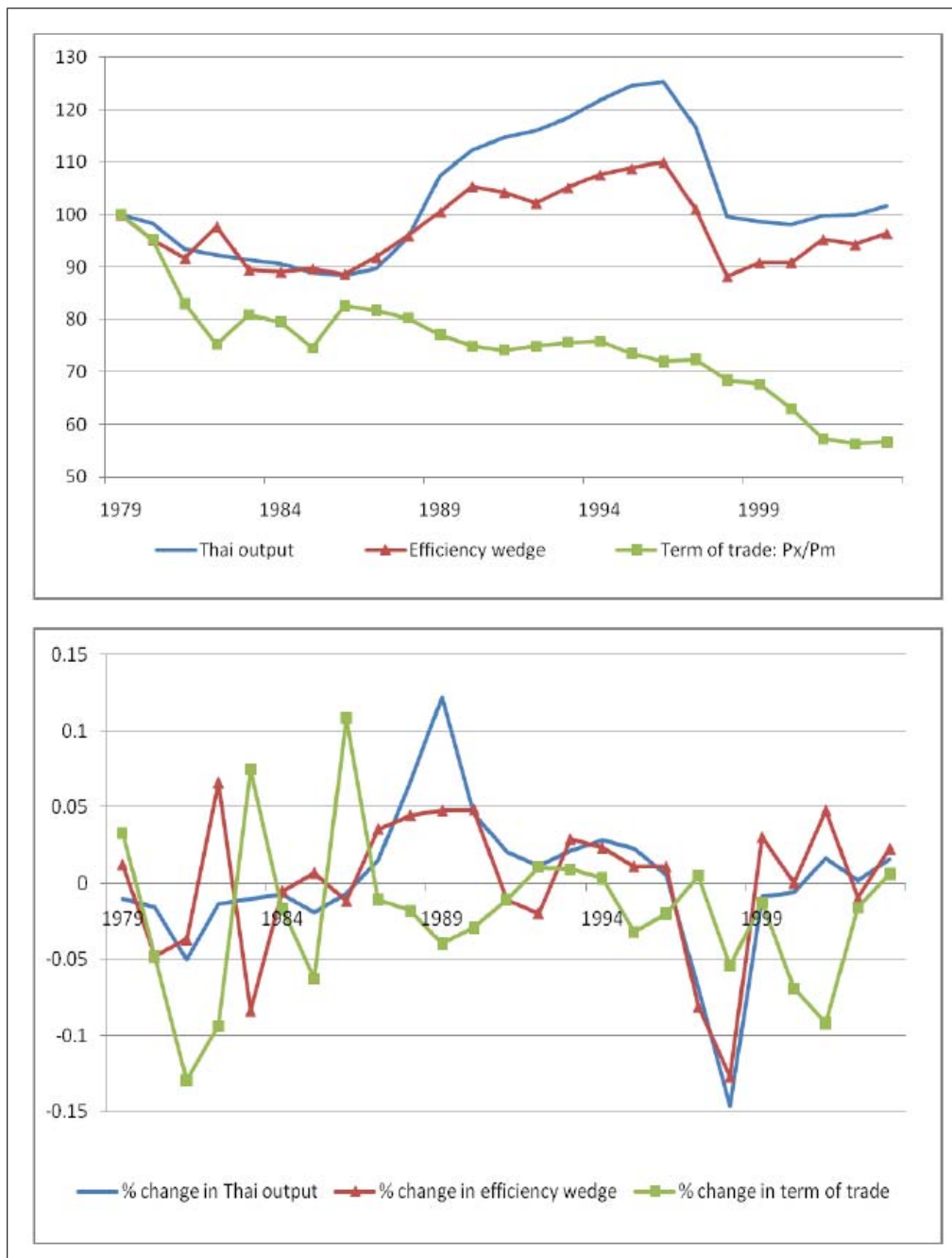
Figure 2-10 plots the Thai output along with the efficiency wedge and the terms of trade during 1979-2003. The upper panel shows all series in indexed value given that the base year is 1979. The lower panel shows the change in each series in percentage terms. It is apparent that the terms of trade is declining over time. In addition, the change in the terms of trade does not seem to be related to the change in real GDP and the change in the efficiency wedge. The correlation coefficient between the change in output and the change in the terms of trade is as low as 0.12 whereas the correlation coefficient between the change in output and the change in the efficiency wedge is 0.75. This suggests that in overall the terms of trade shocks is unlikely to influence the output fluctuations. However, the change in the terms of trade seems to correlate with the change in output during the early 1980s recession and the 1997 crisis. The associated correlation coefficients in the two underlying periods are 0.70 and 0.61, respectively. The deteriorations in the terms of trade in the early 1980s

recession and the 1997 crisis coincide with the decline in output, indicating a large withdrawal of credit to a country. Surprisingly, the deterioration in the terms of trade was also found during the boom period of 1986-1992. The corresponding correlation coefficient is -0.67. It is unexplained by the above conventional concept.

My finding of the 1997 economic downturn is similar to Otsu (2007). He finds that the improvement in the trade balance during the 1997 economic downturn increased the output and this offset some of the sharp fall in output due to the abrupt fall in the efficiency wedge. It must be noted, however, that my study adopts the deterministic process of wedges and draws the same conclusion as Otsu (2007). Moreover, my study covers the longer time horizon than Otsu (2007). This enables me to investigate the source of economic boom in Thailand as shown earlier.

The labour wedge plays a minor role as it has the depressive effect on output during the recessions. But, the model with the labour wedge cannot capture the rise in output during the early 1990s economic boom. Instead, the model with the labour wedge was falling during the boom period and continued falling until 1999. The minor role of the labour wedge in output variations is consistent with the weak development of Thai labour. Unions in Thailand play a trivial role in settling the wage rate; this is because the union density is far from being significant, and the existing unions do not have much bargaining power (Lawler and Suttawet 2000). The wage rate is likely to reflect the marginal product of labour unless there is an intervention from authorities. Hence, the detailed model with union power can be dropped out from the RBC study for Thailand.

Figure 2-10: Detrended Thai output vs. Efficiency wedge and terms of trade during 1979-2003.



## 2.5 Concluding Remarks

Using the BCA method with deterministic wedges, the main findings shed light on the importance of the efficiency wedge that is largely responsible for the variations in the output of Thailand. In particular, the efficiency wedge alone accounted for the output fluctuations in both the boom and the recession periods. In the 1997 crisis, the spread of commercial bank lending rates to small borrowers increased markedly and remained large since then. Meanwhile, the spread of lending rates to large borrowers was almost unchanged. Given that the minimum lending rate to small borrowers is greater than to large borrowers on average, this implies that the small borrowers were facing larger cost of intermediation back then. The difficulties in borrowing were much worse for those customers of finance companies as the spread of prime rates was massive. This evidence points to the difficulties in funding for working capital and labour in production to some firms as compared to others. As such, the efficiency wedge declines at aggregate level during the economic downturn.

In an open economy model, the efficiency wedge is often referred to the reciprocal of the terms of trade: the factors of production are comparable to exports while the output is seen as imports (Kehoe and Ruhl 2008). The terms of trade is defined by the index of export prices relative to that of import prices. In Thailand during 1979-2003, the correlation coefficient between the change in output and the change in the terms of trade is as low as 0.12 whereas the correlation coefficient between the change in output and the change in the efficiency wedge is 0.75. However, the correlation coefficient between the change in output and the change in the terms of trade during 1996-1999 jumps up to 0.61 while the correlation coefficient between the change in output and the change in the efficiency wedge is 0.96. The deterioration in the terms of trade in the 1997 crisis coincides with the decline in output, indicating a large withdrawal of credit to a country. Nonetheless, this conventional concept between

the terms of trade shocks and the efficiency wedge cannot explain the case in which the deterioration in the terms of trade occurred in the boom period of 1986-1992.

# Chapter 3

## Business Cycle Accounting for Australia

### 3.1 Introduction

The source of business cycle fluctuations has been open to debate. There is a large literature on dynamic general equilibrium models that explore how variations in output, investment and employment arise. In a dynamic general equilibrium model, counterfactual scenarios are produced and quantitatively evaluated to determine how well they can explain economic phenomena. Early studies proposed that productivity shocks are the key impulse to economic fluctuations (such as Kydland and Prescott 1982, Hansen 1985 and King et al. 1988). Subsequent studies argued that monetary shocks in sticky wage models (as in Bordo et al. 2000) and market imperfections like union power (as in Cole and Ohanian 2004) can also account for business cycle fluctuations. Moreover, the existence of credit market frictions in an economy as in Bernanke et al. (1999) is argued to contribute to economic fluctuations as well. However, business cycle fluctuations differ across countries and the majority of the literature examines the quantitative ability of business cycle models to fit the U.S. or European experience. This chapter focuses on the source of economic fluctuations in Australia based on a dynamic general equilibrium model.

There are very few studies that employ a dynamic general equilibrium model to

investigate the source of Australian economic fluctuations. Based on quarterly data between 1991:Q1 and 2006:Q2, Nimark (2007) utilizes Bayesian techniques to study a New Keynesian small open economy model for Australia. His result shows that output responds negatively to an unexpected increase in interest rates, and positively to an exogenous increase in the demand for Australian exports, an increase in the export income and a rise in the productivity shock. The exogenous export demand shock is particularly important to the variations in output. A drawback of Nimark (2007) is the single factor of production, i.e. labour, in the model. The role of total factor productivity shocks is also excluded. A subsequent study by Jääskelä and Nimark (2008) is based in a more richly structured New Keynesian open economy model and employs Bayesian techniques on Australian data. Capital and labour are included as factors of production. Unlike the frictionless model of Nimark (2007), Jääskelä and Nimark include Calvo-type nominal frictions and real frictions in the model. All good prices and wages respond sluggishly to the shocks. The main finding is that both foreign and domestic shocks are the important force driving the Australian business cycles under the inflation-targeting regime in 1993-2007. This contrasts with the result of Nimark (2007) in which foreign shocks are important. Apparently, both studies ignore the distortions that cause the deviation of intertemporal marginal rate of substitution in consumption from the marginal product of capital in the Euler equilibrium condition. In order to fill this gap in the literature, I will incorporate the market frictions on investment in addition to other frictions in the prototype model. Furthermore, the sample period in my study is longer than previous studies. It covers the 1982/83 recession and the 1990/91 recession. I can thus assess the importance of frictions across Australian business cycles.

I attempt to examine the crucial distortion that causes business cycle fluctuations in Australia, especially in the 1982/83 recession, the 1990/91 recession and the late



1990s boom. I adopt the Business Cycle Accounting (BCA) method developed by Chari, Kehoe, and McGrattan (2007a) in my study. The BCA method provides useful insights into the aggregate fluctuations since it allows several propagation mechanisms of shocks to be studied simultaneously in a prototype model. The propagation mechanisms of shocks are equivalent to four wedges in the prototype model: the efficiency wedge represents the input-financing frictions in production; the labour wedge represents the residual between the consumption-leisure trade-off and the marginal product of labour; the investment wedge represents the residual between the intertemporal marginal rate of substitution in consumption and the marginal product of capital; the government consumption wedge represents the distortion in international borrowing and lending. In the BCA exercise, I can work out the most important wedges to the Australian business cycles. This paper is the first study of business cycle accounting for Australia.

Using data covering 1980:Q3-2008:Q2, I find that the efficiency wedge is the major force driving the Australian business cycles, particularly the variations in output and investment. The efficiency wedge alone can account for the fall in output in the 1982/83 recession and the 1990/91 recession. The investment wedge plays a minor role in both recessions. The recovery in output after both recessions is well accounted for by the combination of efficiency and labour wedges. The model with just efficiency wedge predicts the amplitude of the recovery in output larger than what actually observed in the actual data. In addition, the combination of these two wedges in the model can predict the amplitude of variations in output and investment nearly the same as what observed in the actual data. I find the highly negative cross correlation between the measured efficiency and labour wedges. This suggests that the labour wedge in Australia appears to counteract the efficiency wedge. Intuitively, some increments in input-financing frictions in production are to be offset by the decreasing

distortions in labour market and vice versa. This suggests that the frictional business cycle model for Australian economy should incorporate the shocks that propagate themselves in an economy through the efficiency wedge and the labour wedge; otherwise, it may not be successful in explaining the aggregate fluctuations. This result supports the detailed model used in Jääskelä and Nimark (2008). However, the variations in hours worked is best explained by the model with the investment and labour wedge. Future study on the Australian labour market should take into account the shocks that transmit themselves as the investment wedge in addition to the labour wedge. Lastly, the expansionary of output in the late 1990s boom is mainly accounted for by the efficiency wedge.

This chapter is organized as follows. Section 3.2 provides the literature review. In section 3.3, the theoretical framework is presented. The BCA findings for Australia are unfolded in section 3.4. Section 3.5 provides the concluding remarks.

## 3.2 Literature Review

This section provides literature review on the Australian business cycles in subsection 3.2.1, the BCA method in subsection 3.2.2 and the parameter values in subsection 3.2.3.

### 3.2.1 Australian Business Cycles

The two most recent recessions in Australia were in 1982/1983 and 1990/1991<sup>1</sup>. Figure 3-1 depicts GDP per capita and its linear time trend at 1.7% per annum during 1960-2007. Among the two recession episodes, it is worth noting that there was a larger fall in output in the 1982/83 recession while the 1990/91 recession was more prolonged. Previous research provide different explanations on the source of business cycle fluctuations in Australia.

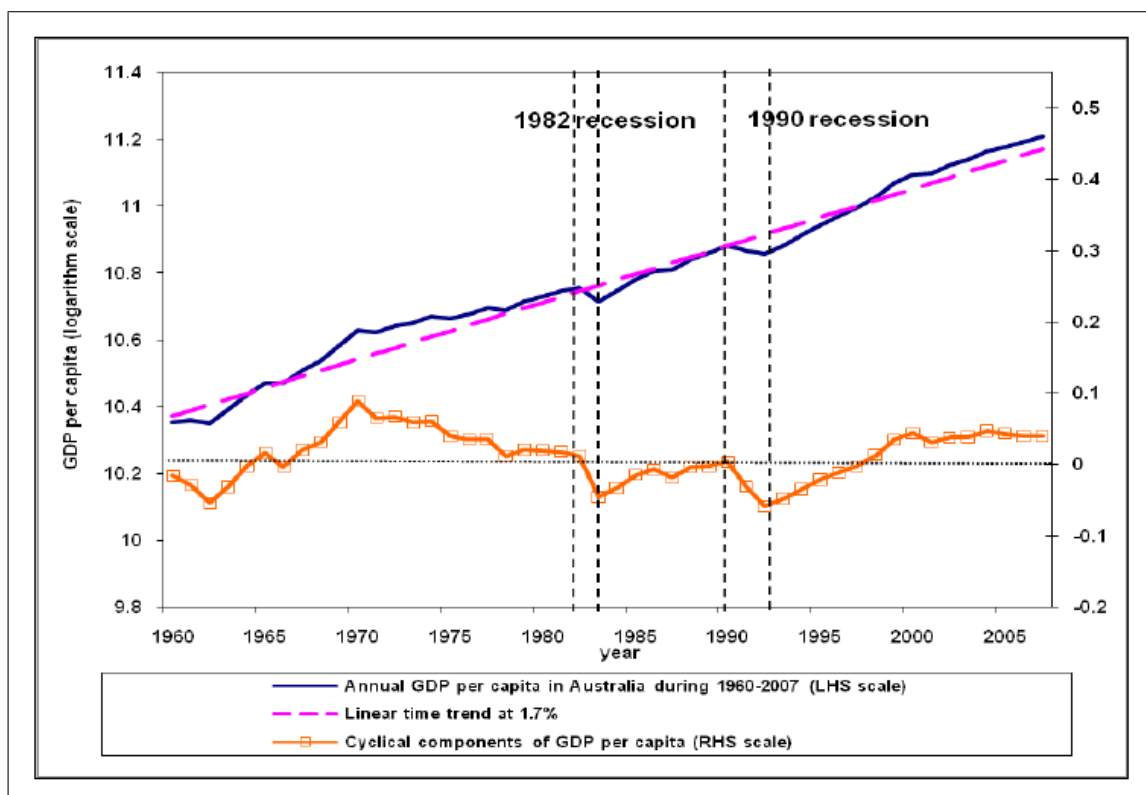
Moreno (1992), for instance, employs a structural vector autoregression model to the Australian data covering 1960-1989. His finding shows that demand shocks<sup>2</sup> play an important role in explaining the short-run fluctuations in output. Meanwhile, the supply shocks greatly explain the fluctuations in price level. Similar empirical framework is found in Dungey and Pagan (2000). In addition to employing a structural vector autoregression model, they also include a foreign sector and asset markets. They find that the 1990/91 recession was caused by the fall in domestic demand and tightening monetary policy, and then prolonged due to the transmission of weak economic activity in overseas. Lowe and Rohling (1993) note that the asset price inflation during 1983-89 which directly raises the corporate equity increases in the availability of loans. On the contrary, the adverse aggregate demand shock after 1989 which re-

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<sup>1</sup>In figure 3-1, recessions prior to 1982/83 were in 1961/62, 1965/66, 1971/72, 1974/75 and 1977/78. Due to the limitation of data of these recessions, I focus only on the 1982/83 and 1990/91 recessions.

<sup>2</sup>Demand shocks can be a change in consumer confidence, for example.

Figure 3-1: Annual real GDP per capita in Australia vs. its linear time trend at 1.7% and cyclical component during 1960-2007 (Logarithm scale).



duces firm equity leads to a tightening credit condition. This raises the firms' leverage and reduces both demand and supply of funding. Therefore, it may explain the more amplified business cycles in Australia during 1980s. All aforementioned studies are not based on the dynamic stochastic general equilibrium approach. Hence, they do not give any clear inferences on how economic agents respond to the shock in the competitive equilibrium allocations.

There are very few studies that employ a dynamic general equilibrium model to investigate the source of Australian economic fluctuations. Based on quarterly data between 1991:Q1 and 2006:Q2, Nimark (2007) utilizes Bayesian techniques to study a New Keynesian small open economy model for Australia. His result shows that

output responds negatively to an unexpected increase in interest rates, and positively to an exogenous increase in the demand for Australian exports, an increase in the export income and a rise in the productivity shock. The exogenous export demand shock is particularly important to the variations in output. A drawback of Nimark (2007) is the single factor of production, i.e. labour, in the model. The role of total factor productivity shocks is also excluded.

A subsequent study by Jääskelä and Nimark (2008) is based in a more richly structured New Keynesian open economy model and employs Bayesian techniques on Australian data. Capital and labour are included as factors of production. Unlike the frictionless model of Nimark (2007), Jääskelä and Nimark include Calvo-type nominal frictions and real frictions in the model. All good prices and wages respond sluggishly to the shocks. The main finding is that both foreign and domestic shocks are the important force driving the Australian business cycles under the inflation-targeting regime in 1993-2007. This contrasts with the result of Nimark (2007) in which foreign shocks are important. Apparently, both studies ignore the distortions that cause the deviation of intertemporal marginal rate of substitution in consumption from the marginal product of capital in the Euler equilibrium condition. In order to fill this gap in the literature, I will incorporate the market frictions on investment in addition to other frictions in the prototype model. Furthermore, the sample period in my study is longer than previous studies. It covers the 1982/83 recession and the 1990/91 recession. I can thus assess the importance of frictions across Australian business cycles.

### **3.2.2 Business Cycle Accounting Method**

The BCA method allows several distortions to be studied simultaneously in a prototype model. This method was developed by Chari et al. (2007a) and is founded on

the Neoclassical growth model with identical households and firms. Households maximize their expected lifetime utility subject to the budget constraint and the capital accumulation law. Two time-varying artificial taxes are introduced into the budget constraint in the forms of the labour income tax and the investment tax. These two taxes will subsequently represent the labour wedge and the investment wedge. Firms maximize their profit with respect to the production technology. By using the actual data with the first-order conditions and the resource constraint, the four measured wedges are obtained.

The four wedges are the efficiency wedge, the labour wedge, the investment wedge and the government consumption wedge. The efficiency wedge represents the total factor productivity in the production function. It is equivalent to the input-financing frictions in production. A fall in the efficiency wedge essentially implies an increasingly inefficient allocation of resource. The labour wedge is denoted by unity less the time-varying labour income tax. In the intratemporal equilibrium condition, it is essentially the residual between the marginal product of labour and the marginal rate of substitution between consumption and leisure. Either the marginal product of labour or the marginal rate of substitution between consumption and leisure do not equate with the equilibrium real wage. A fall in the labour wedge thus implies the larger distortions between the marginal product of labour and the marginal rate of substitution between consumption and leisure. Ahearne, Kydland, and Wynne (2006) show that these distortions can also represent taxes on consumption and entry restrictions into the intermediate goods market. The investment wedge is denoted by the inverse of the sum of unity and the time-varying tax on investment. In the Euler equation, it is essentially the residual between the marginal product of capital and the intertemporal marginal rate of substitution in consumption. A fall in the investment wedge means the larger distortions between the marginal product of capital

and the intertemporal marginal rate of substitution in consumption. The government consumption wedge represents public consumption spending plus net exports in the resource constraint. It is equivalent to the frictions in international borrowing and lending.

