

# A Neoclassical Analysis of The Korean Crisis\*

Keisuke Otsu<sup>†</sup>  
Bank of Japan  
Institute for Monetary and Economic Studies

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## Abstract

In late 1997, Korea experienced a huge and unusual economic crisis. Three main features of this crisis are the sudden recession, the rapid recovery of output, and that consumption fell even more than output did. There is a large body of literature that qualitatively explain the Korean crisis in terms of financial and monetary variables such as exchange rates, price levels and interest rates. This paper complements these studies by quantitatively analyzing the fluctuation of real macroeconomic variables such as real GDP and consumption within a neoclassical framework. A small open economy stochastic neoclassical model can quantitatively account for the crisis taking productivity and real interest rate shocks as exogenous.

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<sup>†</sup>Contact: keisuke.otsu@boj.or.jp

# 1 Introduction

In late 1997, Korea experienced a severe economic downturn. Output, consumption, investment and labor per adult population dropped by 8%, 12%, 25% and 9% respectively in 1998. The crisis was clearly a devastating event and at the same time embeds several puzzles within it. The three striking features of the Korean crisis are the sudden recession, the rapid recovery of output, and the consumption drop even greater than the output drop. The aim of this paper is to quantitatively account for these features with a small open economy neoclassical model.

The sudden output drop is surprising since Korea was showing the strongest and most stable growth prior to the crisis among the rapidly growing East Asian countries. The annual GDP per adult growth rate between 1980 and 1997 averaged 5.6% with a standard deviation of 1.76%. An 8% drop in GDP per adult is over 7 standard deviation points away from the mean growth rate which is nearly a zero probability event.

After the sudden large drop in GDP per adult, Korea returned to its precrisis trend level in two years. This rapid bounce-back of output is astonishing since economies hit by such large shocks typically experience prolonged stagnation. Many studies on past depressions document the slow recoveries such as Cole and Ohanian (2002) for the depressions in US in the 1930s and UK in the 1920s, Kydland and Zarazaga (2002) for Argentina's depression in the 1980s and Hayashi and Prescott (2002) for the Japanese lost decade in the 1990s. Thailand and Indonesia who also experienced crises in late 1997 fit this empirical pattern of slow recoveries from large contractions whereas Korea clearly does not<sup>1</sup>.

The fact that consumption fell more than output during the crisis is puzzling since it goes against the principle of consumption smoothing. Aguiar and Gopinath (2004) point out that consumption volatility is greater than output volatility in developing countries since they are subject to volatile shocks to trend growth rate. However, the recession in Korea was very large and very transitory which makes the lack of consumption smoothing in Korea particularly stunning.

In this paper, I address these three striking features by quantitatively

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<sup>1</sup>Calvo, Izquierdo and Talvi (2005) document episodes of rapid recovery from output collapses where they define recovery as a return to precrisis GDP level. Instead I define recovery as a return to the trend GDP level where the trends for Korea, Thailand and Indonesia are computed by the Hodrick-Prescott filter over 1980-2002 data.

analyzing the effects of exogenous shocks to the Korean economy using a small open economy stochastic general equilibrium model. The procedure used is in line with recent neoclassical studies of depression. I feed observed shocks into the model, compute the equilibrium, and compare the time paths of key variables generated by the model to data over the 1994-2002 period. The main finding is that the model, taking real interest rate and productivity shocks as exogenous, can account for the three features extremely well.

Many studies on the Korean crisis focus on the causes and resolution of the financial crisis, i.e. the abrupt decline of foreign capital inflow, and its qualitative impact on the currency value. For instance, Burnside, Eichenbaum and Rebelo (2000) argues that the prospective government debt reached an unsustainable level due to the ongoing banking crisis and led to the currency crisis. Shin and Hahn (1998) claims that contagious effect from the South East Asian crisis and policy missteps to those effects were the main causes of the financial crisis. This paper complements these studies by modeling the financial crisis as an exogenous rise in country specific real interest rate premium and deducing its quantitative impact on real macroeconomic variables within a small open economy neoclassical framework.

There are recent studies that also attempt to quantify the effect of the financial crisis on the output drop in Korea using sticky price models. Cook and Devereux (2003) develops a sticky price small open economy dynamic general equilibrium model and shows that the exogenous nominal interest rate premium shocks in Korea, Malaysia and Indonesia can account for the output drop in these countries. Gertler, Gilchrist and Natalucci (2003) also uses a sticky price general equilibrium model and shows that the financial accelerator and fixed exchange rate regime were important to amplify the effect of real interest rate shocks and explain the drop in output and investment in Korea. My study differs from these since in addition to the real interest rate shocks I also consider productivity shocks and determine the effect of the two shocks within a neoclassical model where there are no rigidities. Also, I explain not only on the large and temporary contraction in output, but also the drop of consumption greater than output.

Real interest rates and productivity both showed dramatic changes during the crisis. The Korean real lending rate jumped up from 5% to almost 10% in 1998 which coincides with the sudden recession period. Following Neumeyer and Perri (2005), I assume that Korea is a net debtor in the international financial market and that international lenders exogenously determine the country specific spread on loans made to Korean firms. Thus, the large jump

in the real interest rate reflects the reversal of foreign investors' willingness to lend to Korea which represents the financial crisis. On the other hand, total factor productivity was growing by 3.1% on average between 1980 and 1997, suddenly fell by 2.8% in 1998 and then grew by 4.6% the following year. This shows that the sudden recession and rapid recovery in GDP is matched with a similar movement in total factor productivity. The main focus of this paper is not the sources of these exogenous shocks but the quantitative impact of them on key macroeconomic variables.

Quantitative results show that with GHH preference in which there are no income effect on labor supply, the model can account for all three of the striking features taking productivity and real interest rate shocks as given. The fact that the model performed extremely well is surprising since this implies that market imperfections specific to the Korean economy such as crony capitalism, restrictions and regulations, outside of their effects on interest rates or productivity, are not important for understanding the Korean crisis. The impacts of each shocks are also surprising. The depression and recovery of output and labor are mostly explained by productivity shocks while real interest rate shocks primarily affect the composition of output between consumption, investment and trade balance.

Finally, I consider models in which real interest rates endogenously cause fluctuation in productivity in order to check the validity of exogenous productivity shocks. I examine models with endogenous capacity utilization and intermediate goods given real interest rate shocks, and found that neither of these additional features are sufficient to quantitatively explain the fluctuation of measured total factor productivity. Hence, I conclude exogenous shocks to productivity is important in explaining the fluctuation of measured productivity. I conjecture that corporate failures and the breakdown of bank lending may have temporarily reduced productivity by forcing firms to divert resources away from production operations to finding alternative business relationships as in Ohanian (2001).

The remaining of this paper is organized as follows. Section 2 shows recent macroeconomic performance of the Korean economy. Section 3 describes the standard neoclassical small open economy model and the quantitative method. Section 4 presents quantitative results. Section 5 considers the depressing effect of high real interest rates in a neoclassical model. Section 6 discusses possible links between the financial crisis and productivity shocks. The paper is concluded in section 7.

## 2 The Korean Economy

In this section, I present the recent performance of the Korean economy in order to characterize the Korean crisis. First I specify features of the recent Korean macroeconomic fluctuation. Next, I show the large movements of real interest rates and total factor productivity, which I consider as exogenous shocks during the crisis.

### 2.1 The Macroeconomic Performance of Korea Since 1980

In order to explain the macroeconomic performance of Korea, I investigate the Korean economy from three different viewpoints. First, the supply side of the economy: the fluctuations of production factors. Next, the demand side of the economy: the fluctuation of GDP expenditure components. Finally, I compare Korea with other East Asian economies focussing on output and consumption fluctuation.

#### 2.1.1 The Supply Side

On the supply side of the economy, I consider two production factors, labor and capital stock. Both inputs move along with output while most of the output fluctuation is coming from labor fluctuation.

Figure 1 presents the fluctuation of Korean GDP, capital stock and labor. This figure shows that while both capital and labor are procyclical, most of the fluctuation of output during the crisis is coming from labor fluctuation. Total hours worked which consists of hours worked per worker and the number of workers is defined as labor. Capital stock includes tangible assets held by the private and government sectors. All variables shown here are in real terms per adult population detrended by the Hodrick-Prescott filter and presented in the form of deviations from their trend. The downward spike of GDP in 1998 shows how suddenly output fell and how rapidly it recovered. Capital stock moves smoothly because in general it takes time to remove or to build capital stock. On the other hand, labor moves instantaneously. This implies that in order to explain output fluctuation, the model must explain labor fluctuation.

Typically the fluctuation of output cannot be fully explained by the fluctuation of inputs. The remaining factor is known as total factor productivity

or Solow residuals. I will discuss about this object in detail below.

### 2.1.2 The Demand Side

The demand side of the economy consists of consumption, investment and trade balance. Consumption and investment are both procyclical while trade balance is countercyclical and the volatilities of all three are larger than the volatility of output.

Figure 2 presents the fluctuation of Korean GDP and its components. This figure shows that both consumption and investment fell dramatically while trade balance improved during the crisis. The scale on the left axis is for output, consumption, and investment whereas the right axis is for trade balance. Consumption includes private consumption and government purchases of goods and services. Investment corresponds to gross fixed capital formation which includes private and government fixed investment. Trade balance includes net exports and changes in inventories and is divided by GDP.

The striking fact is that consumption is falling more than output during the crisis. This goes against the fundamental economic principle of consumption smoothing. Aguiar and Gopinath (2004) and Neumeyer and Perri (2005) point out that consumption volatility is greater than output volatility in developing countries on average. Aguiar and Gopinath (2004) claims that shocks to the trend of productivity growth can explain this while Neumeyer and Perri (2005) argues that real interest rate shocks are important. The Korean experience is particularly interesting since it shows that this relationship between consumption and output volatility holds even during a crisis period in which fluctuations of output was enormous and transitory.

### 2.1.3 International Comparison

One reason I focus on the Korean crisis is because it was the most surprising case among the East Asian crises. Korea was the most rapidly growing and least volatile East Asian economy since 1980, while it experienced one of the deepest and most short-lived crises in Asia. Also, given that the recession in Korea was most transitory in Asia, consumption fell most relative to output.

Figure 3 shows GDP per adult and consumption per adult detrended by the Hodrick-Prescott filter for the six East Asian countries. The stability through 1980-1997, the sudden drop, and the rapid recovery in Korea can be

seen clearly. Indonesia, Malaysia, and Thailand also show significant drops in real GDP per adult. GDP per adult in Hong Kong, Malaysia and Singapore recovered to trend levels in two years as in Korea but their deviations from trend level in 1998 were small to begin with. The sharp drop in consumption can be seen not only in Korea but also in Indonesia, Malaysia, and Thailand.

