

**International Real Business Cycle Model
with Human Capital and Skill Acquisition Activities***

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This paper investigates whether an international real business cycle model with human capital can explain business cycles in a small open economy. Our model is parameterised and calibrated and incorporates investment-specific technology shocks and human capital into the neoclassical framework. Our model is able to duplicate many of the stylized facts of business cycles in Korea. Human capital in a small open economy plays a useful role in explaining economic fluctuations, and skill acquisition activities are countercyclical. Capital utilization effectively performs the role of intratemporal channel of the shock that leads comovement of labour supply with investment-specific technology.

JEL Classification: E32, F17

Keywords: real business cycles, human capital, skill acquisition activities, capacity utilization

* Received February 27, 2006. Accepted September 15, 2006.

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1. INTRODUCTION

Interest in the relationship between human capital formation and economic growth is both extensive and enduring. Since Romer (1986) and Lucas (1988) emphasize investment in human capital as an important factor contributing to growth, research on business cycles of the economy with human capital has been conducted in several areas. Specifically, Davies and Whalley (1989) suggest that the stock of human capital is about three times as large as the stock of physical capital. Lucas (1988), Rebelo (1991), Caballé and Santos (1993), and In and Doucouliagos (1997) also emphasize that human capital accumulation could be the crucial factor in economic growth and development. Greenwood and Yorukoglu (1997) has introduced IT (information technology) and addressed the relationship between IT and skilled labour. Their basic idea is that the adoption of new technology involves a significant cost in terms of learning, and that the cost of skilling labour needs, to be embodied in the new machines. From these ideas, our point of view is that the development and growth of new technology require human capital.

The economy with human capital has a few important features. First, the accumulation of human capital has a substitution with competing labour activities. Dellas and Sakellaris (1995) show empirical evidence that there is significant substitution between education and labour activities during the business cycle. Generally, during an economic contraction period, unemployment increases, and unemployed labourers will search for new jobs or participate in learning new technology and knowledge to better equip them for a new job. A question is, during the economic contraction, whether unemployment will increase or not. Gordon (1982) found that if real wages are flexible, unemployment does not increase seriously during economic contraction. This result indicates that there is not necessarily substitution between education and labour activities. Second, the education for formation of human capital is achieved by both the public and private sectors. Accordingly, the tax for public education affects economic fluctuation. King

and Rebelo (1990) and Rebelo (1991) examined the effect of taxation on growth and found that long run growth seriously distorted. Lucas (1988) also found that growth and taxation in an endogenous growth model with human capital have a negative effect on welfare. Third, above all, new technology should be accompanied by skilled labour and human capital. Greenwood and Yorukoglu (1997) have pointed out that, as new technology is rapidly developed, more skilled labour is necessary to implement and operate the new inventions. Accordingly, technological progress is based on the accumulation of human capital demanding more time and higher cost. Fourth, the time devoted skill acquisition in formal and informal activities are not directly measurable. Moreover, Lee and Lee (2006) discovered that education does not seem always appear to provide the necessary job skills in Korea. As DeJong (2001) argued, skill acquisition activities are often measured with considerable error and, are rarely recorded on time series basis. Barron, Berger, and Black (1997) also suggest that there is a great deal of error in measure of training. Especially, informal training does not be estimated correctly.

In our paper, we build a small open economy model by incorporating human capital accumulation in the business cycle. Our model differs from previous works at least in three novel respects.

First, the analysis in our paper was motivated by the fact that output is normally divided into simply both capital and labour shares in spite of the fact that labour share contains the share of human capital. If it is considered that output is composed of capital, labour and human capital, the labour share in the normal Cobb-Douglas production function is overestimated. Together with the overestimate of labour share, another problem is that although output reflects the input of human capital, the cost of human capital accumulation is not reflected in the existing business cycle models. Greenwood, Hercowitz, and Krusell (1997) reflect human capital in equipment production. However, Greenwood, Hercowitz, and Krusell (1997) aim to derive investment-specific technology change from human capital. Perli and Sakellaris (1998) incorporate both the physical good and human

capital good productions into their model. The production functions are dependent on capital, unskilled labour and skilled labour. A distinguished feature of this model is that human capital investment is expressed by a production function. This model depends on the existing vast human capital estimation and research. The cost of human capital investment is achieved by both tangible and intangible costs such as education expenditure and labour substitution between education and labour activities. Our paper focuses on skill acquisition activities (see DeJong and Ingram, 2001) as a cost of human capital investment, even though human capital is defined in various ways.

Second, skill acquisition activities need human capital realization. For example, differently from physical investment, skill acquisition activities do not change directly to human capital. Similarly to DeJong and Ingram (2001), we consider the ability of agent to transform time devoted skill acquisition activities into human capital.