In the accounting procedure, the four realized wedges are fed back into the model, separately and in combinations, in order to test the importance of each wedge in the model. The result in Chari et al. (2007a) shows that the efficiency wedge and the labour wedge are important propagation mechanisms for the Great Depression and the 1982 recession in the U.S. The investment wedge does not have depressive effects and is not a promising propagation mechanism for the recession in the U.S.

Recently, several studies have employed this method to study the propagation mechanism of shocks across economies. Ahearne et al. (2006) conclude that the efficiency wedge and the labour wedge greatly contribute to the decline in output and the subsequent recovery in the 1980s Ireland's economic downturn. This is similar to the finding in Chari et al. (2007a) for the U.S. economy.

Other studies also find the significant role of the efficiency wedge and the labour wedge while the investment wedge plays a trivial role. Kersting (2008) find that the labour wedge is the most important distortion that accounts for the U.K. recession and recovery in 1980s. In particular, his finding is consistent with the new labour market policies under the Thatcher Government on reducing the union power and reforming social security as well as unemployment benefits. The implementation of the new policies appears to remove distortions in the labour market. Hence, it plays a substantial role in the economic recovery in the U.K. starting in 1984.

Cociuba and Ueberfeldt (2008) study the economic fluctuations in Canada during 1961-2005. Their result confirms the importance of the efficiency wedge and the labour wedge for the variations in output, investment and labour supply in the Canadian

economy. It further suggests that the relatively increasing effective labour income tax rate, which captures the change in the labour tax rate and consumption tax rate, particularly explains the growth slowdown period between 1980 and 2005 in Canada when compared to the growth rate in the U.S. The finding in Simonovska and Soderling (2008) also suggest that the efficiency wedge and the labour wedge are the main source of macro fluctuations in Chile from 1998 to 2007.

Kobayashi and Inaba (2006) find that the labour wedge is the crucial distortion that accounts for the Japanese decade-long recession in the 1990s. This contrasts with the earlier finding in Chakraborty (2005). Unlike the conclusion of aforementioned studies, Chakraborty (2005) argues that the investment wedge is the most important distortion in explaining the lost decade in Japan. She also argues that the efficiency wedge alone cannot account for business cycle fluctuations in Japan and the role of total factor productivity in literature may have been overemphasized. Meanwhile, the labour wedge is not an important distortion in her study. Kobayashi and Inaba (2006) note that the different source of data, different data constructions and different simulation methods may lead to the disagreements over the explanation for the lost decade in Japan.

The study of international trade often refers to the efficiency wedge as the reciprocal of the terms of trade: the factors of production are comparable to exports while the output is seen as imports (Kehoe and Ruhl 2008). The terms of trade is defined by the index of export prices relative to that of import prices. Kehoe and Ruhl (2008) note that the terms of trade shocks influence a country's income through the reallocations across goods and sectors. The deteriorations in the terms of trade result in the inefficient use of working capital and accordingly lower the efficiency wedge as well as output. In the case of Mexico during 1970-1990, they find that the correlation coefficient between the change in real GDP and the change in the terms of trade is



0.75 whereas the correlation coefficient between the change in the efficiency wedge and the change in the terms of trade is 0.73. Particularly in the 1982 crisis and the 1994 crisis, they find that the deteriorations in the terms of trade clearly coincided with the dramatic fall in output and the efficiency wedge.

### 3.2.3 Parameter Values

In the BCA method, the parameter values in the model must be pinned down before conducting the BCA exercise. A recent study by Harding and Negara (2008) applies the Generalized Method of Moments (GMM) to estimate the baseline real business models for Australia. They suggest an associated range of parameter values to different RBC models. Apparently, their estimation of labour share in income of 0.5607 is relatively low when compared to the adjusted labour share in income across countries in Gollin (2002) which lies between 0.65 and 0.80. As a result, the risk-free real interest rate in their estimation varies between 10.4% and 12.3% in the model with population growth. Their range of risk-free interest rate is obviously high and rarely found in the literature. The key point to explain their relatively low labour share in income is essentially the inclusion of ambiguous categories in the national income. As discussed in Gollin (2002) and Conesa, Kehoe, and Ruhl (2007), the ambiguous categories are non-wage income like gross operating surplus of private unincorporated enterprises and the payments to the self-employed workers and to unremunerated family workers. The labour share should be defined by the ratio of employee compensations to the unambiguous national income (Cooley and Prescott 1995, Gollin 2002 and Conesa et al. 2007). Hence, including the ambiguous national income in the computation yields a misleading interpretation of labour share.

Therefore, I will adopt the measurement of labour income share in Conesa et al. (2007) to estimate this parameter for Australia. The unambiguous national income

is the GDP net of household mixed income and indirect taxes. With the constant returns to scale production technology, the labour share in income  $(1 - \alpha)$  is

$$1 - \alpha = \frac{\text{Total compensation of employees}}{\text{GDP} - \text{Mixed income} - \text{Indirect taxes}}.$$

In addition, I will follow Cooley and Prescott (1995) on the calibration of the rest of parameters by using the steady-state equations in a perfect competitive equilibrium: the steady-state intratemporal condition, the steady state motion of capital and the steady state Euler equilibrium condition. The corresponding parameters are the time allocation between leisure and consumption  $\left(\frac{\phi}{1-\phi}\right)$ , the depreciation rate of capital ( $\delta$ ) and the discount factor ( $\beta$ ), respectively.

$$\left(\frac{\phi}{1-\phi}\right) = (1 - \alpha) \times \frac{y}{c} \times \frac{1-h}{h}$$

$$\delta = \frac{x}{k} + 1 - (1 + \lambda)(1 + \eta)$$

$$\beta = \frac{(1 + \lambda)}{\left(\alpha \times \frac{y}{k}\right) + 1 - \delta}$$

The comparison of calibrated parameters on the yearly basis between Nimark (2007), Jääskelä and Nimark (2008) and Chari et al. (2007a) is shown below.

Parameters	Nimark (2007)	Jaaskela and Nimark (2008)	Chari et al. (2007)
$\alpha$	n.a.	0.2900	0.3500
$\beta$	0.9601	0.9960	0.9700
$\delta$	n.a.	0.0510	0.0464
$\eta$	n.a.	n.a.	0.0150
$\lambda$	n.a.	n.a.	0.0160
$\frac{\phi}{1-\phi}$	n.a.	n.a.	2.2400

As for the parameter values in Nimark (2007) and Jääskelä and Nimark (2008), I convert their parameter values from quarterly basis into yearly basis. It is noted that the relatively high discount factor in Jääskelä and Nimark (2008) implies the very patient household.

### 3.3 Model

This section provides the detail of the benchmark prototype model. Then it explains the accounting procedure, the source of data and the parameter values, accordingly.

#### 3.3.1 Benchmark Prototype Model

I follow the benchmark prototype model in Chari et al. (2007a). The economy is comprised of identical infinitely-lived households and identical competitive firms. Note that all lowercase variables represent per capita values. Assume that the utility function is additively separable, continuously differentiable in its arguments and strictly concave. The household's preference mainly depends on consumption ( $c_t$ ) and leisure ( $l_t$ ). Time endowment is normalized to one. Hours worked ( $h_t$ ) is equal to  $1 - l_t$  since household's time endowment is devoted to leisure and working. In a frictionless economy, the household's expenditures on consumption and investment ( $x_t$ ) are financed by the income from supplying labour ( $w_t h_t$ ), the income from renting capital ( $r_t k_t$ ) and the transfers from government ( $tr_t$ ). Unlike the frictionless economy, the BCA method introduces two time-varying artificial taxes into the budget constraint. They are taxes on labour income ( $\tau_{ht}$ ) and taxes on investment expenditure ( $\tau_{xt}$ ). In the household's optimal decision, the two taxes represent the labour wedge and the investment wedge, accordingly. The capital stock in the future ( $k_{t+1}$ ) is the sum of net capital stock and investment in the current period. To be consistent with the balanced growth path, the capital stock is thus adjusted by the growth rate of popu-

lation ( $\eta$ ) and the rate of labour-augmenting technical progress ( $\lambda$ ). A large number of identical infinitely-lived households maximize their expected life-time utility

$$\max_{c_t, l_t, k_{t+1}} E_0 \left[ \sum_{t=0}^{\infty} \beta^t (1 + \eta)^t U(c_t, l_t) \right], \quad 0 < \beta < 1,$$

$$\lim_{c \rightarrow 0} u_c(\cdot, \cdot) = \infty \text{ and } \lim_{c \rightarrow \infty} u_c(\cdot, \cdot) = 0,$$

$$\lim_{h \rightarrow 0} u_h(\cdot, \cdot) = \infty \text{ and } \lim_{h \rightarrow \infty} u_h(\cdot, \cdot) = 0$$

with respect to the budget constraint

$$c_t + (1 + \tau_{xt})x_t = (1 - \tau_{ht})w_t h_t + r_t k_t + tr_t$$

and the capital accumulation law

$$k_{t+1} = \frac{(1 - \delta)k_t + x_t}{(1 + \eta)(1 + \lambda)}$$

where  $w_t$  is the real wage at period t

$r_t$  is the rental of physical capital at period t

$\beta$  is the discount factor

$\delta$  is the depreciation rate of capital.

A large number of firms maximize their profit with respect to the technology used in production. Factors of production are capital and labour. The firm's output is denoted by  $y_t$ . The firm's production cost is the sum of labour cost ( $w_t h_t$ ) and capital cost ( $r_t k_t$ ). In the competitive equilibrium, firms can earn normal profit only. Assume that all firms use the labour-augmenting technology in their production, profit-maximizing firms will

$$\max_{k_t, h_t} y_t - w_t h_t - r_t k_t$$

subject to

$$y_t = A_t F(k_t, (1 + \lambda)^t h_t)$$

where  $A_t$  is total factor productivity at period  $t$ .

The government is assumed to maintain a balanced-budget in every period. The government receives revenue from taxing investment expenditure and labour income, and spends the revenue on consumption and transfers.

$$g_t + tr_t = \tau_{xt}x_t + \tau_{ht}w_t h_t$$

Lastly, this economy is summarized by the resource constraint

$$y_t = c_t + x_t + g_t$$

where  $g_t$  is government consumption plus net exports.

Equation 3.1 to 3.4 are the equilibrium conditions of the model.

$$-\frac{U_{ht}}{U_{ct}} = (1 - \tau_{ht}) w_t \tag{3.1}$$

$$(1 + \tau_{xt})U_{ct} = \beta E_t U_{ct+1} [A_{t+1} F_{kt+1} + (1 - \delta)(1 + \tau_{xt+1})] \tag{3.2}$$

$$A_t (1 + \lambda)^t F_{ht} = w_t \tag{3.3}$$

$$A_t F_{kt} = r_t \tag{3.4}$$

In the BCA method, the four wedges are derived from the equilibrium equations and the resource constraint in the benchmark prototype economy. They are equivalent to the distortions that deviates an economy from a perfectly competitive equilibrium. The four wedges are:

- Efficiency wedge:  $A_t$

$$A_t = \frac{y_t}{F(k_t, (1 + \lambda)^t h_t)} \quad (3.5)$$

The efficiency wedge is equivalent to the total factor productivity (TFP). It captures the component of output which cannot be explained by the production technology. The efficiency wedge can represent input-financing frictions like that in Bernanke (1983). A fall in the efficiency wedge implies an increasingly inefficient allocation of resource.

- Labour wedge:  $(1 - \tau_{ht})$

$$1 - \tau_{ht} = -\frac{U_{ht}}{U_{ct}} \times \frac{1}{A_t(1 + \lambda)^t F_{ht}} \quad (3.6)$$

The labour wedge is the residual between the marginal product of labour and the marginal rate of substitution between consumption and leisure. In this case, labour demand and/or labour supply are not equal to the real wage in market equilibrium. This represents frictions in the detailed model with union power as in Cole and Ohanian (2004). A fall in the labour wedge that is equivalent to a rise in artificial taxes on labour income leads to an economic slowdown.

- Investment wedge:  $\frac{1}{1 + \tau_{xt}}$

$$(1 + \tau_{xt})U_{ct} = \beta E_t U_{ct+1} [A_{t+1} F_{kt+1} + (1 - \delta)(1 + \tau_{xt+1})] \quad (3.7)$$

The investment wedge is equivalent to the residual between the marginal product of capital and the intertemporal marginal rate of substitution in consumption. A decline in the investment wedge is equivalent to an increase in artificial taxes on investment. This tends to raise frictions in the credit market as can be found in the model of Bernanke et al. (1999). It may cause an economic slowdown due to the shrinking investment.

- Government consumption wedge:  $g_t$

$$g_t = y_t - c_t - x_t \quad (3.8)$$

The government spending wedge is the sum of government consumption spending and net exports in the resource constraint. It represents the international borrowing and lending frictions in a detailed model.

### 3.3.2 Accounting Procedure

Assume that the utility function exhibits constant relative risk aversion (CRRA)

$$U(c_t, l_t) = \frac{\left[ c_t^{1-\phi} (1-l_t)^\phi \right]^{1-\varphi} - 1}{1-\varphi}$$

where  $1/\varphi$  is the intertemporal elasticity of substitution and  $\phi$  is the leisure preference.  $\varphi$  also represents the coefficient of risk aversion.

To be consistent with the balance growth path,  $\varphi$  is set to one. With regard to the change in the interest rates, the income effect completely offsets the substitution effect in the intertemporal consumption. As a result, the change in consumption is in the same proportion to the change in the interest rates. Accordingly, the utility function is reduced to

$$U(c_t, l_t) = (1-\phi) \ln c_t + \phi \ln(1-l_t)$$

Furthermore, it is assumed that firms' production technology are identical and it is characterized by a constant return to scale (CRS) Cobb-Douglas function as below:

$$y_t = A_t k_t^\alpha (1+\lambda)^{(1-\alpha)t} h_t^{1-\alpha}$$

where  $\alpha$  is the share of capital in output.

Therefore, the four measured wedges in this study are as below. Note that the variable with tilde represents the detrended actual per capita series.

- Efficiency wedge:  $A_t$

$$A_t = \frac{\tilde{y}_t}{\tilde{k}_t^\alpha \tilde{h}_t^{1-\alpha}} \quad (3.9)$$

- Labour wedge:  $(1 - \tau_{ht})$

$$(1 - \tau_{ht}) = \frac{\phi}{1 - \phi} \times \frac{\tilde{c}_t}{\tilde{h}_t} \times \frac{h_t^\alpha}{A_t(1 + \lambda)^t(1 - \alpha)\tilde{k}_t^\alpha} \quad (3.10)$$

- Investment wedge:  $\frac{1}{1 + \tau_{xt}}$

$$(1 + \tau_{xt}) \times \frac{(1 - \phi)}{\tilde{c}_t} = \beta E_t \left\{ \frac{(1 - \phi)}{\tilde{c}_{t+1}} \left[ A_{t+1} \times \alpha \left( \frac{h_{t+1}}{\tilde{k}_{t+1}} \right)^{1-\alpha} + (1 - \delta)(1 + \tau_{xt+1}) \right] \right\} \quad (3.11)$$

- Government consumption wedge:  $g_t$

$$\tilde{g}_t = \tilde{y}_t - \tilde{c}_t - \tilde{x}_t \quad (3.12)$$

The efficiency, labour and the government consumption wedges can be measured directly from the data. Meanwhile, obtaining the investment wedge is more complicated as it involves the rational expectation in computation. Therefore, I need to proceed as follows. I first log-linearize the equilibrium conditions around the steady-state. I assume that the wedges follow the first order autoregressive process. Observable variables are  $y_t, x_t, h_t$  while the state variables are  $\log k_t, \log A_t, \tau_{ht}, \tau_{xt}, \log g_t$ .



Also,  $\log k_{t+1}$  is a function of  $\log k_t, \log A_t, \tau_{ht}, \tau_{xt}, \log g_t$ . Therefore, the State Space representation of the model is described by

$$X_{t+1} = BX_t + C\zeta_{t+1}$$

$$Y_{t+1} = DX_t + \omega_t$$

where  $X_t = [\log \tilde{k}_t, \log A_t, \tau_{ht}, \tau_{xt}, \log \tilde{g}_t]'$  and  $Y_t = [\log \tilde{y}_t, \log \tilde{x}_t, \log h_t, \log \tilde{g}_t]$ .

Let  $s_t = (\log A_t, \tau_{ht}, \tau_{xt}, \log g_t)$  and assume that all the wedges follow the AR(1) process, i.e.  $s_{t+1} = P_0 + Ps_t + Q\epsilon_{t+1}$ . I assume that  $\epsilon_t$  is independent and identically distributed and has a normal distribution with zero mean and covariance matrix  $V$ .  $V$  is  $QQ'$  where  $Q$  is the lower triangle matrix. The maximum likelihood method is employed to estimate the stacked matrix of  $P_0, P, Q$ . Then, the maximum likelihood estimates are used to obtain the investment wedge.

$$\text{Mean of wedges is } \begin{bmatrix} 0.2705 & 0.3865 & 0.0408 & -1.2968 \end{bmatrix}.$$

$$\text{Coefficient matrix } P \text{ on lagged state variables is } \begin{bmatrix} 0.9681 & -0.0455 & 0.0653 & 0.0191 \\ -0.0144 & 0.8901 & 0.0909 & 0.0110 \\ 0.0061 & 0.0178 & 0.9749 & -0.0043 \\ -0.0669 & 0.2204 & 0.1269 & 0.9700 \end{bmatrix}.$$

$$\text{Coefficient matrix } Q \text{ where } V = QQ' \text{ is } \begin{bmatrix} 0.0138 & 0 & 0 & 0 \\ 0.0061 & 0.0055 & 0 & 0 \\ -0.0044 & -0.0057 & -0.0150 & 0 \\ 0.0020 & -0.0011 & -0.0116 & 0.0279 \end{bmatrix}.$$

Here,  $\det(V) > 0$  ensures that the likelihood function is maximal.

### 3.3.3 Data

The data used in the BCA procedure cover the period between 1980:Q3 and 2008:Q2. They are seasonally adjusted and obtained from the statistics section of the Australian Bureau of Statistics (ABS) website. The reference year of the data in chain volume measures is 2006/07. I follow the data adjustments in Chari et al. (2007a) as below.

- Household consumption ( $c_t$ ) is defined as household final consumption expenditure on consumer nondurable goods and services *minus* sales tax of consumer non-durable goods *minus* goods and services tax (which took effect in 2000:Q3) of consumer non-durables *plus* services from consumer durable goods *plus* depreciation of consumer durable goods. As the Australian Bureau of Statistics (ABS) does not separate consumer durables from consumer non-durables in household final consumption, the household expenditure on consumer durables is constructed in this study. According to the year 2007 structure of personal consumption expenditure by the Bureau of Economic Analysis, the U.S. Department of Commerce, household consumption on durable goods includes expenditure on furnishings, household equipment and vehicles. Moreover, the rate of return on consumer durable goods is assumed to be 17% per annum as in Chari et al. (2007a). This represents the services from consumer durable goods. The depreciation rate of consumer durables is 16% per annum as suggested by the average ratio of durable goods depreciation to the stock of durable goods in the U.S. during 1960-2006. This is similar to the depreciation rate of durable goods in Baxter (1996) of which is 15.6% per annum.
- Investment ( $x_t$ ) is defined as private and public gross fixed capital formation *plus* changes in inventories *plus* consumer durable goods *minus* sales tax of consumer durables *minus* goods and services tax of consumer durables.

- Output ( $y_t$ ) is defined as real GDP *minus* sales tax *minus* goods and services tax *plus* services from consumer durable goods *plus* depreciation of consumer durable goods.

In this study, total hours worked per week is the average weekly hours worked for wages and salary earners multiplied by employed persons. Population is defined by civilian non-institutional population aged 15-64.

