Does the Solow Residual for Korea Reflect Pure Technology Shocks?

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Abstract

This study investigates the relationship between the measured Solow residual and demand side variables for the Korean economy. The measured Solow residuals are shown to be Granger-caused by some demand side variables such as exports, M1, and government expenditure. A vector error correction model is constructed to investigate dynamic relation between these demand side variables and the Solow residual. Impulse response functions shows that the measured Solow residual moves pro-cyclically with the demand shocks, and that the forecast error variance of the measured Solow residual is mostly explained by past innovations of these demand side variables.

Keywords: Solow residual, Productivity shock, Vector error correction model

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I. Introduction

Since Solow (1957) proposed a residual in growth accounting method as a measure of the contribution of productivity change to the economic growth, the Solow residual has been widely used to estimate productivity change. The Solow residual has been used to measure not only the contribution of productivity growth on the output growth of an economy in empirical studies on economic growth, but also productivity shocks in numerous studies that estimate the effects of these shocks on output fluctuations in real business cycle literature. Despite its prevalent use in empirical studies, the Solow residual has been known as inappropriate to represent the productivity under certain circumstances. Researchers indicated the measured Solow residual can't provide proper measure of total factor productivity change once the assumptions of constant returns to scale, perfect competition, and full employment of factor inputs are relieved.

Firstly, the measured Solow residual would move pro-cyclically because of increasing returns to scale at the firm level. Hall (1989) suggested that output increase will entail movement down an average cost curve, producing pro-cyclical productivity changes when internal increasing returns to scale exists. Caballero and Lyons (1990) showed that external increasing returns and unmeasured factor utilization tied to own-activity of a firm to explain aggregate pro-cyclical productivity.

Secondly, the measured Solow residual would move pro-cyclically when product prices exceed marginal costs due to imperfect competition. Hall (1988, 1989) showed that the measured Solow residual is correlated with some exogenous demand side variables. Evans (1992) also found that many demand side variables such as real government consumption, nominal money supply, and nominal treasury bill rates have significant predictive power over the movements of the measured Solow residual.

Lastly, the measured Solow residual would fail to provide genuine productivity measure without full-utilization of factor inputs. The Solow residual might not be able to capture the true effect of productivity changes on output changes because of both labor hoarding in a recession and greater work effort in a boom (Summers,1986; Mankiw, 1989). Empirically, Burnside and Eichenbaum (1994) showed that factor utilization is most likely cause of the mis-measurement of technology when it is estimated by the Solow residual. Sbordone (1996) also found that firms respond to cyclical movements in economic activity by varying the rate of utilization of their workforce, and that variation in labor utilization generates short run dynamics in total factor productivity.[1]

Under the circumstances, the measured Solow residual deviates from productivity shocks and varies with demand conditions. For example, output price is greater than marginal cost by markup and the price markup changes with demand conditions, under more realistic assumption of imperfect competition. The measured Solow residual would increase with an increase in capital growth, which is determined by capital investments responding to demand shocks, when there is increasing returns to scale. Obviously, the degree of factor utilization also depends on the demand condition.

This paper investigates the link between the measured Solow residual and demand side variables for the Korean economy. First, this study tries to identify demand side variables such as real government consumption, nominal money supply and exports that have significant predictive power over the movements of the measured Solow residual. Then, the study investigates dynamic interaction between the demand variables and the measured Solow residual using a vector error correction model (VECM). The paper follows the line of other empirical studies that employ vector autoregressive models (VAR) to find the link between the two variables (Otto, 1999; Huang, 2000). Otto (2000) applied a structural VAR model to Australian economy, and Huang (2000) applied a VAR model to Taiwanese manufacturing, construction and electricity, gas and water industry.

There exists an extensive literature on total factor productivity (TFP) growth for Korea, which measured as a residual of Solow growth accounting, and their results has been a center of the extended debate on its growth potential. However no other studies have investigated cyclical behavior of the TFP growth, as previous studies of the properties of the Solow residual have focused mostly on measures for the U.S..[2] This research vacuum is rather surprising, considering the strong interest and prolonged debate on TFP growth for the Korean economy. Thus, this study tries to find out whether the hypothesis of correlation between the Solow residual and exogenous demand variables is correct for the Korean economy and what it implies for the growth debate if it is correct.

This paper finds that the Solow residual for Korea is not a strictly exogenous variable but affected by demand shocks. Particularly, this study shows that the measured Solow residuals for Korea can be predictable by some of demand side variables such as exports, M1 and government expenditure. From a vector error correction model, analysis of impulse response functions shows that the measured Solow residuals move pro-cyclically with exogenous demand shocks, especially with M1, and that the forecast error variance of the measured Solow residuals are mostly explained by past innovations of in domestic and foreign demand side variables.

This paper is organized as follows. Section 2 presents theoretical background. Section 3 measures the Solow residual from the Korean economy and discuss its predictability. Section 4 constructs a VECM model to investigate dynamic relation between the measured Solow residual and demand side variables. Section 4 provides some conclusions.