Third, we incorporate investment-specific technology shock and capital utilization in a small open economy model such as Korea. Greenwood, Hercowitz, and Krusell (1997; 1998) showed that a positive shock to marginal efficiency of investment stimulates the formation of new capital and more intensive utilization and accelerated depreciation of old capital. Burnside and Eichenbaun (1996) found that variable capital utilization rates are a quantitatively important source of propagation to business cycle shocks. They show that the model with variable capital utilization does a better job of accounting for business cycle statistics than the standard RBC model. They also argued that the existence of capital utilization rates less than unit makes firm be able to increase the effective capital stock in response to shocks that raise the marginal product of capital.

This paper is organized as follows: section 2 provides a full description of the dynamic stochastic model of a small open economy. Section 3 shows the conditions for optimal allocation of the dynamic programming problem. Section 4 presents the empirical findings in our analysis. Section 5 shows the impulse response and section 6 presents concluding remarks.

2. AN INTERNATIONAL REAL BUSINESS CYCLE MODEL WITH HUMAN CAPITAL AND SKILL ACQUISITION ACTIVITIES

A dynamic stochastic model of a small open economy is developed to investigate the effects of investment-specific technology shocks. The structure of the model is developed by incorporating human capital accumulation into a neoclassical framework.

2.1. Preferences

In our model, the preference follows SCU (Stationary Cardinal Utility) function introduced by Mendoza (1991). Agents who are infinitely lived with the same identical preferences allocate C_t (consumption), N_t (labour supply) and S_t (skill acquisition activities) intertemporally to maximize the utility.

$$V = E \left[\sum_{t=0}^{\infty} U(C_t, N_t, S_t) \exp \left(- \sum_{\tau=0}^{t-1} v(C_\tau, N_\tau, S_\tau) \right) \right]. \quad (1)$$

The instantaneous utility function and time-preference functions are as follows

$$U(\cdot) = \frac{\left[C_t - \frac{(N_t + S_t)^{1+\theta}}{1 + \theta} \right]^{1-\gamma} - 1}{1 - \gamma}, \quad (2)$$

$$v(\cdot) = \beta \ln \left(1 + C_t - \frac{(N_t + S_t)^{1+\theta}}{1 + \theta} \right), \quad (3)$$

$$U(\cdot) < 0, U'(\cdot) > 0, U''(\cdot) < 0, 1 + \theta > 1, \gamma > 1,$$

$$v(\cdot) > 0, v'(\cdot) > 0, v''(\cdot) < 0, \beta > 0.$$

The parameter β is referred to as the consumption elasticity of the rate of time preference. The parameter θ is the elasticity of substitution between consumption and time devoted both labour and skill acquisition activities. The coefficient γ indicates relative risk aversion. In this model, the utility function has two distinct features. First, the utility function is SCU (Stationary Cardinal Utility), which produces a well defined stochastic stationary equilibrium. In other words, our model is based on a stationary economy similarly to Mendoza (1995), and thus does not have any growth factor in the production function, capital accumulation and international trade. Second, the utility function has a variable discount rate. The variable intertemporal discount rate is a concave function as follows, $B(\cdot) > 0$, $B'(\cdot) < 0$ and $B''(\cdot) > 0$. This feature induces consumption and labour to smooth from economic shock. In other words, if consumption increases, the increased consumption decreases the intertemporal discount rate, and in turn the decreased discount rate reduces the utility of current consumption compared with future consumption, and thus decreases current consumption. This interaction causes consumption to smooth, though the effect is small. In the steady-state, the intertemporal discount rate equates to the world's real interest rate according to the accumulation of foreign financial assets. So, intertemporal discount rate or endogenous discount rate is used to ensure that models of small open economies with time separable preferences have a stationary state with accurate, well-defined dynamics around that steady-state.

2.2. Production

The production technology is given by a Cobb-Douglas production function using capital, human capital and labour. Labour and human capital are incorporated into a CES aggregate similarly to Perli and Sakellaris (1998).

$$Y_t = (h_t K_t)^\alpha \left[\pi N_t^\rho + (1-\pi) H_t^\rho \right]^{(1-\alpha)/\rho}, \quad (4)$$

where Y_t is the output of the single good in period t , K_t and h_t are capital stock and capital utilization rate. N_t and H_t are labour input and human capital used in production in period t , respectively. The parameter α represents the share of capital in production. The parameter (π) is the share of labour and $(1-\pi)$ is the share of human capital, respectively. ρ represents the substitution elasticity between labour and human capital. Note that capital utilization has a role of transmitting intratemporarily the effect of the shock to labour supply and other variables.

2.3. Capital Accumulation

The law of motion for capital stock is as follows

$$\begin{aligned} K_{t+1} &= \varepsilon_t i_t + (1 - \delta(h_t)) K_t, \\ \delta(h_t) &= \frac{1}{\omega} h_t^\omega, \end{aligned} \quad (5)$$

where i_t denotes investments, δ is not a constant rate of depreciation but a non-negative function of capital utilization (h_t). The parameter ω represents the elasticity of depreciation with respect to capital utilization. The technology shocks ε_t follow the first-order Markov distribution function.

