Abstract

This study examines the time series behavior of investment, exports and output in South Korea during 1956 to 1996. Impulse response analysis and variance decompositions indicate that investment rates and export growth rates have significant short-run effects on the growth rates of per capita output. While there are long-run effects to the levels of per capital output, statistically all growth rate effects disappear within four years. No special role for equipment investment was found. These findings are consistent with the predictions of the Solow growth model. The study found no empirical support for endogenous growth theory.


JEL classification codes: O4, O1, F4
1. Introduction

It has long been argued that rates of investment and exports are primary determinants of economic growth. Theories stressing the importance of investment in economic development are known collectively as “capital fundamentalism” (King and Levine 1994). Exports can affect growth through externalities such as learning by doing and economies of scale.

The endogenous growth literature provides formal models for these arguments. Since the pioneering work by Romer (1986) and Lucas (1988), new growth theory has provided analytical backing for some of the recurrent themes of the development literature, including the roles of investment and openness to trade.

Most empirical tests of the association among investment, exports, and economic growth consist of cross-country regressions. For example, a number of recent empirical papers utilized Summers and Heston’s (1988) data on real GDP. However, Howard Pack (1994) has pointed out conceptual and methodological problems of commonly used cross-country regressions for tests of the sources of growth and has argued for time series tests. The main problem associated with single equation time series tests of links among investment, exports and output growth lies in simultaneity bias. In other words, causality does not necessarily run from investment or exports to output growth. In this case, single equation estimation suffers from a misspecification problem.

This study employs vector autoregression (VAR) analysis to examine the dynamic relationships among investment rates, output growth and export growth in Korea during 1956-1996. Using identifying restrictions one can investigate the relationships between the variables of interest in both the short-run and long-run.
This study uses Korean data because its growth during the last four decades is widely thought to exemplify an investment-driven and export-led economy. Of course, the availability of quality data is another reason for this selection. While the recent dramatic downturn in Korea also brings into question the idea that Korean economic development was a result of endogenous growth dynamics, this paper shows that there is no time series evidence that endogenous growth stories fit the Korean growth experience. Instead, traditional neoclassical growth models appear to explain the Korean experience much better.

Section 2 provides a brief review of the literature. In section 3, the VAR model is presented. Section 4 presents results from the VAR estimation and discusses implications for new growth theory. Section 5 provides a summary and conclusion.

2. The Debate on the Role of Investment and Exports in Economic Growth

King and Levine (1994) characterized capital fundamentalism as “the belief that the rate of physical capital accumulation is the crucial determinant of economic growth.” The endogenous growth literature, pioneered by Romer (1986) and Lucas (1988), revived capital fundamentalism. The AK models are the simplest endogenous growth models that succinctly show how capital investments can generate sustained economic growth.

AK models assume constant returns to scale technology in capital K, that may be broadly defined to include physical, human, and R & D capital, so that production at time t is given by 

\[ Y = AK, \]

where \( A \) is the level of technology. The model yields the steady state growth rate of income per capita,

\[ g = iA - (n + \delta) \]
where \( i \) is investment rate, \( n \) is the growth rate of population, and \( \delta \) is the rate of depreciation.

Equation (1) suggests the key result of the AK models: a higher investment rate, \( i \), leads to a higher rate of steady state per capita output growth, \( g \). In other words, a change in the investment rate has a permanent effect on the growth rate. This is the first empirical claim that is tested in the paper.

Recently, a number of cross-country regression studies inspired by endogenous growth models have found a strong relationship between the average GDP growth rate and the average share of investment in GDP. Levine and Renelt (1992) critically evaluated these cross-country regressions and found that almost all results are fragile to small changes in regression settings. Still, they identified a “positive, robust correlation” between per capita output growth and investment rates. De Long and Summers (1992) argued that the link between machinery and equipment investment and growth is much stronger than that predicted by the standard neoclassical growth model. They attributed this result to large externalities and learning-by-doing associated with equipment investment.