II. Theoretical Background

This section summarizes some economic circumstances when the measured Solow residual fails to represent productivity changes. We begin with the following production function

$$Y_t = A_t F(K_t, L_t), \qquad (1)$$

where Y_t, K_t and L_t represent real output, capital stock, and labor employment at period t, respectively. A_t is a Hicks neutral technology index, which allows for shifts in the production function. Totally differentiating (1) and dividing it by Y, we can get the following growth equation

$$\dot{Y}/Y = \varepsilon_k \dot{K}/K + \varepsilon_l \dot{L}/L + \dot{A}/A, \qquad (2)$$

where $\dot{Y} = dY_t/dt$ is the derivative of output with respect to time and $\dot{Y}/Y$ is the output growth rate. We use ε_l and ε_k to denote elasticities of output with respect to labor and capital, respectively. The labor and capital are paid according to their marginal products under the perfect competition. Thus, the elasticity of output with respect to labor, ε_l, should equal the labor share of income, ϕ_l, and the elasticity of output with respect to capital, ε_k, should equal the capital share of income, ϕ_k. Thus, we can rewrite equation (2) as

$$\dot{Y}/Y = \phi_k \dot{K}/K + \phi_l \dot{L}/L + \dot{A}/A . \tag{3}$$

Assuming constant returns to scale (CRS) on equation (3), we can have the following measured Solow residual to estimate TFP ($\dot{A}/A$)

$$R = \dot{Y}/Y - (1-\phi_l)\cdot \dot{K}/K - \phi_l \cdot \dot{L}/L . \tag{4}$$

The series is termed as the measured Solow residual, which captures the growth rate of TFP.[3]

The Solow residual can't measure TFP properly if there is increasing returns to scale (IRS) technology. With IRS technology, the sum of output elasticities with respect to capital and labor exceeds one, $\varepsilon_k + \varepsilon_l > 1$. If labor input is paid its marginal productivity, $\varepsilon_l = \phi_l$, then the measured Solow residual becomes

$$R = \dot{A}/A + (\varepsilon_k + \varepsilon_l - 1)\cdot \dot{K}/K . \tag{5}$$

Since the sum of ε_k and ε_l is actually greater than one, the above equation implies that the measured Solow residual would change with a change in capital stock: the measured Solow residual (R) overestimates (underestimates) TFP change ($\dot{A}/A$) as capital stock increases (decreases). Thus, any demand shock affecting the capital growth would also affect the measured Solow residual.

The measured Solow residual can't provide proper measure of TFP change if perfect competition assumption is relieved. Under imperfect competition, the output price is greater than the marginal cost, and there exists a markup of price (*P*) over marginal cost (*MC*). As a result, the labor share of income becomes $\phi_l = MC/P \cdot \varepsilon_l$. In this case, the measured Solow residual (4) changes to

$$R = \dot{A}/A + (1 - MC/P)\cdot \varepsilon_l \cdot \dot{\eta}/\eta, \tag{6}$$

where η represents labor capital ratio, $\eta = L/K$. Thus, the measured Solow residual would deviate from TFP ($\dot{A}/A$) if there exists a change in markup and labor capital ratio. The measured Solow residual overestimates the productivity change if there is an increase in labor capital ratio and markup. For example, when a positive demand shock raises the employed labor capital ratio, the measured Solow residual would also increase since MC/P is less than one. Furthermore, the measured Solow residual also reacts to demand shocks when the price of markup changes with the demand condition. The price markup might go higher when the demand for output is stronger.

The measured Solow residual also reacts to the demand shocks when factors are under-utilized. Notice that the quantity of output produced depends on the quantity of effective factors employed when the factor utilization rate can change over time. Let E_g, for $g=L$ and K, denotes effective factors employed, which determines actual production instead of nominal factors employed. The effective factors are less than nominal factors and can be written as $E_l = \delta_l L$ and $E_k = \delta_k K$, where δ represents factor utility ratio defined in [0, 1]. When δ_{lt} and δ_{kt} are equal to one, there exists no labor hoarding and no under-utilization of capital. The more δ_{lt} and δ_{kt} are closer to zero, the more serious is the problem of under-utilization of labor and capital hoarding. By replacing effective factors into the production function (1), we can rewrite the production function as

$$Y_t = A_t F(\delta_{kt} K_t, \delta_{lt} L_t)\,. \tag{7}$$

Given the above production function, we obtain the following relation

$$\dot{Y}/Y = \varepsilon_C\, \dot{K}/K + \varepsilon_N\, \dot{L}/L + \varepsilon_C\, \dot{\delta}_{kt}/\delta_{kt} + \varepsilon_N\, \dot{\delta}_{lt}/\delta_{lt} + \dot{A}/A\,, \tag{8}$$

where ε_N and ε_C represents elasticities of output with respect to effective labor and capital, respectively. Under the assumptions of perfect competition and constant returns to scale, we can derive the measured Solow residual as

$$R = \dot{A}/A + \varepsilon_C \cdot \dot{\delta}_k / \delta_k + \varepsilon_N \cdot \dot{\delta}_l / \delta_l\,. \tag{9}$$

Thus, the above equation shows that the measured Solow residual reacts to factor utility changes (δ). The measured Solow residual increases as factor employment increases during favorable demand conditions.