Korea seemed to be the least likely candidate for a severe economic downturn since Korean GDP showed the highest and most stable growth among the rapidly growing East Asian economies. Table 1 shows the mean and standard deviation of GDP per adult growth rates for Hong Kong, Indonesia, Malaysia, Singapore, Thailand, and Korea during the 1980-1997 period. This shows that the annual growth rate of Korean GDP per adult was highest on average at 5.6% and had the lowest standard deviation at 1.76%. In spite of the high growth rates and stability prior to the crisis, Korea experienced one of the deepest recessions in the region which was exceptionally short-lived. Also, consumption fell the most relative to output among the Asian countries during the crisis. Table 2 shows summary statistics of the East Asian countries during the crisis. The first column shows GDP per adult relative to the Hodrick-Prescott trend level. Korean GDP per adult was 8.7% below trend which is lowest among the countries<sup>2</sup>. The second column shows the growth rates of GDP per adult between 1998 and 1999. Given one of the most severe economic downturns, Korean GDP per adult grew 9.2% in 1998 whereas the other five countries averaged at 1.7% showing the exceptional speed of recovery in Korea. Finally, the last column shows the growth rate of consumption relative to the growth rate of GDP between 1997 and 1998. Both GDP and consumption growth rates were negative so the ratio is positive in all countries. Korea has the highest ratio which means that consumption fell the most relative to GDP in Korea during the crisis. It is puzzling why the relative volatility of consumption was highest in Korea in which the recession was transitory.

In short, the three unusual features of the Korean crisis are, the sudden recession, the rapid recovery of GDP and the drop of consumption greater than the drop of GDP during the crisis.

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<sup>2</sup>Indonesia and Thailand show larger drops in terms of GDP per adult growth rates.

## 2.2 Real Interest Rates and Productivity

In this section, I introduce the fluctuation of real interest rates and productivity which I consider as the two main shocks to the Korean economy during the crisis. I focus on these two shocks since there were extremely large movements in these variables during the crisis and have theoretical relevance in explaining the three features of the Korean crisis.

### 2.2.1 Real Interest Rates

Figure 4 shows the Korean real domestic lending rate, which I use as the measure of real interest rates, and GDP per adult detrended by Hodrick-Prescott filter. The figure shows that the real interest rate jumped up by nearly 5 percentage points between 1997 and 1998. This reflects the sudden drop of the willingness to lend to Korean firms which represents the financial crisis in Korea. While many papers discuss the cause and resolution of the financial crisis in Korea, I take the fluctuation of real interest rate as exogenous and deduce its impact on the Korean economy.

The real interest rate is the difference between the nominal interest rate and the expected inflation rate. The minimum annual lending rate of the deposit money banks<sup>3</sup> is used as the nominal interest rate. Since this is the minimum rate a domestic firm will face when borrowing from a domestic or foreign bank in the country, it is the relevant measure for the nominal intertemporal terms of trade for my analysis<sup>4</sup>. The expected inflation rate was computed as the average of the current year realization and four preceding year values of inflation in the GDP deflator<sup>5</sup>.

There are several studies that analyze the effects of real interest rate shocks on emerging market business cycles. The empirical regularity that

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<sup>3</sup>Deposit money banks consolidates the commercial banks, excluding trust accounts and overseas branches of commercial banks, and the specialized banks. Commercial banks comprise nationwide banks, local banks, and foreign banks. Specialized banks comprise the industrial bank of Korea, the credit and banking sectors of the agricultural fishery, and livestock cooperatives.

<sup>4</sup>Neumeyer and Perri (2005) use secondary market prices of emerging market bonds to recover nominal U.S. dollar interest rates and obtain real rates by subtracting expected U.S. inflation. Their nominal interest rates were constructed as the 90 day U.S. T-bill rate plus the J.P. Morgan Emerging Market Bond Index (EMBI) Global Spread.

<sup>5</sup>The number of lags were chosen arbitrarily where the more lags included, the smoother the real interest rate series becomes. The choice of lag periods does not affect the quantitative result.



motivated these studies was that real interest rates are counter-cyclical in emerging economies. Neumeyer and Perri (2005) and Uribe and Yue (2003) use a general equilibrium small open economy model with a ‘working capital’ assumption such that firms in emerging economies have to borrow foreign credit in order to hire labor. Since labor cost is a function of real interest rates, shocks to real interest rates directly affect labor demand and cause the economy to fluctuate. Cook and Devereux (2003) uses a sticky price dynamic general equilibrium small open economy model with interest rate shocks to explain the currency crisis in Korea, Thailand, and Malaysia. High interest rates affect domestic absorption through income and substitution effects and cause a contraction mainly in the nontradable sector and consequently a depreciation of the real exchange rate. In Gertler, Gilchrist and Natalucci (2003), real interest rate shocks in a fixed exchange rate regime magnified by the financial accelerator causes a contraction in aggregate demand and consequently GDP given sticky prices.

In this paper, I focus on the incentive effect real interest rates have on consumption. A sudden rise in real interest rates cause negative income and intertemporal substitution effects on current consumption given that Korea was a net debtor. Therefore, real interest rate shocks should help explaining the huge drop in consumption.

### 2.2.2 Productivity

Figure 5 shows total factor productivity and GDP per adult both detrended by Hodrick-Prescott filters. Clearly, there is a positive relationship between productivity and GDP during the crisis as productivity falls dramatically in 1998 and recovers rapidly in 1999. Following the real business cycle literature, I assume productivity shocks as exogenous shocks that affect the production technology in the benchmark model. Later I will relax this assumption.

Productivity shocks were computed as follows. First, I assume a Cobb-Douglas production function,

$$Y_t = z_t K_t^\theta (X_t l_t)^{1-\theta} \quad (1)$$

where  $Y_t$  is real output per adult,  $K_t$  is real capital stock per adult,  $X_t$  is labor augmenting technical progress,  $l_t$  is labor input per adult<sup>6</sup>, and  $\theta$  is the

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<sup>6</sup>Labor was computed as

$$\frac{h_t}{16 * 7} * \frac{e_t}{N_t}$$

capital share set as 0.297<sup>7</sup>.  $z_t$  is detrended productivity which is one of the main objects in this paper and what I refer to as ‘productivity’ further on.

Next, taking the log of (1), we get,

$$\ln SR_t = \ln Y_t - \theta \ln K_t - (1 - \theta) \ln l_t. \quad (2)$$

where  $SR_t = z_t X_t^{1-\theta}$  is known as the Solow residual or total factor productivity (TFP), which was computed from non-detrended per adult population data. I assume  $X_t = (1 + \gamma)X_{t-1}$  so that the trend of TFP growth is coming from the constant growth of labor augmenting technical progress while the fluctuation of TFP about the trend is coming from the fluctuation of  $z_t$ . According to the neoclassical growth theory, per adult values of output, capital, consumption, and investment grow at the same rate as labor augmenting technical progress along the balanced growth path.

Finally, the trend growth rate  $\gamma$  is estimated with a regression of the log of TFP on a linear trend and a constant<sup>8</sup>. By definition, the residuals from this regression are productivity shocks  $\ln z_t$ .

### 3 The Benchmark Model

The model is a canonical small open economy neoclassical model. Cole and Ohanian (1999) defines the neoclassical model as, “the optimal growth model in Cass 1965 and Koopmans 1965 augmented with various shocks that cause employment and output to deviate from their deterministic steady-state paths as in Kydland and Prescott 1982”. They show that productivity shocks alone cannot explain the slow recovery during the Great Depression and that the government policies toward monopoly and the distribution of income are to blame. This study broke the taboo of the real business cycle literature and applied the neoclassical model to large economic fluctuations such as the Great Depression. In this section, I follow their method using a small open economy version of the neoclassical model as the benchmark model in order to analyze the Korean crisis.

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where  $h_t$  is average weekly hours worked,  $e_t$  is employed workers,  $N_t$  is adult population.  $l_t$  is restricted to be between zero and one given that the average weekly hours worked never exceeds  $16 * 7$  hours.

<sup>7</sup>This value is borrowed from Young (1994).

<sup>8</sup>The regression is presented in the appendix.

The economy is a small open economy which consists of a representative household, firm and foreign investors. The household has preference over consumption and labor. The household is facing an incomplete financial market where he can issue debt with a one period non-state-contingent international discount bond at a given rate of return to foreign investors<sup>9</sup>. There is a firm that produces a single good using capital and labor with a Cobb-Douglas production function which depends on productivity. For simplicity, there is no government sector<sup>10</sup>. There are adjustment costs on both capital stock and international debt. The shocks to the economy are real interest rate and productivity shocks described above. All variables in the model except for labor are per adult population values detrended by the trend growth  $X_t$  in order to make the economy stationary.

### 3.1 Household

The representative household chooses how much to work, consume, invest and borrow. The lifetime utility of the representative agent depends on the utility from consumption and disutility from labor;

$$\max U = E_t \sum_{t=0}^{\infty} \beta^t u(c_t, l_t) \quad (3)$$

where  $c_t$  is consumption.

For the functional form of  $u(\bullet)$ , I consider two cases. One is the Cobb-Douglas preference function which is widely used in macroeconomic literature and the other is the GHH preference function which has recently been used in the small open economy literature.

#### Case 1. Cobb-Douglas Preference:

$$u(c_t, l_t) = \frac{(c_t^\Psi (1 - l_t)^{1-\Psi})^{1-\sigma}}{1 - \sigma} \quad (4)$$

where  $1 - l_t$  is leisure,  $0 \leq \sigma < \infty$  is the curvature parameter which represents the relative risk aversion and  $0 < \Psi < 1$  governs weights the household assigns to consumption and leisure.

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<sup>9</sup>Throughout this paper, I assume Korea to be a net debtor for every period. This is true until the second quarter of 2000.

<sup>10</sup>It turns out that shocks to government purchases during the crisis are quantitatively unimportant. Therefore I do not separately define the government sector in the model.

**Case 2. GHH Preference:**

$$u(c_t, l_t) = \frac{(c_t - \chi l_t^\nu)^{1-\sigma}}{1-\sigma}. \quad (5)$$

GHH preference was named after Greenwood, Hercowitz, and Huffman (1988) who introduced this preference function to the dynamic general equilibrium model. It is known that this preference function can be considered as a reduced form of a preference function on consumption and leisure with home production<sup>11</sup>. In this interpretation, market labor is costly since it reduces both leisure and home production. The parameters  $\chi$  and  $\nu$  adjust for the level and curvature of this cost respectively.

Many studies show that this preference assumption is useful to understand open economy dynamics. Mendoza (1991) introduced GHH preference to the small open economy model in order to focus on the interaction of foreign assets and domestic capital as alternative vehicles of savings and consequently generated countercyclical trade balance. Correia, Neves, and Rebelo (1995) pointed out that the problem with Cobb-Douglas preference in a small open economy real business cycle model is that it tends to predict too much consumption smoothing and as a result will generate procyclical trade balance and that GHH preference solves this problem. Raffo (2005) shows that even in a more general setting, a two-country model, GHH preference can generate counter cyclical trade balance by increasing consumption volatility without resorting to counterfactual terms of trade effects.