### 3.3.4 Parameter Values

I adopt the definition of labour income share in Conesa et al. (2007) to estimate this parameter for Australia. In addition, I follow Cooley and Prescott (1995) for the calibration of the rest of parameters. The unambiguous national income is the GDP net of household mixed income and indirect taxes. With the constant returns to scale production technology, the labour share in income ( $1 - \alpha$ ) is

$$1 - \alpha = \frac{\text{Total compensation of employees}}{\text{GDP} - \text{Mixed income} - \text{Indirect taxes}}.$$

The labour share in income for Australia during 1972-2006 is 0.6662. It is consistent with Gollin (2002) whose adjusted labour income share lies between 0.65 and 0.80. Hence, the capital share in income ( $\alpha$ ) is 0.3338. Population growth ( $\eta$ ) during 1972-2007 is 1.5% per annum. The growth rate of labour-augmenting technology on the balanced growth ( $\lambda$ ) is 1.7% over 1960-2007. Without knowledge of the realized labour wedge and the realized investment wedge in the steady state, the rest of parameters are calibrated from the perfect competitive equilibrium. This implies that the labour wedge and the investment wedge vanish in the steady state. The rest of parameters are calibrated from the steady state equations as discussed in Cooley and Prescott (1995). These equations are the steady-state intratemporal condition, the steady state motion of capital and the steady state Euler equilibrium condition. The

corresponding parameters are the time allocation between leisure and consumption  $\left(\frac{\phi}{1-\phi}\right)$ , the depreciation rate of capital ( $\delta$ ) and the discount factor ( $\beta$ ), respectively.

$$\left(\frac{\phi}{1-\phi}\right) = (1-\alpha) \times \frac{y}{c} \times \frac{1-h}{h}$$

$$\delta = \frac{x}{k} + 1 - (1+\lambda)(1+\eta)$$

$$\beta = \frac{(1+\lambda)}{\left(\alpha \times \frac{y}{k}\right) + 1 - \delta}$$

Assuming that households spend one-third of their time on market activities, the calibration gives the time allocation factor of 2.5945. The ratio of investment to capital stock during 1972-2006 is 0.0887. The depreciation rate of capital is thus 5.6438% per annum. The ratio of output to capital stock during 1972-2006 is 0.3433. The discount factor is 0.9611. The comparison of calibrated parameters on the annual basis in this study to those in Nimark (2007), Jääskelä and Nimark (2008) and Chari et al. (2007a) is shown below.

Parameters	This Study	Nimark (2007)	Jaaskela and Nimark (2008)	Chari et al. (2007)
$\alpha$	0.3338	n.a.	0.2900	0.3500
$\beta$	0.9611	0.9601	0.9960	0.9700
$\delta$	0.0564	n.a.	0.0510	0.0464
$\eta$	0.0150	n.a.	n.a.	0.0150
$\lambda$	0.0170	n.a.	n.a.	0.0160
$\frac{\phi}{1-\phi}$	2.5945	n.a.	n.a.	2.2400

Apparently, the discount factor in this study is similar to that in Nimark (2007) but lower than that used in Jääskelä and Nimark (2008). The depreciation rate of capital in this study is very similar to that in Jääskelä and Nimark (2008). However, the

share of capital in production in my study is slightly higher than that in Jääskelä and Nimark (2008)<sup>3</sup>. Overall, the calibrated parameters in my study are similar to those in the standard RBC literature<sup>4</sup>.

## 3.4 Findings

This section presents and discusses the findings of the BCA for Australia. In subsection 3.4.1, the four measured wedges during 1980:Q3-2008:Q2 are displayed. Then, the predictions of models with different wedges are compared to the Australian data, i.e. output, investment and hours worked, in order to assess the importance of each wedge to the Australian business cycles. In subsection 3.4.2, the source of the 1982 recession, the 1990 recession and the late 1990s boom are analyzed. An alternative interpretation of the efficiency wedge is also discussed.

### 3.4.1 Quantitative Analysis

Recall that there are two steps in the BCA method. The first step is to obtain four measured wedges. They are the efficiency wedge, the labour wedge, the investment wedge, and the government consumption wedge from equation 3.9 to 3.12, respectively. The second step is to feed the measured wedges back into the model, either separately or in combinations, in order to simulate the output, investment and hours worked from the model. A model with all wedges will recover the data. The data are plotted along with the model with either just one wedge or in combinations. The model is evaluated by how well it can replicate the data. The time horizon of the result begins in the third quarter of the year. This is to be consistent with the beginning

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<sup>3</sup>They provide no details on how this parameter is calibrated.

<sup>4</sup>Those values used in Chari et al. (2007a) represent the standard case in RBC literature and match the stylized facts of the U.S. economy.

of financial year in Australia.

The relationship between Australian output and the four measured wedges during 1980:Q3-2008:Q2 is shown in figure 3-2. Among the four wedges, the efficiency wedge and the investment wedge coincide with output the most. Table 3.1 shows the standard deviation and cross correlation of the wedge with output. All series are logged and HP-filtered. In this table, the correlation coefficient between the investment wedge and output is 0.62 with the standard deviation to output of 1.72. Meanwhile, the correlation coefficient between the efficiency wedge and output is 0.60 with the standard deviation to output of 0.81. The labour wedge and the government consumption wedge are barely procyclical to output and they are very much more volatile than output.

The discussion of the predictions of output with different wedges is based on figures 3-3 to 3-4 and tables 3.2 to 3.5. Note that all series are logged and HP-filtered in tables 3.2 to 3.5. Figure 3-3 plots detrended output along with the predictions of models with just one wedge. It is clear that the model with efficiency wedge can replicate the fluctuations in output the best. This is affirmed by the statistics in table 3.2 which shows standard deviation and cross correlation of the model output with actual output. In this table, the correlation coefficient between the model with efficiency wedge and output is 0.70 with the standard deviation to output of 1.61. The model with investment wedge is the second best to explain the output fluctuations. The correlation coefficient between the model with the investment wedge and output is 0.63 with the standard deviation of 1.10 relative to output. The government consumption wedge plays a trivial role since it predicts the movement of output against the actual data. Further, as shown in table 3.3, the combination of government consumption wedge with other wedges barely improve the prediction of model to output when compared to the model with just one wedge.

Figure 3-4 plots the Australian output and predictions of output with two wedges. Apparently, the model with efficiency and labour wedges can replicate the output fluctuations very well. Table 3.3 shows standard deviation relative to actual output and cross correlation between the model output with two wedges and actual output. This table affirms that the model with the efficiency and labour wedges is procyclical to output the most and captures output variations the best as its cross correlation coefficient with output is 0.87 and its standard deviation to output is 1.05. Meanwhile, the model with the efficiency and investment wedges is much more volatile than actual output as the standard deviation relative to output is as high as 2.59.

Table 3.4 shows the cross correlations between two wedges whereas table 3.5 shows cross correlations between two model outputs. In table 3.4, the cross correlation coefficient between the efficiency wedge and the labour wedge is -0.62. In table 3.5, the cross correlation coefficient between the model output with efficiency wedge and that with labour wedge is -0.77. The labour wedge somewhat counteracts the efficiency wedge. For instance, if both the efficiency wedge and the labour wedge are simultaneously fed into the model, some increments in input-financing frictions in production are to be offset by the decreasing distortions in labour market and vice versa. Unlike the model with just the efficient wedge that captures only the movement of output very well, the model with the efficiency and labour wedges explains both the movement and extent of output variations very well. In contrast, the model with efficiency and investment wedges predicts too much either rise or fall in output. The cross correlation coefficient between the efficiency wedge and the investment wedge in table 3.4 is 0.47 whereas the cross correlation coefficient between the model output with efficiency wedge and that with investment wedge is 0.81. As discussed earlier the model with just the efficiency wedge is already capable to account for the variations

in output, the simultaneity of the efficiency and investment wedges in the model thus exacerbates the variations in output when compared to the actual data as shown in figure 3-4. The presence of these two wedges in a model is not likely to capture the amplitude of the Australian output cycles. In the bottom panel of the same figure, the model with investment and labour wedges is clearly not promising as it fails to replicate the output variations. To sum up, the efficiency wedge is the main force driving the output fluctuations.

The discussion of the predictions of investment with different wedges is based on figures 3-5 to 3-6. Figure 3-5 plots the Australian investment along with the predictions of models with just one wedge. It is very clear in this figure that the model with the efficiency wedge can best explain the business cycles of investment. However, its prediction for the ratio of investment to output after 2004:Q1 appears to be low. The model with the investment wedge captures the fluctuations in investment but predicts the ratio of investment to output to be higher than observed. The labour wedge is not important to investment as can be seen in figure 3-6. Figure 3-6 displays the comparison between Australian investment and predictions of models with two wedges. The inclusion of the labour wedge in addition to the efficiency wedge in the upper panel of figure 3-6 does not yield any significant difference in output variations when compared to the model with just efficiency wedge. The overall ratio of investment to output in the model is smaller than the data. In the lower panel of the same figure, the inclusion of the labour wedge in addition to the investment wedge drives the model simulated data against the actual data in some periods, for example 1993:Q1. In conclusion, the efficiency wedge is crucial to the fluctuations in investment.

The discussion of the predictions of hours worked with different wedges is based on figures 3-7 to 3-8. Figure 3-7 plots the Australian hours worked along with the



predictions of models with just one wedge. In this figure, the model with investment wedge appears to explain the fluctuations in hours worked better than other models. Figure 3-8 plots the Australian hours worked and the predictions of models with two wedges. In this figure, the model with the investment and labour wedges can capture the variations in hours worked very well until 2003. After 2003, the model predicts too much increase in hours worked, and this results in the deviation of the model from the actual data.

Table 3.1: Standard deviation and cross correlation of the wedge with output during 1980:Q3-2008:Q2.

Wedge	S.D. relative to output	Cross correlation of the wedge with output (t-k), k=								
		-4	-3	-2	-1	0	1	2	3	4
Efficiency	0.81	0.24	0.32	0.45	0.57	<b>0.60</b>	0.30	-0.03	-0.27	-0.43
Labour	1.50	-0.33	-0.23	-0.11	0.03	0.19	0.39	0.56	<b>0.63</b>	<b>0.63</b>
Investment	1.72	0.37	0.50	0.59	<b>0.64</b>	0.62	0.49	0.27	0.02	-0.20
Government	2.90	<b>0.17</b>	0.13	0.10	0.06	0.02	-0.11	-0.15	-0.15	-0.11

Table 3.2: Cross correlation between the model output with one wedge and actual output during 1980:Q3-2008:Q2.

Model output with	S.D. relative to output	Cross correlation between the model output with one wedge and actual output (t-k), k=								
		-4	-3	-2	-1	0	1	2	3	4
Efficiency wedge	1.61	0.31	0.44	0.57	0.69	<b>0.70</b>	0.46	0.13	-0.16	-0.37
Labour wedge	1.46	-0.45	-0.42	-0.37	-0.29	-0.15	0.08	0.32	0.50	<b>0.60</b>
Investment wedge	1.10	0.37	0.50	0.60	<b>0.65</b>	0.63	0.50	0.26	0.01	-0.22
Government wedge	0.95	-0.17	-0.34	-0.47	-0.59	<b>-0.63</b>	-0.59	-0.42	-0.20	-0.02

Table 3.3: Cross correlation between the model output with two wedges and actual output during 1980:Q3-2008:Q2.

Model output with	S.D. relative to output	Cross correlation between the model output with two wedges and actual output (t-k), k=								
		-4	-3	-2	-1	0	1	2	3	4
Efficiency & Labor wedges	<b>1.05</b>	-0.13	0.09	0.37	0.65	<b>0.87</b>	0.80	0.64	0.45	0.26
Efficiency & Investment wedges	2.59	0.35	0.49	0.61	0.71	<b>0.71</b>	0.50	0.19	-0.09	-0.32
Efficiency & Government wedges	1.17	0.29	0.33	0.40	<b>0.47</b>	0.46	0.15	-0.16	-0.38	-0.50
Labour & Investment wedges	1.13	-0.21	-0.05	0.11	0.26	0.42	0.59	<b>0.67</b>	0.65	0.57
Labour & Government wedges	1.98	-0.41	-0.47	<b>-0.50</b>	-0.49	-0.41	-0.23	0.04	0.27	0.45
Investment & Government wedges	0.55	<b>0.45</b>	0.43	0.38	0.29	0.18	-0.03	-0.20	-0.33	-0.41

Table 3.4: Cross correlation between two wedges during 1980:Q3-2008:Q2.

Two wedges (A,B)	Cross correlation of A with B (t-k), k=								
	-4	-3	-2	-1	0	1	2	3	4
Efficiency, Labour	0.27	0.12	-0.03	-0.26	<b>-0.62</b>	-0.56	-0.54	-0.53	-0.46
Efficiency, Investment	0.09	0.26	0.39	0.45	<b>0.47</b>	0.33	0.20	0.06	-0.08
Efficiency, Government	-0.17	-0.20	-0.16	-0.08	0.08	0.19	0.22	0.24	<b>0.25</b>
Labour, Investment	-0.38	-0.42	-0.36	-0.26	-0.20	0.06	0.25	0.41	<b>0.51</b>
Labour, Government	0.17	0.08	-0.06	-0.15	-0.22	<b>-0.31</b>	-0.29	-0.28	-0.21
Investment, Government	-0.25	-0.21	-0.14	-0.11	-0.12	0.02	0.11	0.21	<b>0.26</b>

Table 3.5: Cross correlation between two model outputs during 1980:Q3-2008:Q2.

Model output with wedges (A,B)	Cross correlation of model outputs with A and B (t-k), k=								
	-4	-3	-2	-1	0	1	2	3	4
	Efficiency, Labour	0.32	0.10	-0.13	-0.41	<b>-0.77</b>	-0.66	-0.60	-0.54
Efficiency, Investment	0.06	0.29	0.50	0.67	<b>0.81</b>	0.61	0.40	0.21	0.00
Efficiency, Government	-0.24	-0.43	-0.57	-0.67	<b>-0.69</b>	-0.43	-0.18	0.05	0.25
Labour, Investment	-0.35	-0.48	-0.54	-0.58	<b>-0.64</b>	-0.33	-0.06	0.17	0.37
Labour, Government	0.43	0.46	0.41	0.36	0.33	0.02	-0.21	-0.41	<b>-0.53</b>
Investment, Government	-0.27	-0.44	-0.57	-0.72	<b>-0.86</b>	-0.60	-0.34	-0.08	0.15

Figure 3-2: Detrended Australian output vs. Four measured wedges during 1980:Q3-2008:Q2.

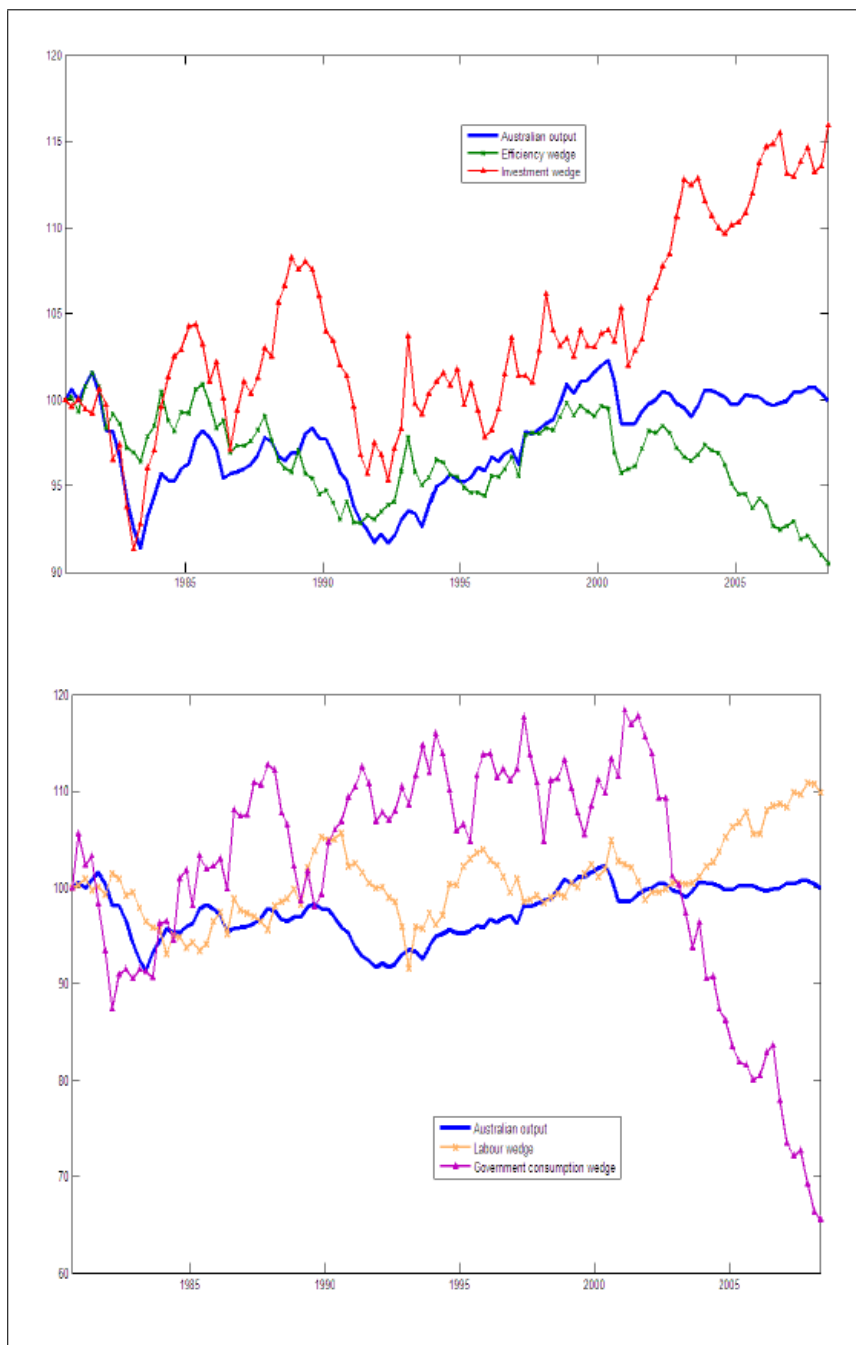


Figure 3-3: Detrended Australian output vs. Predictions of models with just one wedge during 1980:Q3-2008:Q2.

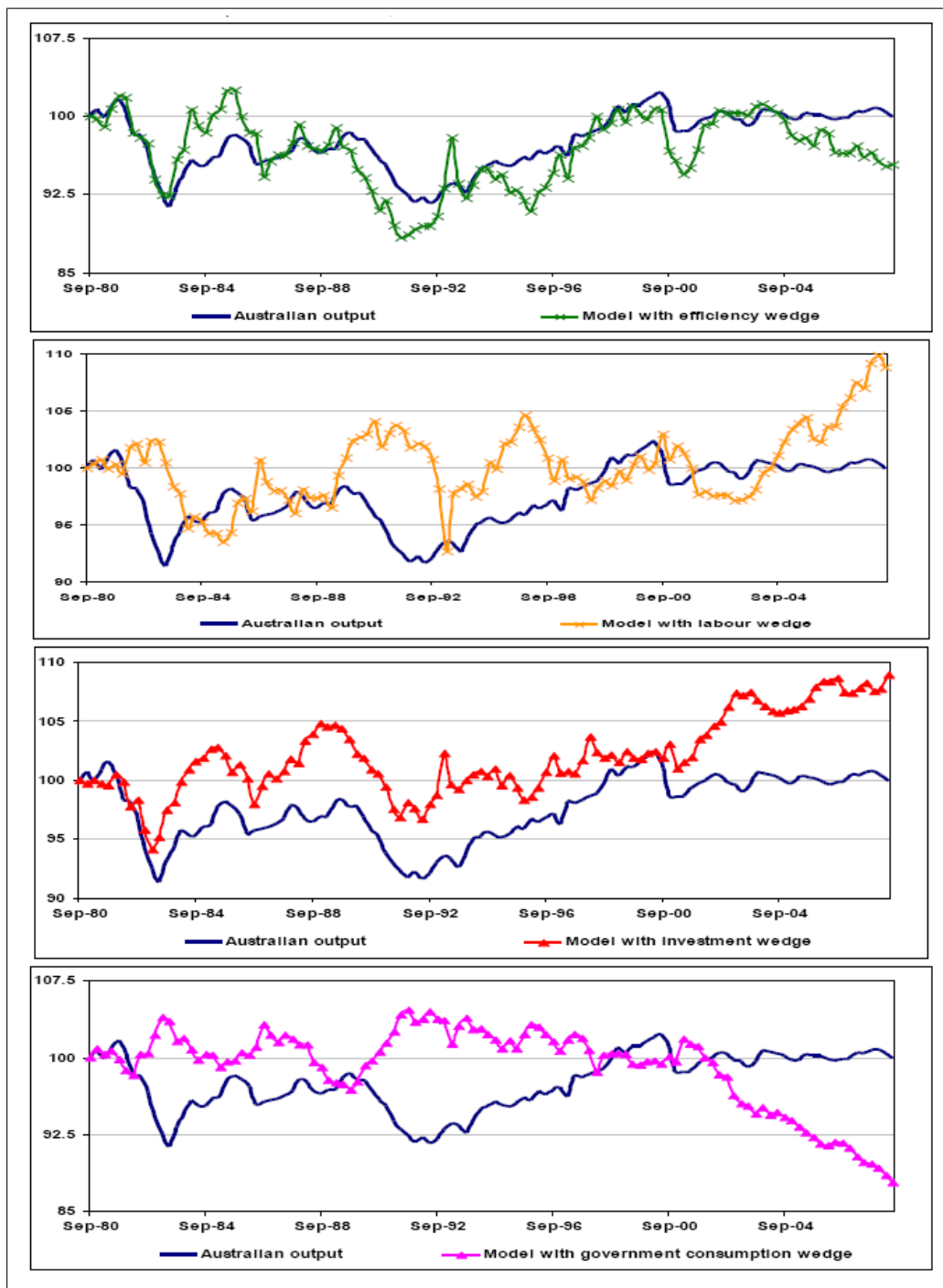


Figure 3-4: Detrended Australian output vs. Predictions of models with two wedges during 1980:Q3-2008:Q2.

