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Charles Harvie
University of Wollongong, charvie@uow.edu.au

M. Pahlavani
University of Sistan & Baluchestan, Iran

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Testing for Structural Breaks in the Korean Economy 1980-2005: An Application of the Innovational Outlier and the Additive Outlier Models

Charles Harvie

and

Mosayeb Pahlavani

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Testing for Structural Breaks in the Korean Economy 1980-2005: An Application of the Innovational Outlier and Additive Outlier Models

by

Charles Harvie*
School of Economics and Information Systems
University of Wollongong, NSW, 2522, Australia

and

Mosayeb Pahlavani
Faculty of Economics and Administration Sciences
University of Sistan and Baluchistan, Zahedan, Iran

Abstract

This paper employs quarterly time series data to endogenously determine the timing of structural breaks for various macroeconomic variables in Korean economy. The Innovational Outlier (IO) as well as Additive Outlier models (Perron, 1997) are then used to test for non-stationarity of the Korean macroeconomic data. After accounting for the single most significant structural break, the results from the (AO) model clearly indicate that the null of at least one unit root cannot be rejected for all of the series under investigation. This finding is consistent with our finding based on the conventional unit root test. However, by applying the IO procedure in the presence of a structural break we find the interesting result that two of the variables under investigation become stationary.

The timing of structural breaks for key macroeconomic data under the IO and AO approaches appear to be quite different. Using the IO approach seven of the ten macroeconomic variables focused upon have important structural breaks corresponding with the timing of the Asian financial crisis of 1997. On the other hand, using the AO approach, only one of the ten variables appears to have a structural break related to the Asian financial crisis, while the remaining nine variables have quite diverse structural breaks that depend on key policy changes or other factors contributing to economic turbulence.

JEL classification numbers: C12, C22, C52

Key words: structural break, unit root test, and Korean economy

*Corresponding author email address: charvie@uow.edu.au

1. Introduction

The economic growth and transformation of the Korean economy from 1962 to the present has been truly remarkable (see, for example, Harvie and Lee, 2003a and 2003b). From being a poverty stricken and economically backward country in 1962 with a GDP per capita of only US$82, by 2005 this exceeded US$16,000 and the country had become the fourth largest economy in Asia (after China, Japan and India on a PPP basis) and the twelfth largest in the world (again on a PPP basis) (see Wikipedia, 2005). Export driven growth provided the basis for this rapid and sustained period of economic growth, such that by 2005 Korea had become the world's eleventh largest exporting nation (Central Intelligence Agency, 2006) and thirteenth largest importing nation (Central Intelligence Agency, 2005). The country had, therefore, achieved an impressive record of growth and integration into the high tech global economy.

The economy has, however, experienced periods of economic turbulence: the heavy and chemical industries drive of the early 1970s, the economic and political turmoil arising from the assassination of President Park in 1979, the export driven rapid expansion of the economy in the late 1980s, the growth slowdown in 1992-93 from stabilization policy aimed at reducing inflationary pressure, the collapse of the exchange rate in late 1997 that exposed long standing weaknesses in the country's development model, the subsequent severe economic slowdown in 1998, the 'tech wreck' of 2001 arising from slowing world demand for IT related products upon which the economy is heavily dependent for export growth, the credit card bubble of 2002 and 2003 and the subsequent weakening of domestic demand.

In this context the primary aim of the paper is twofold. First, to conduct a robust empirical analysis of the timing of major structural breaks for the Korean economy, employing macroeconomic data covering the period 1980Q1 to 2005Q1, utilizing the Innovational Outlier (IO) and Additive Outlier (AO) models developed by Perron (1997). This empirical analysis also involves a comparison of results for non stationarity of the data using the conventional Augmented Dickey Fuller (ADF) unit root test, with that obtained from the IO and AO models. It is essential to correctly identify structural breaks in data for any economy: to avoid model misspecification and coefficient bias using such data, and to ensure that tests for data non-stationarity are robust. Second, to provide an interpretation of the major factors that have contributed to these structural breaks, specifically in terms of key policy changes and other domestic and external sources of economic turbulence.

The structure of the paper is as follows. Section 2 briefly overviews Korean macroeconomic developments from the early 1960s to 2005. Section 3 briefly discusses conventional unit root tests that do not take into consideration the potential existence of structural breaks, and presents empirical results based on the Augmented Dickey–Fuller (ADF) test. Section 4 conducts a brief review of testing procedures which do take into account the presence of potential structural breaks in the data, discusses the Perron (1997) Innovational Outlier (IO) and Additive Outlier (AO) models, and presents empirical findings based on these methodologies. This section also provides the context to explain the reasons behind, and the importance of, the identified structural breaks. Finally, section 5 presents some concluding remarks.

2. An overview of the Korean macro-economy

This section provides the context for our empirical analysis, and the importance of robust identification of potential structural breaks in macroeconomic data for an economy prone to periods of economic turbulence. For identification and analysis of periods of economic turbulence in the case of Korea, and hence for the existence of potential structural breaks, it is useful to break its period of prolonged growth into a number of phases: the establishment of a growth and development strategy (1962-71), the heavy and chemical industries drive (1972-79), economic stabilization and liberalization (1980-89), economic opening up, global integration and financial crisis (1990-97), post crisis reform and restructuring (1998 to the present). Each of these periods is now briefly discussed in turn

Growth and development strategy 1962-71

This period saw the introduction of sweeping economic reforms emphasizing exporting, focusing on labour intensive light manufacturing industries (see Harvie and Lee, 2003a, 2003b; Lee, 1996; Ranis, 1971; Smith, 2000; Song, 1990). Export targets were agreed between government and individual firms, with emphasis placed on the development of firms best able to expand export capacity and acquire and utilize technology. Government owned banks facilitated this process through their preferential allocation of credit to such firms. Consequently, from the early days of economic development, a relationship based system developed among firms, their banks and the government (Smith, 2000).