The representative agent maximizes (3) subject to the budget constraint,

$$w_t l_t + r_t k_t + \frac{\Gamma d_{t+1}}{R_t} = c_t + i_t + d_t + \Phi(\Delta k_t) + \Pi(d_{t+1}) \quad (6)$$

and capital law of motion

$$\Gamma k_{t+1} = i_t + (1 - \delta)k_t \quad (7)$$

where  $k_t$  is capital stock,  $i_t$  is investment,  $d_t$  is foreign debt,  $1 - \frac{1}{R_t}$  is the real interest rate for  $d_t$  and  $w_t$  and  $r_t$  are real wage and rental rates respectively. For simplicity, I assume that the population growth rate is constant and

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<sup>11</sup>Greenwood, Rogerson, and Wright (1995) show the mapping from a home production model to a GHH model.

define  $\Gamma = (1 + \gamma)(1 + n)$  where  $\gamma$  is the growth rate of labor augmenting technical progress and  $n$  is the population growth rate.

The country is a small open economy so it takes  $R_t$  as given. It is common to assume adjustment cost for capital stock in small open economy models because otherwise the volatility in investment will be too high. I assume the functional form of the capital adjustment cost function  $\Phi(\Delta k_t)$  to be  $\phi \frac{(k_{t+1} - k_t)^2}{2}$ . Introducing adjustment cost on international debt is one way to induce stationarity in a small open economy model with incomplete markets<sup>12</sup>.  $\Pi(d_{t+1})$  is debt adjustment cost which I assume to have the functional form  $\pi \frac{(d_{t+1} - d)^2}{2}$  where  $d$  is the steady state level of foreign debt. I choose  $\pi$  to be arbitrarily small such that this portfolio adjustment cost will not affect the short run dynamics of the model.

The first order conditions for the household are, the labor first order condition;

$$-\frac{u_{l_t}}{u_{c_t}} = w_t \quad (8)$$

the Euler equation for capital;

$$u_{c_t}(\Gamma + \phi(k_{t+1} - k_t)) = \beta E_t [u_{c_{t+1}} \{r_{t+1} + 1 - \delta + \phi(k_{t+2} - k_{t+1})\}] \quad (9)$$

and the Euler equation for international debt;

$$u_{c_t} \left( \frac{\Gamma}{R_t} - \pi(d_{t+1} - d) \right) = \beta E_t u_{c_{t+1}}. \quad (10)$$

where the marginal utilities of consumption and leisure for the Cobb-Douglas case are;

$$\begin{aligned} u_{c_t} &= \Psi c_t^{\Psi(1-\sigma)-1} (1 - l_t)^{(1-\Psi)(1-\sigma)} \\ -u_{l_t} &= (1 - \Psi) c_t^{\Psi(1-\sigma)} (1 - l_t)^{(1-\Psi)(1-\sigma)-1} \end{aligned} \quad (11)$$

while for the GHH case they are;

$$\begin{aligned} u_{c_t} &= (c_t - \chi l_t^\nu)^{-\sigma} \\ -u_{l_t} &= (c_t - \chi l_t^\nu)^{-\sigma} \chi \nu l_t^{\nu-1}. \end{aligned} \quad (12)$$

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<sup>12</sup>This debt adjustment cost is one of several ways to remove the random walk component in the Euler equation for international asset holdings introduced by Schmitt-Grohe and Uribe (2003). They also introduce models with an endogenous discount factor, debt elastic interest rates and complete asset markets claiming that all models deliver virtually identical results.

### 3.2 Firm

The firm produces a single storable good with a Cobb-Douglas production function,

$$y_t = z_t k_t^\theta l_t^{1-\theta} \quad (13)$$

where  $y$  is the detrended per adult output, and  $z_t$  is the productivity. Thus, the firm's problem is,

$$\max \pi_t = y_t - w_t l_t - r_t k_t. \quad (14)$$

The first order conditions are,

$$r_t = \theta \frac{y_t}{k_t} \quad (15)$$

and

$$w_t = (1 - \theta) \frac{y_t}{l_t}. \quad (16)$$

### 3.3 International Capital Market

The country is a small open economy such that it cannot affect the real interest rate. Thus, all interest rate shocks are given to the economy by the international financial market. The fluctuation of real interest rates can come from the world interest rate or the country specific interest rate premium. Hence,

$$R_t = R_t^* S_t$$

where  $R_t^*$  is the real world interest rate and  $S_t$  is the country specific spread. It turns out that the observed world interest rate<sup>13</sup> is not important in explaining the fluctuation of any variable of interest. Therefore, I assume that the world interest rate is constant for simplicity. In other words, I assume that all of the fluctuation of real interest rates comes from the country specific spread. Following Neumeyer and Perri (2005), I assume that domestic private borrowers always pay back in full but each period the local government can confiscate the interest payments to foreign lenders. Therefore, the default risk is bared solely by the international lenders.

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<sup>13</sup>Real rate of return on 3 month US treasury bills was used as the real world interest rate.

Cook and Devereux (2003) makes a distinction between the exogenous country specific risk premia determined by foreign investors and domestic interest rates where the two are connected through a monetary policy rule. Gertler, Gilchrist and Natalucci (2003) further assume that the domestic interest rates depend on the choice of exchange rate regime by the monetary authority. In Korea, real interest rates using country specific risk premium data computed by Neumeyer and Perri (2005) and real domestic lending rate both show similar hikes during the crisis. This reflects the fact that the Korean government took tight monetary policy during the financial crisis in order to contain the currency crisis. For simplicity, in this paper I assume no freedom for monetary policy and assume that foreign investors directly decide domestic real interest rates. Note that the source of the fluctuation of the real interest rates is not the main issue in the paper, the quantitative impact of it on the Korean macroeconomy is.

### 3.4 Shock Process

Real interest rate and productivity shocks are assumed to follow an autoregressive process;

$$\begin{pmatrix} \ln z_t \\ \ln S_t \end{pmatrix} = \begin{pmatrix} \rho_z & 0 \\ 0 & \rho_s \end{pmatrix} \begin{pmatrix} \ln z_{t-1} \\ \ln S_{t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{zt} \\ \varepsilon_{st} \end{pmatrix} \quad (17)$$

$$\begin{pmatrix} \varepsilon_{zt} \\ \varepsilon_{st} \end{pmatrix} \sim N(0, V)$$

where the errors are allowed to be correlated<sup>14</sup>. The variance-covariance matrix of the errors looks like,

$$V = \begin{pmatrix} \sigma_z^2 & \sigma_{zs} \\ \sigma_{zs} & \sigma_s^2 \end{pmatrix}.$$

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<sup>14</sup>I estimated the unrestricted process;

$$\begin{pmatrix} \ln z_t \\ \ln S_t \end{pmatrix} = \begin{pmatrix} \rho_{zz} & \rho_{zs} \\ \rho_{zs} & \rho_{ss} \end{pmatrix} \begin{pmatrix} \ln z_{t-1} \\ \ln S_{t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{zzt} \\ \varepsilon_{sst} \end{pmatrix}.$$

However, The results show that the cross terms of the persistence matrix are statistically insignificant. Therefore I assumed the cross terms to be zero. The error terms are negatively correlated which is consistent with the observation by Neumeyer and Perri (2005).

Future shocks are anticipated using this process given current shocks. The expected persistence of the shocks depend on parameters  $\rho_z$  and  $\rho_s$  which are between zero and one.

### 3.5 Competitive Equilibrium

A competitive equilibrium is,  $\{c_t, l_t, k_{t+1}, d_{t+1}, y_t, i_t, w_t, r_t, R_t\}_{t=1}^{\infty}$  such that; (1) The household optimizes given  $\{w_t, r_t, R_t\}_{t=1}^{\infty}$  and  $d_1, k_1$ , (2) The firm optimizes given  $\{w_t, r_t, z_t\}_{t=1}^{\infty}$ , (3) Markets clear, (4) The resource constraint holds:

$$y_t = c_t + i_t + tb_t + \phi \frac{(k_{t+1} - k_t)^2}{2} + \pi \frac{(d_{t+1} - d)^2}{2} \quad (18)$$

where the trade balance is defined as

$$tb_t = -\Gamma \frac{d_{t+1}}{R_t} + d_t, \quad (19)$$

and (5) The shocks follow the process (17).

## 4 Quantitative Analysis

The main objective of this paper is to assess how well the neoclassical model predicts the fluctuation of key variables as a reaction to exogenous shocks during 1994-2002. In this section, I discuss the method and results of the quantitative results. First I describe the method used to obtain values of parameters defined in the model. Next, I explain the approach used to simulate the model. Finally, I discuss the simulation results.

### 4.1 Parameter Values

The benchmark parameters are listed in Table 3.  $\theta$  was borrowed from Young (1994). All other parameters were obtained from the 1980-2002 data.  $n, l, \frac{y}{k}$ , and  $\frac{tb}{y}$  were directly calculated as the average of the data.  $\gamma$  was estimated by the regression presented in the appendix.  $\delta$  is the average of  $\delta_t$  calculated from the capital accumulation equation

$$N_{t+1}K_{t+1} = N_tI_t + (1 - \delta_t)N_tK_t,$$



where  $N_t$  is the adult population at date  $t$ .  $\beta$  was calibrated from the steady state capital Euler equation combining equations (9) and (15),

$$\Gamma = \beta(\theta \frac{y}{k} + 1 - \delta).$$

$\Psi$  was calibrated from the steady state labor first order condition combining equations (8) and (16)

$$\frac{1 - \Psi}{\Psi} = (1 - \theta) \frac{y}{cl}.$$

The values of  $\chi$  and  $\nu$  for GHH preference were calibrated to match the elasticity of labor supply to that in the Cobb-Douglas preference case for  $\sigma = 1$ <sup>15</sup>.  $d$  was obtained from steady state versions of equations (18) and (19).  $\rho_z$  and  $\rho_S$  were estimated by equation (17).  $\phi$  is chosen to match the volatility of simulated investment to the volatility of investment data for each case.

## 4.2 Simulation Method

One basic assumption is that the economy is growing along a balanced growth path during the 1994-2002 period where the fluctuation is defined by deviations from this path. In this section, I describe the method used to simulate the fluctuation of the Korean macroeconomy during the crisis.

The simulation uses linearized versions of equilibrium conditions following the method introduced by Uhlig (1997) to compute linear decision rules for endogenous variables. The decision rules depend on state variables – capital stock, foreign debt, and exogenous shocks. Fluctuation of exogenous shocks are the residuals from regressions of  $\ln S_t$  and  $\ln z_t$  respectively on linear trends and constants for 1994-2002. I substitute these linearly detrended shocks into linear decision rules to compute fluctuations of endogenous state variables assuming that they are at their steady state values in the initial period 1994. Then I compute the fluctuation of the other endogenous variables by plugging the fluctuation of exogenous shocks and computed endogenous state variables into their linear decision rules. Finally, the simulated series are detrended by the Hodrick-Prescott filter in order to make them comparable to detrended data.