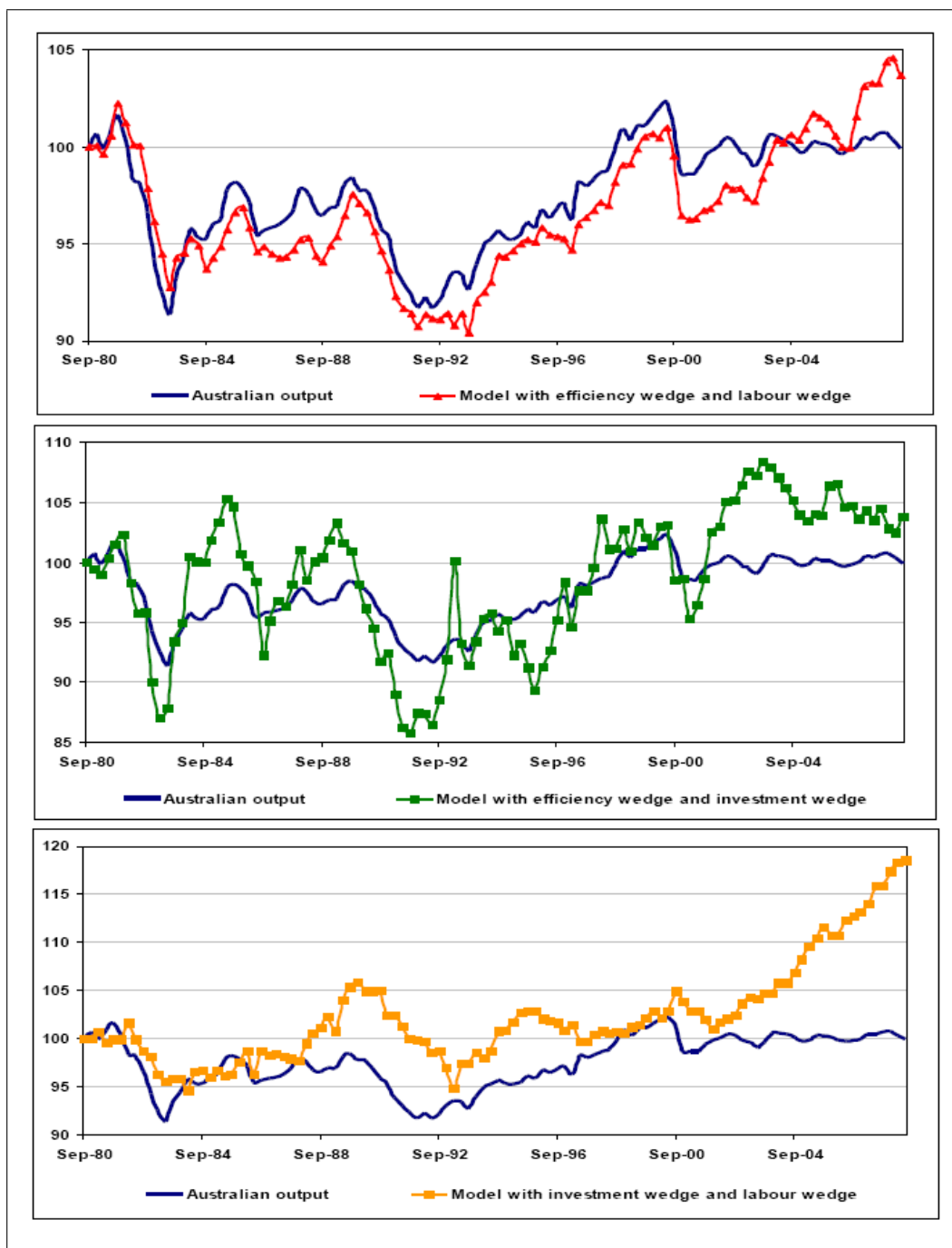




Figure 3-5: Australian investment (as a ratio to output) vs. Predictions of models with just one wedge during 1980:Q3-2008:Q2.

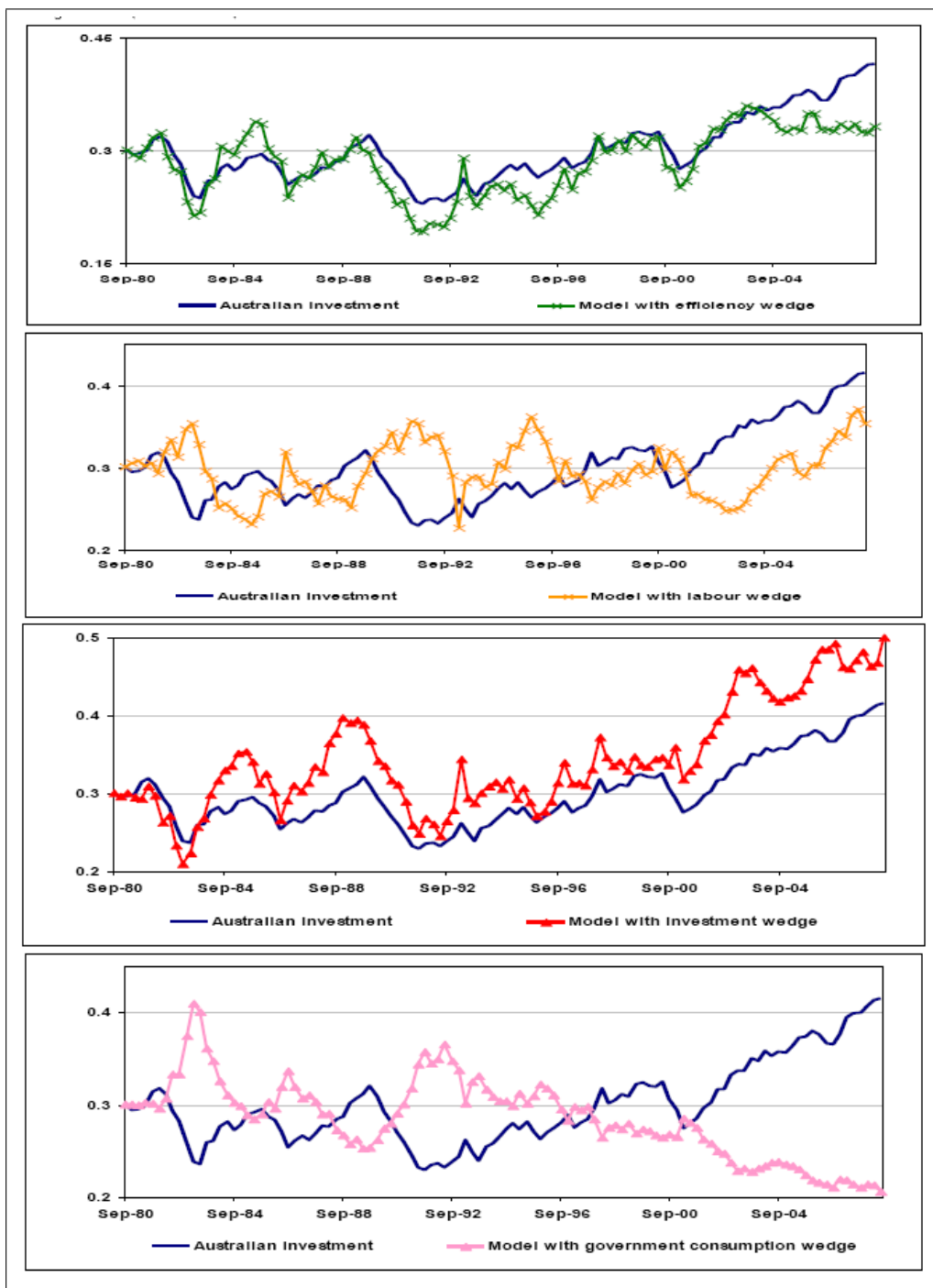


Figure 3-6: Australian investment (as a ratio to output) vs. Predictions of models with two wedges during 1980:Q3-2008:Q2.

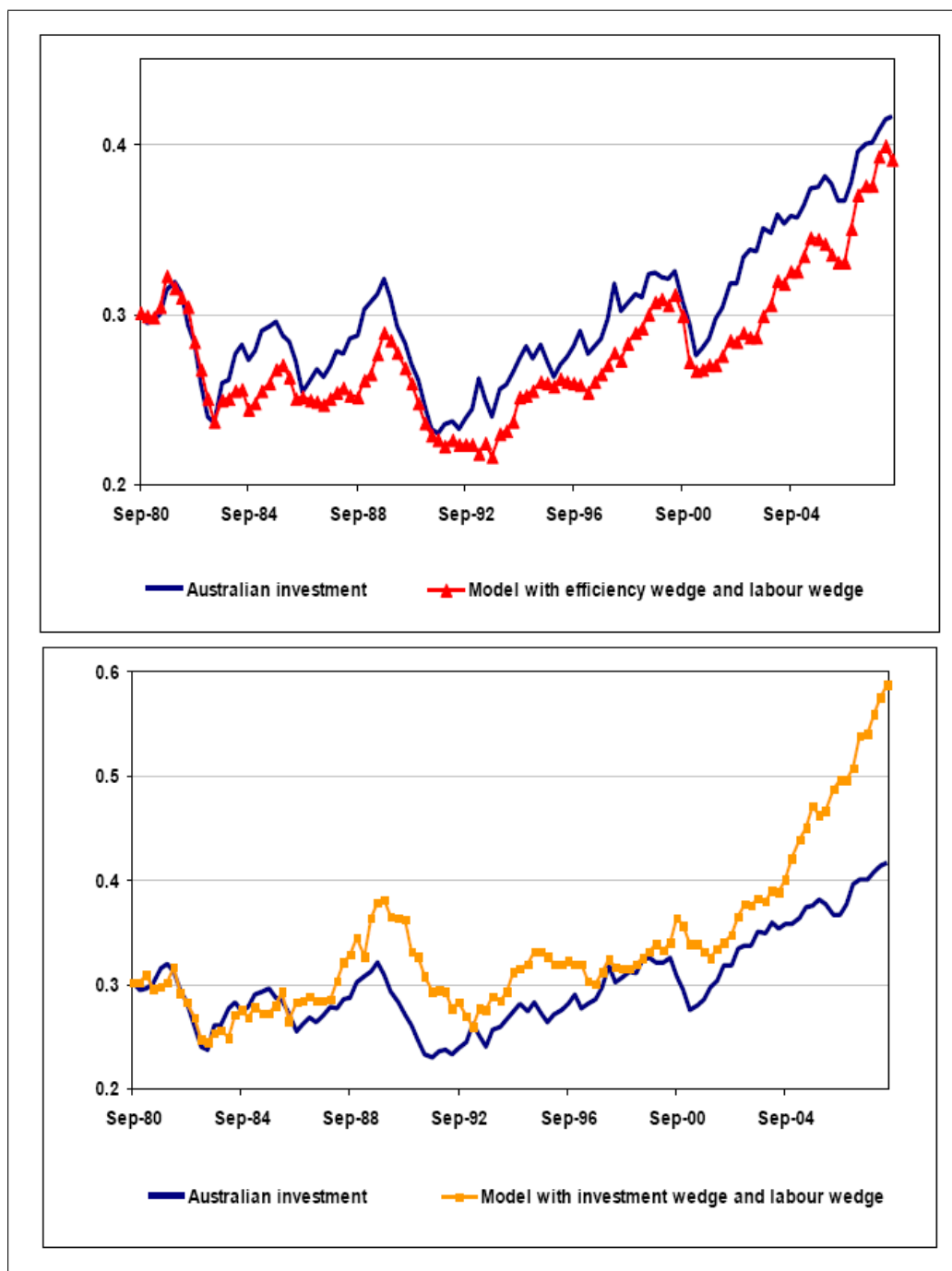


Figure 3-7: Australian hours worked vs. Predictions of models with just one wedge during 1980:Q3-2008:Q2.

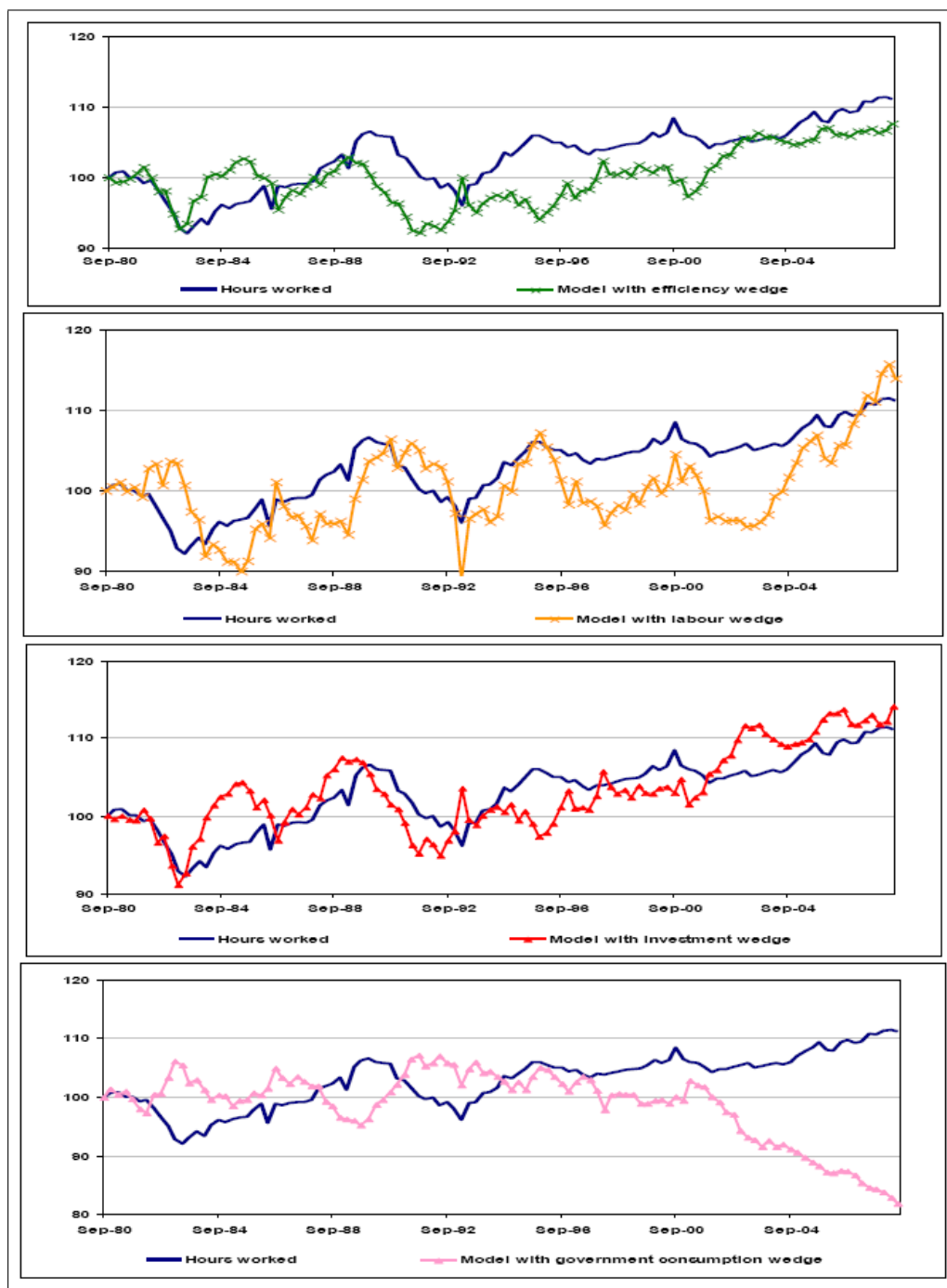
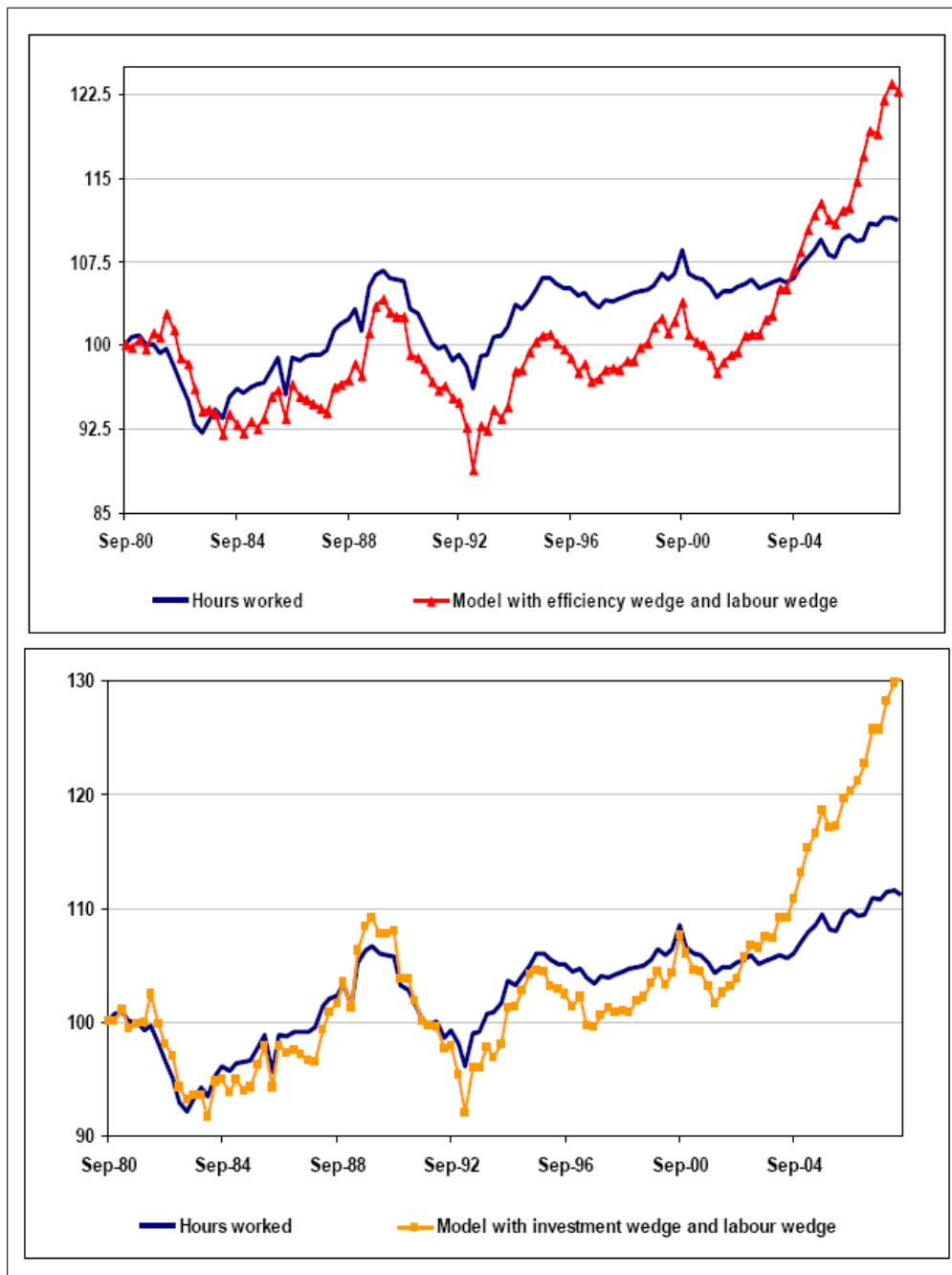


Figure 3-8: Australian hours worked vs. Predictions of models with two wedges during 1980:Q3-2008:Q2.



### 3.4.2 Recessions and Booms in Australia

This subsection further discusses the source of recessions and booms in Australia in more detail. The discussions are based on the findings in subsection 3.4.1. The particular interest is drawn on the following episodes: the 1982/83 recession, the 1990/91 recession and the late 1990s boom.

As revealed in subsection 3.4.1, the efficiency wedge is the most important distortion that explains the Australian business cycles. The fall in output in the 1982/83 recession is mainly caused by the increasingly inefficient allocation of production factors as shown in figure 3-3. However, the model with just the efficiency wedge predicts the recovery faster than the actual data. Having both the efficiency and labour wedges in the model, the prediction of output can clearly explain the recovery period. This is consistent with the Australian economic history. In this particular episode, there was a substantial institutional reform namely the Prices and Incomes Accords between mid-1983 and early-1996 under the Labor government.

Chapman (1998) documents consequences of the Accords in his study as follows. Due to the high wage inflation of 30% in 1974-75 and 18% in 1981-82 and the increment of real unit labour costs by 10% during 1972-75, the Prices and Incomes Accords essentially aimed to bring down the wage inflation and reduce the real unit labour costs. To achieve these goals, the Prices and Incomes Accord, which directly affected the centralized wage-setting arrangements, restricted the rise in nominal wage such that it grew at a slower pace than the inflation rate. In other words, the real wages were to be reduced substantially under the Accords.