In contrast, Mankiw, Romer, and Weil (1992) argued that the neoclassical (Solow) model, once augmented to include human capital, successfully explains the observed correlation between growth of income and the share of investment for a cross section of nations. Auerbach, Hassett, and Oliner (1994) also extended the standard Solow model to incorporate multiple capital goods (equipment investment and structure investment) and argued that the point estimates in the De Long and Summers’ regressions, excluding one outlier (Botswana), are fully consistent with a neoclassical model. In a time series analysis, Jones (1995) found that the key equation (1) of AK
models is easily rejected in a sample of fourteen OECD countries since 1950: while investment rates are nonstationary and show a strong positive trend, growth rates are stationary and have declined. In this sense, he concluded that AK models do not provide a good explanation of the engine of growth in these countries.

As for the effects of exports on growth, neoclassical trade theorists advocate the gains from free trade using the concept of static comparative advantage. Along with the direct benefits of free foreign trade through specialization, potential dynamic benefits of free trade have also been suggested. Some development economists, however, called for active trade policies because of argued coordination failures. This approach differs from traditional import substitution in that it advocates active policy to promote exports in goods of increasing skill and technology content (Pack and Westphal 1987). While citing very different mechanisms, these two schools agree in predicting a link between exports and growth.

Support for openness to trade or even more active export promotion, also comes from endogenous growth theory, which has examined the linkage between international trade and a country’s economic performance. Grossman and Helpman (1991) argued that knowledge spillovers arising from international trade will spur domestic innovation. Young (1991) proposed a model in which international trade spurs growth by generating economy-wide spillovers through learning by doing. Parente and Prescott (1994) conjectured that trade openness lowers barriers to technology adoption. Romer (1993) argues to overcome “idea gaps”, developing countries should strive to open their economies.
Proxying such spillover effects with the growth rate of exports and the change in the export share of GNP, the second central empirical claim tested in this study is that an increase in these export proxies has a permanent effect on the growth rate. This aspect of the paper builds on several existing empirical studies. Feder (1983) specified a simple two sector dynamic model based on an extended neoclassical production function that included exports as an additional factor of production for the non-export sector. The rationale for this specification was that the export sector generates positive inter-sectoral externalities in the non-export sector. Feder’s model has been widely used and in most studies, the estimated effects of exports is significantly positive. However, Salvatore (1983) argued that the link between growth, industrialization, and exports is inherently simultaneous. Esfahani (1991) estimated a simultaneous model consisting of three equations of output growth, exports, and imports, and found that exports were insignificant, reinforcing skepticism on the validity of single-equation results.

Researchers also found reverse causality going from output growth to growth of exports. Jung and Marshall (1985) performed Granger causality tests on 37 countries. In 9 countries they found that output growth Granger-caused export growth. In only 4 countries did the causality run the other way. In the remaining 23 countries they could not establish one-way causality.

Overall, the evidence of persistent effects to per capita output growth is mixed. In this paper, we formally test endogenous growth theory in the context of the Korean growth experience. In particular, we test whether export growth and investment rate shocks have persistent effects on per capita output growth rates.

3. Vector Autoregression (VAR) analysis
In this paper we utilize a VAR methodology, estimating the impulse responses of the rate of per capita GNP growth to shocks in investment rates and export growth. Impulse response analysis allows for a convenient representation of the time path of effects. In addition, we conduct forecast error variance decompositions to uncover the short-run relationships among variables. The data used in the study cover the period 1956-1996 and include: the annual growth rate of per capita real GNP (\(\Delta y_t\)), the ratio of real equipment and machinery investment to real GNP (\(i_t^E\)), the ratio of real gross investment to real GNP (\(i_t^G\)), the share of real exports to real GNP (\(x_t^S\)).

One must first address stationarity and cointegration issues to determine how variables should be included in the VAR system. Table 1 presents results from the Dickey-Fuller unit root test, which is a test for stationarity. The test-statistic tests the null hypothesis of \(\pi = 0\) in the following equation.

\[
\Delta Z_t = \alpha_0 + \pi Z_{t-1} + \alpha_1 t + \sum \beta_i \Delta Z_{t-1} + \epsilon_t
\]

where the sum is taken over the \(p\) lags. Equation 5 is the augmented Dickey-Fuller regression equation with a time trend. Following Campbell and Perron (1991), \(P\) was reduced until the last lag was significant starting with \(P=P_{\text{max}}\) (6 in this study). If all the lags were insignificant, \(P\) was set to zero.