This development strategy proved to be highly successful. The average annual growth rate was 8.8 per cent during 1962-1971, double that prior to 1962. Per capita income increased from US$82 in 1961 to US$286 in 1971. The industrial structure of the country changed dramatically, with the share of manufacturing increasing from 12 per cent to 20 per cent of GDP over the same period. Exports increased rapidly from US$41 million in 1961 to US$1,133 million in 1971 (a 28 fold increase), representing an average annual growth rate of 39 per cent. The strategy increased domestic savings and employment, and enabled the economy to benefit from economies of scale in production and technology transfer.

The heavy and chemical industries (HCI) drive (1972-79)

Despite the previous impressive outcomes the development strategy changed from the early 1970s, arising from a number of adverse side effects from the export driven growth (see Harvie and Lee, 2003a, 2003b). First, it contributed to a sectoral imbalance between the light and heavy industry sectors. Second, the export orientated industrialization program widened the gap between those engaged in export business and those in domestic business. Finally, by the early 1970s light industry exports began to weaken, highlighting the need to develop new exportable products. Consequently, in May 1973, Korea shifted from general export promotion and incentives to the targeting of strategic HCIs (steel, heavy machinery, automobiles, industrial electronics, shipbuilding, non ferrous metals and petrochemicals). Industry neutral incentives for exports were replaced by industry specific and, in some cases, firm specific measures involving generous government assistance (Smith, 2000). The main tool of promotion was, again, preferential access to credit from government

owned banks, funded predominantly by external bank borrowing that resulted in a rapid rise in foreign debt. Other HCI incentives included subsidies, tax reductions and exemptions (Rhee, 1994). Without such government incentives large companies would not have been willing to bear the risk and cost of such extensive investment in these industries.

The HCI promotion strategy resulted in a number of economic problems: rapid monetary expansion and increased budget deficits, investments were made without sufficient analysis of their viability and impact on the overall economy, and there were many overlapping investments, the focus on strategic industries resulted in enormous economic inefficiency, the socialization of bankruptcy risk, combined with the low interest rate ceilings, contributed to moral hazard in the banking and corporate sectors, that encouraged, for firms in targeted sectors, excessively high levels of debt and an emphasis on market share rather than profitability and shareholder value (Huh and Kim, 1994). The HCI drive gave a major boost to the growth of the *chaebo*l, which radically transformed the industrial structure and market concentration (OECD, 1994, p.60).

The economy showed signs of overheating during 1976-78, accompanied by a rapid increase in wages that surpassed the growth of labour productivity. This was exacerbated further by the Middle East construction boom in 1976 and its impact on domestic land prices. These caused one of the country's worst bouts of inflation that resulted in weakened export competitiveness, and slowed export and overall economic growth.

Economic stabilization and liberalization (1980-89)

Against a backdrop of: the second oil price crisis; a bad agricultural harvest; and a domestic political crisis with the assassination of President Park in October 1979, the first negative rate of GDP growth since the emergence of Park's regime (1961-79) emerged in 1980, and consumer price inflation soared to 28.7 per cent. HCI investment and a global and domestic economic downturn combined to leave many of the heavily targeted industries of the 1970s with severe over-capacity problems in the early 1980s. Against this background a major shift by the new government focused policy upon economic stabilization, trade liberalization, financial liberalization, market opening, promotion of small and medium enterprises, antitrust legislation, greater opening to foreign investment, preferences for specific industries to be reduced, and structural change toward the development of more technology based industries (Smith, 2000).

By the mid 1980s the economic stabilization measures had achieved their desired objectives, as inflation decreased and the economy recovered its competitiveness, productivity and growth. From 1986 to 1989 economic conditions were given a further boost by favourable external conditions from the three lows – low oil price, weak US dollar, and low global interest rates. In 1986, for the first time in Korea's modern history, the nation's current account shifted into the black, where it remained until 1990, the balance of payments was in sizeable surplus, exports exceeded imports and domestic savings exceeded domestic investment for the first time since the First Five Year Plan (Harvie and Lee, 2003b). The economy registered a high annual growth rate of 12 per cent. Industrial restructuring also made headway with the share

of the manufacturing sector in total GNP rising from 29.7 per cent in 1980 to 32.3 per cent by 1987. By late 1988, however, a presidential election, the Olympic games, abnormally high wages and incomes growth, steeply rising land prices, and ongoing structural problems in the economy combined to severely jolt economic stability and economic growth slowed to 8 per cent in 1989 (Lee, 1996).

Economic opening and the onset of financial crisis (1990-97)

The period of the 1990s witnessed Korea's increased integration into the global economy through further external trade and financial liberalization that represented a natural extension to the liberalization measures adopted during the 1980s. However, the seeds of the financial crisis that were to hit in late 1997, already planted during the periods previously discussed, were further exacerbated by developments and measures implemented during 1990-97.

Economic growth remained strong during this period with the exception of an economic slow down in 1992-93 arising from a significant slowdown in investment expenditure, as well as decline in consumption expenditure, as part of a stabilization policy to reduce inflationary pressure during 1990-91. However, the benign macroeconomic environment of the 1990s, characterized by: high GDP and export growth until 1996; low inflation; fiscal surpluses in general; high savings and investment; low unemployment; and, until 1996, modest trade and current account imbalances, hid growing financial weaknesses in the heavily indebted and weakly profitable corporate sector, reflecting the tendency of business conglomerates to diversify into capital-intensive industries, and financial sector and an unprecedented accumulation of short term debt (Australian Department of Foreign Affairs and Trade, (1999); Corsetti, Pesenti and Roubini, 1998; Economist (The), 1998; Kwon, 1998; Lee, 1999a and 1999b; Min, 1998; Park, 1998; and Radelet and Sachs, 1998a and 1998b). The latter increasingly exposed the country to financial turbulence in global and regional markets. This process was driven by the financial liberalization of the early 1990s as an already fragile domestic financial system, a legacy from earlier periods, was encumbered by moral hazard, poor supervision and regulation, heavy government intervention, poor accounting standards and lack of transparency and underdeveloped capital markets, contributed to a significant increase in short term capital flows (mainly in the form of debt and relative to foreign exchange reserves)[1].