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<sup>15</sup>The calibration of  $\chi$  and  $\nu$  are shown in the appendix.

### 4.3 Quantitative Results

In this section, I present the simulation results for the benchmark model. Results for Cobb-Douglas preference and GHH preference are summarized in table 4 and 5 as well as figures 6 and 7. The tables report the standard deviation of simulated output, labor and consumption relative to the standard deviation of data. Simulations were done with each shocks separately as well as with both shocks together in order to understand the impacts of each shocks. The tables report results for  $\sigma = 1, 2$  and 5 whereas the figures correspond to simulation results with  $\sigma = 1$ .

#### 4.3.1 Results with Cobb-Douglas Preference

The benchmark model with Cobb-Douglas preference fails to quantitatively account for the three features of the Korean crisis. With both productivity and real interest rate shocks, the model predicts an increase in output during the crisis. The main reason is because the income effect from real interest rate shocks causes labor to increase during the crisis. In order to understand the mechanism behind this result, it is useful to consider the impact of each shocks separately.

**Results with only Productivity Shocks** During the crisis there was a huge fluctuation of productivity shocks which affects not only production, but also the decisions of the household. The solid line in figure 6 shows that with only productivity shocks the model with Cobb-Douglas preference can explain the fluctuation of labor and output but cannot explain the huge drop in consumption during the crisis. Table 4 shows that the model can explain 74% of labor fluctuation and 85% of output fluctuation but only 6% of consumption fluctuation with  $\sigma = 1$ .

A temporary drop in productivity reduces the marginal product of labor and capital and reduces wage and rental rates. This affects consumption and labor decisions through income and substitution effects. Low wage rates cause consumption and labor to decrease through the intratemporal substitution effect since the wage rate is the relative price of leisure. At the same time, low wage and rental rates have negative income effects that reduce consumption and increase labor. Also, in order to smooth marginal utilities of consumption over time, the household will decrease net savings<sup>16</sup>. This

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<sup>16</sup>In the Cobb-Douglas preference case, it turns out that both investment and trade

causes an increase in consumption and decrease in labor. The sum of these effects determines the changes in consumption and labor where in the setting of this paper, both fall in reaction to productivity drop. Along with the drop in labor, the sudden drop in productivity explains the sudden drop in output. The quick recovery can be explained by the reverse effects of the rapid post crisis productivity growth.

The fact that consumption doesn't fluctuate much with Cobb-Douglas preference is because there is a trade-off between fluctuation of consumption and fluctuation of labor due to the income effect of labor. This can be shown with linearized equilibrium conditions. First, from the bond Euler equation (10), the marginal utility of consumption is virtually constant on expectation in every period<sup>17</sup> given that the real interest rate is constant. Totally differentiating  $u_c$  and setting this as a constant gives the condition

$$\tilde{c}_t = \frac{(1 - \Psi)(1 - \sigma)}{\Psi(1 - \sigma) - 1} \frac{l}{1 - l} \tilde{l}_t$$

where  $\tilde{x}_t$  denotes the deviation of  $x_t$  from its steady state. This condition simply shows the trade off between consumption and leisure when marginal utility is constant where the trade off depends on  $\sigma$ . The linearized version of the labor-leisure first order condition is,

$$\tilde{w}_t = \tilde{c}_t + \frac{l}{1 - l} \tilde{l}_t.$$

This condition says that when there is a shock to wage, consumption and labor will fluctuate and there is a trade off between the fluctuation of the two. Combining the two conditions give

$$\tilde{c}_t = \frac{(1 - \Psi)(\sigma - 1)}{\sigma} \tilde{w}_t. \quad (20)$$

When  $\sigma = 1$ , the preference (4) takes the log form and is separable between consumption and leisure as  $u = \Psi \log(c_t) + (1 - \Psi) \log(1 - l_t)$ . In this case,  $u_c$  depends only on consumption so consumption should be flat, or in other words  $\tilde{c}_t = 0$ , on expectation<sup>18</sup>. Higher  $\sigma$  generates higher fluctuation of

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balance falls when net savings falls. This is not the case in the model with GHH preference.

<sup>17</sup>Since  $\pi$  is set arbitrarily small, the fluctuation in portofolio adjustment cost is negligible.

<sup>18</sup>On expectation, consumption should follow a flat path since portfolio adjustment cost is negligible. The decimal fluctuation of simulated consumption comes from expectational errors.

consumption and lower fluctuation of labor by affecting the trade off between the two. The fluctuation of simulated consumption and labor relative to data are 20% and 40% respectively with  $\sigma = 5$  whereas with  $\sigma = 2$  they are 13% and 55% and with  $\sigma = 1$  they are 6% and 74%.

The result that productivity can explain output fluctuation well is consistent with literature such as Cooley and Prescott (1995) which uses a standard closed economy real business cycle model and concludes that 78% of the postwar US output fluctuation can be attributed to productivity shocks<sup>19</sup>. The result that the benchmark model with Cobb-Douglas preference cannot explain the fluctuation of consumption is consistent with literature such as Correia, Neves and Rebelo (1995).

**Results with only Real Interest Rate Shocks** The sudden rise of real interest rates during the crisis affects the household through income and intertemporal substitution effects. The dotted line in figure 6 shows that the model with only real interest rates predicts labor and output to increase during the crisis. Since these results are counterfactual, they are reported as not applicable in table 4.

Given that Korea is a net borrower, high real interest rates cause negative income effects on consumption and leisure. High real interest rates also decrease current consumption and leisure through intertemporal substitution effects where real interest rate is the price of current goods relative to the price of future goods. Therefore current consumption decreases and current labor increases from both effects. Investment must fall in order to maintain the equality of real interest rates and the return on capital. Trade balance improves since the cost on borrowing rises dramatically when real interest rates increase.

Since the intertemporal elasticity of substitution is high when  $\sigma$  is low<sup>20</sup>, the household is willing to allow the period by period utility to fluctuate more so consumption and leisure will be more sensitive to real interest rate shocks. For instance, with  $\sigma = 5$  the fluctuation of simulated consumption relative to data is 40% whereas with  $\sigma = 2$  it is 87% and with  $\sigma = 1$  it is

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<sup>19</sup>The results cannot be directly compared since the countries, time frames and the frequencies of periods are different. More importantly, they report the average result of a large number of simulations using shocks drawn from a distribution whereas I report the single result using observed shocks during a crisis.

<sup>20</sup>The intertemporal elasticity of substitution is not exactly  $\frac{1}{\sigma}$  in this model because the periodical utility function includes both consumption and labor.

143%.

The result such that output will increase during a financial crisis is consistent with the result of Chari, Kehoe, and McGrattan (2005) which shows that the economy will expand when a country faces sudden stops in foreign capital inflows. The sudden stop in their model has the same effect as the real interest rate shock in my model<sup>21</sup>. They conclude that in order to generate an output drop during a sudden stop period, the model also needs a shock that depresses production. It turns out that even with productivity shocks, the model with Cobb-Douglas preference cannot predict an output drop during the financial crisis.

**Results with Productivity and Real Interest Rate Shocks** The key result for the model with Cobb-Douglas preference and both shocks is that the model fails to account for the fluctuation of output and labor.

As shown in figure 6, labor increases during the crisis because the increasing effect of real interest rate shocks dominate the decreasing effect of productivity shocks. The increase in labor dominates the direct negative effect of productivity drop on output and causes output to increase during the crisis. Hence, even with productivity shocks, the model predicts expansion during the financial crisis with Cobb-Douglas preference with  $\sigma = 1$ <sup>22</sup>.

### 4.3.2 Results with GHH Preference

The main result is that the benchmark model with GHH preference can account for all three key features of the Korean crisis extremely well taking productivity and real interest rate shocks as exogenous. Moreover, the impacts of both shocks are interesting. Productivity shocks explain most of the fluctuation in labor and output. Real interest rate shocks are important in explaining the large drop in consumption.

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<sup>21</sup>They assess effects of sudden stops implicitly using collateral constraints on foreign borrowing. In a general equilibrium model, the lagrangian multiplier on the binding constraint will appear in the bond Euler equation in a similar fashion as the real interest rate.

<sup>22</sup>With higher  $\sigma$  such as  $\sigma = 5$ , the labor increasing effect of real interest rates relatively weakens and output decreases while labor increases. With  $\sigma = 50$ , labor and output both decrease.

**Results with only Productivity Shocks** A striking result with GHH preference and only productivity shocks is that the volatility of consumption increased dramatically compared to the Cobb-Douglas preference case. However, as shown in table 5, the model with only productivity shocks can still only account for 61% on consumption volatility, which is not enough to explain the drop in consumption greater than output.

As in the Cobb-Douglas case, a drop in wage and rental rates reduce consumption from income and intratemporal substitution effects. However, since there is no income effect on labor in the GHH preference case, labor only depends on intratemporal substitution effect of wage decline. In other words, the marginal rate of substitution of labor on consumption  $\chi\nu l_t^{\nu-1}$  doesn't depend on consumption level so there is no trade off between the fluctuation of labor and consumption. In addition, as shown by the solid line in figure 7, the model correctly predicts the improvement in trade balance during the crisis unlike the Cobb-Douglas case. This implies that the household further reduced consumption by reducing borrowing in order to smooth marginal utilities over time. Thus, consumption fluctuates more than in the Cobb-Douglas preference case<sup>23</sup>.

The reason consumption fluctuates more than in the Cobb-Douglas case is because there is no income effect on labor with GHH preference. This can be shown with linearized equilibrium conditions. First, as in the Cobb-Douglas preference case, setting  $u_{c_t}$  constant gives the condition

$$\tilde{c}_t = \frac{\chi\nu l_t^{\nu}}{c} \tilde{l}_t.$$

This condition shows that consumption and labor will move proportionally in order to remain the marginal utility constant. It turns out that the results do not depend on  $\sigma$  because this condition is independent of  $\sigma$ . Next, linearizing the labor-leisure first order condition with GHH preference (8) gives,

$$\tilde{w}_t = (\nu - 1)\tilde{l}_t.$$

This shows that unlike the Cobb-Douglas case, there is no trade off between consumption fluctuation and labor fluctuation due to the lack of income

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<sup>23</sup>As mentioned above, GHH preference is a reduced form of home production. In this setting, a drop in market labor can be interpreted as an increase in home labor. Thus, the model implies that the decrease of consumption was compensated by home production.

effects on labor. A combination of these two gives,

$$\tilde{c}_t = \frac{\chi\nu l^\nu}{c(\nu-1)} \tilde{w}_t \quad (21)$$

where the labor elasticity is set equal to the labor elasticity in the Cobb-Douglas case with  $\sigma = 1$ . It turns out that  $\frac{(1-\Psi)(\sigma-1)}{\sigma} < \frac{\chi\nu l^\nu}{c(\nu-1)}$  for any value of  $\sigma \geq 1$  so that the reaction of consumption in the GHH case is larger than that in the Cobb-Douglas case from (20) and (21).