2.4. Human Capital Accumulation

The laws of motion for human capital stock are as follows

$$\begin{aligned}
 H_{t+1} &= g(S_t) + (1 - \delta_H)H_t, \\
 g(S_t) &= \frac{1}{\mu} S_t^\mu,
 \end{aligned}
 \tag{6}$$

where H_t and S_t are human capital and skill acquisition activities, respectively. δ_H is a constant rate of depreciation in human capital stock. Note that “the potential convexity of $g(S_t)$ does not introduce increasing returns to labour’s input to production, because there remain decreasing returns to labour hours in the production functions and the opportunity cost of S_t is increasing in S_t (DeJong and Ingram, 2001)”.

2.5. Trade and Financial Structure

The financial structure is linked with trade balance. In our model, it is assumed that international capital mobility is perfect likely to Mendoza (1991). Financial structure assumes that an agent in the economy is a small participant and this representative agent has access to world capital markets to borrow and lend foreign financial assets (A_t). Holdings of foreign financial assets (A_{t+1}) evolve according to

$$TB_t = A_{t+1} - (1 + r^*)A_t,
 \tag{7}$$

where TB_t is trade balance, and r^* is the exogenously determined world’s real interest rate.

2.6. Resource Constraint

The model completes with a resource constraint as follows

$$\begin{aligned}
& (h_t K_t)^\alpha \left[\pi N_t^\rho + (1-\pi) H_t^\rho \right]^{(1-\alpha)/\rho} - \frac{\phi_K (K_{t+1}/\varepsilon_t - K_t/\varepsilon_t)^2}{K_t/\varepsilon_t} \\
& = C_t + \frac{K_{t+1}}{\varepsilon_t} - \left(1 - \frac{1}{\omega} h_t^\omega \right) \frac{K_t}{\varepsilon_t} + A_{t+1} - (1+r^*)A_t,
\end{aligned} \tag{8}$$

where ϕ_K is parameter to restrict the adjustment costs. Resource constraint shows the distribution of output. According to the aggregate resource constraint of the economy, the sum of consumption, investment and the balance of trade can not be exceeded by gross domestic product. The first term of the left hand side is output, and the second term expresses capital adjustment costs, which follows Greenwood, Hercowitz, and Krusell (1997).

3. MODEL SOLUTION AND PARAMETER CALIBRATION

The social planner selects paths of consumption, labour supply and skill acquisition activities to maximise the whole life-time utility. To solve the dynamic programming problem, household's optimal intertemporal decisions are to choose the control variables $(C_t, K_{t+1}, H_{t+1}, A_{t+1}, h_t, N_t, S_t)$ in period t , given the state of the economy as described by K_t, H_t, A_t and ε_t . To solve the dynamic programming problem, the Lagrangian problem is built and the first order conditions for the utility maximization are derived. A feature of these first-order conditions is that this model reflects the property of a small open economy business cycle model. The variable intertemporal discount rate and foreign financial assets are features of a small open economy business cycle model. If consumption increases, the increased consumption decreases the intertemporal discount rate, and in turn the decreased discount rate reduces the utility of current consumption compared with future consumption, and thus decreases current consumption. This interaction causes consumption to smooth.

We employ a linear approximation method, such as the undetermined coefficient method (Christiano, 1998), to solve the dynamic programming problem. We use economic theory as the basis for restricting the general framework for finding numerical values for parameters. Under the restriction that the average ratio of net foreign interest payments to GDP is around 3%, the consumption elasticity (β) is computed as 0.095 from the steady-state condition, which equates to the world real interest rate with the discount rate of the preference.

The coefficient of relative risk aversion (γ) is set to 1.001 from Mendoza (1991a). The inverse of the intertemporal elasticity of substitution in labour supply (θ) is set at 0.23, which is computed from the average ratio (0.24) of working hours to total hours similarly to Greenwood, Hercowitz and Krusell (1997). The elasticity of depreciation with respect to capital utilization (ω) is computed as 1.4 under the condition that the depreciation rate of capital (δ) is 0.025 in the steady state. The depreciation rate of human capital (δ_H) is also set at 0.025 (0.1 in annual rate) from Perli and Sakellaris (1998). The world's real interest rate (r^*) is set as 0.01, which is computed from average value of Prime Bank Lending Rate of USA less inflation of USA. The coefficient of adjustment cost of capital stock is set as 6.8, which equates the volatility of investment in model data to that in Korean. The relevant parameters of production are calculated from national income data. An average quarterly value of 0.5122 over the 1970:1-2005:1 period is used for capital share (α) of national income. The labour share (π) is assumed as 0.5, and the elasticity of substitution between labour and human capital is set at 0.5, so that $\rho = -1$ from Perli and Sakellaris (1998). In the steady-state, we set the value of μ at 1.38 under supposition that this ratio of skill acquisition activities to labour would equal 0.3 in the steady-state from DeJong and Ingram (2001). By using the relative price (q),¹⁾ we estimate the stochastic shock process for investment-specific technology as follows

¹⁾ The stochastic process for investment-specific technology is estimated by using quarterly data of the ratio of private consumption deflator to machinery and equipment investment deflator.