Such fragilities were of little concern, however, in an environment of rapid growth of exports and output. With the deterioration of the country's terms of trade and resulting growth slowdown in export values in 1996 and 1997, however, the highly over-leveraged corporate sector came under intense profitability and cash flow pressures. In 1997 a number of *chaebol* became insolvent or had to seek protection from creditors. An already shaky financial sector, arising from imprudent and excessive lending to the *chaebol*, experienced a further sharp deterioration in non-performing loans. Government action to tackle this problem head on was lacking. By October 1997 further pressure began to be strongly applied by international investors on the currency as concerns over the third major fragility, excessive short term foreign debt, came in to play. The ability of the country to meet its short-term interest and debt

[1] Korea's short term foreign debt was high relative to its international reserves, a consequence of its decision to liberalize short term borrowing rather than direct investment inflows (Australian Department of Foreign Affairs and Trade (1999)).

repayments was questioned as useable foreign exchange reserves diminished alarmingly. The consequence was the financial and economic crisis of 1997-98.

Reform and restructuring 1998-present

Korea made remarkable advances after the 1997 financial crisis, achieving an average annual growth rate of 6 per cent over the period 2000-04, enabling it to be one of Asia's few expanding economies. Despite this, turbulence within the economy from domestic and external sources was still prevalent. In 2001 the slowing global economy and falling exports due to the 'tech wreck' (reduced global demand for IT products and falling semi-conductor prices) accounted for the drop in the growth rate to 3.3 per cent. The credit card bubble of 2001 and 2002 contributed to strong domestic demand, but this was reversed in late 2002 as households reduced consumption following a period of rapid accumulation of debt and once again, in 2003, the economy entered a recession. Despite weak domestic demand the acceleration of real export growth, to a historical high of 20 per cent, supported output growth of 4.6 per cent in 2004. Exports slowed significantly in the first half of 2005, due in part to weaker demand from Chin which had become an increasingly important trading partner.

Key contributory factors to the country's economic performance from 1998-present have been: reform progress in areas of weakness exposed by the financial crisis, market opening to international competition, strength in key sectors of the economy, particularly in the information and communications technology (ICT) sector, and strong external demand particularly from China which has emerged as its biggest trading partner. The country's economic performance is also underpinned by significant inputs of labour and capital, reflecting still-rapid population growth, rising labour force participation rates and a high level of investment. Nearly half of the major business groups (the *chaebol*) have disappeared, while foreign ownership of listed companies has increased from 15 per cent to 42 per cent. Rising foreign direct investment includes an important foreign presence in the banking sector.

According to the OECD (2005) there are a number of outstanding issues essential to the maintenance of the economy's performance: maintaining macroeconomic stability and sound public finances, the need to upgrade the innovation system to promote faster productivity gains by improving the R&D framework, improving labour productivity which stands at around one-half of the OECD average, strengthening product market competition, restructuring tertiary education to enhance human capital, enhancing labour market flexibility, further improving corporate governance, increasing efficiency in the corporate sector, ensuring better supervision of the financial sector and reducing the legacy of extensive government intervention in the economy, upgrading competition policy and continuing the process of opening up to international trade and foreign direct investment.

In the context of this brief overview of the Korean economy the remainder of this paper is devoted to: analyzing macroeconomic data for the Korean economy with the objective of conducting a robust empirical analysis of the existence and timing of major structural breaks in the economy, and linking such breaks, where relevant, with key economic developments as identified in this section of the paper.

3. Unit Root Tests without Structural Breaks

It is essential to test for the existence of a unit root when using time-series data for model estimation. Failure to do so means that the standard asymptotic distribution theory does not apply, resulting in model misspecification, coefficient bias and spurious estimation inferences (Campbell and Perron, 1991; Afandi, 2005).

The standard procedure for detecting non-stationary behaviour in data is to use the Augmented Dickey–Fuller (ADF) test (Dickey and Fuller, 1979, 1981) using the following equation:

$$\Delta y_t = \mu + \beta t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + \varepsilon_t \qquad (1)$$

where y_t is the time series being tested, t is a time trend variable, Δ denotes the first difference operator, and k is the number of lags which are added to the model to ensure that residuals, ε_t, are white noise. The Akaike Information Criterion (AIC) or Schwartz Information Criterion (SBC) are then used to determine the optimal lag length in the ADF equation. The ADF test is principally concerned with the estimation of α in the above equation, that is we test the hypothesis H_0: α =0. The rejection of the null hypothesis implies that y_t is stationary and integrated of order zero, or *I(0)*. In other words the null hypothesis of a unit root is rejected if the value of the t-statistic for α (in absolute value) is greater than the critical value reported by MacKinnon (1991). Our empirical results applying the ADF test to Korean macroeconomic date for the period 1980(Q1)-2005(Q1) are reported in Table 1. This shows that the null hypothesis of a unit root cannot be rejected for any of the series under investigation.