It is clear that the implementation of the Prices and Incomes Accords starting in mid 1983 is captured by the labour wedge in my model as the real wage did not equate the measured marginal product of labour with the measured consumption-leisure trade-offs. But, rather, the real wage was greatly influenced by the agreement

between the Federal Government and trade union. This is likely to raise the wedge between the marginal product of labour and the marginal rate of substitution between consumption and leisure. This view is supported by Gruen and Stevens (2000). They state that

“Labour productivity growth in the 1980s was probably slower than it would otherwise have been because of the Prices and Incomes Accords negotiated between the trade union movement and the Federal Government at the time. Those Accords held down real wage growth, and thereby generated faster growth in employment but as a consequence labour productivity growth was slower (Chapman 1990, Steven 1992).” (p.38-39)

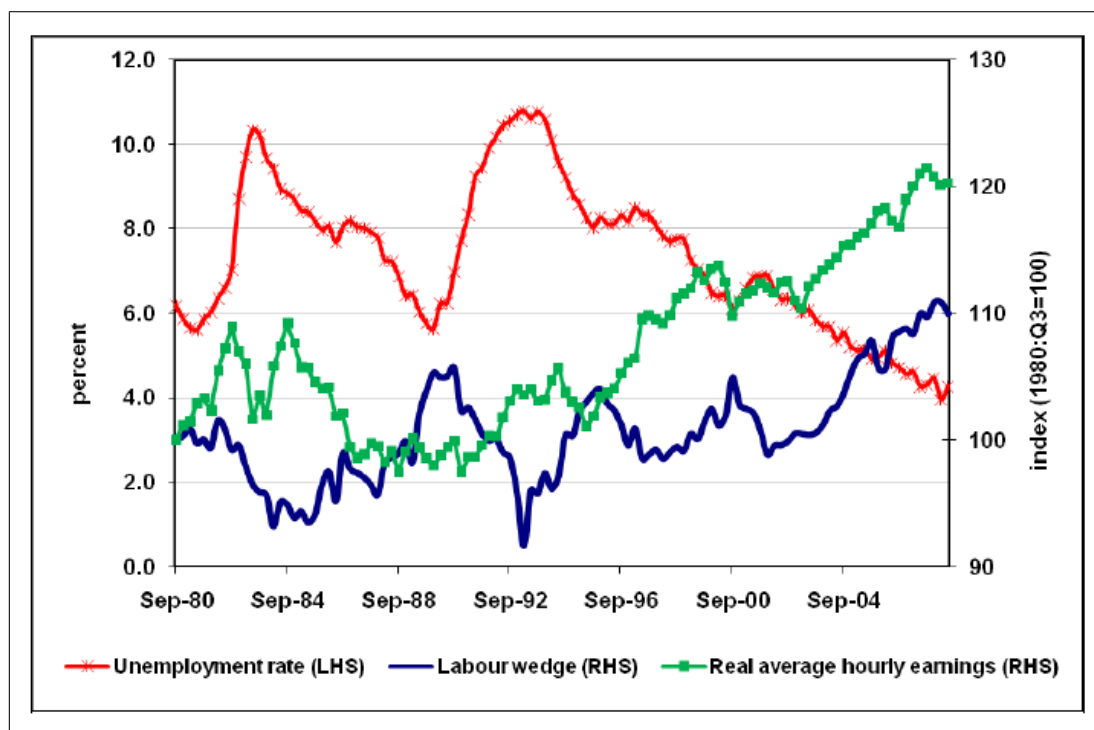
Figure 3-9 plots the measured labour wedge along with the unemployment rate and the real average hourly earnings. The real average hourly earnings are calculated by the average hourly earnings less the CPI inflation. The data are available from the ABS database. The real average hourly earnings appears to exhibit the U-shape during the implementation of the Prices and Income Accords. In this figure, it is interesting that the labour wedge seems to be the reflection of the unemployment rate.

In the 1990/91 recession, the fall in output is best explained by the efficiency wedge as displayed in figure 3-3. However, the model with efficiency wedge and the model with investment wedge cannot capture the amplitude of the recovery after 1993 onwards. Most notably, there must have been a structural change in 1993 as the actual output and investment increased while the actual hours worked decreased. In figure 3-9, the real average hourly earnings between the late 1992 and the early 1993 nearly levelled off. From the BCA result of the underlying period, the model output, investment and hours worked with the efficiency wedge spike up, and so do those models with the investment wedge. Meanwhile, those models with the labour

wedge drop dramatically. These results point the way to an increase in the labour wedge. Further, Chapman (1998) documents that the last Accord was implemented during 1993-95 and the centralization in wage setting was explicitly substituted by the enterprise-based bargaining. This essentially leads to the gradual rise in the real wages when compared to those in the late 1980s. The unemployment rate was nearly 11% in 1993 while it was around 6% in 1990 as shown in figure 2-9.

An alternative interpretation of the efficiency wedge is also the central of interest in this subsection. In an open economy model, the efficiency wedge is often referred to the reciprocal of the terms of trade: the factors of production are comparable to exports while the output is seen as imports (Kehoe and Ruhl 2008). The terms of trade is defined by the index of export prices relative to that of import prices. Figure 3-10 plots the Australian output along with the efficiency wedge and the terms of trade during 1980-2008. The top panel shows all series in indexed value given that the base period is 1980:Q3. It is apparent that the terms of trade rose dramatically after 2004. This is mainly driven by the commodities boom, especially iron ore. The middle and bottom panels shows the change in each series in percentage terms. The correlation coefficient between the change in output and the change in the terms of trade is as tiny as 0.0032 whereas the correlation coefficient between the change in output and the change in the efficiency wedge is 0.67. This suggests that in overall the terms of trade shocks is unlikely to influence the output fluctuations. Notwithstanding, the terms of trade may somewhat account for the output variations in 2004:Q1-2007:Q2 as the correlation coefficient between the change in output and the change in the terms of trade rises dramatically to 0.57. In the same period, the correlation coefficient between the change in output and the change in the efficiency wedge is 0.60. The improvement in the terms of trade is consistent with large borrowings from abroad, and this may stimulate the domestic economic activities. The above explanation

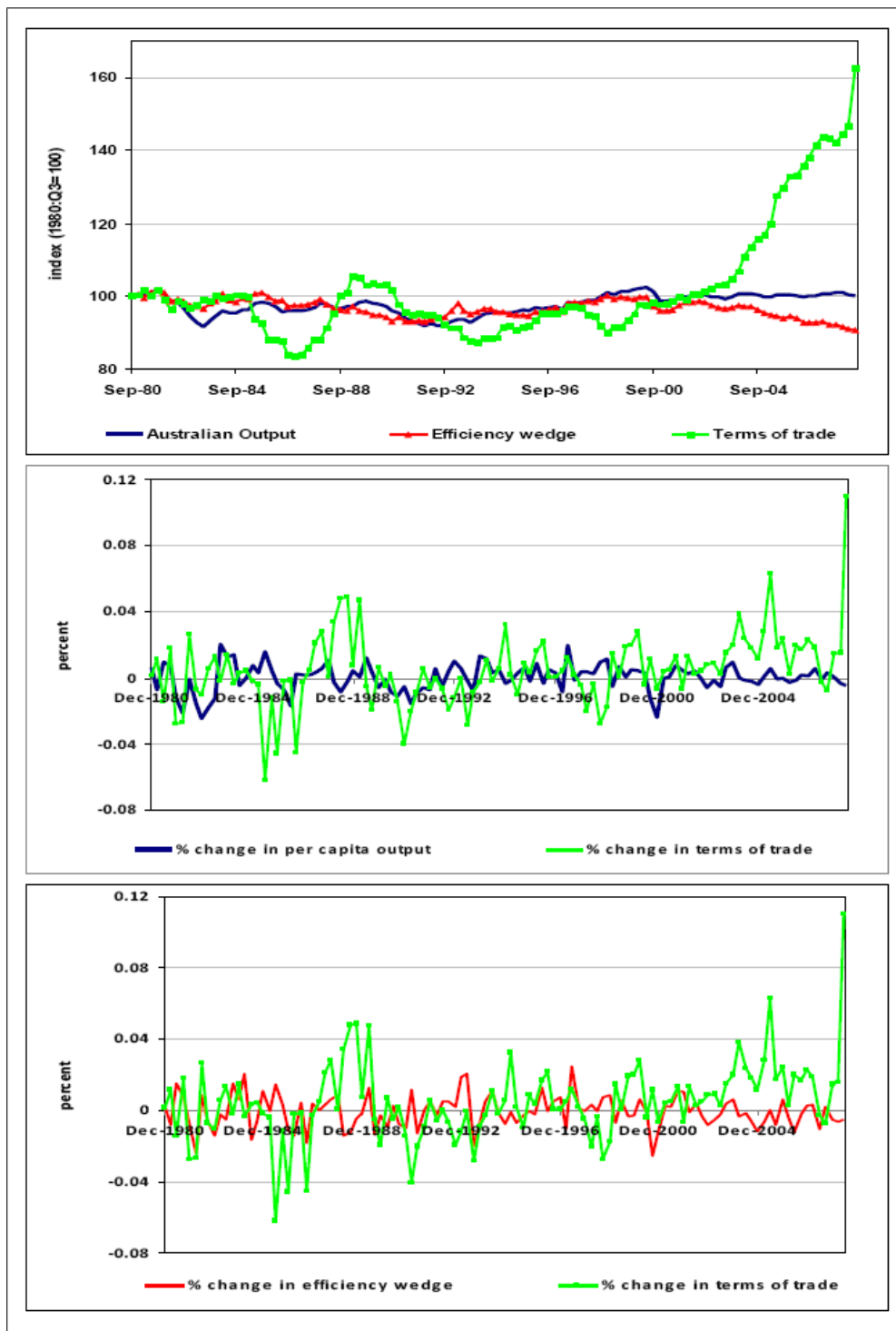
Figure 3-9: Unemployment rate (LHS) vs. Measured labour wedge and real average hourly earnings (RHS) during 1980:Q3-2008:Q2.



should be treated with caution when applying to the period of 2007:Q3-2008:Q3: the change in the terms of trade is still on the sharp rise whereas the change in output starts to go down.



Figure 3-10: Australian output vs. Efficiency wedge and terms of trade during 1980:Q3-2008:Q2.



### 3.5 Concluding Remarks

This paper examines the propagation mechanism that causes the business cycle fluctuations in Australia, particularly the 1982/83 recession and the 1990/91 recession. The BCA method is employed as the tool of study. The main findings are the dominant role of the efficiency wedge and the minor role of the investment wedge in both recessions. Interestingly, the recovery in both recessions can be accounted for by variations in the input-financing frictions and the structural change in the labour market. When focusing on the entire sample period of 1980:Q3 - 2008:Q2, the model with the efficiency and labour wedges can capture both movement and amplitude of output and investment very well. However, the variations in Australian hours worked is best explained by the model with the investment and labour wedges. Future study on the Australian labour market should take into account the shocks that transmit themselves as the investment wedge in addition to the labour wedge. The government consumption wedge can be ignored.

## Chapter 4

# Capital-Labour Substitution and Indeterminacy in Two-Sector Models

### 4.1 Introduction

Belief-driven fluctuations have been an active research subject in the application of dynamic general equilibrium models over the past decade. Non-fundamental factors like sunspot shocks can cause aggregate fluctuations when there exists indeterminacy in these models. Indeterminacy may arise due to increasing returns to scale, decreasing marginal cost or certain types of market imperfections. This chapter focuses on the existence of belief-driven fluctuations in a two-sector competitive market model with sector-specific externalities.

Among the literature on belief-driven expectation models, indeterminate equilibria generally arise from sufficiently high returns to scale. Benhabib and Farmer (1994) show that sufficiently high returns to scale for indeterminacy arise at around 1.43 in a one-sector Neoclassical growth model with constant elasticity labour supply. However, this degree of returns to scale is unlikely to be empirically plausible. Using the U.S. data at micro-level during 1959-89, Basu and Fernald (1997) argue that the production can have an increasing returns to scale of 1.26 at most. A successful

attempt to produce a theoretical model with indeterminacy at modest increasing returns to scale is found in a two-sector model. Benhabib and Farmer (1996) who first analyzed the two-sector competitive market model suggest that the minimum returns to scale in both consumption sector and investment sector is around 1.07 in order to obtain equilibrium indeterminacy. Subsequent studies by Harrison and Weder (2000), Weder (2000) and Harrison (2001) find that only externalities in the investment sector matter in generating belief-driven fluctuations. An investigation on the ultimate source by Harrison and Weder (2002) shows that the indeterminacy stems from the externalities of capital in the investment sector. It is notable that all the studies rest on a Cobb-Douglas production technology. The main feature of Cobb-Douglas technology is the unitary elasticity of substitution between capital and labour. However, it is questionable whether the Cobb-Douglas technology is empirically plausible and what it implies.

Recent empirical literature suggest that the elasticity of substitution between capital and labour differs from one. For instance, Klump, McAdam, and Willman (2007) conclude that the elasticity of substitution is between 0.50 and 0.60. Chirinko (2008) suggests the aggregate elasticity of substitution between capital and labour is between 0.40 and 0.60. This implies that the use of Cobb-Douglas production function in many theoretical studies may not be consistent with the empirical studies. Therefore, it is worthwhile to investigate how a non-Cobb-Douglas technology affects the equilibrium indeterminacy in the two-sector competitive market model and check if indeterminacy remains empirically plausible.

This chapter aims to investigate the relationship between the capital-labour substitution and the sector-specific externalities in multiple stationary equilibria. The corresponding rate of returns to scale is also examined whether it is consistent with the empirical evidence. My finding is that an economy with lower substitutability

between capital and labour when compared to the Cobb-Douglas production technology requires a higher degree of externalities in order to produce indeterminate equilibria. Intuitively, the low substitutability implies the complementary use between production factors in a sector. This retards the mobility of factors between the consumption and investment sectors. In the belief-driven equilibria, the consumers' optimistic belief is fulfilled as long as the rate of returns is sufficiently high such that current consumption is given up for investment. The rate of returns hereby indicates the sectoral externality. In such a production environment, the minimum requirement of externalities for indeterminacy therefore becomes larger so that it can successfully break the tightly coupled factors within sector, and subsequently raises the production of investment goods. As a result, the current relative price of investment goods falls. In the next period, consumers enjoy more consumption goods and the relative price of investment good rises. The ascending pricing sequence yields capital gains.

The main finding is irrespective of the degree of relative risk aversion as summarized in the following. The benchmark case is the logarithmic utility in consumption. In this case, the indeterminate equilibria are determined solely by externalities in investment as concluded in previous literature. The larger requirement of externalities in investment is needed for indeterminacy when capital and labour become more complementary factors in production as compared to the Cobb-Douglas production technology. Based on the elasticity of substitution of 0.5 as suggested in Klump, McAdam, and Willman (2007) and Chirinko (2008), the minimum requirement of returns to scale for indeterminacy is 1.1236 and still lies within the range suggested in empirical studies. Meanwhile, the minimum requirement of returns to scale in Cobb-Douglas technology is 1.0774. When consumers become more or less risk-averse, externalities in the production of consumption play a role (Harrison 2001). A more risk-averse consumer has the change in their intertemporal consumption in the smaller

proportion to the change in interest rates. With the Cobb-Douglas production technology, the minimum degree of externalities in investment for indeterminacy is an increasing function of the externalities in consumption (Harrison 2001). This minimum requirement of externalities in investment is higher when capital and labour are complementary. Given the elasticity of substitution of 0.5, the degree of risk aversion of 2.0 and no externalities in consumption, the corresponding rate of returns to scale for indeterminacy is still as mild as 1.1550. In contrast, a less risk-averse consumer has the change in their intertemporal consumption in the larger proportion to the change in interest rates. In the benchmark production function, the indeterminate equilibrium thus requires smaller externalities in investment as the externalities in consumption rise (Harrison 2001). However, the minimum requirement of externalities in both sectors increase as capital and labour become less substitutable. Given the elasticity of substitution of 0.5, the degree of risk aversion of 0.5 and no externalities in consumption, the corresponding rate of returns to scale for indeterminacy is as low as 1.0880. Overall, indeterminate equilibria in which capital and labour are complementary factors still arises from a mild degree of returns to scale.

This chapter is organized as follows. Section 4.2 provides the literature review. Section 4.3 describes the details of the model. Section 4.4 provides the results and discusses the main findings. Section 4.5 concludes this chapter.

## 4.2 Literature Review

Animal spirits, sunspots and self-fulfilling prophecies<sup>1</sup> can be interchangeably used to refer models with multiple stationary equilibria (Farmer and Guo 1994). In other words, the fluctuations in economic activities, i.e. output, employment, consumption and investment, can be driven by non-fundamental factors like consumers' belief when indeterminacy exists. There have been a large number of studies over the past decade that produce models with indeterminacy in various aspects. The literature review in this chapter will focus only on the studies regarding indeterminacy and two-sector dynamic general equilibrium models.<sup>2</sup>

Benhabib and Farmer (1996) are the first to show the existence of equilibrium indeterminacy in a two-sector model with sector-specific externalities based on the typical parameter values in real business cycle models. The two sectors are consumption and investment. The contribution of their study is the existence of indeterminacy that rests on the standard slope of the labour demand and the labour supply curves. This contrasts with indeterminacy in one-sector models which rest on a sufficiently high returns to scale and accordingly an upwardly sloping labour demand curve as shown in Benhabib and Farmer (1994). In a one-sector model, Benhabib and Farmer (1994) show that the sufficiently high returns to scale for indeterminacy is around 1.43. The degree of returns to scale at 1.43 is not likely to be empirically plausible. Employing the U.S. data at micro-level during 1959-89, Basu and Fernald (1997) argue that the production can have mild increasing returns to scale at best. The two-sector model in Benhabib and Farmer (1996) succeeds in reducing the returns to scale down to 1.07 for indeterminacy. However, a drawback in their study is that sector-specific exter-

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<sup>1</sup>In recent years, the term "irrational exuberance" has also been used.

<sup>2</sup>Benhabib and Farmer (1999) have provided a survey of literature on models with indeterminacy in all aspects.

nalities are the same in both sectors. This has brought the question to later studies on of which sector externalities actually produce the indeterminate equilibrium.

It turns out that only the returns to scale in the investment sector play the central role in generating indeterminate equilibria. This applies to both internal and external returns to scale. Weder (2000) adopts the Cournot equilibrium model and finds that the sufficiently high internal returns to scale in the investment sector is important for multiple equilibria. Likewise, Harrison and Weder (2000) find that sufficiently high externalities in the investment sector can produce the indeterminate equilibrium in perfect competition model. They further show that adding aggregate externalities into the model does not decrease the minimum required sector-specific externalities for indeterminacy. The results from this class of models are based on the logarithmic utility in consumption.

Instead of relying entirely on the log-utility function in consumption, Harrison (2001) examines the relationship between the coefficient of relative risk aversion and the equilibrium indeterminacy. She finds that the equilibrium indeterminacy is independent of externalities in consumption sector when the income effect exactly offsets the substitution effect in the consumer's intertemporal consumption with regard to the change in the interest rate. Consumption is thus changed by the same proportion to the change in the interest rate. This is the case for the logarithmic utility in consumption. However, the equilibrium indeterminacy is attributable to externalities in both consumption and investment sectors when the income effect outweighs the substitution effect. In this case, the consumer will have a smaller change in their consumption with respect to the change in the interest rate. As a result, the requirement of externalities in the investment sector for indeterminacy is increasing in the externalities in consumption sector. Nonetheless, the requirement of externalities in the investment sector for indeterminacy is inversely related to the externalities in



consumption sector when the income effect is smaller than the substitution effect. The change in consumption relatively exceeds the change in the interest rate. This allows a trade-off between the externalities in consumption and investment sectors to obtain indeterminacy.

Moreover, Harrison and Weder (2002) examine the source of indeterminacy in the two-sector model and find that it is ultimately the externalities from capital in the investment sector that yields the indeterminate equilibrium. They also find that the source of indeterminacy in the one-sector model is primarily generated by the externalities from labour.

Unlike the above studies which are characterized as closed economy models, Weder (2001) establishes a small open economy two-sector model. In his study, the perfect capital market facilitates households' borrowing and lending internationally in order to smooth their consumption at a fixed world interest rate. This tends to decouple investment from the realization of consumption and the utility curvature. He notes that the household's consumption smoothing must not be cancelled out by the increasing returns, however. The striking result shows that the almost constant returns to scale together with the corresponding pricing sequence towards stable equilibria are able to produce indeterminacy. The above result still holds even when the economy confronts the borrowing constraints from abroad given that the interest rate responds sluggishly to the rise in debt.