According to the results, the null hypothesis of a unit root is rejected for the rate of growth of per capita real GNP, the gross investment rate, the equipment investment rate, and the change in the share of real exports in real GNP. Per capita real GNP and the exports to GNP ratio are nonstationary in levels. The nonstationarity of the real exports share in GNP, along with the stationarity of the growth rate of per capita real GNP implies that there is no long-run
relationship between the two variables; while the former has permanent components, the latter always fluctuates around a constant long-run mean. This simple point was utilized by Jones (1995) to criticize the AK model of endogenous growth. In his study of 14 OECD countries he found investment rates were nonstationary, while the growth rates of output were always stationary. In this regard, based on the time series property of the data, we conclude that changes in the real export share in real GNP do not have a long-run effect on the growth rate of per capita real GNP.

It is possible that while per capita GNP is nonstationary in levels, there may be some long-run relationship between the level of per capita GNP and the level of investment and exports. If so, one must take into account this long run relationship when specifying the VAR. The unit root tests in Table 1 confirm that equipment investment ($I_t^E$), gross investment ($I_t^E$) and exports ($X_t$) are all stationary in first differences, or, nonstationary in log levels. To test for the possibility of cointegration between the log levels of per capita GNP, investment, and exports, the multivariate cointegration test outlined by Johanson and Juselius (1990) was used.

The results for the test are given in Table 2. Two test statistics are utilized: the trace statistic and the maximum eigenvalue statistic. In addition, the test was done both using equipment investment and gross investment as the investment variable. The results for the trace statistic show that there is no evidence of cointegration between the three variables at the 10 percent level. The statistic for zero cointegrating vectors ($r=0$) when equipment investment is used, 30.61, and gross investment, 30.24, are both less than the critical value at the 10 percent level, 32.09. The trace statistics for the hypothesis of more than one cointegrating vectors
(r ≤ 1 and r ≤ 2) are all significantly lower than the 10 percent critical values listed. The same holds for the maximum eigenvalue test. The evidence suggests that there is no cointegrating relationship between per capita output, investment, and exports.  

Given the lack of evidence for cointegration, we return to examining the dynamic relationships between investment rates, export growth, and per capita GNP growth by specifying a trivariate reduced form VAR with each equation containing \( p \) lags of the three variables in the system. To motivate the three variable VAR, consider a simple model of the relationships between investment, exports, and output, that is capable of representing either the endogenous growth approach or the Solow model. In both Solow and the AK models, the level of output depends on the level of technology (or knowledge) in the economy, \( A \). Output may also depend on current investment and exports.

\[
Y_t = F(A_t, I_t, X_t)
\]  

(3)  

In exogenous models, the rate of growth of \( A \) is determined outside the model, so policy is not effective. In the AK model, the long run rate of growth of output also depends on the level of technology, \( A \). There are various ways to endogenize improvements in technology, notably through “learning by doing.” In the development literature, such learning can potentially be gained either through exporting, due to interactions with technologically more advanced foreign firms; or through investing, due to the use of better quality foreign technology (or newer vintage technology). One way to proxy for these learning effects is through previous output, investment, and export levels. Thus,

\[
A_t = g(B_1(L) Y_{t-1}, B_2(L) I_{t-1}, B_3(L) X_{t-1})
\]  

(4)
where $B_i(L)$ are polynomial lag operators that capture the dynamic relationship between knowledge and investment, exports, and output. In endogenous growth models these effects may persist in the long-run. In contrast, in the Solow model, there is no long-run effect in these relationships, though there may be a short-run effect as an economy adjusts to a new steady state. Plugging (4) into (3) one can obtain a relationship between current output and past levels of output and, both, current and past levels of investment and exports.

\[
Y_t = f(D_1(L) Y_{t-1}, D_2(L) I_t, D_3(L) X_t)
\]

In the main result in endogenous growth models, as described in equation (1), investment shocks, and possibly export shocks, will not only result in increased output levels, but will also result in increased growth rates of output. Allowing for the possibility that investment may in principle depend on past exports and output, while exports may depend on past investment and output, a three variable dynamic system with output, investment, and exports can be derived. These relationships represent the basis for our VAR modeling strategy that can allow for the possibility of such spillovers between our variables of interest.