Based on our discussion in the previous section, however, the Korean economy has been subject to considerable economic turbulence over the period 1980-2005, suggestive that macroeconomic variables are likely to have been subject to a number of structural breaks, such as that from the stabilization programs in the early 1990s, the terms of trade shock of the mid 1990s, the financial and economic crisis of 1997-98, the tech wreck of 2001, the aftermath of the credit card bubble of 2001-02. Hence the results of the ADF test on macroeconomic data could be biased towards not rejecting the unit root hypothesis, since it does not allow for the existence of such structural breaks. Therefore, it is of interest to analyze how these results can be affected by allowing for the existence of potential structural breaks in the data. For this purpose we use both the Perron (1997) Innovational and Additive outlier (IO, and AO) models to make more robust conclusions about the time series properties of the data series under investigation.

4. Unit Root Tests in the Presence of Potential Structural Breaks

As is well known, the issue of structural change, and its consequential implications for structural breaks, in macroeconomic time series data must be robustly addressed in order to ensure non spurious results of unit root tests of such data. There can, of course, be many reasons for structural change, and these can include such diverse circumstances as economic crises, policy changes or regime shifts. For this reason it is

Table 1. Data description and ADF test results for Korean economy macroeconomic data, 1980Q1-2005Q1

Description of series	Variable	Period of the Data	ADF *t*-statistic	Optimal lag length	Inference
GDP at 1995 constant price	Ln (GDP95)	1980Q1-2005Q1	-2.205	7	Unit Root
Gross National income at current price	Ln (GNI)	1980Q1-2005Q1	-1.872	8	Unit Root
Private Consumption at current price	Ln (Pc)	1980Q1-2005Q1	-1.258	5	Unit Root
Government Consumption at current price	Ln (Gc)	1980Q1-2005Q1	-0.424	4	Unit Root
Gross Fixed Capital Formation at current price	Ln (GFCF)	1980Q1-2005Q1	-1.657	4	Unit Root
Total Export($US)	Ln (X)	1980Q1-2005Q1	-0.941	8	Unit Root
Total Imports($US)	Ln (IM)	1980Q1-2005Q1	-0.623	2	Unit Root
Consumer Price index	Ln (CPI)	1980Q1-2005Q1	-2.193	0	Unit Root
Money Supply at current price	Ln (Ms)	1980Q1-2005Q1	-1.624	1	Unit Root
Exchange Rate (National currency per $US)	Ln (ER)	1980Q1-2005Q1	-2.012	0	Unit Root

Note: (1) The null hypothesis of a unit root cannot be rejected at the 5 per cent significance level for all variables under investigation. (2) The optimal lag length (k) is determined by the Schwartz Information Criterion (SBC). The data used was obtained from the IMF's International Financial Statistics (IFS).

Source: Derived by the authors.

extremely important to test the null hypothesis of structural stability against the alternative of a one-time structural break. If potential structural changes are not allowed for in the specification of an econometric model but are, in fact, present, the results may be spurious because they can be biased towards the erroneous non-rejection of the non-stationarity hypothesis (Perron 1989; Perron 1997; Leybourne and Newbold; 2003; Pahlavani, Valadkhani and Worthington, 2005).

Vogelsang and Perron (1998) describe the long-running debate which was sparked by Nelson and Plosser (1982) when they concluded that most macroeconomic time series contain a unit root, and thus implied that shocks to these series are permanent. Perron (1989) challenged this, showing that a rejection of the unit root hypothesis is possible for many macroeconomic time series if a one–time shift in the trend function is taken into account. He argued that many macroeconomic time series may be better described as having temporary shocks fluctuating around a broken deterministic trend function. Afandi (2005) noted that Perron (1989) introduced three models. The first model is a crash model where the conventional unit root test (ADF model) is augmented by incorporating a dummy break and a dummy post-break intercept that represents shifts in the intercept. The second model captured the effects of the 1973 oil price shock by incorporating a dummy post-break slope representing a change in the trend due to the slow-down in economic growth following the shock. The third model combines these two effects (change in the slope and change in the intercept) in order to represent the effects on the world economy of the 1929 Stock Market Crash which precipitated the Great Depression of the 1930s.

According to Vogelsang and Perron (1998), Perron's (1989) key assumption is that the break date of the trend function is fixed (exogenous), and chosen independently of the data. In fact, previously, the time of any structural break was assumed to be known *a priori* in accordance with the underlying asymptotic distribution theory. As mentioned above the standard Dickey-Fuller procedure (ADF) was then extended by adding dummy variables representing different intercepts and slopes. However, Christiano (1992) and others have criticized this approach, arguing that considering the timing of the break as an exogenously known event invalidates the distribution theory underlying conventional testing (Pahlavani, Valadkhani and Worthington, 2005).

Consequently, the assumption of considering the timing of the breaks as a known event has drawn much criticism in subsequent papers. In response, a number of studies, including Zivot and Andrews (1992), Perron (1994, 1997), Lumsdaine and Papell (1997) and Bai and Perron (2003) to name just a few, have proposed different ways of estimating the time of the break *endogenously*. These studies have shown that this endogenous approach lessens the bias in the usual unit root tests. As Perron (1997, p.356) states: "…if one can still reject the unit-root hypothesis under such a scenario it must be the case that it would be rejected under a less stringent assumption".[2]

[2] For a more detailed explanation concerning unit root tests in the presence of structural breaks, see Phillips and Xiao (1998) and Maddala and Kim (2003).

In the following section the unit root test on Korean macroeconomic data is conducted again, but in this case allowing for structural breaks by estimating the timing of the break *endogenously*.

4.1. Innovational and Additive Outlier Models

Perron (1994, 1997) advanced a class of test statistics which allows for two different forms of structural breaks: namely, the Additive Outlier (AO) model, which is more relevant for series exhibiting a sudden change in the mean (the crash model), and the Innovational Outlier (IO) model, which is designed to capture changes in a more gradual manner over time. In other words, Perron distinguishes breaks that occur suddenly from those which occur slowly over time by identifying two types of structural breaks and applying different models to each of them.