We showed that the measured Solow residual cannot be a genuine measure of productivity changes unless the conditions of perfect competition, constant returns to scale technology, and full employment of labor and capital are all satisfied. Under these circumstances, the measured Solow residual will usually be affected by demand side variables.

III. Properties of the Solow Residual for Korea

1. The Measured Solow Residual

The data set is constructed from the various sources derived from the Bank of Korea dada basis to estimate the Solow residuals for the period of 1980 I-2003 III. Capital stock is the real amount of tangible fixed assets, and labor input is proxied by number of workers, and gross domestic products (GDP) is used for outputs. All variables are changed into 1995 constant prices to deflate into real terms.

To measure TFP, factor shares of capital, labor and intermediate inputs should be calculated. Assuming perfect competition and CRS, the factor shares are equal to its cost shares of outputs, and their sum equals to one. Thus, the share of labor income is derived by dividing total payments to labor by value added, and the share of capital income by one minus the share of labor. The shares represent continuous Divisia index because growth rates are continuous in time. Thus, in actual estimation, continuous variables are changed into discrete variables by Tornqvist approximation. In the approximation, continuous growth rate is replaced by difference in natural log, and continuous income shares are approximated by arithmetic averages of the income shares in period t and t-1.

For the demand side variables, domestic real government consumption is real government spending in *National Accounts*, and nominal money supply is end of the year values of M1 obtained form *Korean Statistical Information System* (KOSIS). The world oil price is domestic first purchase price of crude oil, taken from the *Energy Information Administration* (EIA), an official energy statistics provider of the U.S. government. The real U.S. GDP is obtained from KOSIS. All the variables are deflated into 1995 constant prices.

Figure 1 plots the measured Solow residuals for Korea along with the output growth rate for comparison. For Korea, the measured Solow residuals and GDP co-move pro-cyclically. The two variables were declining or low during the 1980-81, 1988-90, and 1992-93 recessions and were rising or high during the 1986-88, 1990-92, and

1995-96 booms. This evidence, when taken together with the notion that Solow residual measures productivity changes, appears to be supportive to the real business cycle theorists' interpretation of the origin of business cycles. However, as shown in the previous section, under various plausible conditions the measured Solow residual might not genuinely reflect productivity changes. We shall examine this issue in detail in the next section.

2. Predictability of the Solow Residual

Following the work of Evans (1992) and Otto (1999), we try to find some evidence on whether it is reasonable to view the Solow residual series for Korea as reflecting exogenous productivity shocks. We consider whether lagged values of a number of macroeconomic variables help to forecast the Solow residual series. The following regression model is used,

$$\Delta R_t = c + \rho(L)dR_{t-1} + \lambda(L)\Delta x_{t-1} + \varepsilon_t, \qquad (10)$$

where $\rho(L)$ and $\lambda(L)$ are polynominals in lag operator L and x is a vector of potential explanatory variables. The polynominals from three to seven are investigated to ensure enough lags to eliminate any serial correlation in ε_t. The variables in x include various foreign and domestic demand side variables such as oil prices, U.S. GDP, terms of trade, exports, and government consumption expenditure, and money stock (M1). These variables are included to capture other types of shocks that are widely believed to affect the Korean economy.

Table 1 reports the p-values obtained from performing an F-test of the hypothesis that $\lambda(L) = 0$ for the various choices of x. Given the relatively large number of possible choices for x, each variable is tested sequentially rather than jointly. To reduce the possible bias resulting from misspecification of the model, we pursued the following strategy. First, we considered sufficient lags of both dependent (ΔR_t) and independent variables (Δx_{t-1}) to ensure serially uncorrelated residuals. Second, the results in Table 1 should be considered to find variables that Granger-cause the Solow residuals. Thus, the results are to find whether the Solow residulals are exogenous from varying shocks other than technology. Thus, it is sufficient enough to find a variable that Granger-causes the Solow residual in order to reject the strict exogenous hypothesis. Lastly, we will construct a more general model, consisted with all of the significant variables in Table 1, to check the robustness of the individual Granger causality tests in the next chapter.

Of all the variables considered, exports, M1, and government consumption have some ability to predict the Solow residual. The prediction power of the government spending vanishes in the model that includes exports, M1, and government spending in the same equation, as the lags of the government spending become jointly insignificant to predict the Solow residual. The other two variables, however, remain significant at the 1-5 % level depending on the size of lags. This is also the case if government spending is omitted from the regression.

The results in Table 1 suggest that the measured Solow residual series for Korea can't be considered to be a pure reflection of exogenous technology shocks. This finding is consistent with that obtained by Evans (1992) for the U.S., Otto (1999) for Australia, and Huang (2000) for Taiwan. Evans (1992) found that government spending and money supply (M1) Granger-cause the U.S. Solow residual, and Otto (1999) showed that the terms of trade and a measure of the term spread have predictive power for the measured Solow residual of Australia. Using Taiwanese industry level data, Huang (2000) showed that M1B has significant predictive power over the Solow residual of the manufacturing industry, M1B and U.S. GDP over that of the construction industry, and U.S. GDP, M1B, Government consumption over that of the electricity, gas and water industry.