Allowing for this dynamic interaction, the following three-equation VAR of investment rates, export growth, and per capita GNP growth is estimated:

\[
i_t = \alpha + \sum \delta_j \Delta y_{t-j} + \sum \kappa_j i_{t-j} + \sum \pi_j \Delta x_{t-j} + u_{1t}
\]

\[
\Delta x_t = \alpha_2 + \sum \delta_2 \Delta y_{t-j} + \sum \kappa_2 i_{t-j} + \sum \pi_2 \Delta x_{t-j} + u_{2t}
\]

\[
\Delta y_t = \alpha_3 + \sum \delta_3 \Delta y_{t-j} + \sum \kappa_3 i_{t-j} + \sum \pi_3 \Delta x_{t-j} + u_{3t}
\]

where $i_t$ are investment rates (the share of real investment in real GNP), $\Delta x_t$ is the growth rate of exports, $\Delta y_t$ is the growth rate of per capita real GNP, $u_{it}$ are iid disturbance terms, and sums are
taken over the $p$ lags. Lag length is selected using a likelihood ratio test outlined by Enders (1995). The investment rate is measured alternatively by total investment or equipment investment. The above VAR allows one to examine the impact and persistence of investment rate and export shocks on per capita GNP growth. Thus, it provides for direct examination of the implications of endogenous growth theory as explained in equation (1).

The literature shows no consensus in specifying the appropriate form of export growth in relation to output growth. The proposed forms include the real exports share of real GNP, the growth rate of real exports, and the change in the export share of GNP. Among them, this study uses the last two types. Since this study covers each of two types of investment rates and export growth, it contains four three-variable VAR systems.

4. Impulse Response and Variance Decomposition Results

In order to identify the impulse response functions for a VAR, one needs to impose some identification restrictions on the VAR errors. To this end, this study uses the Choleski decomposition. In estimating the three variable VAR systems the errors are orthogonalized with $i_t$ first, $\Delta x_t$ second, and $\Delta y_t$ last. This restriction implies that a shock to $\Delta y_t$ has no contemporaneous effect on $i_t$ and $\Delta x_t$, while a shock to $i_t$ or $\Delta x_t$ has contemporaneous effects on $\Delta y_t$. Moreover, the instantaneous response of $i_t$ to $\Delta x_t$ is forced to be zero. The rationale for putting $\Delta y_t$ last is in part to give export growth and investment rates the greatest possible explanatory power. Variables that are higher in the ordering are credited with greater explanatory power in a VAR system. All possible orderings were tested to see whether greater persistence of
per capita GNP growth rates to export and investment shocks were possible. Other orderings yielded qualitatively similar results.

Results from Granger causality tests do not suggest a direct line of causation between per capita GNP growth, investment rates and the change in the export share of GNP. The exception is that per capita GNP growth, the equipment investment rate, and the gross investment rate Granger cause export growth. This is consistent with the results from Jung and Marshall (1985).

This evidence does not support the notion of export led growth as the root cause of Korean growth. The Granger causality tests show instead that while strong export growth has been important in the dynamics of Korean growth, it was not the main initial thrust behind the growth that has been observed. It might still be the case that export growth could have large, persistent effects on per capita output growth, as new growth theory outlines. However, the causality evidence suggests that either an investment shock or some other factor causing per capita output growth to increase would have to be the root cause of the growth in exports.

The causality results for export growth imply that it should follow investment rates in the VAR ordering, as it does. While the evidence also suggests that per capita output growth should precede export growth in the ordering, we continue initially with per capita output growth ordered last to give export growth and investment growth their maximum impact and thus give endogenous growth theory its best opportunity to be supported by the data. Later we examine how changing the ordering of variables in the Choleski decomposition affects the results.

Figures 1 shows impulse responses and standard errors for the response of annual growth rate of per capita real GNP to a one standard deviation shock in each of the different investment
and export variables.\textsuperscript{5, 6} The VARs are all specified with a one year lag. Considering the small sample size (41 observations), this study presents impulses with upper and lower one standard error bounds.