According to Vogelsang and Perron (1998) and Pahlavani, Valadkhani and Worthington (2005), the IO model is appropriate where it is more logical to conceptualize the breaks as occurring gradually rather than suddenly. Following Perron (1994), the IO1 version of the model allows for gradual change in the intercept only, while the IO2 version of the model allows for gradual change in both the intercept and the slope of the trend function, as follows:

$$\text{IO1}: x_t = \mu + \theta DU_t + \beta t + \delta D(T_b)_t + \alpha x_{t-1} + \sum_{i=1}^{K} c_i \Delta x_{t-i} + e_t \tag{2}$$

$$\text{IO2}: x_t = \mu + \theta DU_t + \beta t + \gamma DT_t + \delta D(T_b)_t + \alpha x_{t-1} + \sum_{i=1}^{K} c_i \Delta x_{t-i} + e_t \tag{3}$$

where T_b denotes the time of the break, which is unknown and determined endogenously, DU_t is the intercept dummy ($DU_t = 1$ if $t > T_b$ and zero otherwise), DT_t is the slope dummy ($DT_t = T_t$ if $t > T_b$ and zero elsewhere), and finally, $D(T_b)_t$ is the crash dummy ($D(T_b)_t = 1$ if $t = T_b + 1$ and zero otherwise). The null hypothesis of a unit root is rejected if the absolute value of the *t*-statistic for testing $\alpha=1$ is greater than the corresponding critical value. According to Colletaz and Serranto (1998), Perron (1997) applies three different methods in estimating the break date:

- minimizing the value of the t statistic for testing $\alpha = 1$,
- maximizing the absolute value of the *t* statistic on the break parameters associated with a change in either the intercept ($|t_{\hat{\theta}}|$) or the slope ($|t_{\hat{\gamma}}|$), and
- minimizing the value of the t statistic on the break parameters associated with the change in either the intercept ($|t_{\hat{\theta}}|$) or the slope $|t_{\hat{\gamma}}|$.

Vogelsang and Perron (1998) note that the truncation lag parameter, *k,* is determined using the data-dependent method proposed by Ng and Perron (1995). In this methodology, for any given value of T_b, *k* is determined according to the significance (at 5% or 10%) of the *t*-ratio on the coefficient associated with the last lag in the estimated auto-regression. The optimum *k* (or k^*) is selected such that the coefficient on the last lag in an auto-regression of order k^* is significant and that the last coefficient in an auto-regression of order greater than k* is insignificant, up to a

maximum order k= kmax (Perron, 1997; Lumsdaine and Papell, 1997; Pahlavani, Valadkhani and Worthington, 2005).

In contrast to the gradual change in the IO model, the AO model assumes structural changes take place instantaneously. The additive outlier model demonstrates a change in the slope of the trend function only, but both segments of the trend function are joined at the time of the break. Moreover, as is clear from the above explanation, while the Innovational Outlier model (IO) involves a one-step testing procedure, the Additive Outlier (AO) testing procedure consists of a two-step procedure. In other words, testing for a unit root in the AO framework is done using a two-step procedure (Perron, 1994; Vogelsang and Perron, 1998, Afandi, 2005). First, the series is de-trended by regressing it on the trend components (including constant, time-trend and dummy break:

$$y_t = \mu + \beta t + \gamma DT_t^* + \tilde{y}_t \tag{4}$$

where $\tilde{y}_t$ is the de-trended series and $DTt= 1(t>T_b)(t-T_b)$. Since equation (4) assumes that a structural break only impacts on the slope coefficient the second step uses the following regression, without trend function, to the residual of the first step in order to test for a change in the slope coefficient:

$$\tilde{y}_t = \alpha \tilde{y}_{t-1} + \sum_{i=1}^{K} c_i \Delta y_{t-i} + e_t \tag{5}$$

Similar to the IO methodology, these equations are estimated sequentially for all possible values of T_b ($T_b = k + 2,\ldots,T$-1) where T is the total number of observations so as to minimize the t-statistic for α =1. The lag length is data-determined using a general to specific approach, based on the significance of the t-statistic. In this methodology the break date is assumed to be unknown and determined endogenously. The null hypothesis is rejected if the t-statistic for α is larger in absolute value than the corresponding critical value. An alternative, which is more widely used, is to select T_b as the value over all possible break dates that minimizes (or maximizes) the value of the t-statistic on γ=0 (Harris and Sollis, 2003; Pahlavani, Valadkhani and Worthington, 2005).

4.2. Empirical results from the IO and AO Models

In order to decide which particular IO model is most relevant the following model selection procedure is adopted. First, the least restrictive model (IO2) is estimated and, if $t_{\hat{\gamma}}$ is significant at the 5 per cent level or better, then the results are reported in Table 2. If $t_{\hat{\gamma}}$ is not statistically significant then the results from the IO1 model are presented. In order to determine the sudden effect of an unknown structural break, the AO model is also estimated, and the results are presented in Table 3.

In these models we apply the method of determining the appropriate lag length endogenously. A data-dependent method for selecting the value of lag length K is applied in this research. According to Ng and Perron (1995) (see also Ben-David and Papell, 1998), it is better to use the data-dependent method rather than making an *a priori* choice of a fixed K. They suggest starting with an upper bound of Kmax. We consider K as Kmax if the last lag included in the estimated equation is significant. If

the last lag considered is not significant then K is reduced by one. We continue this procedure until the last lag becomes significant. If no lags are significant then K is set to zero. Following Lumsdaine and Papell (1997) and Pahlavani, Valadkhani and Worthington, (2005), we consider the maximum (Kmax) equal to eight and, if the coefficient on the eighth lag is significant based on a t-test (i.e. at least 1.645 in absolute value), then we let K=Kmax. If not K is continually reduced until significance is achieved, otherwise K is set equal to zero.