Table 1 Benchmark Parameter Values

Parameter	Definition	Value
β	Consumption elasticity of the rate of time preference	0.095
γ	Coefficient of relative risk aversion	1.001
θ	Inverse of the intertemporal elasticity of substitution in labour supply and skill acquisition activities	0.23
α	Capital share in output	0.5122
π	Labour share in output	0.5
$1/(1-\rho)$	Elasticity of substitution between labour and human capital	0.5
δ	Depreciation rate of capital	0.025
ω	Elasticity of depreciation with respect to capital utilization	1.40
δ_H	Depreciation rate of human capital	0.025
ϕ_K	Adjustment cost of capital stock	6.8
μ	Elasticity of human capital realization with respect to skill acquisition activities	1.38
r^*	World's real interest rate	0.01

$$\ln q_t = \text{constant} + \text{trend} \times \ln \gamma_q + \varepsilon_t,$$

where $\varepsilon_{t+1} = \psi \varepsilon_t + w_{t+1}$ with $0 < \psi < 1$ and $\varepsilon_t \sim N(0, \sigma_w)$.

Using quarterly 1970:1-2005:1 data, the estimated parameters are

$$\ln \gamma_q = 0.005, \quad \psi = 0.94, \quad \sigma = 0.023, \quad \text{with D.W.} = 2.07,$$

$$(44.17) \quad (26.93)$$

where the numbers in parentheses are t -statistics.

4. EMPIRICAL FINDINGS

4.1. Model Simulations

In this section, the key empirical findings of the actual moments obtained from Korean data are reported. Table 2 summarizes the major features of an actual economy. The standard deviations of the actual data from table 2 show that investment (8.28) is more volatile than output (2.50), and consumption (2.42) is less. The standard deviation of labour supply shows the lowest value (1.77), while interest payments show the highest value (11.25).

From table 3, the benchmark model fairly well mimics the real economy in the standard deviation. For instance, the standard deviations in the real economy and benchmark economy of consumption show similar low values (2.42 vs. 1.64). The standard deviation of the benchmark economy mimics fairly well the major feature of the real economy in investment (8.28, 8.90), labour supply (1.77, 1.85) and trade balance (1.96, 1.85). On the other hand, the benchmark economy is underestimated in the standard deviation of interest payments (11.25, 5.26). As Burnside and Eichenbaum (1997) referred, capital utilization rates (3.75) are very volatile relative to the stock of physical capital (0.55) in the benchmark economy.

In the case of autocorrelation coefficients, the benchmark economy mimics well the real economy for output (0.74, 0.69), consumption (0.82, 0.70), investment (0.73, 0.69) and capital stock (0.93 vs. 0.95), labour supply (0.69, 0.67) and trade balance (0.79, 0.69). However, the correlations of economy variables with output in the real economy mimic closely the benchmark in

Table 2 Statistical Moments: Korean Data

	Standard deviation	First-order serial correlation	Correlation with output (ρ_{x,GDP_t})				
	σ_x/σ_{GDP_t}	$\rho_{x,t,t-1}$	-2	-1	0	1	2
Output	2.50 (0.198)	0.74 (0.063)	0.57 (0.092)	0.74 (0.063)	1.0	0.74 (0.063)	0.57 (0.092)
Consumption	2.42 (0.276)	0.82 (0.096)	0.45 (0.112)	0.64 (0.079)	0.81 (0.039)	0.64 (0.098)	0.48 (0.127)
Investment	8.28 (0.549)	0.73 (0.055)	0.51 (0.082)	0.66 (0.054)	0.78 (0.041)	0.66 (0.063)	0.56 (0.075)
Savings	8.08 (0.922)	0.48 (0.075)	0.31 (0.094)	0.30 (0.083)	0.37 (0.093)	0.30 (0.090)	0.25 (0.093)
Capital stock	2.92 (0.207)	0.93 (0.010)	-0.23 (0.086)	-0.10 (0.090)	0.04 (0.088)	0.17 (0.083)	0.27 (0.084)
Labour supply	1.77 (0.145)	0.69 (0.092)	0.37 (0.106)	0.55 (0.092)	0.68 (0.059)	0.69 (0.065)	0.60 (0.086)
Interest payments	11.25 (1.054)	0.55 (0.089)	-0.32 (0.093)	-0.37 (0.110)	-0.54 (0.085)	-0.34 (0.105)	-0.28 (0.110)
Trade balance (<i>TB/Y</i>)	1.96 (0.214)	0.79 (0.058)	-0.44 (0.102)	-0.59 (0.080)	-0.60 (0.080)	-0.49 (0.112)	-0.37 (0.125)
Corr (<i>S, I</i>)					0.63 (0.059)		