An obvious limitation of the results obtained from equation (10) is that we can't find any dynamic interaction between the variables for they are obtained from a reduced form model. Thus, we construct a vector autoregressive model in order to formally identify dynamic effects of the variables affecting the Solow residual in the next section.

IV. Dynamic Analysis of the Solow Residual

1. Construction of the Model

The measured Solow residuals shouldn't be correlated with exogenous demand shocks if the residuals reflect only the productivity changes. To investigate systematically whether the measured Solow residuals for Korea are independent with the demand shocks, we employ a VAR that consists of the measured Solow residuals and demand variables that have a predictive power over the measured Solow residual in the previous section. Dmand shocks should have no association with the Solow residual if the residual represents pure technological shocks. Thus, any evidence of predictive power of the demand side variables on the measured Solow residual would imply inadequacy of the measured Solow residual in representing productivity changes.

To investigate the effect of demand side variables on the Solow residuals, we estimate a four-variable VAR system consisted with the measured Solow residual of Korea (Res), the domestic real government consumption (G), the money supply (M1) and the exports (Exp). As an exogenous variable to the system, a dummy representing the oil shock in 1980 (1980 I-1981 I) and the financial crisis in 1988(1997 III-1998 III) is introduced to capture extreme outside shocks.

Table 1 reports ADF tests in levels and first differences for the demand variables along with the Solow residual. The tests suggest the existence of one unit roots for every series, and indicate the time series variables are integrated of order 1, I(1).[4] We also tested whether there is long run relationship among the variables. It is possible to derive long-run equilibrium among them without suffering from the statistical problems of spurious regressions.

Table 2 presents the results of Johansen's cointegration test to find how many long run relationships and, thus, cointegration vectors exist in the parameter matrix. Test results show that a restricted constant, which allows a non-zero drift in the unit root process, is included in the multivariate system of equations. The lag value of the VAR was set equal to three to ensure that the residuals of the multivariate system are Gaussian. The null hypotheses, r=0, was rejected at 5% level (see Osterwald-Lenum, 1992 for critical values), but the null hypothesis r<=1 couldn't be rejected. Thus, the estimated likelihood ratio test indicates that there is one conintegration vector, and a long-run relationship is present in the underlying data generating process of the time series variables.

Based on the test results, we employ a vector error correction model (VECM) to estimate variance decomposition and impulse response function to investigate dynamic interactions among the measured Solow residual and demand variables. The VECM model includes the lagged error correction term of cointegration analysis, which acts as a long-run identifying restriction. If the cointegration vectors are valid, as the test statistics confirmed, a simple VAR analysis would provide inefficient estimates.

The measured Solow residual is affected by demand side variables if forecast errors of the measured Solow residual are explained considerably by past innovations of the other demand side variables. The Solow residuals are independent of demand side variables if the measured Solow residuals are not affected by exogenous demand shocks. Otherwise, the Solow residuals are correlated with the demand side variables.

Results of variance decomposition and impulse response depend on the methods used in constructing the orthogonalized innovations. The standard Cholesky factorization is used to construct the innovations in this study because the theory imposes no a priori restrictions on the parameters of the model. The ordering of the variables for the factorization is Exp-M1-G-Res based on subjective prior on the causal relation between the variables. This ordering presumes that foreign shocks cause business cycles to which demand policy responds, especially for small open country.[5] Our VECM system is with lag length of four, which is chosen to minimize AIC.

2. Dynamic Responses of the Solow Residual to Demand Shocks

To analyze the response of the measured Solow residual to the other exogenous demand side variables, we investigated impulse response functions and error decomposition analysis. One important and unavoidable issue in innovation accounting is the method of decomposition of the VECM residuals into structural disturbances. There are several standard ways of identifying these structural errors. This study uses Choleski decomposition. Figure 2 reports the impulse response functions that are the stimulated response of the measured Solow residual to the other three variables Time period of the impulse response function spreads over 10 years and measured in terms of standard deviations.

The effect of one standard deviation shock of the exports on the measured Solow residual was positive over the whole period, and the response of the residual peaks at period 5 and diminished afterwards. The effect of the shock of M1 on the residual was positive and peaking 3 quarters after the initial shock and vanished thereafter. The effect of the shock of the government spending on the residual was positive and peaking 5 quarters after the shock. The responses of the measured Solow residual to the shocks of the exogenous variables imply that the residual is correlated with the demand side variables. The pattern and size of the shocks seemed to be very similar irrespective of the variables.

Investigation of impulse response functions shows that the measured Solow residual moves pro-cyclically closely with the demand shocks. For the Taiwanese manufacturing industry, Huang (2000) reported that the demand side variables such as U.S. GDP, domestic M1B and government consumption all exerted positive impacts on the measured Solow residuals using a VAR model. He also found the same relationship between the Solow residuals and demand shocks in the construction and energy industries in Taiwan. Otto (1999) also reported that the Solow residual responded to demand side shocks positively in the short run for the Australian manufacturing industry. He showed about 30% of the variability in the Solow residual can be attributed to demand shocks, using a structural VAR model of capacity utilization.