The results in Panel a) of Figure 1 imply that a shock in the gross investment rate has strong impacts on $\Delta y_t$ for three years. Thus an impulse response analysis suggests a strong short-run relationship between the growth rate of per capita GNP and the gross investment rate. However, after four years impulse responses are not significantly different from zero. In terms of the point estimates, the effects of the gross investment rate are also negligible after four years.

Panel b) shows that a similar short-run relationship holds between the equipment investment rate and the growth rate of per capita GNP. Thus, there is no effective difference in using the equipment investment rate as compared with the gross investment rate. This finding from a time series study is inconsistent with the results of cross-country studies such as De Long and Summers (1992) which emphasize the special role of equipment investment in economic growth.

As shown in Panel c), impulse responses of $\Delta y_t$ to a shock in the growth rate of exports display a similar pattern. A one standard error band implies that a shock in the growth rate of exports has impacts on $\Delta y_t$ for only three years. Meanwhile, Panel d) indicates that the time paths of the effects of the change in exports’ share in real GNP ($\Delta x_t^{\delta}$) on $\Delta y_t$ are similar to those found between the growth rate of exports ($\Delta x_t$) and $\Delta y_t$. From these results we conclude that export growth, whether measured by the growth rate of exports or by the change in exports’ share of GNP, has a significant impact on the growth rate of per capita GNP for up to 3 years in Korea.
Figure 2 addresses the issue of whether the impulse responses are sensitive to the ordering of variables in the Choleski decomposition. Within each of the four VARs which generated the results in Figures 1, there are six possible orderings of the three variables. For each VAR, the VAR was estimated for all six possible orderings and impulse responses were calculated along with standard errors. At each horizon, the maximum possible response across all six responses of per capita output growth to an investment rate shock and an export growth shock is plotted in Figures 2. The figure confirms the short-term impact of the shock on per capita output growth and the declining effect over time. In all cases, the response of per capita output growth is never significantly different from zero after three years following the shock. This shows that the finding that investment rate and export growth shocks have a transitory effect on per capita output growth is not sensitive to the ordering of variables.

Returning to the three variable VAR with the ordering investment rate, export growth, and per capita output growth, the variance decompositions with a three-year horizon are listed in Tables 3 and 4 (standard errors are in parentheses). As anticipated, each time series accounts for the majority of its own past values. Table 3 shows that in the $i_t^G - \Delta x_t - \Delta y_t$ VAR the innovation in the gross investment rate explains 20.4% of the three-year forecast error variance of the growth rate of per capita real GNP ($\Delta y_t$). As reported in Table 4, $i_t^G$ explains almost the same percentage of the forecast error variance of $\Delta y_t$ in the $i_t^G - \Delta x_t - \Delta y_t$ VAR. Each of these shares is statistically significant. Therefore, variance decompositions confirm strong short run effects of the gross investment rate on the growth rate of per capita real GNP in both VARs. Meanwhile, the equipment investment rate ($i_t^E$) explains nearly 10% of the forecast error variance of $\Delta y_t$ in both
VARs. This suggests that the equipment investment rate explains a much smaller fraction of per capita output growth variation than the gross investment rate.

The innovations in the rate of export growth ($\Delta x_t$) account for around 20% of the three-year forecast error variance of $\Delta y_t$ in the $i_t G$-$\Delta y_t$ VAR. This is the same fraction accounted for by the gross investment rate. In contrast to the growth rate of exports, the change in the exports share of GNP ($\Delta x_t^s$) explains only 11.67% of the forecast error of $\Delta y_t$ in the $i_t E$-$\Delta x_t^s$-$\Delta y_t$ VAR. In the $i_t E$-$\Delta x_t^s$-$\Delta y_t$ VAR, that number becomes smaller (6.83%) and insignificant.

Earlier impulse response analysis implied that both $i_t G$ and $i_t E$ have similar dynamic relationships with $\Delta y_t$. However, variance decompositions suggest that the share of the forecast error variance of $\Delta y_t$ explained by $i_t G$ is much larger than that explained by $i_t E$. Similarly, variance decompositions indicate that innovations in $\Delta x_t$ account for more of the forecast variance error of $\Delta y_t$ than $\Delta x_t^s$.