Generating countercyclical trade balance with GHH preference through large consumption volatility was a major triumph in the small open economy real business cycle literature such as Mendoza (1991) and Correia, Neves and Rebelo (1995). However, the model still cannot predict the fall in consumption to be greater than the fall in output during the Korean crisis. Therefore, the GHH model with only productivity shocks is not enough to explain the Korean crisis.

**Results with only Real Interest Rate Shocks** Unlike the Cobb-Douglas case, the model with GHH preference cannot generate fluctuation in current labor and output because there is no income nor intertemporal substitution effects on current labor. As shown by the dotted line in figure 7, labor and output do not react immediately to the rise in real interest rates but react in the next period through the drop of investment during the crisis. Trade balance improves because the borrowing cost is higher when real interest rates increase as in the Cobb-Douglas case.

From the production function and the labor first order condition, it can be shown that real interest rate shocks cannot generate fluctuation in current labor and output with GHH preference. The production function (13) gives

$$\tilde{y}_t = (1 - \theta) \tilde{l}_t$$

since  $\tilde{z}_t = 0$  and  $k_t$  is predetermined. Combining the household labor-leisure first order condition (8) and the firm first order condition (16) gives

$$\tilde{y}_t = \nu \tilde{l}_t.$$

Given that  $\nu \neq (1 - \theta)$ , the only solution to the two equations is  $\tilde{y}_t = \tilde{l}_t = 0$ . In other words, current labor and output do not react to real interest rate shocks since there are no income nor intertemporal substitution effects on

current labor. On the other hand, future labor and output are affected by the drop of current investment. The relationship between the fluctuation of future output and capital stock can be shown by the production function (13), labor first order condition (8), and the firm first order condition (16). Combining the equations for period  $t + 1$  and  $\widetilde{z}_{t+1} = 0$  we get,

$$\widetilde{y}_{t+1} = \frac{\nu\theta}{\nu + \theta - 1} \widetilde{k}_{t+1} = \nu \widetilde{l}_{t+1}$$

where  $0 < \frac{\nu\theta}{\nu + \theta - 1} < 1$ . Thus, as future capital decreases in response to high real interest rates, future labor and output will fall as well. Since the data shows that the increase in real interest rates and the Korean crisis occurred in the same period, this cannot be the main source of output and fluctuation.

The impact of real interest rate shocks on consumption works in the same manner as in the Cobb-Douglas case. Table 5 shows that when  $\sigma$  is low the consumer allows consumption to fluctuate more. However, labor and output do not depend on  $\sigma$  because the degree of consumption smoothing does not affect labor supply.

**Results with Productivity and Real Interest Rate Shocks** The main finding is that with GHH preference, the model can explain all three key features of the Korean crisis extremely well given both real interest rate and productivity shocks. Moreover, most of the depression and recovery of labor and output is explained by productivity shocks whereas real interest rate primarily affects the economy through the division of output between consumption, investment and trade balance.

The success of the model with both shocks is summarized both in table 5 and figure 7. All variables react to real interest rate and productivity shocks through the same mechanism as in the single shock cases. Labor and output are mainly affected by changes in productivity since there is no income nor intertemporal substitution effects on current labor. Hence, labor falls solely in response to the fall in productivity through the intratemporal substitution effect during the crisis. Output unambiguously falls because of the direct effect of productivity drop and the decrease in labor. Real interest rate does not affect current output because with the GHH preference there is no income nor intertemporal substitution effects on current labor. The main impact the real interest rate has on the economy is shifting the division of output between consumption, investment and trade balance. In particular,



high real interest rates cause consumption and investment to fall and trade balance to improve. This role of real interest rate shocks is important since without it the model cannot account for the drop of consumption greater than the drop of output during the crisis.

The result such that real interest rate shocks do not affect current labor or output is surprising because conventional wisdom says that high real interest rates have large depressing effects on the economy. In the following section I will show that the potential roll of this effect is limited.

## 5 Working Capital on Labor

In this section I introduce a model in which high real interest rates have depressing effects on current labor and output due to borrowing cost on wage payments. The main result is that this channel is insufficient to explain the output drop in Korea during the crisis.

In the benchmark model, high real interest rates depress investment which in turn depress production in the future. However, in order to explain the output drop in current output with the rise in real interest rates, it must have a depressing effect on current labor. Christiano and Eichenbaum (1992) introduced the ‘working capital’ assumption on labor in a closed economy setting and created a labor market distortion which depends on real interest rates. They assume that firms have to borrow a fixed fraction of the wage-bill from abroad due to a friction in technology to process the wage payment to the household. When the real interest rate is high, hiring labor becomes costly so that labor demand falls. Neumeyer and Perri (2005) adopted this structure into the small open economy framework and generated business cycles that are negatively correlated to real interest rate fluctuations.

The fraction of wage that must be paid in advance is fixed at  $0 \leq \Omega \leq 1$  such that the firm will borrow  $\Omega w_t l_t$  in the beginning of the period and payback  $\left(1 + \left(1 - \frac{1}{R_t}\right)\right) \Omega w_t l_t$  at the end of the period. This additional cost accrues within the period so the firm’s problem remains static. The firm’s problem is now

$$\max \pi_t = y_t - \left(1 + \left(1 - \frac{1}{R_t}\right) \Omega\right) w_t l_t - r_t k_t \quad (22)$$

rather than (14). As a result, the firm's first order condition for labor will be

$$w_t = \frac{(1 - \theta)R_t}{R_t + (R_t - 1)\Omega} \frac{y_t}{l_t} \quad (23)$$

rather than (16). Trade balance is redefined as

$$tb_t = -\Gamma \frac{d_{t+1}}{R_t} + d_t + \frac{(1 - \theta)(R_t - 1)\Omega}{R_t + (R_t - 1)\Omega} y_t \quad (24)$$

rather than (19) where the additional term is the cost of working capital, which is paid to international investors.

For all simulations,  $\Omega$  is set at  $\Omega = 1$  while productivity shocks are set at zero for all periods. Hence, the only type of shocks to the economy are the real interest rate shocks. The main results are summarized in table 6 and figure 8.

With Cobb-Douglas preference, the model predicts an increase in labor during the crisis even in the limit case where  $\Omega = 1$ . The income effect on labor from high real interest rates dominates the additional depressing effect of working capital on labor such that labor and output fluctuate in the opposite direction as in the benchmark model for reasonable values of  $\sigma$ . With an extremely high  $\sigma$  the model can predict a drop of labor in 1998 since the depressing effect dominates the income and intertemporal substitution effects of high interest rates. However, the model cannot quantitatively account for more than 35% of labor fluctuation for any value of  $\sigma$ .

With GHH preference, the model with working capital on labor matches the magnitude of labor fluctuation exactly. However, the model can only account for 54% of the output fluctuation. Intuitively speaking, setting productivity equal to zero for all periods forces the model to omit part of the output fluctuation. The higher the  $\sigma$  the smaller the consumption fluctuation whereas labor and output fluctuation do not depend on  $\sigma$ .

From these results, the Cobb-Douglas preference case is once again unable to account for the crisis. Even with GHH preference, the model with real interest rate shocks and working capital on labor can explain only 54% of output fluctuation. In contrast, the benchmark model with productivity shocks can explain over 90% of output fluctuation. Therefore, productivity is the key shock for output fluctuation. In the following section, I consider the relationship between the financial crisis and productivity shocks in order to make a deeper assessment on productivity shocks during the Korean crisis.

## 6 Endogenous Productivity Shocks

In this section, I extend the model to deepen the understanding of productivity shocks during the Korean crisis. The benchmark model is modified in order to assess whether the sudden rise in real interest rates, i.e. the financial crisis, can cause a fall in measured productivity during the Korean crisis.

First I introduce endogenous capacity utilization with working capital on labor. In this model high real interest rates reduce labor demand which reduces the marginal product of effective capital stock. This leads to a reduction in capacity utilization which appears as a fall in productivity. Second, I introduce working capital on intermediate goods. In this model high real interest rates make the intermediate good expensive and cause a shift in the production mix which shows up as a drop in productivity. The results show that the quantitative impact of real interest rates on measured productivity through these two channels are limited.

### 6.1 Endogenous Capacity Utilization

One can argue that during the financial crisis, firms cut back the utilization of existing capital stock which appears as a fall in measured productivity. In this section, I show that endogenous capacity utilization can not fully explain the fluctuation of measured productivity during the Korean crisis.

I follow Greenwood, Hercowitz and Huffman (1988) and assume endogenous capacity utilization. Capacity utilization will increase production but is also costly because the higher the utilization, the faster the capital stock depreciates. In their model an exogenous disturbance to the marginal return on investment affects the marginal return on utilization and causes the economy to fluctuate. Meza and Quintin (2005) introduces endogenous capacity utilization as an amplification mechanism of exogenous productivity shocks. Gertler, Gilchrist and Natalucci (2003) introduces endogenous capacity utilization in a sticky price setting given real interest rate shocks. Instead, in my model real interest rate shocks will affect labor demand because of the working capital assumption on labor and thus, affects the marginal return on capacity utilization.

The firm faces a working capital requirement on labor as in the previous section. The firm hires labor and effective capital  $u_t k_t$  for production. The

profit maximization problem is now

$$\max \pi_t = y_t - \left(1 + \left(1 - \frac{1}{R_t}\right) \Omega\right) w_t l_t - r_t u_t k_t \quad (25)$$

rather than (14) where  $u_t$  is capacity utilization and

$$y_t = (u_t k_t)^\theta l_t^{1-\theta} \quad (26)$$

rather than (13). The first order condition for effective capital is

$$\theta \frac{y_t}{u_t k_t} = r_t \quad (27)$$

rather than (15). The firm is indifferent between capacity utilization and capital stock because they are linear products in both production and cost.

The household budget constraint changes to

$$w_t l_t + r_t u_t k_t + \frac{\Gamma d_{t+1}}{R_t} = c_t + i_t + d_t + \phi \frac{(k_{t+1} - k_t)^2}{2} + \pi \frac{(d_{t+1} - d)^2}{2} \quad (28)$$

rather than (6) assuming that the household is renting effective capital  $u_t k_t$ , where the capital accumulation equation is

$$i_t = \Gamma k_{t+1} - (1 - \delta u_t^\varpi) k_t \quad (29)$$

rather than (7).  $\delta u_t^\varpi$  is the endogenous depreciation rate where the value  $\varpi = 1.42$  was borrowed from Greenwood, Hercowitz and Huffman (1988). The steady state value of  $u_t$  is chosen to be one in order to make the steady state depreciation rate equal to  $\delta$ . The capital Euler equation (9) changes to

$$u_{c_t} (\Gamma + \phi(k_{t+1} - k_t)) = \beta E_t [u_{c_{t+1}} \{r_{t+1} + 1 - \delta u_t^\varpi + \phi(k_{t+2} - k_{t+1})\}] \quad (30)$$

The optimality condition for utilization is

$$r_t = \delta \varpi u_t^{\varpi-1}. \quad (31)$$

Everything else is the same as the model with working capital on labor presented in the previous section.