All the previous studies in this area rest on a Cobb-Douglas technology. In other words, these studies rely on the case in which the elasticity of substitution between capital and labour is exactly equal to one. Recent empirical studies in the growth theory argue that the elasticity of substitution is unlikely to be one. Using the U.S. data between 1953 and 1998, Klump, McAdam, and Willman (2007) conclude that the elasticity of substitution is significantly smaller than one. Another study by Chirinko

(2008) also shows that the elasticity of substitution is most likely to be between 0.40 and 0.60.

When taking into account the empirical evidence of non-unitary elasticity of substitution, the use of Cobb-Douglas technology in the dynamic general equilibrium model may not be warranted. For this reason, this chapter incorporates the CES technology into the two-sector model for the study of self-fulfilling fluctuations. To my knowledge, this chapter will be the first study that introduces a CES technology to shed further light on empirical plausibility of indeterminacy in the two-sector dynamic general equilibrium model.

Inconsistent results across different elasticity of substitutions is a major concern when employing CES technology into a model as noted in Klump and Saam (2008). This may be because the steady state allocations change when the elasticity of substitution is varied. To deal with the underlying concern, Klump and Saam (2008) strongly recommend the use of a normalized CES function. Klump and De La Grandville (2000) and Klump and Preissler (2000) suggest a normalized CES production function that maintains all the steady-state quantities at the baseline values while the elasticity of substitution is varied. Klump and Saam (2008) further suggest the calibration of corresponding efficiency and distribution parameters in production when the elasticity of substitution is varied. The recent study by Guo and Lansing (2008) adopts a normalized CES production function as in Klump and De La Grandville (2000) and Klump and Preissler (2000) to study the one-sector dynamic general equilibrium model with indeterminacy. In the calibration of steady state parameter, Guo and Lansing (2008) adopt Klump and Saam's calibration technique. They recompute the efficiency term and the distribution parameter in production whenever the elasticity of substitution is varied. This calibration is to keep the steady state income share of capital at 0.3 and maintain other steady

state quantities to match the stylized facts. In this study, I will adopt the normalized CES production function as in Klump and De La Grandville (2000) and Klump and Preissler (2000) employ Klump and Saam's technique in the calibration of the share of capital in production to keep the steady state share of capital income constant.

### 4.3 Model

The model in this study is based on the two-sector competitive model in Benhabib and Farmer (1996). I also adopt the normalized CES technology as used in Klump and De La Grandville (2000), Klump and Preissler (2000) and Guo and Lansing (2008). The economy consists of firms and consumers. Firms produce two types of commodities, i.e. consumption goods and investment goods by using capital and labour. Competitive rent and competitive wage are the equilibrium cost per unit of capital and labour, accordingly. All markets are clear. In equilibrium, costs per unit of input are the same across the two sectors. There exists sector-specific externalities in each sector of production but there is no aggregate externality. Consumers supply factors of production to firms. Consumers maximize their lifetime utility which depends on consumption and leisure subject to the budget constraint and the capital accumulation law. The equilibrium analysis is based on the rational expectation.

#### 4.3.1 Firms

A large number of identical firms in the consumption good sector maximize their profit ( $\Pi_{ct}$ ) which is described by

$$\Pi_{ct} = c_t - w_t h_{ct} - r_t k_{ct}$$

subject to the constant returns to scale (CRS) production of the consumption good

$$c_t = M [\alpha k_{ct}^\rho + (1 - \alpha)h_{ct}^\rho]^{\frac{1}{\rho}} C_t^{\frac{\mu_c}{1+\mu_c}},$$

$$M > 0, \quad 0 < \alpha < 1, \quad \rho = \frac{\sigma - 1}{\sigma}, \quad \mu_c \geq 0,$$

where  $c_t, w_t, h_{ct}, r_t, k_{ct}$  and  $\alpha$  are the consumption goods, the competitive real wage, the labour used in consumption good production, the competitive real interest rate, the capital used in consumption good production and the distribution parameter of capital in production, respectively.  $\sigma$  is the elasticity of substitution between capital and labour in production. With  $\sigma = 1$ , the production function boils down to the Cobb-Douglas technology. With  $\sigma < 1$ , capital and labour are complementary in production. With  $\sigma > 1$ , capital and labour are substitutable in production. With  $\sigma \rightarrow 0$  (or  $\sigma \rightarrow \infty$ ), capital and labour become perfectly complementary (or perfectly substitutable) in production.  $C_t$  is the economy-wide average production of the consumption good with the degree of sector-specific externalities at  $\mu_c$ . Therefore,  $C_t^{\frac{\mu_c}{1+\mu_c}}$  represents the productive externality in consumption good sector. To maintain all steady state allocations across different  $\sigma$ ,  $M$  represents an efficiency term which will be recomputed whenever  $\sigma$  is varied as done in Guo and Lansing (2008). In the Cobb-Douglas case,  $M$  is equal to one. The expression of  $M$  will be derived at the end of this subsection.

Similarly, a large number of identical firms in the investment good sector maximize their profit ( $\Pi_{xt}$ )

$$\Pi_{xt} = p_t x_t - w_t h_{xt} - r_t k_{xt}$$

with respect to the CRS production technology in the investment good sector

$$x_t = N [\alpha k_{xt}^\rho + (1 - \alpha) h_{xt}^\rho]^\frac{1}{\rho} X_t^\frac{\mu_x}{1 + \mu_x},$$

$$N > 0, \quad \mu_x \geq 0,$$

where  $p_t$ ,  $x_t$ ,  $h_{xt}$  and  $k_{xt}$  are the relative price of investment goods in terms of consumption goods, the investment goods, the labour used in investment good production and the capital used in investment good production, respectively.  $X_t$  is the economy-wide average production of the investment good with the degree of sector-specific externalities at  $\mu_x$ . Therefore,  $X_t^\frac{\mu_x}{1 + \mu_x}$  represents the productive externality in investment good sector. To maintain all steady state allocations across different  $\sigma$ ,  $N$  represents an efficiency term which will be recomputed whenever  $\sigma$  is varied. Again,  $N$  is equal to one in the Cobb-Douglas case. The expression of  $N$  will be derived at the end of this subsection.

It should be noted that the firms' production possibility frontier (PPF) and the social PPF will be exactly the same when there are no externalities in both the consumption sector and the investment sector ( $\mu_c = \mu_x = 0$ ). The relative price of investment will be equal to one and the model boils down to an one-sector competitive model without returns to scale. However, the firms' PPF and the social PPF will be different when there *are* externalities in the consumption good sector and/or the investment good sector ( $\mu_c > 0$ ,  $\mu_x > 0$ ). The social PPF will be convex to the origin in both the consumption good and the investment good due to the spillover effect of externalities on production at the social level. The firms' PPF will be a downward-sloping straight line owing to the CRS production. The slope of the social PPF corresponding to a given production level of the consumption good determines the relative price of investment. Moving along the social PPF will thus yield different relative prices of investment. Firms are price-taker in a perfect competition market. Therefore, the relative price of investment is determined on the social PPF.

Resources in this economy are fully allocated to the two production sectors. So, the economy-wide average employment ( $H_t$ ) must be equal to the sum of employment in both sectors. Also, the economy-wide average capital ( $K_t$ ) has to be equal to the sum of capital in both sectors.

$$H_t = H_{ct} + H_{xt} \quad \text{and} \quad K_t = K_{ct} + K_{xt}$$

Factor intensities are identical across both sectors. So, the share of labour and the share of capital used in the consumption good sector are the same and it is denoted by  $\Omega_t$ , we have

$$\Omega_t \equiv \frac{h_{ct}}{h_t} = \frac{k_{ct}}{k_t} \quad \text{and} \quad 1 - \Omega_t \equiv \frac{h_{xt}}{h_t} = \frac{k_{xt}}{k_t}$$

The competitive equilibrium is symmetric. All firms are price-takers and earn normal profits in equilibrium. This implies that the output of an individual firm is equal to the sectoral average output. In other words,  $c_t = C_t$  and  $x_t = X_t$ . Alternatively, we can rewrite the production technology in the consumption sector and the investment sector as displayed by equation 4.1 and 4.2, respectively.

$$c_t = M [\alpha k_t^\rho + (1 - \alpha)h_t^\rho]^{\frac{1+\mu_c}{\rho}} \Omega_t^{1+\mu_c} \quad (4.1)$$

$$x_t = N [\alpha k_t^\rho + (1 - \alpha)h_t^\rho]^{\frac{1+\mu_x}{\rho}} (1 - \Omega_t)^{1+\mu_x} \quad (4.2)$$

where  $M = \frac{\bar{c}^{\frac{1}{1+\mu_c}}}{\bar{\Omega} [\alpha \bar{k}^\rho + (1-\alpha)\bar{h}^\rho]^{\frac{1}{\rho}}}$  and  $N = \frac{\bar{x}^{\frac{1}{1+\mu_x}}}{(1-\bar{\Omega}) [\alpha \bar{k}^\rho + (1-\alpha)\bar{h}^\rho]^{\frac{1}{\rho}}}$

The firm's first order conditions with respect to  $h_{ct}$ ,  $h_{xt}$ ,  $k_{ct}$  and  $k_{xt}$  are the following.

$$w_t = \frac{c_t}{h_{ct}} \times \frac{(1 - \alpha) h_{ct}^\rho}{[\alpha k_{ct}^\rho + (1 - \alpha) h_{ct}^\rho]} \quad (4.3)$$

$$w_t = p_t \frac{x_t}{h_{xt}} \times \frac{(1 - \alpha) h_{xt}^\rho}{[\alpha k_{xt}^\rho + (1 - \alpha) h_{xt}^\rho]} \quad (4.4)$$

$$r_t = \frac{c_t}{k_{ct}} \times \frac{\alpha k_{ct}^\rho}{[\alpha k_{ct}^\rho + (1 - \alpha) h_{ct}^\rho]} \quad (4.5)$$

$$r_t = p_t \frac{x_t}{k_{xt}} \times \frac{\alpha k_{xt}^\rho}{[\alpha k_{xt}^\rho + (1 - \alpha) h_{xt}^\rho]} \quad (4.6)$$

Equation 4.3 and 4.4 give us the demand for labour in the consumption and the investment sector, respectively. The labour demand in both sectors is equal to the competitive wage in equilibrium. Equation 4.5 and 4.6 give us the demand for capital in the consumption and the investment sector, respectively. The capital demand in both sectors is equal to the competitive rent in equilibrium.

As a result, the relative price of the investment good in terms of the consumption good can be derived by using equation 4.3 and 4.4 (or equation 4.5 and 4.6).

$$p_t = \frac{M^{1+\mu_c}}{N^{1+\mu_x}} [\alpha k_t^\rho + (1 - \alpha) h_t^\rho]^{\frac{\mu_c - \mu_x}{\rho}} \frac{\Omega_t^{\mu_c}}{(1 - \Omega_t)^{\mu_x}} \quad (4.7)$$

### 4.3.2 Consumers

Consumers have separable utility in consumption and leisure. Time endowment is normalized to be one and consumers have disutility in supplying labour. The utility in consumption exhibits constant relative risk aversion (CRRA). Meanwhile, disutility in supplying labour is a linear function as labour is indivisible (Hansen 1985). A large number of identical infinitely-lived consumers maximize their expected utility

$$E_0 \sum_{t=0}^{\infty} \beta^t \left( \frac{c_t^{1-\varphi} - 1}{1 - \varphi} - \eta h_t \right),$$

$$0 < \beta < 1, \quad 0 < \varphi < \infty, \quad \eta > 0$$

subject to the budget constraint

$$c_t + p_t x_t = w_t h_t + r_t k_t,$$

and the perpetual capital accumulation law.

$$k_{t+1} = (1 - \delta)k_t + x_t,$$

Note that  $\beta, \eta, \varphi$  and  $\delta$  are the discount factor, the constant term, the inverse of the elasticity of substitution between consumption at different periods and the depreciation rate of capital, respectively. From Blanchard and Fischer (1989, Chapter 2), the inverse of the elasticity of substitution between consumption at different periods is defined by

$$\varphi = -\frac{u''(c) c}{u'(c)}$$

which also represents the coefficient of relative risk aversion. With  $\varphi = 1$ , the utility function collapses to the logarithmic utility in consumption. The utility in consumption between two periods is concave to the origin. When the consumer is less risk-averse ( $\varphi < 1$ ), the curvature of the utility function is increasing. When the consumer becomes more risk-averse ( $\varphi > 1$ ), the curvature of the utility function is decreasing and getting close to a straight line as  $\varphi \rightarrow \infty$ .

In the perfect foresight competitive equilibrium, the consumer's first order condition with respect to  $c_t, h_t$  and  $k_{t+1}$  are the following.

$$\frac{1}{c_t^\varphi} = \lambda_t \tag{4.8}$$

$$\eta = \lambda_t w_t \tag{4.9}$$

$$\frac{p_t}{c_t^\varphi} = \beta \frac{1}{c_{t+1}^\varphi} [r_{t+1} + p_{t+1}(1 - \delta)] \tag{4.10}$$



The optimal current consumption is determined by equating the marginal utility in consumption with the shadow price of wealth ( $\lambda_t$ ) as shown in equation 4.8. Equation 4.9 presents the optimal decision in labour supply which depends on the the real wage valued at the shadow price of wealth. Equation 4.10 presents the optimal intertemporal decision in consumption which depends on the returns from capital and the relative price of investment. Obviously, this equation is the distinction between one-sector and two-sector models on the grounds that the optimal intertemporal choice in consumption of the one-sector model is solely explained by the future rate of returns on capital at a given discount factor and depreciation rate of capital while this is not the case in the two-sector model.

The transversality condition is also applied to ensure that there is no capital left in the terminal period.

$$\lim_{t \rightarrow \infty} \beta^t \frac{k_{t+1}}{c_t} = 0$$

### 4.3.3 Steady State

Before proceeding to the dynamic analysis of the model, the values of the parameters must be pinned down and the stationary state values of key variables must be computed. Varying  $\sigma$  may result in varying the equilibrium allocation. This can lead to a spurious analysis when comparing results from different  $\sigma$ . To avoid the spurious analysis, Klump and Saam (2008) strongly suggest the use of a normalized CES function. Therefore, I adopt the normalized CES function and maintain all stationary state quantities in the benchmark case as in Klump and De La Grandville (2000), Klump and Preissler (2000). The chosen benchmark case is the Cobb-Douglas technology or  $\sigma = 1$ . The parameters that are independent of  $\sigma$  and stationary state quantities are taken from the Cobb-Douglas case. Meanwhile, the parameters that

are dependent on  $\sigma$  will be recomputed whenever  $\sigma$  is varied such that the associated stationary quantities remain unchanged.

There are four freely-varying parameters: the elasticity of substitution between capital and labour ( $\sigma$ ), the coefficient of relative risk aversion ( $\varphi$ ) and the sector-specific externalities in both sectors ( $\mu_c$  and  $\mu_x$ ). In my notations, the parameters denoted by a bar represent the parameters taken from the Cobb-Douglas case:  $\bar{\alpha} = 0.3$ ,  $\bar{h} = 0.3$ ,  $\bar{\beta} = 0.99$  and  $\bar{\delta} = 0.025$ . In the real business cycle approach, these parameter values are calibrated in order to match the U.S. post-war aggregate data. The capital share of income ( $\bar{\alpha}$ ) is equal to 30% in order to match the average capital share in GNP net of ambiguous income<sup>3</sup>. Households' time spent on working ( $\bar{h}$ ) is equal to 30% out of the total time endowment in order to match the long-run fraction of working-age non-civilian at 75% and the steady-state fraction of time spent in market activity at 40% (Kydland 1995). Without the productivity growth, the quarterly discount factor ( $\bar{\beta}$ ) is equal to 0.99 in order to match the steady-state real interest rate of 1% per quarter. Lastly, the quarterly depreciation rate of capital ( $\bar{\delta}$ ) is equal to 2.5% in order to match the steady-state ratio of investment to capital.

The steady-state share of input used in the consumption sector ( $\bar{\Omega}$ ) is obtained by solving the steady-state version of equation 4.5, 4.10 and the capital accumulation law. Using the steady-state version of equation 4.2 and the capital accumulation law, I get the steady-state capital stock. I solve all these steady-state values at  $\sigma = 1$ . The steady state share of input used in the consumption sector ( $\bar{\Omega}$ ), the steady-state capital stock ( $\bar{k}$ ), the steady-state relationship between relative price ( $\bar{p}$ ) and the real interest rate ( $\bar{r}$ ) from the Euler equation are as below.

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<sup>3</sup>Gollin (2002) reports that the range of adjusted labour share in income is between 0.65 and 0.80 in most countries.

$$\begin{aligned}\bar{\Omega} &= 1 - \frac{\bar{\alpha} \bar{\delta}}{\frac{1}{\bar{\beta}} - 1 + \bar{\delta}} \\ \bar{k} &= \left[ \frac{\left( (1 - \bar{\Omega}) \bar{h}^{1-\bar{\alpha}} \right)^{1+\mu_x}}{\bar{\delta}} \right]^{\frac{1}{1-\bar{\alpha}(1+\mu_x)}} \\ \frac{\bar{\beta} \bar{r}}{\bar{p}} &= 1 - \bar{\beta} (1 - \bar{\delta})\end{aligned}$$

The last parameter to be determined is  $\alpha$ . I adopt Klump and Saam's (2008) technique. I recompute  $\alpha$  whenever  $\sigma$  is varied to maintain the capital share in income at 30%. Therefore, the calibration of  $\alpha$  is described by

$$\alpha = \frac{\bar{\alpha}}{\bar{\alpha} + (1 - \bar{\alpha}) \left( \frac{\bar{k}}{\bar{h}} \right)^\rho}.$$

#### 4.3.4 Dynamics Of The Model

The procedure of the dynamic analysis is as follows. I first log-linearize six static equations and two dynamic equations around the steady state. Six static equations are the normalized production of consumption good, the normalized production of investment good, the firm's demand for labour, the firm's demand for capital, the relative price of investment good and the household's labour supply, respectively. Two dynamic equations are the Euler equilibrium condition and the law of motion for capital. Capital stock is the state variable and consumption is the co-state variable in the state space representation. The state space representation of the dynamic model can be linearly solved and it boils down to a two-dimensional dynamic model.

Define  $U_t = [p_t, x_t, r_t, w_t, h_t, \Omega_t]'$  and  $V_t = [k_t, c_t]'$ . The log-linearized static equa-

tions around the steady-state are as follows:

$$\begin{aligned}
(1 + \mu_c)(1 - \bar{\alpha}) \hat{h}_t + (1 + \mu_c) \hat{\Omega}_t &= -(1 + \mu_c) \bar{\alpha} \hat{k}_t + \hat{c}_t \\
\hat{x}_t - (1 + \mu_x)(1 - \bar{\alpha}) \hat{h}_t + (1 + \mu_x) \frac{\Omega}{1 - \Omega} \hat{\Omega}_t &= (1 + \mu_x) \bar{\alpha} \hat{k}_t \\
\hat{w}_t &= \varphi \hat{c}_t \\
\hat{w}_t + (1 - \rho + \rho(1 - \bar{\alpha})) \hat{h}_t + \hat{\Omega}_t &= -\rho \bar{\alpha} \hat{k}_t + \hat{c}_t \\
\hat{r}_t + \rho(1 - \bar{\alpha}) \hat{h}_t + \hat{\Omega}_t &= (-1 + \rho - \rho \bar{\alpha}) \hat{k}_t + \hat{c}_t \\
\hat{p}_t - ((\mu_c - \mu_x)(1 - \bar{\alpha})) \hat{h}_t - (\mu_c + \frac{\Omega}{1 - \Omega} \mu_x) \hat{\Omega}_t &= (\mu_c - \mu_x) \bar{\alpha} \hat{k}_t
\end{aligned}$$

The log-linearized dynamic equations around the steady-state are as below:

$$\begin{aligned}
\varphi \hat{c}_{t+1} - \varphi \hat{c}_t &= \bar{\beta}(1 - \bar{\delta}) \hat{p}_{t+1} + (1 - \bar{\beta}(1 - \bar{\delta})) \hat{r}_{t+1} - \hat{p}_t \\
\hat{k}_{t+1} + (\bar{\delta} - 1) \hat{k}_t &= \bar{\delta} \hat{x}_t
\end{aligned}$$

To sum up, the log-linearization around the steady state of static equations and dynamic equations can be described by the system in equation 4.11 and 4.12, respectively.

$$D U_t = E V_t \quad (4.11)$$

$$F V_{t+1} + G V_t = Q U_{t+1} + R U_t \quad (4.12)$$

Equation 4.11 and equation 4.12 can be combined into a two-dimensional dynamic system as shown in equation 4.13.

$$V_{t+1} = \underbrace{[F - QD^{-1}E]^{-1} [RD^{-1}E - G]}_J V_t \quad (4.13)$$

In order to obtain indeterminacy, both eigenvalues of matrix  $J$  have to be inside the unit circle. This equilibrium is a sink which implies that there are an infinite number of equilibrium paths towards the stationary equilibrium. The steady state is unique. Recall that capital stock is predetermined and consumption is non-predetermined in the dynamic system. In a sink equilibrium, there are an infinite number of values of consumption associated with an initial capital stock towards the stationary competitive equilibrium. Consumers' optimistic/pessimistic expectations becomes self-fulfilling in such equilibrium.