Pack (1994) has expressed reasonable doubts as to whether endogenous growth models can account for the East Asian growth experience. Pack suggests that, given what is known from other research, only models that emphasize the role of international trade can provide an adequate explanation of this growth performance. This study does imply that the growth rate of exports has a significant effect on the growth rate of per capita real GNP; but, interestingly, the effective time horizon (3 years) is too short to interpret the finding as empirical support for endogenous growth theory. This research also casts doubt on Sengupta’s (1993, 1994) claim that the relationship between openness and growth in Korea supports new growth theory. His results
were obtained from the estimation equations specified in terms of level differences, not in terms of growth rates.

According to the Solow (neoclassical) model, a permanent increase in the investment rate has only a temporary effect on the per capita income growth rate. In the long run, the level of output per capita is permanently higher, but the per capita growth rates return to long run productivity growth. This shrinkage in the effect of a shock to investment rates stems from the “diminishing returns to capital” assumption of the Solow model. Figure 1 indicate that impulse responses of the growth rate of per capita output to shocks on investment rates do show the diminishing pattern predicted by the Solow model.

Jones (1995) has argued that if the empirical evidence shows a fairly long time-horizon over which investment rates affect the rate of output growth, the AK model of endogenous growth can be viewed as capturing a good approximation to economic growth. Under Jones’ criteria, this study does not provide any empirical support of the AK model of endogenous growth.

As seen in equation (1), new growth theory predicts that a permanent shock to the investment rate should result in a permanently higher growth rate for output per capita. However, the results in Figure 1 show that export and investment shocks have only transitory effects on output per capita. One possible explanation may be that the shocks themselves reflect transitory increases. Panels a) and b) in Figure 3 show that the shocks to investment, for both the gross investment rate and the equipment investment rate, are highly persistent. This provides even stronger evidence against new growth theory. The persistent shocks to the investment rate only
have short, transitory effects on output per capita.

Panels c) and d) in Figure 3 do show that the shocks to exports are transitory. Both export growth and the change in the export share of real GNP return to original levels three years after the initial shock. Recall, this is also the time frame observed for real effects on output per capita. Figure 4 shows, however, that the export shocks do have persistent effects on the investment rate. In sum, export shocks increase the investment rate and output per capita growth rate, but the impact on the growth rate of output per capita is only transitory.

Overall, the results show that investment and export shocks have transitory effects on the growth rates of output per capita. As the growth rates in the impulse responses never turn negative, both exports and investment shocks do result in permanently higher investment rates and output per capita levels in the economy. However, there is no evidence that the growth rates are persistently higher. Instead, the growth rate of output per capita appears to return to steady state rates after three years following the shock. These results are entirely consistent with the traditional Solow model of growth and directly contradict predictions from new growth theory.

5. Summary and Conclusion

This study evaluated two popular explanations of economic growth in newly industrializing countries, namely increased rates of investment and export-led growth, by examining the dynamic relationships between the growth rate of per capita GNP, investment rates, and the growth rate of exports in Korea during 1956-1996. The main findings are:

(1) In the short-run, both investment rates and export growth have strong impacts on the growth rate of per capita GNP. The short-run relationships implied by the impulse response
analysis are supported by variance decompositions. Among various definitions of investment rates and export growth, variance decompositions imply that the gross investment rate and the growth rate of exports are two distinguishable factors behind short run changes in the growth rate of per capita GNP.

(2) In the long-run, any shocks in investment rates and export growth do not have effects on the growth rate of per capita GNP. In other words, both investment rates and export growth have positive, but transitory effects on the growth rate of per capita GNP.

(3) The gross investment rate and the equipment investment rate have similar dynamic relationships with the growth rate of per capita GNP. Therefore, this study could not distinguish a special role for the equipment investment rate in GNP growth.

(4) The finding of transitory effects of investment rates on the growth rate of per capita output is consistent with the prediction of the Solow growth model; it contradicts the argument of a simple endogenous model that predicts that a permanent increase in investment rates will have either permanent, or at least fairly long, impacts on the growth rate of per capita output.