Using the sequential approach the regression equation is run with the values for *Tb* of (2…t-1), for each time series. The values of the t-statistic for variable α are recorded and compared. From this comparison the break point is then selected by the value of Tb which minimizes the t-statistic on the coefficient α. The unit root null hypothesis is rejected in favour of the alternative hypothesis if the t-statistic for α is significant and greater than the critical values tabulated by Perron (1997). Results from using the Innovational Outlier (IO) model are reported in Table 2:

As shown in Table 1 the empirical results derived from the conventional ADF unit root test provide no evidence against the null hypothesis of a unit root for any of the series under investigation. Similarly, as shown in Table 3, the results from applying the AO, which takes into account the sudden effects of a potential break, again support the null hypothesis of a unit root for all of the series under investigation. The results based on the IO model in Table 2, however, show that by taking into account the existence of a gradual effect of a potential structural break, two of the variables under investigation (IM and ER) become stationary. The Zivot-Andrews (1992) method yielded identical results with the same two variables found to be stationary.[3]

The timing of the structural changes based on the IO model (impacting on both the intercept and the slope (IO2) or intercept only (IO1) of each series) are represented by a solid line in Figure 1, and with a dotted line for the AO model.

The timing of any structural break (T_b) for each series using both the IO and AO approaches are shown in Tables 2 and 3, respectively. From Table 2 the IO model shows that endogenously determined T_{bs} closely approximate, for seven of the ten variables, major structural breaks occurring in the financial crisis year of 1997 (ER in the second quarter), (GDP95, GNI, GFCF and IM in the third quarter), (Gc and CPI in the fourth quarter). For Ms the timing of the structural break is found to be the second quarter of 1991, for Pc the third quarter of 1993, while for X it was found to be the third quarter of 2000.

Potential reasons for the timing of these structural breaks using the IO model for each of these variables is also provided in Table 2. In the cases of GDP95, GNI, GFCF, IM Gc and CPI, the impact of the Asian currency crisis and contagion from the third quarter and, more intensely, during the fourth quarter of 1997 is the most obvious explanation for their structural break at this time. For Ms the strong growth of GDP in 1990 and 1991 arising from strong domestic demand, particularly in the construction sector, was met by the introduction of strong anti-inflationary stabilization measures

[3] The results from applying the Zivot-Andrews testing procedure are not reported here, but are available on request from the authors.

Table 2. Innovational Outlier Model for Determining the Break Date in Intercept (IO1), or Both Intercept and Slope (IO2)

Series	Model	Lag K	$t_{\hat{\gamma}} \setminus t_{\hat{\theta}}$	$\hat{\alpha}$	$t_{\hat{\alpha}}$	Inference	Break T_b	Possible causes
Ln(GDP95)	IO1	7	-3.50	0.563	-3.06	Unit root	1997:03	Asian financial crisis
Ln (GNI)	IO1	8	-2.47	0.906	-2.31	Unit root	1997:03	Asian financial crisis
Ln (Pc)	IO2	8	3.27	0.827	-2.98	Unit root	1993:03	The anti inflationary measures of 1990-91 resulted in a sharp decline in investment and consumption spending and slowdown in economic growth during 1992-93, and declining wage push.
Ln (Gc)	IO1	8	-2.66	0.597	-3.53	Unit root	1997:04	Asian financial crisis
Ln (GFCF)	IO1	8	-2.811	0.856	-3.13	Unit root	1997:03	Asian financial crisis
Ln (X)	IO2	8	-3.07	0.708	-3.61	Unit root	2000:03	Tech wreck, global economy slowdown, semi-conductor price crash.
Ln (IM)	IO1	7	-4.91	0.681	-4.91	Stationary	1997:03	Asian financial crisis
Ln (CPI)	IO2	8	2.46	0.883	-4.01	Unit root	1997:04	Asian financial crisis
Ln(Ms)	IO2	7	3.79	0.655	-4.73	Unit root	1991:02	Anti-inflationary stabilization measures arising from strong demand (construction investment in particular)
Ln (ER)	IO2	3	4.32	0.560	-5.43	Stationary	1997:02	Asian financial crisis, chaebol bankruptcies, industrial unrest, poor trading performance, rising short term debt and inability to service this debt.

Note: critical values at the 1%, 5% and 10% levels are equal to -5.57, -5.08 and -4.82, respectively for IO2, while for the IO1 model the critical values at the 1%, 5% and 10% levels are equal to -5.41 , -4.80 and -4.58, respectively. The innovational outlier model (IO2) allows for breaks in both intercept and slope, while (IO1) allows for a break just in the intercept. These methodologies assume that changes occur gradually. T_b is selected as the value which minimizes the absolute value of the t-statistic on the parameter associated with the change in slope in the IO2 model or change in intercept in the IO1 model, (K Max= 8).