Table 2 reports the decomposition results of forecast error variances of the measured Solow residual for Korea. The variance decompositions give an indication of the quantitative importance of the responses of the Solow residual to demand shocks. These results confirm the conclusions drawn from reviewing the impulse response functions; there is a strong direct relationship between the measured Solow residual and shocks to the demand side variables.

Large part of the forecast error variance of the measured Solow residual was explained by the innovations of the other variables. Exports explained about 12% of the forecast error variance of the residual 10 quarters after the shock, and about 14% after 20 quarters. Money supply (M1) explained about 15% of the forecast error variance of the residual 5 quarters after the shock, and about 21% after 20 quarters. Government spending explained about 16% of the variance in 5 quarters and about 21% after 20 quarters. The innovations in the two domestic demand variables explained about 42% of the forecast error variance of the residual 20 quarters after the initial shock. The innovations in all these three demand variables explained up to about 56% of the forecast error variance. These results provide the evidence that demand side variables are correlated with the measured Solow residual, implying that the measured Solow residual is inappropriate as a measure of productivity changes.

3. Sensitivity Analysis

The above analysis is based on arbitrary presumptions, including lags, and model specifications, that may change its basic results. Thus, we provide some basic extensions to the analysis to test the sensitivity of our results.

Given the choice of lag length of four, alternative lag lengths were investigated to find out their impacts on the results. Figure 3 presents the estimated response of the Solow residual to demand shocks for all values of lags from 2 to 6. For all lag choices, impacts of demand shocks on the Solow residual are positive. The one distinctive feature of lag length experiments is that external shocks as represented in exports (Exp) quantitatively dominates the other domestically demand shocks (M1, G). The impact of the monetary shocks diminishes as lag becomes larger.

Although all variables in the system are characterized by autoregressive unit root, some researchers prefer to use the original undifferenced series because of the possible loss of valuable information due to the differencing (Sims, 1980). Thus, we derived a impulse response function from a VAR model with lag length of two, which is determined to minimize both AIC and SC.

Figure 4 presents the impulse response functions derived from the VAR. These functions show dynamic responses of the Solow residual to a one standard deviation shock of each demand variables. One standard deviation confidence interval bands are also structured to test the significance of the response to a particular shock. The response is considered significant if confidence intervals do not pass through the zero line. The effect of one standard deviation shock of the exports on the measured Solow residual is positive over the whole period, and the response of the residual peaks at period two and diminishes slowly afterwards. The effect of the shock of M1 on the residual is positive and significant. It is peaking 5 quarters after the initial shock and vanishes thereafter. The effect of the shock of the government spending on the residual was positive and peaking 9 quarters after the shock. All these shocks are temporary as their own responses disappear over the years (see graphs in the second column). The responses of the measured Solow residual to the shocks of the exogenous variables imply that the residual is correlated with the demand side variables. The effect of the shock of M1 on the residual is most prominent among those three demand variables. In short, impulse responses derived from the VAR confirms the basic results derived in the previous section.

V. Conclusion

This study investigates the relationship between the measured Solow residual and demand side variables for the Korean economy. Empirical results of the study show that the measured Solow residuals can be predicted by demand side variables such as exports, money supply, and government spending. From the vector error correction model, investigation of impulse response functions shows that the measured Solow residuals move pro-cyclically with the demand shocks, and that the forecast error variance of the measured Solow residuals are mostly explained by past innovations of in domestic and foreign side demand variables. Among the demand variables, monetary shock exerts the most prominent impact on the measured Solow residual.

The Korean economy has always faced rising demand through out the developing period during 1960-1990, and this was true to all East Asian developing countries. Thus, the measured Solow residuals of these countries might overestimate their true technology changes. This disparity between the true technology changes and the measured Solow residual can be prominent if the residual of East Asian countries are compared with those of other countries in which demand moves up and down following business cycles. In this case, there is a possibility that productivities in East Asian countries can be overstated than those in the other countries. On the East Asian productivity debate, the results that the measured Solow residual moves pro-cyclically suggests that productivity comparison among the countries must be cautious because it can be biased by demand shocks.

The correlation between the measured Solow residual and demand side variables suggests the Solow residual is inaccurate measure of productivity. The study indicates three sources that cause a noise in the measured Solow residual: increasing returns to scale, imperfect competition and under-employment of factor inputs. Thus, the Solow residual can be measured more accurately to represent genuine productivity if these three factors are considered in actual estimation, both theoretically and empirically. Isolating the effects of these factors from the Solow residual makes promising topic of further research considering the vast use of the residual in estimating productivity.

The range of the demand side variables considered in this paper was not comprehensive due to lack of data. The possible omitted demand variables that may affect the measured Solow residual may include interest rates, exchange rates, and more broadly defined foreign demand than U.S. GDP. Extension of the dataset, however, won’t change the basic results of the paper even though it may provide other possible demand variables that have a predictive power on the Solow residual.