The model reduces to a single shock model where the only shock is real interest rate shocks while measured productivity fluctuates endogenously.

The mechanism of this additional feature works as follows. Given the rise in real interest rates, labor demand falls because of the working capital assumption. The fall in labor input reduces the marginal return on effective capital,  $u_t k_t$ . Since capital stock is predetermined, utilization will fall. The fall in utilization will reduce output since effective capital is an input.

Figure 9 and table 7 summarize the results for the model with  $\sigma = 1$ . In addition to the variables presented in previous sections, I also present the fluctuation of measured productivity. In this model, measured productivity is obviously  $u_t^o$  from (13) and (26).

With Cobb-Douglas preference, labor fluctuates in the opposite direction even in the limit case  $\Omega = 1$  because the income and intertemporal substitution effects from real interest rate shocks dominate the working capital cost as in the previous section. Labor increases during the crisis, which increases the marginal product of effective capital. Thus, utilization increases which causes a further increase in output in addition to the effect from labor increase<sup>24</sup>.

For the GHH case,  $\Omega$  was set at  $\Omega = 0.67$  in order to match the volatility of labor to data. Although the fluctuation of labor is explained well, the fluctuation of output cannot be explained well compared to the case in which productivity shocks are taken as exogenous. The reason is because the model can only explain 36% of the measured productivity fluctuation<sup>25</sup>. Hence, the role of endogenous capacity utilization seems to be limited.

## 6.2 Intermediate Good Model

Next, I consider a case in which real interest rate shocks affect the firm's measured productivity through working capital on intermediate goods. Under this assumption, firms have to borrow from abroad in advance of production in order to pay for intermediate goods. The results show that this additional feature cannot explain the fluctuation of measured productivity well.

The model is a simplified version of the model in Chari, Kehoe and McGrattan (2005) in which the inefficiency in borrowing is observationally equivalent to a fall in productivity. The firm produces aggregate gross output  $q_t$

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<sup>24</sup>With an extremely high  $\sigma$  the model with Cobb-Douglas preference predicts labor and output to fall in 1998. However, the model cannot explain for more than 21% productivity fluctuation and 35% of output fluctuation for any value of  $\sigma$ .

<sup>25</sup>Even in a limit case in which  $\omega = 1$  such that the depreciation rate is a linear function of utilization, the model can only explain 57% of productivity fluctuation.

from capital, labor and the intermediate good  $m_t$ . I assume working capital on the intermediate good such that the firm must borrow  $\Omega m_t$  from abroad in the beginning of the period in order to process intermediate goods where  $0 \leq \Omega \leq 1$ . After production occurs, the firm pays back  $\left(1 + \left(1 - \frac{1}{R_t}\right)\right) \Omega m_t$ . Final output is defined as gross output  $q_t$  net of intermediate goods  $m_t$  such that  $y_t = q_t - m_t$ .

The firm's problem will be

$$\max \pi_t = q_t - w_t l_t - r_t k_t - \left(1 + \left(1 - \frac{1}{R_t}\right) \Omega\right) m_t \quad (32)$$

rather than (14), where I assume

$$q_t = m_t^\alpha (k_t^{\widehat{\theta}} l_t^{1-\widehat{\theta}})^{1-\alpha}. \quad (33)$$

$\widehat{\theta}$  is no longer equal to the capital share  $\theta$  in the national income accounting sense. I show the mapping from  $\theta$  to  $\widehat{\theta}$  in the appendix. The firm's first order conditions will be

$$1 + \left(1 - \frac{1}{R_t}\right) \Omega = \alpha \frac{q_t}{m_t}, \quad (34)$$

$$r_t = (1 - \alpha) \widehat{\theta} \frac{q_t}{k_t} \quad (35)$$

rather than (15) and

$$w_t = (1 - \alpha)(1 - \widehat{\theta}) \frac{q_t}{l_t} \quad (36)$$

rather than (16).

The household's problem and resource constraint are identical to those in the benchmark model. Trade balance is now defined as

$$tb_t = -\Gamma \frac{d_{t+1}}{R_t} + d_t + \left(1 - \frac{1}{R_t}\right) \Omega m_t$$

rather than (19).

As in the previous section, measured productivity<sup>26</sup> fluctuates endogenously. In this model, high real interest rates increase the cost of intermediate goods. This exogenous shock to the input cost will show up as a drop of measured productivity through the shift in factor allocation.

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<sup>26</sup>The computation of measured productivity fluctuation is provided in the appendix.

Figure 10 and table 7 show the results of the intermediate good model with  $\sigma = 1$ .  $\Omega = 1$  was chosen to maximize the effect of the real interest rate shocks on intermediate goods. The average intermediate goods to gross output ratio for the 1980-2002 period was used to calibrate  $\alpha = 0.65$  from (34).

For the intermediate good model with Cobb-Douglas preference, the key effects of the real interest rate rise are twofold. On one hand, high real interest rates make the intermediate good costly. The effect on labor depends on the elasticity of substitution between inputs. On the other hand, as previous results, high real interest rates have income and intertemporal substitution effects on labor. Once again income and intertemporal substitution effects on labor are so strong that the model predicts an increase in labor during the crisis. This increases the marginal product of the intermediate good. The direct effect on the intermediate goods dominates the secondary effect in this case such that the intermediate goods and measured productivity fall during the crisis<sup>27</sup>. In this setting, the labor increase offsets the effect of the intermediate goods decrease on output<sup>28</sup>.

With GHH preference, the model can explain only 29% of the fluctuation of productivity. Another issue is that the model predicts the trough of final output to be in 1999, not 1998. The key effect of high real interest rates is that they reduce demand for the intermediate goods as in the Cobb-Douglas case. In addition, high interest rates depress investment and consequently future capital stock. In this setting, intermediate goods increase as real interest rates fall in 1999 whereas gross output remains low because of low capital stock. Thus, the trough of final output which is defined as the difference between gross output and intermediate goods is predicted to be in 1999. High  $\sigma$  reduces consumption fluctuation while labor, output and productivity fluctuation do not depend on  $\sigma$  as in previous results.<sup>29</sup>

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<sup>27</sup>The relationship between intermediate goods and measured productivity is stated in the appendix.

<sup>28</sup>With high  $\sigma$  such as  $\sigma = 5$ , the second effect becomes relatively small such that the model predicts labor and final output to fall in 1998. However, the model cannot account for more than 45% of productivity fluctuation for any value of  $\sigma$ .

<sup>29</sup>The Cobb-Douglas production function is a special case of a general form  $q_t = \left( \alpha^{\frac{1}{\epsilon}} m_t^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha)^{\frac{1}{\epsilon}} \left( k_t^{\hat{\theta}} l_t^{1-\hat{\theta}} \right)^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}}$  where the elasticity of substitution  $\epsilon = 1$ . With higher elasticity of substitution, the fluctuation of measured productivity will be greater. For instance, with  $\epsilon = 1.2$ , the model can explain 77% of the productivity fluctuation. Note that in terms of productivity fluctuation relative to output fluctuation, this number

## 7 Conclusion

After many years of very high growth and very little volatility, Korea has experienced a ‘roller-coaster’ like macro activity in late 1990s. The three puzzles of the Korean crisis are the sudden recession, the rapid rebound of output, and the consumption drop even greater than the output drop. I construct a canonical small open economy dynamic general equilibrium model in order to address these puzzles. The main result is that the model with GHH preference taking real interest rate and productivity shocks as exogenous can quantitatively account for all three features extremely well. Moreover, the quantitative analysis shows that the driving force of the recession and recovery of output and labor is productivity whereas real interest rate shocks are important to explain the large drop of consumption. Thus, if there is anything to blame for the economic downturn, it must be causing a temporary drop in productivity.

One candidate of the explanation for temporary productivity drop can be a temporary loss of ‘organizational capital’, i.e. “the knowledge and know-how firms use to organize production” as in Ohanian (2001). I conjecture that organizational capital was lost due to a shift in managerial labor from planning and organizing production towards finding alternative funds during the banking crisis or looking for alternative business relationships when firm bankruptcies occurred. For instance, Koo and Kiser (2001) states that credit crunch was mild in Korea compared to other Asian countries because the corporate sector was able to counter the reduction of bank loans with commercial bond and equity issues. Also, Bongini, Ferri and Hahm (2000) shows that more than 11% of listed non-financial firms filed for bankruptcy during the crisis. As revealing the source of productivity shocks is beyond the scope of this paper, the modeling and measurement of organizational capital is left for future research.

Finally, it is interesting to see how well productivity and interest rate shocks account for the macro performance in other Asian countries during the crisis. As shown in section 2, while other East Asian countries experienced considerably large drops in output and consumption in 1998, they showed recovery patterns different from Korea. It remains to be examined to what extent the neoclassical model can explain the differences and similarities in

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reduces to 47% as the model explains 165% of output fluctuation. For values larger than  $\epsilon = 1.3$ , the model becomes unstable and reliable results cannot be obtained.



macroeconomic performances in these countries during the crisis.

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## 8 Appendix

### 8.1 Computation of Trend

TFP can be divided into fluctuation and trend as,

$$\ln SR_t = (1 - \theta) \ln X_t + \ln z_t.$$

From the assumption of constant growing labor augmenting technical progress,  $X_t = (1 + \gamma)^t X_0$  so

$$\ln X_t = t \ln(1 + \gamma) + \ln X_0.$$

Thus,

$$\ln SR_t = \alpha_1 + \alpha_2 t + \varepsilon_t$$

where

$$\begin{aligned}\alpha_1 &= (1 - \theta) \ln X_0, \\ \alpha_2 &= (1 - \theta) \ln(1 + \gamma), \\ \varepsilon_t &= \ln z_t.\end{aligned}$$

Therefore, the growth rate of labor augmenting technical progress can be estimated by,

$$\gamma \approx \ln(1 + \gamma) = \frac{\alpha_2}{1 - \theta}.$$

where the residuals to this regression is productivity  $\ln z_t$ .

### 8.2 Calibration of GHH Parameters

The parameter  $\nu$  was calibrated to match the wage elasticity of labor in the GHH preference with that of the Cobb-Douglas preference following Correia, Neves, and Rebelo (1995).  $\chi$  was calibrated to match the steady state level of labor.