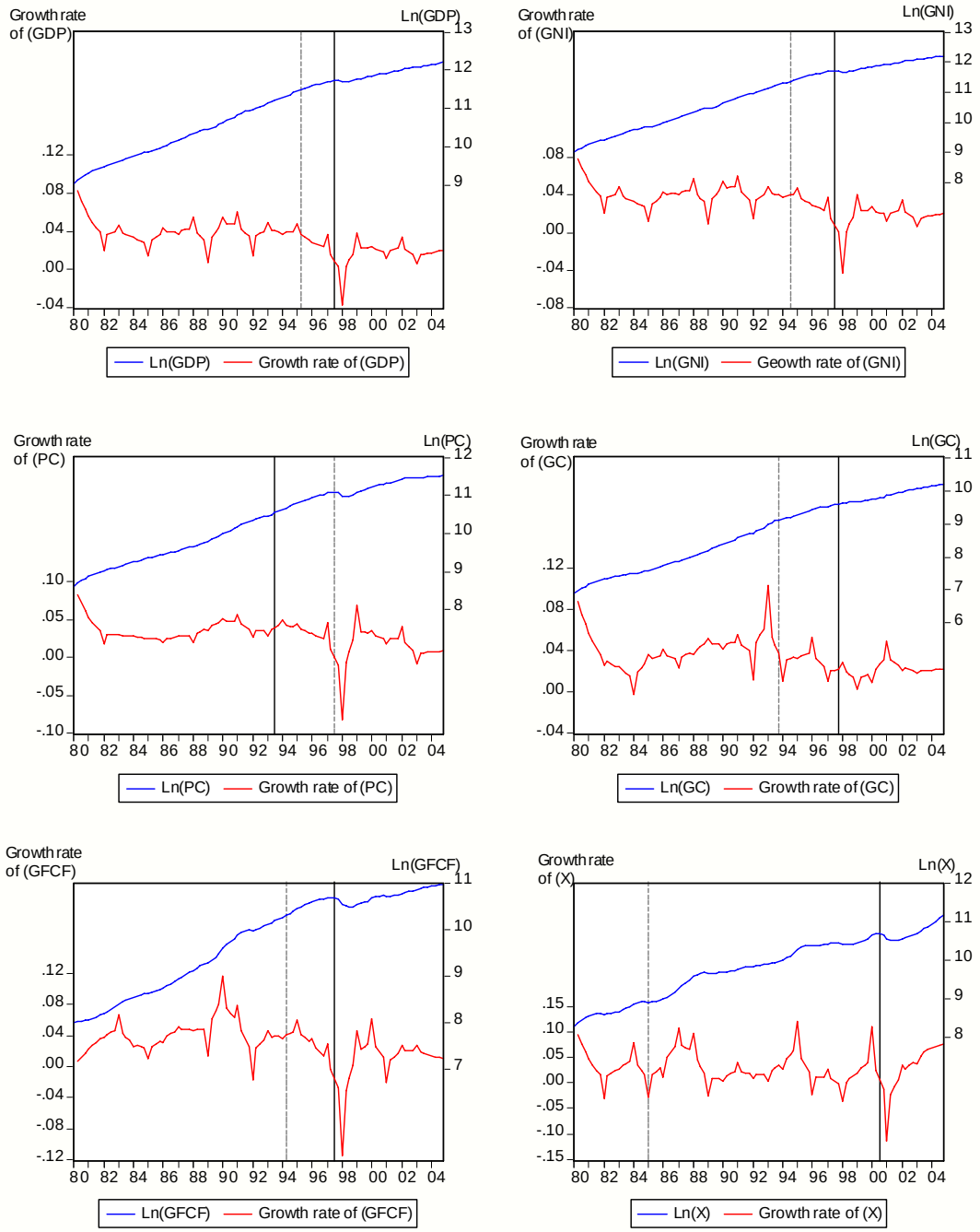
Source: Derived by the authors.

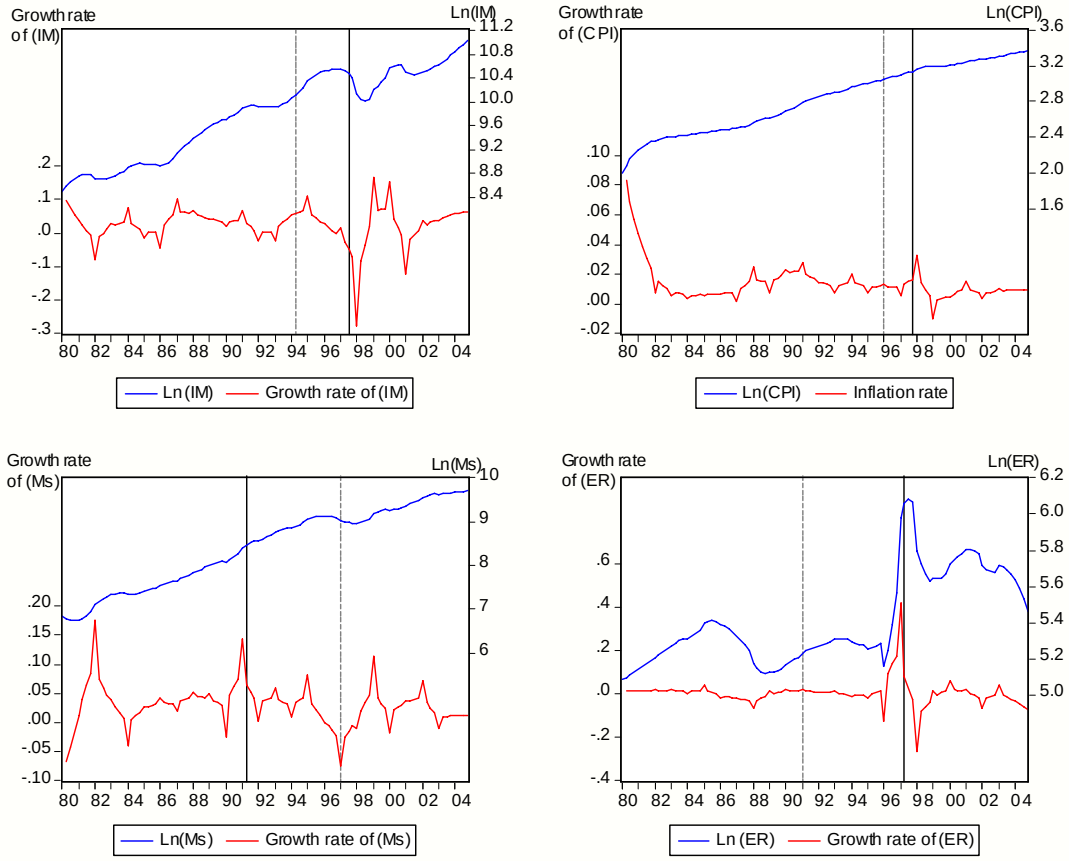
Table 3. Additive Outlier Model (AO) for Determining the Timing of Breaks