The results suggest that we should interpret the Korean development experience within a neoclassical growth framework. The present approach may offer a valuable alternative strategy for the study of the East Asian growth experience.
Figure 1. Impulse responses of $\Delta y_t$ to shocks in $i_t^G$, $i_t^E$, $\Delta x_t$, and $\Delta x_t^s$, from 3 variable VARs

a) $\Delta y_t$ to $i_t^G$ shock

b) $\Delta y_t$ to $i_t^E$ shock

c) $\Delta y_t$ to $x_t$ shock

d) $\Delta y_t$ to $x_t^s$ shock
Figure 2. Maximum impulse responses of $\Delta y_t$ to shocks in $i^G_t$, $i^E_t$, $\Delta x_t$, and $\Delta x^s_t$.
Figure 3. Impulse responses of $i_t^G$, $i_t^E$, $\Delta x_t$, and $\Delta x_t^s$ to their own shocks

a) $i_t^G$ to $i_t^G$ shock

b) $i_t^E$ to $i_t^E$ shock

c) $\Delta x_t$ to $\Delta x_t$ shock

d) $\Delta x_t^s$ to $\Delta x_t^s$ shock
Figure 4. Impulse responses of $i_t^G$ to shock in $\Delta x_t$ and $\Delta x_t^s$

a) $i_t^G$ to $\Delta x_t$ shock

b) $i_t^G$ to $\Delta x_t^s$ shock
### Table 1. Unit Root Tests

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
<th>P</th>
<th>ADF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta y_t$</td>
<td>growth rate of per capita GNP</td>
<td>0</td>
<td>-4.23*</td>
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<tr>
<td>$\Delta I^E_t$</td>
<td>growth rate of equipment investment</td>
<td>3</td>
<td>-4.22*</td>
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<td>growth rate of gross investment</td>
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<td>equipment investment/GNP</td>
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</tr>
<tr>
<td>$i^G_t$</td>
<td>gross investment/GNP</td>
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<td>-3.30*</td>
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<tr>
<td>$\Delta X_t^s$</td>
<td>change in exports/GNP ratio</td>
<td>0</td>
<td>-4.66*</td>
</tr>
</tbody>
</table>

* denotes significance at the 10% level (critical value: -3.13)

### Table 2. Cointegration Tests for $y_t$, $I^E_t$, $I^G_t$, $X_t$

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>trace statistic with $I^E_t$</th>
<th>trace statistic with $I^G_t$ (0.90)</th>
<th>$\lambda_{max}$ statistic with $I^E_t$</th>
<th>$\lambda_{max}$ statistic with $I^G_t$ (0.90)</th>
</tr>
</thead>
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<td>$r \leq 2$</td>
<td>0.018</td>
<td>0.031</td>
<td>7.563</td>
<td>0.221</td>
</tr>
<tr>
<td>$r \leq 1$</td>
<td>0.717</td>
<td>1.252</td>
<td>17.957</td>
<td>9.996</td>
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<tr>
<td>$r = 0$</td>
<td>30.612</td>
<td>30.240</td>
<td>32.093</td>
<td>10.712</td>
</tr>
</tbody>
</table>

Test statistics are for the trace and maximum eigenvalue tests described in Johansen and Juselius (1990).
Table 3. Variance decompositions at 3-Year horizon in $i_t - \Delta x_t - \Delta y_t$ VARs