Setting  $u_c$  constant and linearizing  $u_c$  for the Cobb-Douglas preference around the steady state yields,

$$\tilde{c}_t = \frac{(1 - \Psi)(1 - \sigma)}{\Psi(1 - \sigma) - 1} \frac{l}{1 - l} \tilde{l}_t.$$

Next, linearizing the labor first order condition around the steady state and substituting the condition above yields,

$$\frac{\sigma l}{1 - \Psi(1 - \sigma)} \tilde{l}_t = (1 - l) \tilde{w}_t.$$

Thus, the constant marginal utility of consumption wage elasticity of labor for the Cobb-Douglas preference is,

$$\left[ \frac{\partial l_t}{\partial w_t} \right]_{\bar{w}_c}^{Cobb-Douglas} = \frac{1 - \Psi(1 - \sigma)}{\sigma} \frac{1 - l}{l}.$$

On the other hand, the wage elasticity of labor for the GHH preference is,

$$\left[ \frac{\partial l_t}{\partial w_t} \right]^{GHH} = \frac{1}{\nu - 1}.$$

Setting these two equal,

$$\nu = 1 + \frac{\sigma}{1 - \Psi(1 - \sigma)} \frac{l}{1 - l}. \quad (37)$$

Once we calibrate  $\nu$  we can calibrate  $\chi$  from the steady state version of the labor first order condition in equilibrium to get

$$\chi = \frac{1 - \theta}{\nu} \frac{y}{l^\nu}. \quad (38)$$

### 8.3 Mapping Parameters from the GHH model to the Intermediate Good Model

In this section, I will show how some parameters can be mapped from the GHH model to the intermediate good model. I also show how the measured productivity can be computed.

#### 8.3.1 $\hat{\theta}$

I assume that  $\beta$  is equal in the benchmark model and the intermediate good model. Therefore from (15) and (35),

$$(1 - \alpha) = \frac{y \theta}{q \hat{\theta}} \quad (39)$$

And from (34) and the fact that  $y = q - m$ ,

$$\frac{y}{q} = 1 - \frac{\alpha R}{R + (R - 1)\Omega}.$$

Combining these with (33),

$$\widehat{\theta} = \frac{(1 - \alpha)R + (R - 1)\Omega}{(1 - \alpha)(R + (R - 1)\Omega)}\theta$$

where  $\widehat{\theta} > \theta$ .

### 8.3.2 $\widehat{\chi}$ and $\widehat{\nu}$

From (36) and (39),

$$w_t = (1 - \widehat{\theta})\frac{\theta y_t}{\widehat{\theta} l_t}.$$

Thus, from (8) and (11)

$$\widehat{\Psi} = \frac{1}{1 + (1 - \widehat{\theta})\frac{\theta y}{\widehat{\theta} c} \frac{1-l}{l}}.$$

$\chi$  and  $\nu$  are adjusted accordingly as

$$\widehat{\nu} = 1 + \frac{\sigma}{1 - \widehat{\Psi}(1 - \sigma)} \frac{l}{1 - l}$$

and

$$\widehat{\chi} = (1 - \widehat{\theta})\frac{\theta y}{\widehat{\theta} \widehat{\nu} l^{\widehat{\nu}}}.$$

### 8.3.3 Measured Productivity

The linearized version of (33) gives

$$y\widetilde{y}_t + m\widetilde{m}_t = \alpha q\widetilde{m}_t + (1 - \alpha)q(\widehat{\theta}\widetilde{k}_t + (1 - \widehat{\theta})\widetilde{l}_t).$$

Using (39), this can be rewritten as

$$y\widetilde{y}_t = \left(\alpha \frac{q}{m} - 1\right) m\widetilde{m}_t + y\frac{\theta}{\widehat{\theta}}(\widehat{\theta}\widetilde{k}_t + (1 - \widehat{\theta})\widetilde{l}_t)$$

Thus, from linearized version of (13),

$$\widetilde{z}_t = \left(\alpha \frac{q}{m} - 1\right) \frac{m}{y}\widetilde{m}_t - \left(\frac{\widehat{\theta} - \theta}{\widehat{\theta}}\right)\widetilde{l}_t.$$

## 9 Tables and Figures

Table 1. Growth and Stability of Asian Countries (1980-1997)<sup>30</sup>

	$g^y$	$std$
<i>HongKong</i>	3.87	3.31
<i>Indonesia</i>	4.11	2.07
<i>Malaysia</i>	4.00	3.11
<i>Singapore</i>	4.74	3.27
<i>Thailand</i>	4.63	3.23
<i>Korea</i>	5.60	1.76

Table 2. Summary Statistics of Asian Countries<sup>31</sup>

	$y_{98}$	$g_{98}^y$	$g_{97}^c/g_{97}^y$
<i>HongKong</i>	-0.050	1.31	1.11
<i>Indonesia</i>	-0.055	-1.38	0.59
<i>Malaysia</i>	-0.034	2.92	1.27
<i>Singapore</i>	-0.005	3.50	1.26
<i>Thailand</i>	-0.081	2.37	0.91
<i>Korea</i>	-0.087	9.19	1.44

Table 3. Parameter Values of The Benchmark Model

$\theta$	Capital Share	0.297
$\beta$	Discount Factor	0.967
$\delta$	Depreciation Rate	0.037
$\Psi$	Consumption-Leisure Parameter	0.263
$\Gamma$	Growth Trend	1.061
$\nu$	Curvature Parameter of GHH Preference	1.34
$\chi$	Level Parameter of GHH Preference	1.17
$\rho_z$	Persistence of Productivity Shocks	0.80
$\rho_s$	Persistence of Real Interest Rate Shocks	0.65

<sup>30</sup>  $g^y$  stands for the average percentage growth rate of real GDP per adult.  $std$  stands for the standard deviation of GDP per adult growth rates.

<sup>31</sup>  $y_{98}$  stands for the deviation of GDP per capita in 1998 relative to its trend.  $g_{98}^y$  is the percentage growth rate of real GDP per adult between 1998 and 1999.  $g_{97}^c/g_{97}^y$  is the ratio of the growth rates of real consumption to real GDP per adult between 1997 and 1998.

Table 4. Simulation Results: Cobb-Douglas Preference<sup>32</sup>

	$\sigma = 1$			$\sigma = 2$			$\sigma = 5$		
	$Z$	$R$	$Z\&R$	$Z$	$R$	$Z\&R$	$Z$	$R$	$Z\&R$
$\sigma^y/\sigma_{data}^y$	0.85	<i>n.a.</i>	<i>n.a.</i>	0.75	<i>n.a.</i>	<i>n.a.</i>	0.67	<i>n.a.</i>	0.46
$\sigma^l/\sigma_{data}^l$	0.74	<i>n.a.</i>	<i>n.a.</i>	0.55	<i>n.a.</i>	<i>n.a.</i>	0.41	<i>n.a.</i>	<i>n.a.</i>
$\sigma^c/\sigma_{data}^c$	0.06	1.43	1.47	0.13	0.87	0.97	0.20	0.40	0.57

Table 5. Simulation Results: GHH Preference

	$\sigma = 1$			$\sigma = 2$			$\sigma = 5$		
	$Z$	$R$	$Z\&R$	$Z$	$R$	$Z\&R$	$Z$	$R$	$Z\&R$
$\sigma^y/\sigma_{data}^y$	0.92	0.13	0.96	0.92	0.13	0.96	0.92	0.13	0.96
$\sigma^l/\sigma_{data}^l$	0.87	0.13	0.90	0.87	0.13	0.90	0.87	0.13	0.90
$\sigma^c/\sigma_{data}^c$	0.61	0.44	1.03	0.61	0.25	0.85	0.61	0.14	0.75

Table 6. Simulation Results: Modified Models with  $\sigma = 1$ <sup>33</sup>

	WKL		CU		IMG	
	$CD$	$GHH$	$CD$	$GHH$	$CD$	$GHH$
$\sigma^y/\sigma_{data}^y$	<i>n.a.</i>	0.54	<i>n.a.</i>	0.70	<i>n.a.</i>	1.88
$\sigma^l/\sigma_{data}^l$	<i>n.a.</i>	1.00	<i>n.a.</i>	1.00	<i>n.a.</i>	2.20
$\sigma^c/\sigma_{data}^c$	1.46	1.09	1.38	1.01	1.45	1.47
$\sigma^z/\sigma_{data}^z$	<i>n.a.</i>	<i>n.a.</i>	<i>n.a.</i>	0.36	0.55	0.29

<sup>32</sup>Standard deviation of simulated series relative to data.  $Z$ ,  $R$  and  $Z\&R$  stand for simulations with productivity shocks, real interest rate shocks and both.

<sup>33</sup>WKL stands for the model with working capital on labor. CU stands for the model with endogenous capacity utilization. IMG stands for the model with intermediate goods. CD and GHH stand for Cobb-Douglas preference and GHH preference respectively.



Figure 1. Korean Production Factors<sup>34</sup>

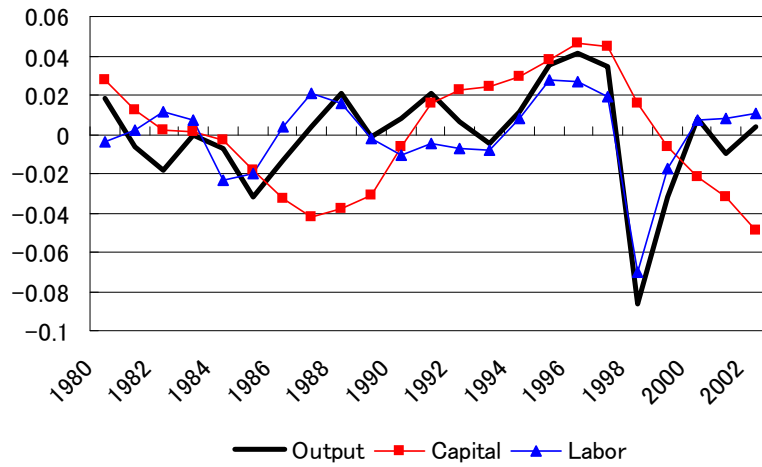
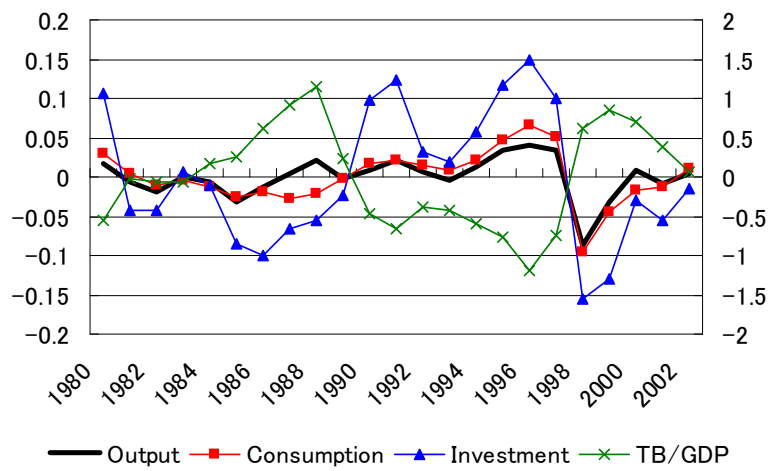


Figure 2. Korean GDP Components<sup>35</sup>



<sup>34</sup>Source: Pyo (2003) for capital stock Korea National Statistical Office Statistical Database (KOSIS) for labor.