Note: The Korean data are obtained from the Database of Bank of Korea, divided by the 15+ population, logged and detrended by a Hodrick-Prescott filter with the smoothing parameter set at 1,600. Output is real GDP, consumption and investment are total real values based on 1970:1-2005:1 period at constant prices in 2000. Labour supply is calculated by multiplying the average weekly working hours by the number of employed. Capital stock is gross capital stock, and interest payments are the net of foreign interest paid and received. Trade balance is divided by GDP. The values in parenthesis represent the standard deviations estimated by GMM (Generalized Method of Moment) using the Hansen-Heaton-Ogaki gauss program (Ogaki, 1993).

Table 3 Statistical Moments: Benchmark Economy

	Standard deviation	First-order serial correlation	Correlation with output ($\rho_{x,GDP}$)				
	$\sigma_{xt}/\sigma_{GDPt}$	$\rho_{xt,xt-1}$	-2	-1	0	1	2
Output	2.50 (0.144)	0.69 (0.043)	0.45 (0.066)	0.69 (0.043)	1.0	0.69 (0.043)	0.45 (0.066)
Consumption	1.64 (0.095)	0.70 (0.042)	0.44 (0.067)	0.69 (0.044)	0.99 (0.001)	0.71 (0.042)	0.47 (0.065)
Investment	8.90 (0.514)	0.69 (0.044)	0.48 (0.063)	0.71 (0.041)	0.99 (0.001)	0.67 (0.046)	0.40 (0.069)
Savings	3.82 (0.219)	0.68 (0.044)	0.46 (0.065)	0.70 (0.043)	0.98 (0.001)	0.68 (0.044)	0.44 (0.067)
Capital stock	0.55 (0.030)	0.95 (0.008)	-0.38 (0.072)	-0.23 (0.079)	-0.02 (0.084)	0.28 (0.078)	0.47 (0.065)
Labour supply	1.85 (0.107)	0.67 (0.046)	0.44 (0.066)	0.68 (0.044)	0.97 (0.004)	0.68 (0.045)	0.44 (0.067)
Skill acquisition activities	1.78 (0.108)	0.43 (0.096)	-0.30 (0.077)	-0.47 (0.065)	-0.69 (0.041)	-0.50 (0.062)	-0.34 (0.073)
Capital utilization	3.75 (2.218)	0.62 (0.051)	0.47 (0.064)	0.69 (0.044)	0.94 (0.009)	0.62 (0.051)	0.36 (0.073)
Interest payments	5.26 (0.349)	0.67 (0.124)	0.14 (0.085)	0.09 (0.082)	0.01 (0.087)	-0.09 (0.086)	-0.157 (0.084)
Trade balance (TB/Y)	1.85 (0.107)	0.69 (0.044)	-0.50 (0.062)	-0.72 (0.041)	-0.98 (0.003)	-0.64 (0.049)	-0.37 (0.072)
Corr (S, I)					0.97 (0.002)		

Note: The model statistics are based on the sample average values of 100 simulations of 141 quarters. We generated histories of 200 observations and truncated the first 59 observations so that the results do not depend on initial condition of the state variables of the model (Ambler, Cardia, and Zimmermann, 2002). The standard deviations of the benchmark model are re-adjusted by those of GDP in real data. The values in parenthesis represent the standard deviations estimated by GMM (Generalized Method of Moment) using the Hansen-Heaton-Ogaki gauss program (Ogaki, 1993).

trade balance (-0.60 , -0.98), which shows countercyclical effect.

In addition, skill acquisition activities show a countercyclical effect (-0.69) similarly to DeJong and Ingram (2001) and Perli and Sakellaris (1998). Moreover, the correlation of capital utilization with output in the benchmark economy represents a procyclical effect (0.94). In general, our model mimics fairly well the distinguishing features of empirical regularity.

On the other hand, the correlations between savings and investment are 0.63 and 0.97 in the actual economy and the benchmark economy, respectively. From Mendoza (1991), savings are defined by trade balance plus investment. As Mendoza (1991) referred, savings-investment correlation has been the debate because of its alleged implications on the degree of international capital mobility. From the numerous empirical analyses, the positive correlations between savings and investment have been documented. The results are interpreted as evidence against perfect capital mobility. In the world of perfect capital mobility, if investment increases, trade balance deteriorates, and thus foreign capital flows into the economy, and then savings are able to drop. Accordingly, low savings-investment correlations make the inference of imperfect capital mobility possible. However, Obstfeld (1986) has shown that a deterministic dynamic-equilibrium model with perfect capital mobility produces positive correlation between savings and investment as a result of persistent productivity changes or population growth. In other words, as Obstfeld (1986) proved and Mendoza (1991) showed, in our model, the high correlation between savings and investment is not related to the degree of international capital mobility. However, as Obstfeld (1986) referred, the high correlation between savings and investment depends on the persistence of the shock.