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Table 1. Predictability of the Solow residual for Korea

Variables	LM(5)	χ^2 statistics for $\lambda(L)=0$
Foreign		
Oil prices	3.38 (0.56)	3.32 (0.65)
U.S. GDP	4.14 (0.52)	1.81 (0.87)
Terms of trade	5.79 (0.32)	0.95 (0.96)
Exports	7.14 (0.21)	17.18 (0.01)
Domestic		
M1	5,40 (0.36)	7.11 (0.06)
Government spending	11.24 (0.04)	21.08 (0.00)

Notes: Tests are based on equation (10) in this paper, and all variables are transformed by taking logarithms and first differences. The order of the lags in the polynominal $\lambda(L)$ is five except exports and M1 with seven and three, respectively. The numbers in the parentheses are p-values of the test statistics. LM(5) refers to a Lagrange multiplier test for residual serial correlation up to order five.

Table 2. Unit root tests

Variables		Number of lags in ADF test regression			
		1	2	3	4
Exports	Level	-1.92	-2.02	-2.02	-2.33
	1st difference	-6.45*	-4.53*	-4.84*	-4.36*
M1	Level	-2.81	-2.77	-3.22	-2.72
	1st difference	-5.75*	-4.49*	-5.24*	-4.61*
Government spending	Level	-0.61	-0.42	-0.41	-0.18
	1st difference	-8.42*	-6.26*	-5.78*	-4.81*
Solow residual	Level	-2.19	-2.48	-2.62	-2.29
	1st difference	-5.75*	-4.80*	-5.08*	-4.98*

Notes: Test regressions contain a constant, a linear time trend and one to four lags of the dependent variable. * rejects the null hypothesis of unit root existence at 1% significance level.

Table 3. Johansen's log likelihood test for cointegration (number of lags=3)

H_0: rank=r	Eigenvalue	Likelihood Ratio	5% Critical Value	1% Critical Value	No of CEs
R=0	0.293	53.46	47.21	54.46	None*
R$\leq$1	0.194	21.82	29.68	35.65	At most 1
R$\leq$2	0.020	2.11	15.41	20.04	At most 2
R$\leq$3	0.002	0.21	3.76	6.65	At most 3

Notes: Test regression assumes a linear deterministic trend in the data. * denotes rejection of the hypothesis at 5% significance level. The test indicates 1 cointegrating equation at 5% significance level.

Table 4. Decomposition of forecast error variances

Period	S.E.	Exp	M1	G	Res
1	0.01	2.04	2.20	0.67	95.08
2	0.02	8.29	7.91	1.60	82.20
3	0.02	10.51	13.01	4.37	72.11
4	0.02	10.39	15.03	7.52	67.06
5	0.03	11.55	14.66	15.77	58.02
7	0.03	11.83	17.21	17.27	53.69
10	0.03	12.17	18.07	18.89	50.86
15	0.03	13.30	19.53	20.32	46.85
20	0.04	14.06	20.93	21.37	43.64

Note: Ordering is Exp-M1-G-Res.

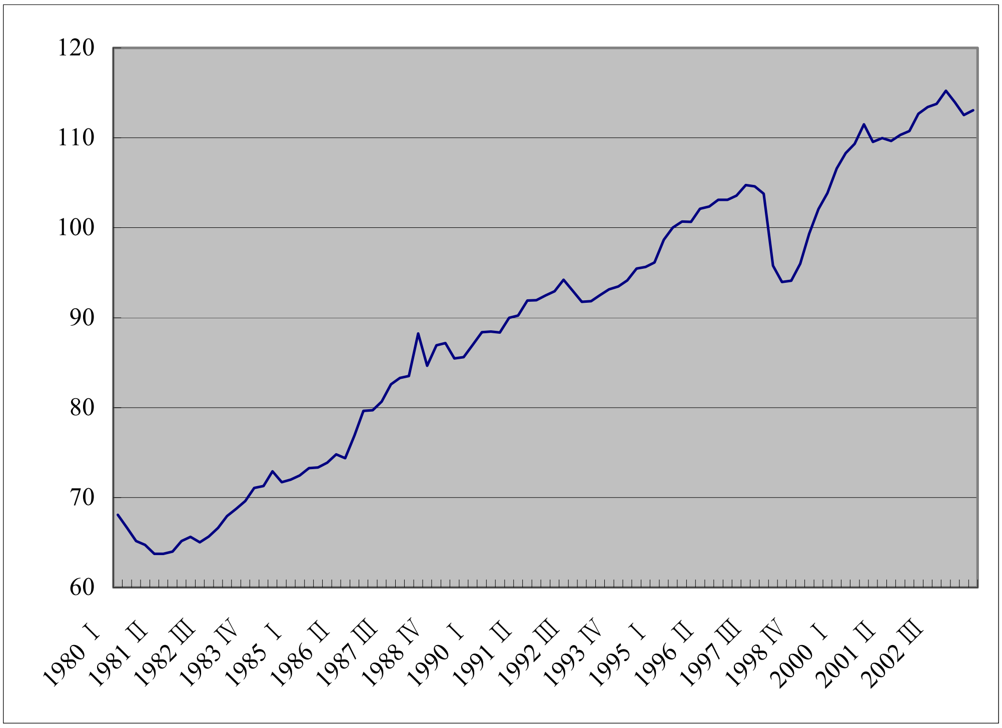


Figure 1. The Solow residual for Korea (1995 II=100)