## 4.4 Findings

This study aims to investigate the relationship between the sector-specific externalities ( $\mu_c$  and  $\mu_x$ ) and the elasticity of capital-labour substitution ( $\sigma$ ). The above relationship at different degrees of relative risk aversion ( $\varphi$ ) is also examined. To achieve the goals, this section will be divided into two parts. Firstly, I will explore the relationship between these parameters in the model with  $\varphi = 1$  in subsection 4.4.1. Recall that  $\varphi = 1$  implies the logarithmic utility function. In this subsection, I also conduct an impulse response analysis with respect to sunspot shocks. The impulse response analysis will demonstrate how the economy in the stationary steady state reacts to the shock. Secondly, I will allow  $\varphi$  to vary and explore the relationship between the four parameters in subsection 4.4.2. All results will be presented numerically to show whether the required degree of externalities for indeterminacy at different  $\sigma$  and  $\varphi$  is empirically plausible.

### 4.4.1 Model With $\varphi = 1$

There are three cases in this investigation. In the first case, there are only externalities in investment sector . In the second case, there are only externalities in consumption

sector. The third case allows for externalities in both sectors. The impulse response analysis is also conducted in order to demonstrate how the economy in the stationary steady state reacts to sunspot shocks. The main findings are the following.

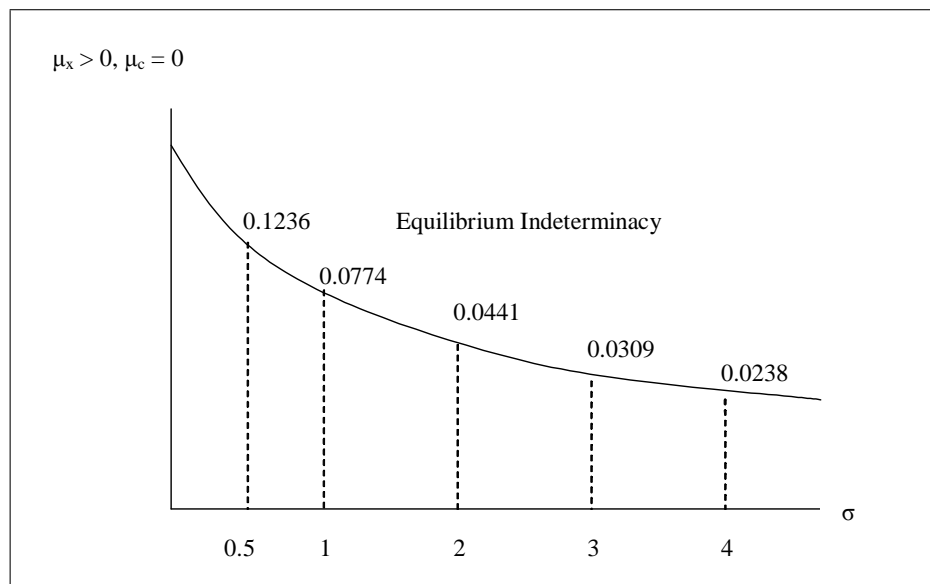
*In the first case where  $\mu_x > 0$  and  $\mu_c = 0$ ,* the result shows that the degree of externality in the investment sector is inversely related to the elasticity of substitution for the existence of indeterminacy. In figure 4-1, the equilibrium regions between determinacy and indeterminacy are separated by the downward sloping curve. The area above the curve represents the parameter constellation for equilibrium indeterminacy. With  $\sigma = 1$ , the production technology boils down to the Cobb-Douglas case. I find the minimum  $\mu_x$  at 0.0774 for indeterminacy in the Cobb-Douglas case regardless of  $\mu_c$ . This is reminiscent of Harrison (2001). My result further shows that, when varying  $\sigma$  in the model, the minimum  $\mu_x$  for the belief-driven fluctuations changes as well. Particularly, a larger  $\mu_x$  is needed when capital and labour are less substitutable as shown in figure 4-1. With the required degree of externality in the investment good sector, it is noted that the belief-driven fluctuations occur even when there are no externalities in the consumption sector.

*In the second case where  $\mu_x = 0$  and  $\mu_c > 0$ ,* all equilibria are determinate for any  $\mu_c$ . This implies that the externality in the consumption sector plays no role in generating indeterminacy. The intuition for the insignificant role of consumption externalities for indeterminacy is that the income effect completely offsets the substitution effect in the consumer's intertemporal consumption with regard to the change in the interest rate.

*In the third case in which  $\mu_x = \mu_c > 0$ ,* the result is the same as the first case. Figure 4-2 plots the result and it is exactly the same as that in figure 4-1. This affirms the role of externalities in the investment sector for indeterminacy.

With logarithmic utility, the result concurs with Harrison and Weder (2000),

Figure 4-1: Minimum externalities in investment for indeterminacy at different elasticities of substitution.

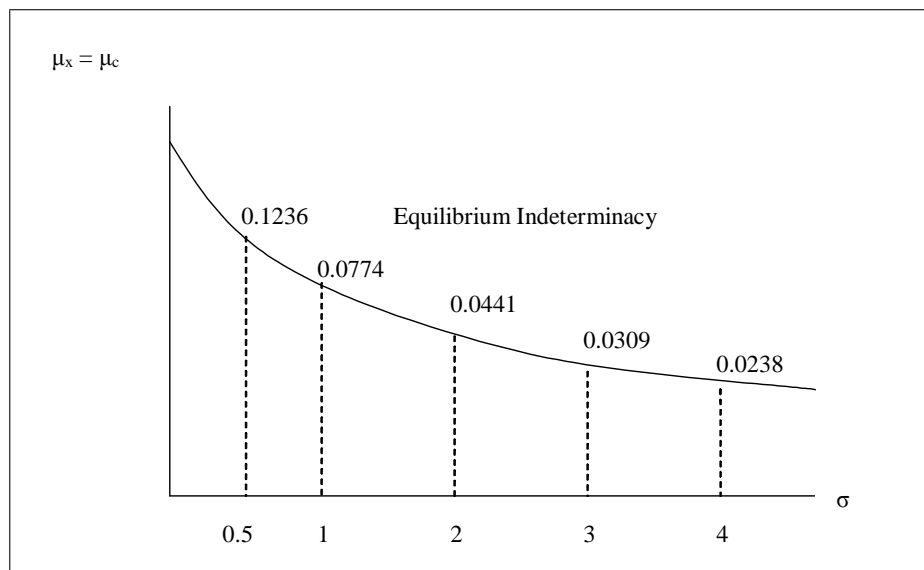


Weder (2000) and Harrison (2001) in the belief-driven fluctuations that stem from the sufficiently high externalities in the investment sector. Regardless of the elasticity of substitution, the externalities in consumption sector do not influence equilibrium indeterminacy when  $\varphi = 1$ .

The next step in this subsection is to find the explanation of how the occurrence of indeterminacy is affected by the capital-labour substitution. By conducting an impulse response analysis to sunspot shocks, I can show how the economy in the stationary steady state are influenced by the shocks. To introduce the sunspot shock into the our analysis, I use the stochastic version of equation 4.13 as below. Recall that capital stock is a predetermined variable and consumption is a non-predetermined variable.

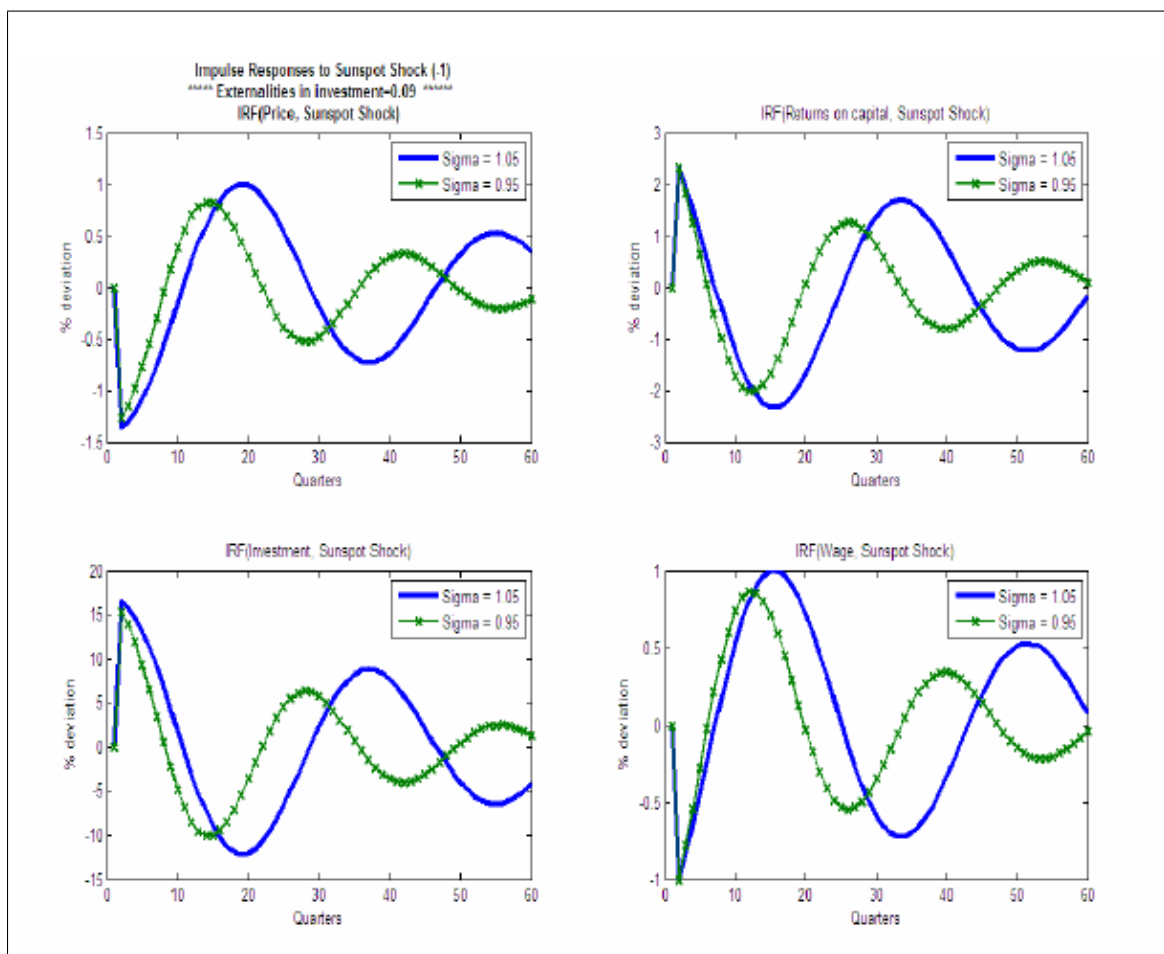
$$\begin{bmatrix} \hat{k}_{t+1} \\ \hat{c}_{t+1} \end{bmatrix} = J \begin{bmatrix} \hat{k}_t \\ \hat{c}_t \end{bmatrix} + \begin{bmatrix} 0 \\ \epsilon_{t+1} \end{bmatrix}, \quad \text{where } \epsilon_{t+1} \text{ is a sunspot shock.}$$

Figure 4-2: Minimum requirement of externalities for indeterminacy at different elasticities of substitution.



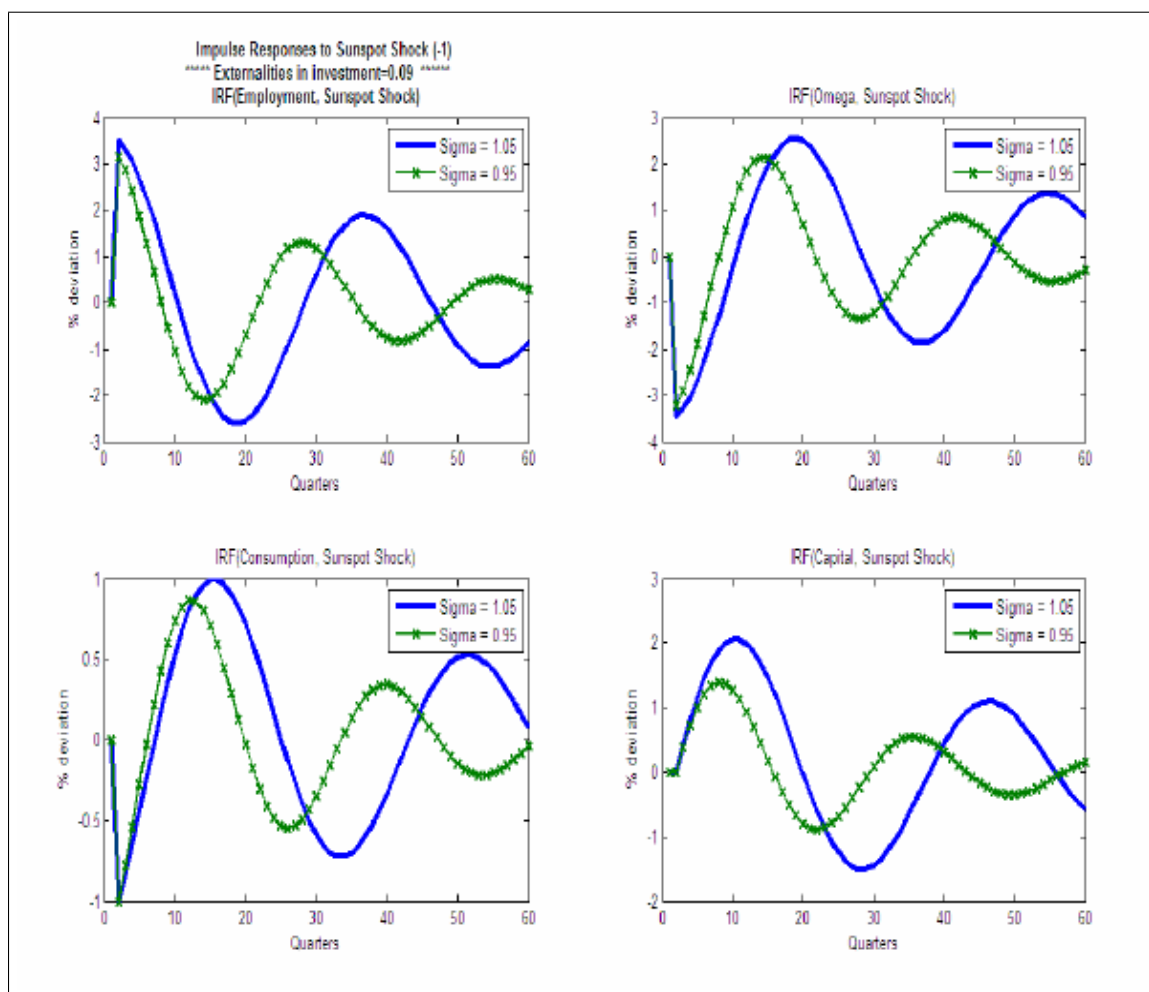
If consumers are optimistic about the future returns, then they will give up their current consumption for investment and enjoy more consumption in the future. To fulfil the consumers' belief, the rate of returns in future, i.e. the interest rates and the relative price of investment, must rise. In this two-dimensional dynamic system with both eigenvalues of matrix  $J$  being inside the unit circle, I can obtain the response of consumption and capital to the negative sunspot shock at a given time horizon. Moreover, I can also obtain the response of other variables in the static equilibrium, i.e. the relative price of investment, investment, returns on capital, real wage, labour and the share of input used in consumption good production, to sunspot shocks by using the relation in equation 4.11. Let the time horizon of impulse response to sunspot shocks be 60 quarters and the initial one time sunspot shock be  $-1$ . In addition, let the externalities in investment sector be 0.09 ( $\mu_x = 0.09$ ) and the externalities in consumption sector be zero ( $\mu_c = 0$ ). The impulse responses of the system in steady state to sunspot shocks with  $\sigma = 0.95$  and  $\sigma = 1.05$  are compared



Figure 4-3: Impulse response of  $p$ ,  $r$ ,  $x$ ,  $w$  to sunspot shocks.

in figure 4-3 and 4-4, respectively. When  $\sigma = 0.95$ , eigenvalues are  $0.94 + 0.22i$  and  $0.94 - 0.22i$ . When  $\sigma = 1.05$ , eigenvalues are  $0.97 + 0.17i$  and  $0.97 - 0.17i$ . This exercise will test whether the system in steady state with different  $\sigma$  reacts similarly or differently to the optimistic self-fulfilling expectation.

It is clear that the economy with  $\sigma = 1.05$  is more sensitive to the sunspot shock than that with  $\sigma = 0.95$  as shown in figure 4-3 and 4-4. The share of input used in the consumption sector ( $\Omega$ ) with  $\sigma = 1.05$  (capital and labour are substitutable) responds relatively more to the shock than the case where  $\sigma = 0.95$  (capital and

Figure 4-4: Impulse response of  $h, \omega, c, k$  to sunspot shocks.

labour are complementary). This is displayed in the upper right panel in figure 4-4. With the same externalities in the investment sector ( $\mu_x = 0.09$ ), this implies the higher mobility of inputs between the two production sectors when capital and labour are more substitutable. This also implies that the mobility of inputs between the two production sectors are more sluggish when capital and labour are complementary: one unit of forgone consumption can be effectively converted into 16.5 units of investment good with  $\sigma = 1.05$  while it can be converted into only 15.3 units of investment good with  $\sigma = 0.95$  as shown in the lower left panel in figure 4-3. Therefore, we observe the deeper fall in the relative price of investment ( $p$ ) right after the shock when  $\sigma = 1.05$  as shown in the upper left panel in figure 4-3.

The key propagation mechanism of the optimistic expectation on returns is through the ascending pricing sequence as explained in Harrison (2001) and Harrison and Weder (2002). The ultimate source of indeterminacy is the externalities from capital in the investment sector (Harrison and Weder 2002). With sufficiently high externalities in the investment sector, indeterminacy arises. However, the requirement of externalities in investment for indeterminacy changes when the elasticity of substitution is different from one. This is the contribution of my study. The occurrence of self-fulfilling expectation with the capital-labour substitution can be explained as follows.

Suppose that consumers have optimistic expectations of future returns that include capital gains from the ascending pricing sequence. With sufficiently high returns on investment in the form of externalities, the consumers will give up their consumption for investment in the current period. This results in a decline of the relative price of investment in the current period. In the next period, consumers enjoy more consumption while the relative price of investment increases. The sufficiently high externalities in the investment sector complete the ascending pricing sequence which

indeed yields the capital gains. Nevertheless, the requirement of externalities in investment for indeterminacy are higher when capital and labour are complementary ( $\sigma < 1$ ). The tightly coupling of capital and labour within the same production hinders the mobility of inputs between the two production sectors. Higher externalities in the investment sector are needed to convert the forgone consumption into investment goods effectively.

On the contrary, the smaller externalities in the investment sector is needed for indeterminacy when capital and labour are substitutable ( $\sigma > 1$ ). The ascending pricing sequence for optimistic expectation can be obtained more easily since capital and labour are not tightly coupled within the same production. Therefore, the smaller requirement of externalities in the investment sector is needed for indeterminacy when capital and labour are more substitutable.

#### 4.4.2 Model With Varying $\varphi$

It is still inconclusive about the precise value of the coefficient of relative risk aversion. In the real business cycle approach,  $\varphi$  is approximately equal to one so that the underlying economy is growing along the balanced growth path. In contrast, some studies on the equity premium puzzle like Mehra and Prescott (1985) and Kocherlakota (1996) show that consumers are likely to be more risk-averse and the  $\varphi$  is greater than one: the upper bound is 10 in Mehra and Prescott (1985) while it is nearly 20 in Kocherlakota (1996). Lucas (1990) notes that the coefficient of relative risk aversion should not exceed two; otherwise, the cross-country interest differentials will be incredibly large. Hansen and Singleton (1983) conclude that the coefficient of relative risk aversion lies between zero and two. From the above discussion, the main focus of this subsection can be divided into three categories with regard to the degree of consumer's risk aversion: less risk averse consumers ( $\varphi < 1.0$ ), the benchmark case ( $\varphi = 1.0$ ) and more risk averse consumers ( $\varphi > 1$ ). I assign  $\varphi = 0.5$  to represent the less risk averse consumers and  $\varphi = 2.0$  to represent the more risk averse consumer.

There are two cases in this investigation. In the first case where  $\mu_c = 0$ ,  $\varphi > 0$ , I will find the minimum required  $\mu_x$  for indeterminacy at  $\sigma = 0.5$ ,  $\sigma = 1$  and  $\sigma = 2.0$ . In the second case, I will find the minimum required  $\mu_c$  and  $\mu_x$  for indeterminacy when  $\varphi = 0.5, 1.0, 2.0$  and  $\sigma = 0.5, 1.0, 2.0$ .