4.2. Autocorrelation Functions

A generalized Q test proposed by Cogley and Nason (1995) is useful to evaluate whether the persistence of the model is to match that of actual data. The generalized Q statistics are derived from autocorrelation functions

(ACF), and set up as follows

$$Q = (\hat{c} - c)' \hat{V}_c^{-1} (\hat{c} - c), \quad (9)$$

where, the vector, \hat{c} is the autocorrelation function (ACF) of actual data, and c is the model generated autocorrelation function (ACF). The model ACF were obtained by 100 simulations, estimating the ACF for each simulation, and taking the sample average as follows

$$c = (1/N) \sum_{i=1}^N c_i, \quad (10)$$

where c_i is autocorrelation function on each simulation, and N is number of simulations. The covariance matrix, \hat{V}_c , is computed by taking the ensemble average of the outer product of ACF for simulated data

$$\hat{V}_c = N^{-1} \sum_{i=1}^N [c_i - c][c_i - c]'. \quad (11)$$

Generalized Q statistics are approximately chi-square with degrees of freedom equal to the number of elements in c . For generalized Q test, the lags of ACF should be decided. In our analysis, we select to evaluate the first 8 lags of ACF following Cogley and Nason (1995).

As can be seen from table 4, under the 5% significance level, the null hypothesis that the ACFs of output, consumption, investment, labour supply and trade balance have been generated by the model cannot be rejected. Specifically, the generalized Q statistics of output, consumption, investment and trade balance are 9.17, 7.95, 8.20 and 8.21, respectively. However, the generalized Q statistics of labour supply is slightly high, and the null hypothesis is rejected at 10% significance level. Overall, our model fairly

Table 4 Generalized Q Statistics

	Output	Consumption	Investment	Labour supply	Trade balance
Q	9.17	7.95	8.20	13.84	8.21
p -value	0.328	0.438	0.415	0.086	0.414

well generates the persistence of major macroeconomic variables similarly to actual data.

5. IMPULSE RESPONSE ANALYSIS

This section studies the impulse response of macroeconomic aggregates induced by investment-specific technology shock. The effects of investment-specific technology shocks on the macroeconomic variables can be investigated analytically when the model is not complicated. However, if a model includes various macroeconomic variables and parameters, then the direction and magnitude of the macroeconomic effects from the shocks are less straightforward and often produce ambiguous results, depending on the relative size of several parameters. Accordingly, impulse response analysis is a useful and insightful shock evaluation procedure to assess the dynamic characterization of a system. In this study of impulse response analysis, we utilize the linear policy function derived from the undetermined coefficient method.

Figure 1 plots the impulse response of the major macroeconomic variables to a 1% shock in investment-specific technology. As can be seen from figure 1, a positive shock leads the macroeconomic variables to increase though the features are different.

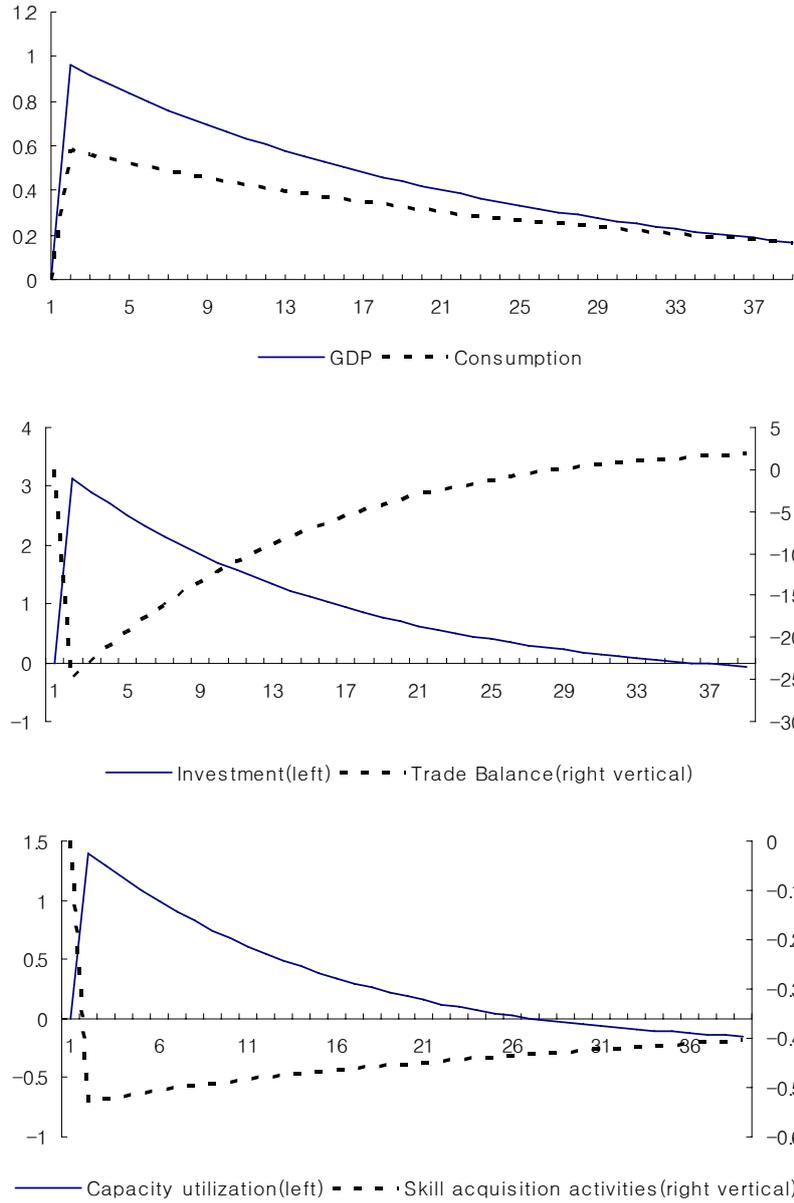
A positive investment shock reduces the cost of capital utilization, and hence induces a higher capital utilization rate. The higher capital utilization increases the use of capital stock, and raises labour's marginal productivity, which results in a higher employment level for given current capital stock. The higher employment and the higher utilization increase the GDP. The technology shock has two effects on consumption. First, the intratemporal substitution effect in which the shock increases the marginal productivity of labour, and raises the opportunity cost of leisure compared with consumption.