<table>
<thead>
<tr>
<th>Percent of forecast error variance in</th>
<th>Typical shock in $i_t^G$</th>
<th>$\Delta x_t$</th>
<th>$\Delta y_t$</th>
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</thead>
<tbody>
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<td>$i_t^G$</td>
<td>98.40</td>
<td>1.32</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>(4.78)</td>
<td>(3.21)</td>
<td>(3.42)</td>
</tr>
<tr>
<td>$\Delta x_t$</td>
<td>6.23</td>
<td>92.23</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td>(5.20)</td>
<td>(7.22)</td>
<td>(4.31)</td>
</tr>
<tr>
<td>$\Delta y_t$</td>
<td><strong>20.39</strong></td>
<td><strong>20.41</strong></td>
<td>59.20</td>
</tr>
<tr>
<td></td>
<td>(10.05)</td>
<td>(9.23)</td>
<td>(11.21)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percent of forecast error variance in</th>
<th>Typical shock in $i_t^E$</th>
<th>$\Delta x_t$</th>
<th>$\Delta y_t$</th>
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</thead>
<tbody>
<tr>
<td>$i_t^E$</td>
<td>97.13</td>
<td>2.01</td>
<td>0.86</td>
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<tr>
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<td>(4.88)</td>
<td>(3.53)</td>
<td>(3.21)</td>
</tr>
<tr>
<td>$\Delta x_t$</td>
<td>5.68</td>
<td>91.49</td>
<td>2.83</td>
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<tr>
<td></td>
<td>(5.47)</td>
<td>(7.36)</td>
<td>(4.97)</td>
</tr>
<tr>
<td>$\Delta y_t$</td>
<td><strong>12.03</strong></td>
<td><strong>14.71</strong></td>
<td>73.26</td>
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<tr>
<td></td>
<td>(7.21)</td>
<td>(8.13)</td>
<td>(12.42)</td>
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</table>
Table 4. Variance decompositions at 3-Year horizon in $i_t - \Delta x_{t}^{a} - \Delta y_{t}$ VARs

<table>
<thead>
<tr>
<th>Percent of forecast error variance in</th>
<th>$i_t^G$</th>
<th>$\Delta x_{t}^{a}$</th>
<th>$\Delta y_{t}$</th>
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<tbody>
<tr>
<td>$i_t^G$</td>
<td>94.90</td>
<td>5.02</td>
<td>0.08</td>
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<td>(7.12)</td>
<td>(6.71)</td>
<td>(2.30)</td>
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<tr>
<td>$\Delta x_{t}^{a}$</td>
<td>7.20</td>
<td>87.02</td>
<td>5.78</td>
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<tr>
<td>(6.81)</td>
<td>(9.31)</td>
<td>(6.20)</td>
<td></td>
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<tr>
<td>$\Delta y_{t}$</td>
<td>17.22</td>
<td>11.67</td>
<td>71.11</td>
</tr>
<tr>
<td>(8.94)</td>
<td>(8.12)</td>
<td>(11.45)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percent of forecast error variance in</th>
<th>$i_t^E$</th>
<th>$\Delta x_{t}^{a}$</th>
<th>$\Delta y_{t}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i_t^E$</td>
<td>95.31</td>
<td>2.95</td>
<td>1.74</td>
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<td>(6.06)</td>
<td>(4.94)</td>
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<tr>
<td>$\Delta x_{t}^{a}$</td>
<td>0.16</td>
<td>95.86</td>
<td>3.98</td>
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<td>(3.57)</td>
<td>(7.21)</td>
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<tr>
<td>$\Delta y_{t}$</td>
<td>10.41</td>
<td>6.83</td>
<td>82.76</td>
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<td>(7.37)</td>
<td>(7.12)</td>
<td>(11.23)</td>
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</tbody>
</table>
References


Endnotes

1 Results in Table 1 are given for the case where one can reject that the variable is nonstationary. If the variable is listed as stationary in differences, it is nonstationary in levels.

2 While per capita GNP is not cointegrated with investment, GNP is cointegrated with investment. As the unit root tests in Table 3 show, the investment to GNP ratio in Korea is stationary over the sample. The remainder of the paper focuses on per capita GNP instead of GNP as the implications of new growth theory outlined in equation (1) are primarily concerned with the impact of investment and export shocks on per capita output growth. GNP and exports are not cointegrated.

3 Results are available from the authors upon request.

4 Others have also applied alternative structural restrictions including long-run restrictions, as in the case of Blanchard and Quah (1988). We did not impose long-run restrictions as this is precisely what is being tested in the current analysis.

5 In Figure 1, and henceforth, $\Delta x_t$ is the export variable used in the VARs for all investment results and $i_t^G$ is used in the VARs for all export results. The results are similar if $\Delta x_t^E$ and $i_t^E$ are used instead, respectively.