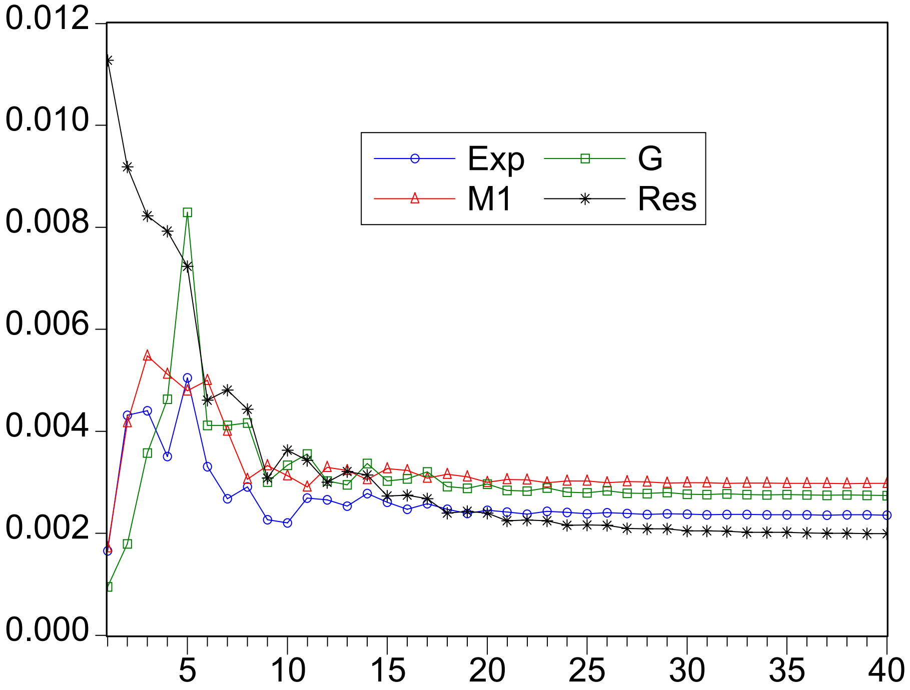
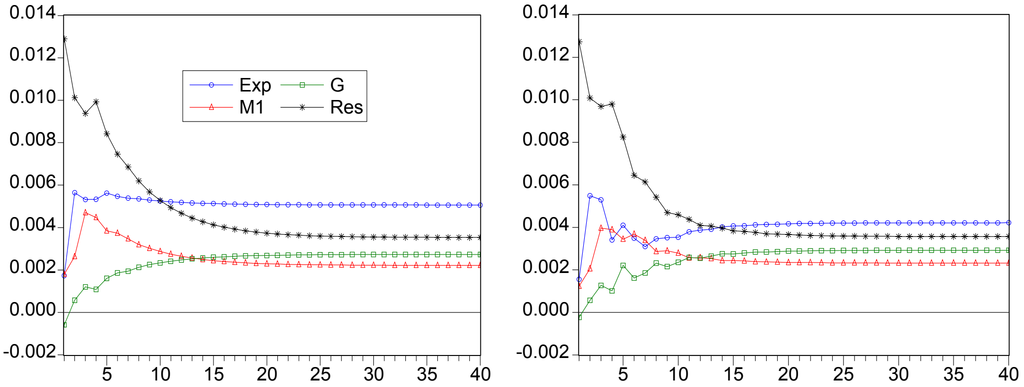
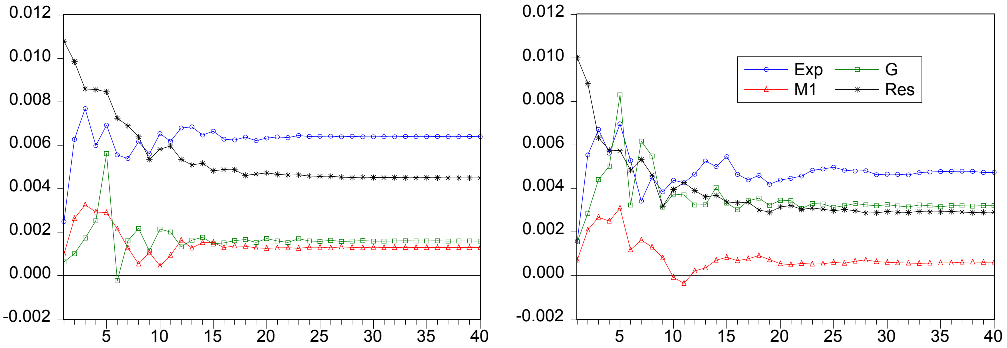