Hence, the labour supply increases, whereas consumption decreases. Second, the income effect incorporates the effect of the changed intertemporal discount rate. The technology shock, given optimal future consumption, makes less investment possible, and so can cause an increment in current consumption. As can be seen from figure 1, GDP increases more than consumption to the shock, and then decreases faster than consumption, reflecting decrease of consumption by substitution effect.

The effects of the shock on investment have three channels. First, because the shock reduces the cost of capital utilization and then increases the use of capital stock, the depreciation rate increases. The higher depreciation induces investment to increase. Second, the shock increases the efficiency of future capital stock (K_{t+1}). The increased efficiency of future capital stock causes a positive substitution effect from consumption and foreign financial assets to investment. Third, the increase in efficiency of future capital stock means less investment is required to keep the optimal future capital stock compared with given optimal future consumption. This effect causes investment to decrease. The shock on skill acquisition activities also has both income effect and substitution effect. The income effect from the shock increases skill acquisition activities.

On the other hand, if the increase in efficiency of investment is linked with the increase in labour supply and skill acquisition activities are delayed, and thus decrease. As can be seen from figure 1, substitution effect overwhelms income effect, as a result, the effect of the shock on investment decreases skill acquisition activities.

Figure 1 Impulse Response: Investment-Specific Technology Shock



The shock also has both income effect and substitution effect on future foreign financial assets. Interestingly, the curve illustrates the initial worsening of the trade balance in response to an investment-specific technology and the subsequent swing toward a long-run equilibrium path over time. The investment-specific technological change of our model is derived from the relative price of new equipment. A positive investment-specific technology shock implies the decrease of price of domestic capital goods and thus the increase of the relative prices of both exports and imports to domestic capital stock. The price effect reduces the trade balance. In other words, the higher domestic productivity causes domestic economic activity to become more efficient than foreign economic activity. However, the shock increases GDP, and then raises exports and imports, and thus the trade balance increases.

6. CONCLUDING REMARKS

This paper develops an international real business cycle model of a small open economy. The model has three production factors: capital stock, human capital and labour, and has investment-specific technology shock. Our model is parameterized and calibrated, incorporating the neoclassical framework with physical capital, human capital, skill acquisition activities and investment-specific technology. We apply Christiano's (1998) undetermined coefficient method in order to simulate our benchmark model. Quantitative analysis based on our benchmark model economy matches distinguishing features of the measured economy. Our model is able to duplicate many of the stylized facts of business cycles in Korea. Overall, the model economy performs fairly well and mimics the real economy; that is, it demonstrates a similar pattern to the real economy. More importantly, skill acquisition activities in a small open economy play a useful role in explaining economic fluctuations. Skill acquisition activities also are countercyclical similarly to the studies of Perli and Sakelaris (1998) and DeJong and Ingram (2001).

Furthermore, capital utilization variable effectively performs the roles of intra and intertemporal channels of the shock that leads comovement of labour supply with the investment-specific technology. Moreover, capital utilization rates are more volatile than the physical capital stock similarly to the study of Burnside and Eichenbaum (1996). Impulse response analysis shows clearly the properties and effects of investment-specific technology shock as well as the basic pattern of a small open economy such as Korea.