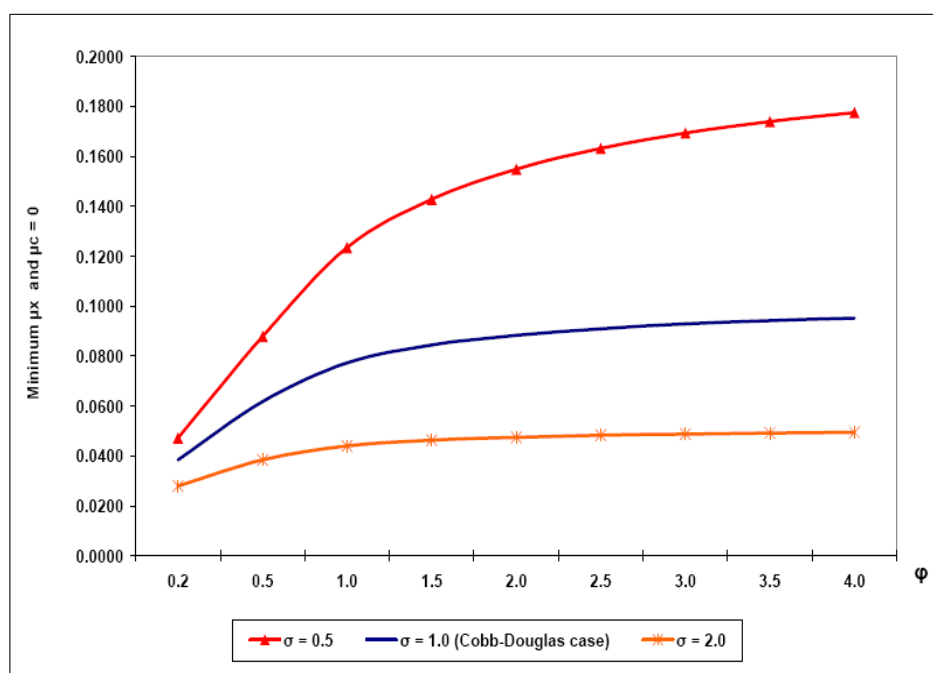
*In the first case where  $\mu_c = 0$ ,  $\varphi > 0$ ,* the result shows that the minimum required  $\mu_x$  for indeterminacy is monotonically increasing in  $\varphi$  at a given  $\sigma$  as can be seen in figure 4-5. A numerical example of the result is provided in table 4.1. The result of the case where  $\sigma = 1$  is similar to Harrison (2001). When  $\varphi < 1$ , consumers are less risk-averse and inclined to accept a variation in their consumption. With the small rewards of investment in terms of externalities, the less risk-averse consumers are ready to give up their consumption. This is why smaller  $\mu_x$  is needed to complete

the pricing sequence of belief-driven expectation. On the contrary, a larger  $\mu_x$  is needed for indeterminacy when  $\varphi > 1$ . The larger returns on investment in the form of externalities will induce the risk-averse consumers to accept the volatility in their consumption. Note that the nature of risk-averse consumers is to smooth their consumption. Apart from the characteristics of consumers that influence the equilibrium indeterminacy, the main result shows that the minimum required  $\mu_x$  varies across  $\sigma$  at a given  $\varphi$ . Specifically, a smaller degree of  $\sigma$  increases the minimum required  $\mu_x$  at a given  $\varphi$ . When  $\sigma < 1$ , a higher  $\mu_x$  is needed to increase the mobility of input between the two production sectors. Otherwise, the pricing sequence associated with the belief-driven shocks cannot be fulfilled. With  $\sigma > 1$ , the mobility of capital and labour is more free between the two production sectors. As a result, small externalities in investment are needed to complete the corresponding pricing sequence for belief-driven shocks.

Table 4.1: Minimum externalities in investment for indeterminacy at different degrees of relative risk aversion and elasticities of substitution

	Minimum $\mu_x$ and $\mu_c = 0$ when		
$\varphi =$	$\sigma = 0.5$	$\sigma = 1$	$\sigma = 2.0$
0.2	0.0472	0.0384	0.0280
0.5	0.0880	0.0618	0.0385
1.0	0.1236	0.0774	0.0441
1.5	0.1429	0.0845	0.0463
2.0	0.1550	0.0884	0.0475
2.5	0.1633	0.0910	0.0483
3.0	0.1694	0.0929	0.0488
3.5	0.1740	0.0942	0.0492
4.0	0.1776	0.0953	0.0495

Figure 4-5: Minimum externalities in investment for indeterminacy at different elasticities of substitution and degrees of relative risk aversion.





*In the second case*, there are four varying parameters. To make the presentation of four varying parameters fit into a two-dimensional diagram, I have to hold one parameter constant within the same diagram and varying across diagrams. Here,  $\sigma$  is chosen to vary across different diagrams in order to give a clear picture of the role of  $\sigma$ . Notice that the vertical axes in these three diagram are different in levels. Therefore, it ends up with three scenarios and three diagrams as shown in figure 4-6, 4-7 and 4-8. Note that the area above each curve in all figure represents the parameter constellation for indeterminate equilibrium and the curve itself gives the minimum requirement of indeterminacy. A set of numerical example is displayed in table 4.2.

*Scenario 1:  $\sigma = 1.0$  and  $\varphi = 0.5, 1.0, 2.0$*

The production technology is Cobb-Douglas case and the result is reminiscent of Harrison (2001). With  $\varphi > 1$ , the risk-averse consumer requires higher returns to compensate for more volatility in her consumption. This results in an increase in both  $\mu_c$  and  $\mu_x$  with a rise in  $\varphi$ . When  $\varphi < 1$ , the less risk-averse consumer who is likely to accept a volatile consumption would need smaller returns to induce her to change her consumption. This leads to a trade-off between  $\mu_c$  and  $\mu_x$ .

*Scenario 2:  $\sigma = 0.5$  and  $\varphi = 0.5, 1.0, 2.0$*

The result is similar to that in scenario 1 except that all the parameter constellation for indeterminate equilibrium at a given  $\varphi$  shift upwards. This is because the more capital is complementary to labour in production, the more externalities in investment are needed to complete the corresponding pricing sequence of belief-driven expectation.

*Scenario 3:  $\sigma = 2.0$  and  $\varphi = 0.5, 1.0, 2.0$*

The result is similar to that in scenario 1 except that all the parameter constellation for indeterminate equilibrium at a given  $\varphi$  shift downwards. This is because the more capital can substitute for labour in production, the less externalities in investment are

Table 4.2: Minimum requirement of externalities for indeterminacy at different degrees of relative risk aversion and elasticities of substitution

	$\sigma = 0.5$			$\sigma = 1.0$			$\sigma = 2.0$		
	$\varphi = 0.5$	$\varphi = 1.0$	$\varphi = 2.0$	$\varphi = 0.5$	$\varphi = 1.0$	$\varphi = 2.0$	$\varphi = 0.5$	$\varphi = 1.0$	$\varphi = 2.0$
$\mu_c =$	Min. $\mu_x$	Min. $\mu_x$	Min. $\mu_x$	Min. $\mu_x$	Min. $\mu_x$	Min. $\mu_x$	Min. $\mu_x$	Min. $\mu_x$	Min. $\mu_x$
-0.20	0.0973	0.1236	0.1508	0.0661	0.0774	0.0870	0.0402	0.0441	0.0471
-0.15	0.0951	0.1236	0.1519	0.0650	0.0774	0.0874	0.0399	0.0441	0.0472
-0.10	0.0928	0.1236	0.1530	0.0640	0.0774	0.0877	0.0394	0.0441	0.0473
-0.05	0.0905	0.1236	0.1540	0.0628	0.0774	0.0881	0.0390	0.0441	0.0474
0.00	0.0880	0.1236	0.1550	0.0618	0.0774	0.0884	0.0385	0.0441	0.0475
0.05	0.0854	0.1236	0.1560	0.0603	0.0774	0.0887	0.0380	0.0441	0.0476
0.10	0.0827	0.1236	0.1569	0.0590	0.0774	0.0890	0.0375	0.0441	0.0477
0.15	0.0798	0.1236	0.1578	0.0575	0.0774	0.0893	0.0369	0.0441	0.0478
0.20	0.0769	0.1236	0.1587	0.0560	0.0774	0.0896	0.0363	0.0441	0.0479

needed to complete the corresponding pricing sequence of belief-driven expectations.

Figure 4-6: Minimum requirement of externalities for indeterminacy under Cobb-Douglas technology.

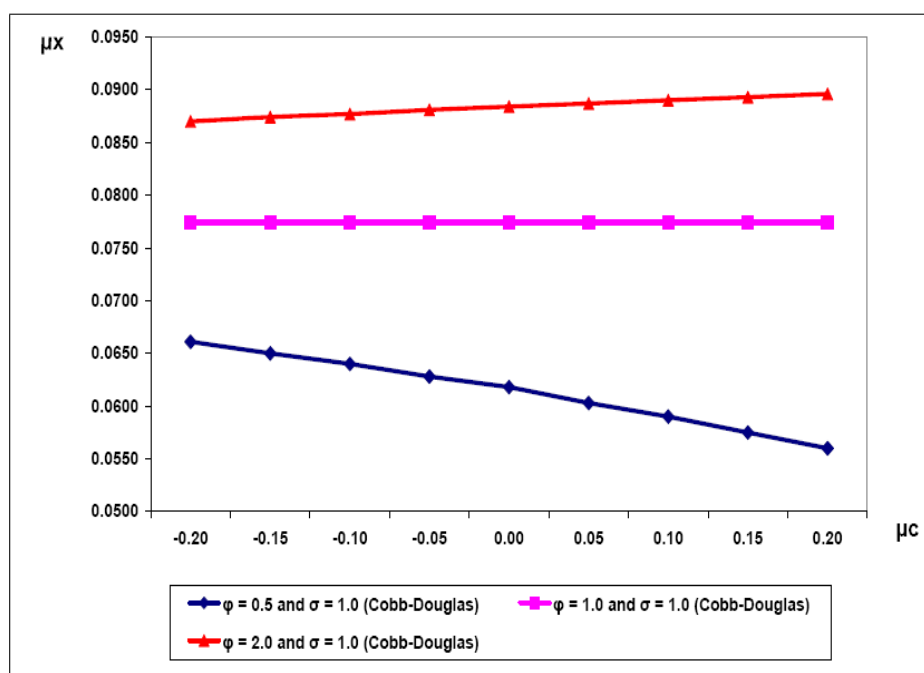


Figure 4-7: Minimum requirement of externalities for indeterminacy when capital and labour are complementary.

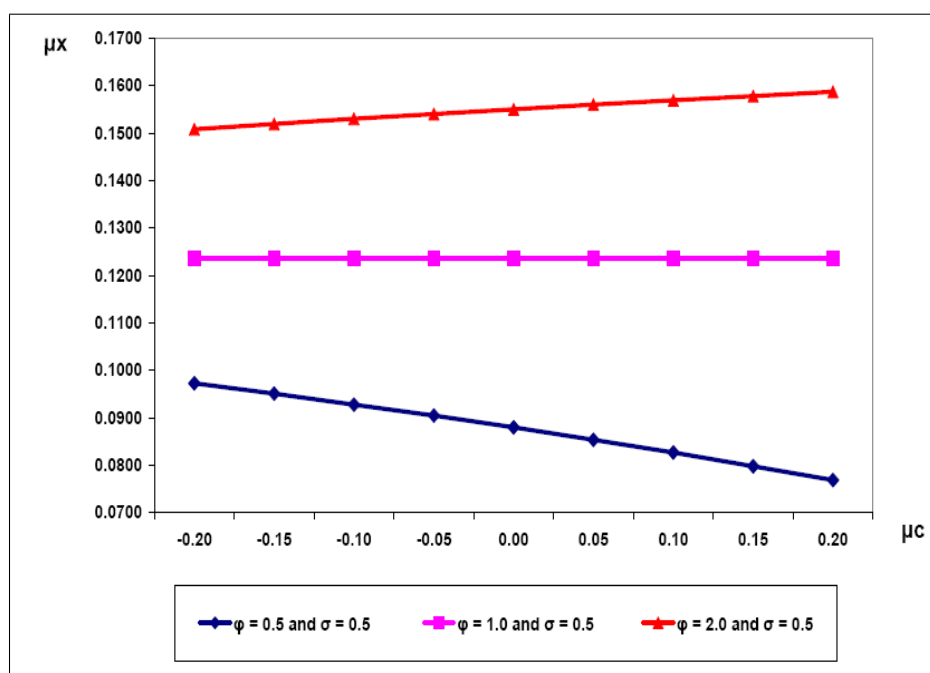
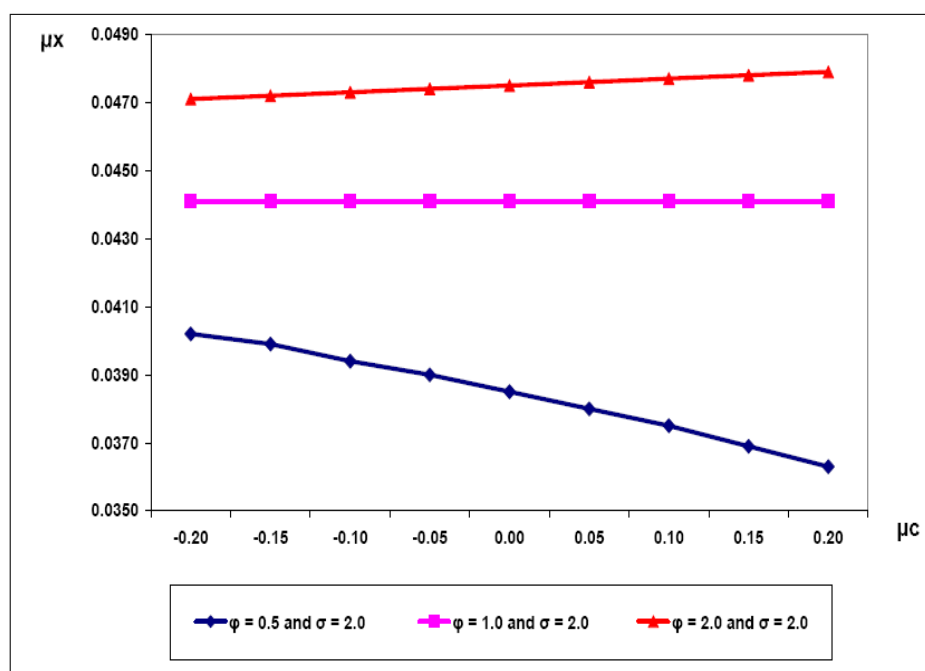


Figure 4-8: Minimum requirement of externalities for indeterminacy when capital and labour are substitutable.



## 4.5 Concluding Remarks

This chapter examines the relationship between capital-labour substitution and equilibrium indeterminacy in a two-sector competitive model. Based on the log-utility, the main finding is that sufficiently higher externalities in investment sector are needed for indeterminacy when capital and labour are less substitutable ( $\sigma < 1$ ), regardless of externalities in the consumption sector. This is because larger externalities in the investment are needed to compensate for the sluggish mobility of inputs between the two production sectors. Otherwise, the pricing sequence associated with the belief-driven shocks cannot be complete. On the contrary, the requirement for indeterminacy is smaller when capital and labour are more substitutable ( $\sigma > 1$ ). This is due to the higher mobility of inputs between the two production sectors. The smaller externalities in investment can complete the pricing sequence corresponding to the belief-driven expectation.

Based on the elasticity of substitution of 0.5 in Klump, McAdam, and Willman (2007), minimum required returns to scale for indeterminacy is 1.1236. This is essentially larger than 1.0744 which is required for the Cobb-Douglas technology. However, the returns to scale of 1.1236 is still empirically plausible as Basu and Fernald (1997) report the maximum value of 1.26. Therefore, with enough increasing returns to scale consumers' expectation can still drive the fluctuations in aggregate variables under the small capital-labour substitution production technology.

# Chapter 5

## Conclusion

Understanding the source of aggregate fluctuations is the center of interest to macroeconomists. Over the past few decades, the real business cycle approach has been solidly developed on the dynamic general equilibrium principle. This approach becomes a promising avenue to researchers as it provides convincing interpretation of how aggregate fluctuations arise.

The three essays in this thesis are based on the real business cycle approach. Chapter 2 and 3 employ the Business Cycle Accounting method developed by Chari et al. (2007a) to explore the major driving forces behind economic fluctuations in Thailand and Australia, respectively. Chapter 4 adopts the two-sector competitive model in Benhabib and Farmer (1996) to examine the relation between capital-labour substitution and sectoral externalities for indeterminacy.

Chapter 2 results reveal the importance of the efficiency wedge to the output variations in Thailand. In particular, the efficiency wedge alone accounted for the 1980s economic recession, the late 1980s economic boom, and the 1997 economic downturn in Thailand. The labour wedge may explain in part the fall in output in the 1997 economic downturn. However, it plays no significant role in the rest of the sample period. This implies that the labour wedge is not the main force in driving the Thai output. The investment wedge and the government consumption wedge are not important.

Chapter 3 has shown that the efficiency wedge is the major force driving the

Australian business cycles, particularly the variations in output and investment. The efficiency wedge alone can account for the fall in output in the 1982/83 recession and the 1990/91 recession. The investment wedge plays a minor role in both recessions. The recovery in output after both recessions is well accounted for by the combination of the efficiency and the labour wedges. The model with just the efficiency wedge predicts the amplitude of the recovery in output larger than what was observed in the actual data. There is highly negative cross correlation between the measured efficiency and labour wedges. This suggest that the labour wedge in Australia appears to be counteracting against the efficiency wedge. Intuitively, some increments in input-financing frictions in production are to be offset by the decreasing distortions in labour market and vice versa. This suggests that the frictional business cycle model for Australian economy should incorporate shocks that propagate themselves in the economy through these two wedges; otherwise, it may not be sufficient to explain the aggregate fluctuations. However, the variations in hour worked is best explained by the model with the investment and the labour wedges. Future study on the Australian labour market should take into account shocks that transmit themselves through both the investment and the labour wedges. Lastly, the expansionary of output in the late 1990s boom is mainly accounted for by the efficiency wedge. It is noted, however, that the model with just the efficiency wedge and the model with the efficiency and labour wedges provide the predictions of output that largely deviate from the actual output after 2004.

Recent studies argue that the role of the efficiency wedge in business cycles may be overemphasized and suggest the use of variable factor utilization in production. These studies are, for example, Ohanian (2001) and Meza and Quintin (2007). In particular, Meza and Quintin (2007) find that capital utilization and labour hoarding are in part responsible for the decline in the efficiency wedge during the 1990s crisis



in Latin American and Asian countries. The variable capital utilization function in their study is based on Greenwood et al. (1988) in which the depreciation rate of capital varies with respect to the capital utilization rate. This specification of variable utilization is different from that used in Chari et al. (2007a) of which capital services are dependent on the capital stock and variable hours worked of workers. The specification in the latter study seems to ignore the higher cost of wear and tear when capital being used more intensively. Hence, it is very interesting for future research to incorporate the variable capital utilization as in Greenwood et al. (1988) to the BCA method and check the robustness of accounting results.

Chapter 4 has shown that an economy with lower capital-labour substitutability than the Cobb-Douglas technology requires a higher degree of externalities in order to produce indeterminacy. Intuitively, the low substitutability implies that capital and labour are complementary factors of production. This retards the mobility of factors between the consumption and investment sectors. In the belief-driven equilibria, the consumers' optimistic expectation on returns is fulfilled as long as the rate of returns is sufficiently high such that current consumption is given up for investment. The rate of returns hereby indicates sectoral externalities. In such a production environment, the minimum requirement of externalities for indeterminacy therefore becomes larger so it can successfully break the tightly coupling factors within the sector, and raises the production of investment goods effectively. As a result, the current relative price of investment goods falls. In the next period, consumers enjoy more consumption goods and the relative price of investment goods rises. The ascending pricing sequence yields capital gains and the consumers' belief is finally fulfilled. Based on the logarithmic utility in consumption and the elasticity of substitution of 0.5 as suggested in Klump et al. (2007) and Chirinko (2008), the minimum requirement of returns to scale for indeterminacy is 1.1236, and it still lies within the range found in most empirical

studies.

The role of variable capital utilization in the sectoral externalities and indeterminacy cannot be ignored. A recent study by Guo and Harrison (2001) incorporate the variable capital utilization in their model and obtain the very small degree of sector-specific externalities for indeterminacy at 1.02. In a model with variable utilization, the elasticity effect of capacity utilization arises when the depreciation rate of capital varies positively to the intensified use of capital; as a result, the marginal gain of capacity utilization is positively related to the level of employment but inversely related to the level of capital stock (Wen 1998). Furthermore, capacity utilization can exhibit as another productive factor of production; this is called the returns-to-scale effect (Wen 1998). However, the production used in Guo and Harrison (2001) rests on the Cobb-Douglas technology. Therefore, it is very interesting for future research to investigate the minimum requirements of sectoral externalities for indeterminacy in non-Cobb-Douglas technology with variable capital utilization.

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