Figure 2. Response of the Solow residual to demand shocks

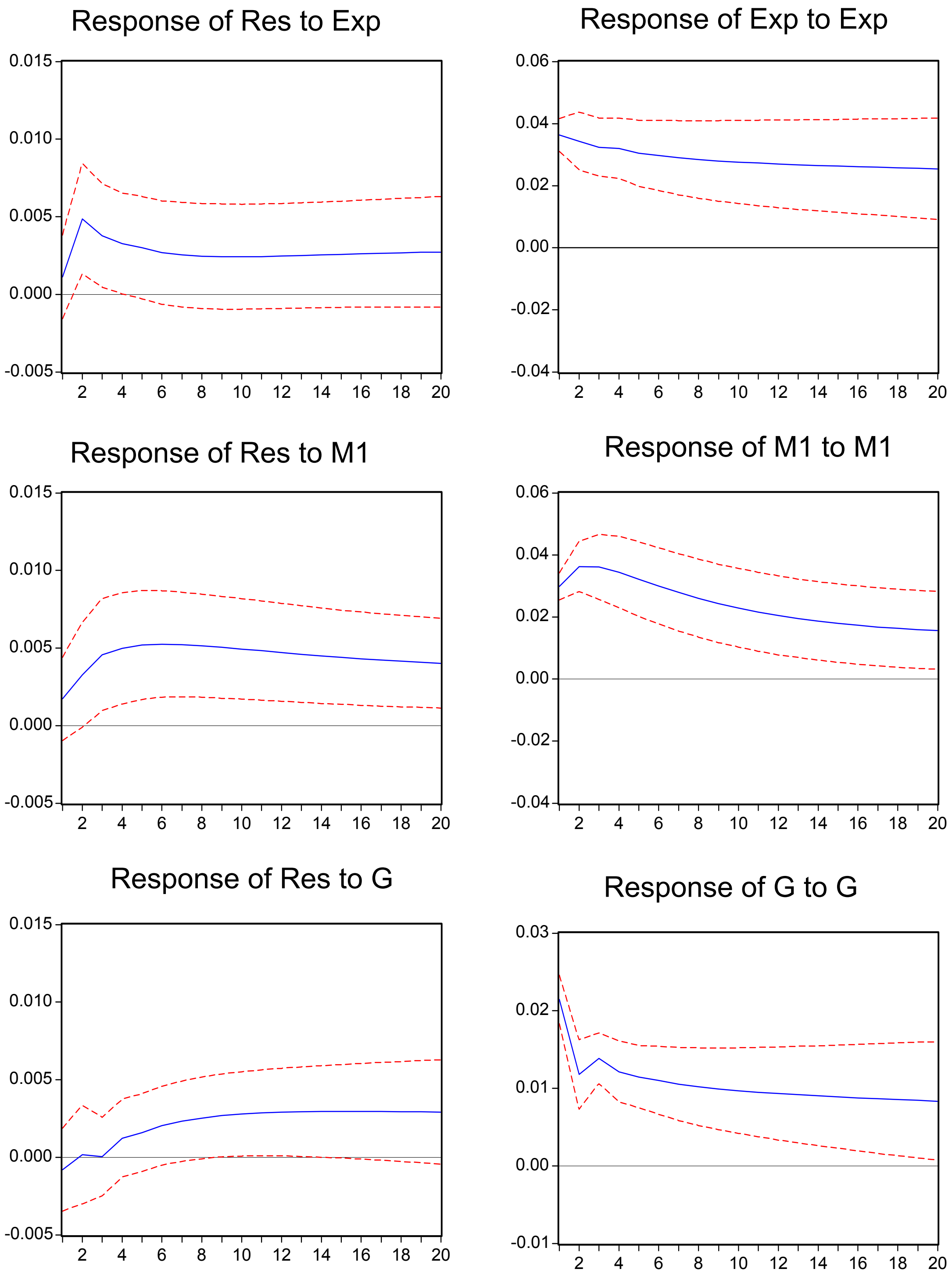


(A) Lag=2 (B) Lag=3



(C) Lag=5 (D) Lag=6

Figure 3. Impact of lags on response of the Solow residual to demand shocks



Response of Res to Exp

Response of Exp to Exp

Response of Res to M1

Response of M1 to M1

Response of Res to G

Response of G to G

Figure 4. Response of the Solow residual to demand shocks in a VAR model

Notes

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[1] Basu (1996) compared the relative importance of cyclical fluctuations in labor and capital utilization, increasing returns to scale, and technology shocks as explanations for pro-cyclical productivity, and concluded that cyclical factor utilization is the most important variable.

[2] Except Huang (2000) and Otto (1999), previous studies of the properties of the Solow residual have focused mostly on measures for the U.S.

[3] This approach was developed by Solow (1957), Kendrick (1961), Denison (1979), and Jorgenson and Griliches (1967).

[4] The results don't depend on specification of the test regressions even though the test regressions reported include a constant and a linear time trend.

[5] We have also examined some alternative ordering and the results are similar to those reported in the paper.