APPENDIX: DATA SOURCE

The Korean real data are mainly obtained from the database of the Bank of Korea. All series are composed of quarterly observations from 1970:1 to 2005:1 and adjusted seasonally by X-12 ARIMA. Output: real GDP, 2000 price. Consumption: final consumption expenditure, 2000 price. Investment: gross fixed capital formation, 2000 price. Capital stock: gross capital stock extended from J.Y. Kim (1996), 2000 price. Labour supply: the number of employed labourers \times weekly hours worked. Population: population aged 15 years and over. Interest payments: (nominal investment income to overseas nominal investment income from overseas) / GDP deflator. Trade balance: (exports of goods and services imports of goods and services) / GDP. World interest rate: prime bank lending rate of USA.

REFERENCE

- Ambler, S., E. Cardia, and C. Zimmermann, "International transmission of the business cycle in a multi-sectoral model," *European Economic Review*, 46, 2002, pp. 273-300.
- Barron, J. M., M. C. Berger, and D. A. Black, "How well do we measure training?," *Journal of Labour Economics*, 15, 1997, pp. 507-528.

- Burnside, C. and M. Eichenbaum, "Factor-horading and the propagation of business cycle shocks," *American Economic Review*, 86, 1997, pp. 1154-1174.
- Caballé, J. and M. S. Santos, "On endogenous growth with physical and human capital," *Journal of Political Economy*, 101, 1993, pp. 1042-1059.
- Christiano, L. J., "Solving dynamic equilibrium models by a method of undetermined coefficients," Technical working paper 225, National Bureau of Economic Research, 1998.
- Cogley, T. and J. M. Nason, "Output dynamics in real business cycle model," *American Economic Review*, 85, 1995, pp. 492-511.
- Davies, J. and J. Whalley, "Taxes and capital formation: How important is human capital?," Working paper 2899, National Bureau of Economic Research, 1989.
- DeJong, D. N. and B. F. Ingram, "The cyclical behavior of skill acquisition," *Review of Economic Dynamics*, 4, 2001, pp. 536-561.
- Dellas, H. and P. Sakellaris, "On the cyclicity of schooling: theory and evidence," Working paper 95-12, University of Maryland, 1995.
- Gordon, R. J., "Why U.S. wage and employment behaviour differs from that in Britain and Japan," *Economic Journal*, 92, 1982, pp. 13-44.
- Greenwood, J., Z. Hercowitz, and G. W. Huffman, "Investment, capacity utilization, and the real business cycle," *American Economic Review*, 78, 1988, pp. 402-417.
- Greenwood, J. Z. and M. Yorukoglu, "1974," Carnegie-Rochester Conference Series on Public Policy, 46, 1997, pp. 49-95.
- Greenwood, J., Z. Hercowitz, and P. Krusell, "Long-run implication of investment-specific technological change," *American Economic Review*, 87, 1997, pp. 342-362.
- _____, "The role of investment-specific technological change in the business cycle," Working paper, University of Rochester, 1998.
- In, F. and C. Doucouliagos, "Human capital formation and US economic growth: a causality analysis," *Applied Economics Letters*, 4, 1997, pp.

- 329-331.
- Kim, J. Y., "Gross Capital Stock in Korea: Capital Stock Estimation in Private and Government Sectors," *Korean Economy Research Institute*, in Korean, 1996.
- Kim, J. Y. and J. H. Yoon, "Investment-specific technology shock in an international real business cycle model: The Korea case," *Korean Economic Review*, 20(1), 2004, pp. 75-93.
- Kind, R. G. and S. Rebelo, "Public policy and economic growth: developing neoclassical implication," *Journal of Political Economy*, 98, 1990, pp. 126-150.
- Lee, B. J. and M. J. Lee, "Quantile regression analysis of wage determinants in the Korean Labor Market," *Journal of the Korean Economy*, 7, 2006, pp. 1-31.
- Lucas, R. E., Jr., "On the mechanics of economic development," *Journal of Monetary Economy*, 22, 1988, pp. 3-42.
- Mendoza, E. G., "Capital controls and the gains from trade in a business cycle model of a small open economy," *IMF staff papers*, 38, 1991a, pp. 480-505.
- _____, "Real business cycles in a small open economy," *American Economic Review*, 81, 1991b, pp. 797-818.
- _____, "The terms of trade, the real exchange, and economic fluctuation," *International Economic Review*, 36, 1995, pp. 101-137.
- Obstfeld, M., "Capital mobility in the world economy: theories and measurement," *Carnegie-Rochester Conference Series on Public Policy*, 26, 1985, pp. 55-103.
- Ogaki, M., "GMM: A user guide," RCER Working paper 340, University of Rochester, 1993.
- Perli, R. and P. Sakellaris, "Human capital formation and business cycle persistence," *Journal of Monetary Economics*, 42, 1998, pp. 67-92.
- Rebelo, S., "Long-run policy analysis and long run growth," *Journal of Political Economy*, 99, 1991, pp. 500-521.

Romer, P. M., "Increasing returns and long run growth," *Journal of Political Economy*, 94, 1986, pp. 1002-1037.