<sup>35</sup>Source: Korea National Statistical Office Statistical Database (KOSIS)

Figure 3. Asian Output and Consumption (1980-2002)<sup>36</sup>



<sup>36</sup>Source: World Bank “World Development Indicators” except for Korea

Figure 4. Output and Real Interest Rates<sup>37</sup>

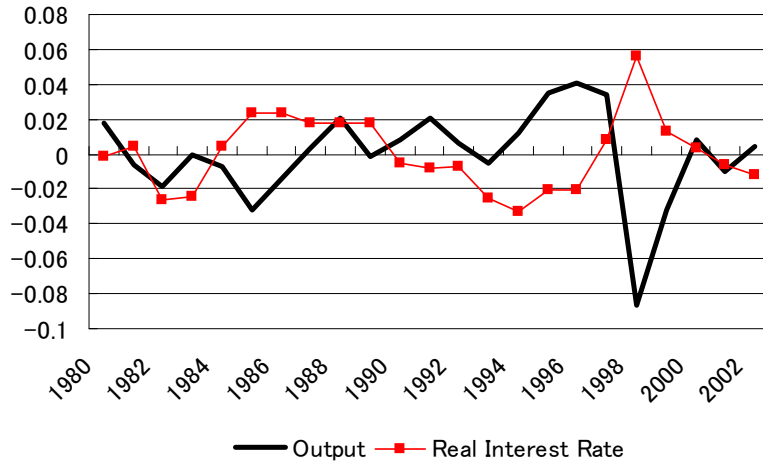
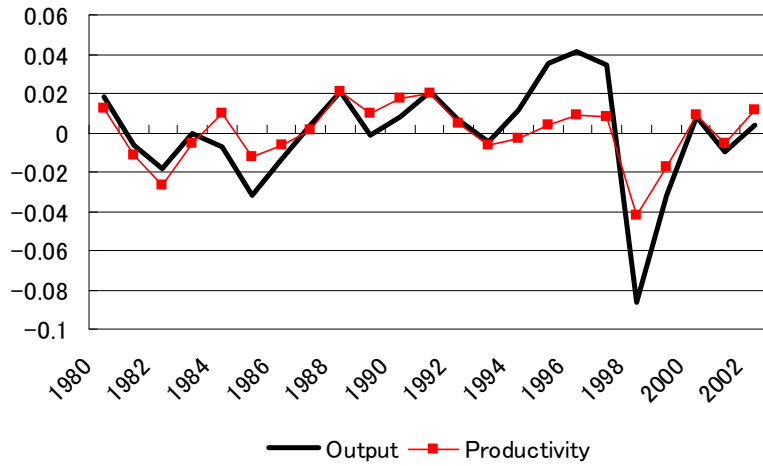


Figure 5. Output and Productivity<sup>38</sup>



<sup>37</sup>Source: Korea National Statistical Office Statistical Database (KOSIS) for output, IMF “International Financial Statistics” for real interest rate.

<sup>38</sup>Source: Korea National Statistical Office Statistical Database (KOSIS) for output, author’s calculation for productivity.

Figure 6. Result: Benchmark Model with Cobb-Douglas Preference with  $\sigma = 1$



Figure 7. Result: Benchmark Model with GHH Preference with  $\sigma = 1$



Figure 8. Result: Model with Working Capital on Labor with  $\sigma = 1$

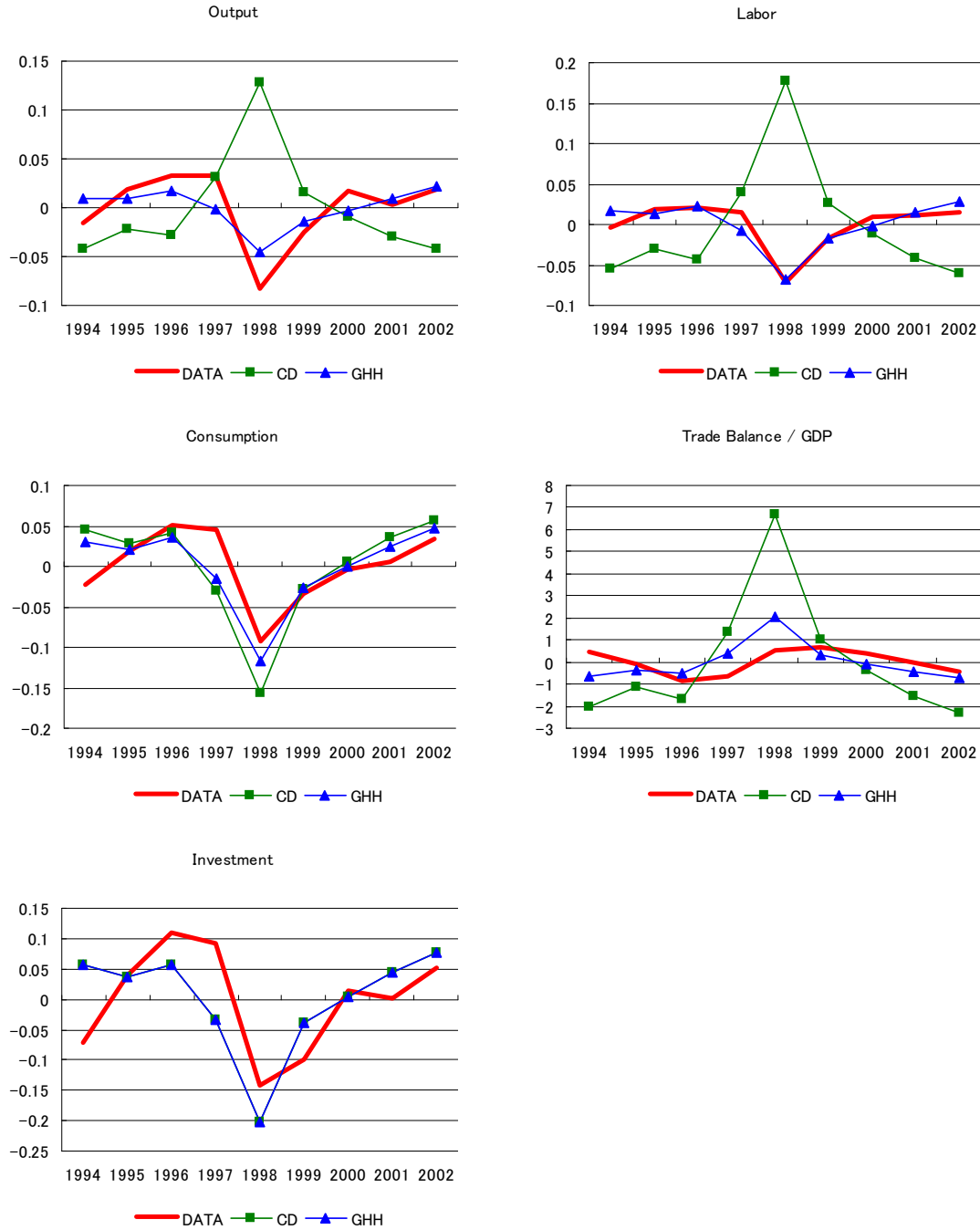


Figure 9. Result: Model with Endogenous Capacity Utilization with  $\sigma = 1$

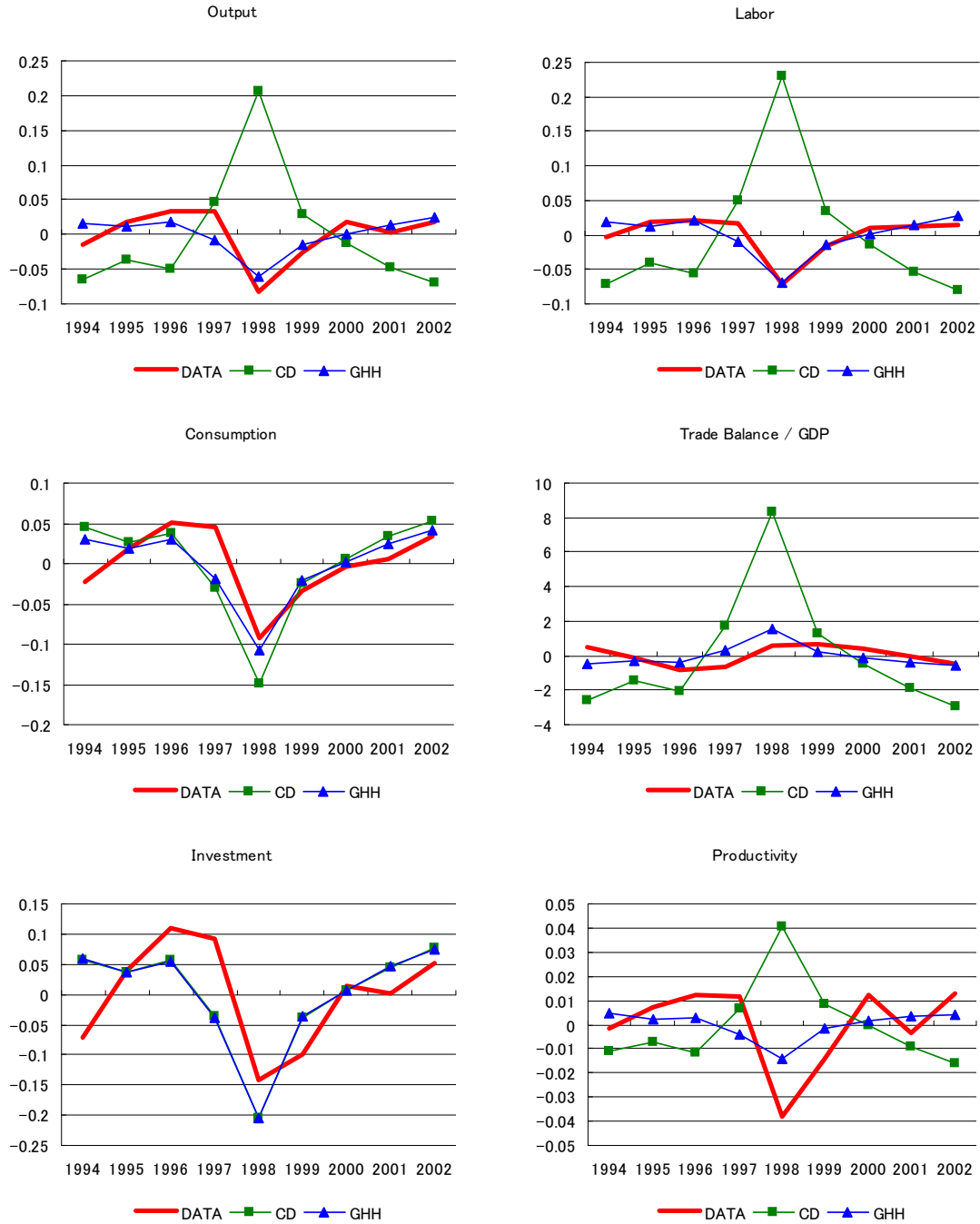


Figure 10. Result: Intermediate Good Model with  $\sigma = 1$