Series	K	$\hat{\gamma}$	$t_{\hat{\gamma}}$	$\hat{\alpha}$	$t_{\hat{\alpha}}$	Inference	Break T_b	Possible causes
Ln (GDP95)	4	-0.01	-6.65	0.616	-4.61	Non-stationary	1995:02	Business cycle peaked in 1995; terms of trade deterioration; weakening yen; end of the equipment and infrastructure investment boom.
Ln (GNI)	8	-0.018	-13.5	0.590	-4.31	Non-stationary	1994:03	Expansionary government policy; equipment and infrastructure boom.
Ln (Pc)	8	-0.016	-8.81	0.861	-2.65	Non-stationary	1997:03	Asian financial crisis
Ln (Gc)	8	-0.006	-3.74	0.687	-3.01	Non-stationary	1993:04	Stabilization policy designed to reduce inflationary pressure.
Ln (GFCF)	8	-0.029	-14.4	0.717	-3.76	Non-stationary	1994:02	Equipment and infrastructure investment boom
Ln (X)	8	-0.014	-8.32	0.736	-3.25	Non-stationary	1985:01	Reduced inflation; improved competitiveness and productivity
Ln (IM)	7	-0.014	-6.43	0.809	-2.84	Non-stationary	1994:02	Expansionary government policy; domestic market opening to foreign competition; liberalization of foreign capital inflows; construction and domestic infrastructure investment boom; rising private consumption; increased imports of capital goods (32.5 per cent), industrial materials (32.6 per cent) and consumer goods (27.8 per cent).
Ln (CPI)	4	-0.004	-7.87	0.890	-4.01	Non-stationary	1996:01	Price stability became the government's primary focus. Stable agricultural prices, increased competition from imports and subdued consumption spending contributed to low inflation particularly in the second half of 1996. The decline in inflation was also facilitated by excess capacity arising from the equipment and investment boom of 1994-95, and by a softening of global demand.
Ln (Ms)	7	-0.018	-8.77	0.804	-3.12	Non-stationary	1997:01	The Hanbo debacle. On 23 January Korea's second biggest steel company imploded under a US$5.9 billion debt, which took out its entire parent group the then fourteenth largest Korean conglomerate. The Bank of Korea swiftly injected 6 trillion won (US$7 billion) in liquidity to prevent a possible chain reaction of bankruptcies.
Ln (ER)	3	0.009	5.27	0.829	-2.64	Non-stationary	1991:01	Strong economic growth; rapid growth of imports; investment and consumer (industrial materials and consumer goods) boom; trade and current account blowout

Note: critical values at the 1%, 5% and 10% levels are equal to -5.28, -4.65 and -4.38, respectively. The additive outlier model (AO) allows for a break in the slope and, in this methodology, changes are assumed to occur rapidly. T_b is selected as the value, which minimizes the absolute value of the t-statistic on the parameter associated with change in slope in (AO) model, (K Max= 8).
Source: Derived by the authors.

Figure 1. Plots of the series and estimated timing of structural breaks





Note: The time (T_b) of structural breaks based on: (a) the IO2 or IO1 model (impacting on both the intercept and the slope or Intercept only of each series) is shown by a solid line (b) the AO model (impacting on the slope only) is indicated by the dotted line.

Source: Derived by the authors.

by the authorities that included the tightening of monetary conditions. For Pc the structural break in quarter three of 1993 is likely to be a reflection of the success of the anti inflationary measures of 1990-91, which resulted in a sharp decline in investment, consumption spending and overall economic slowdown during 1992-93. This also contributed to declining wage push and further constrained private consumption spending. The structural break for X in the third quarter of 2000 can be linked to a sharp decline in economic growth in the US economy and globally, declining demand for Korea's exports, particularly of IT products (reflected in declining semi-conductor sales) as well as a decline in semi-conductor prices. While, overall, export growth for the whole of 2000 was quite strong, by the second half of the year a deterioration was becoming apparent.

From Table 3 the AO model shows that endogenously determined T_{bs} for the ten macro variables of interest are, noticeably, quite different from those specified using the IO models. For GDP95 the endogenous structural break is found to occur in the second quarter of 1995. This coincided with a peak in the business cycle at this time, and subsequent downturns in the semi-conductor, metals and petrochemical businesses and a deterioration in the terms of trade (from a decline, in particular, in the price of semi-conductors). Korea was hit by its worst terms of trade conditions since the oil shock of 1979 with a drop in export prices (semiconductor prices)

beginning in the second quarter of 1995, which had a profound effect on Korea's macroeconomic performance.

For GNI the endogenous structural break is found to occur in the third quarter of 1994. This coincided with the implementation of an expansionary economic plan under the, then, new government led by Kim Young Sam; an equipment and infrastructure investment boom; the further opening up of domestic markets to foreign competition; the liberalization of foreign capital inflows; a strong export performance assisted by a high yen which gave Korean exporters a competitive advantage over Japanese exporters; a boom in construction and domestic infrastructure investment; and steadily rising private consumption.

For Pc the endogenous structural break is found to occur in the third quarter of 1997. During this period of time the contagion effect from the Asian financial crisis was contributing to rapid declines in the value of regional currencies and in regional stock markets. This compounded already deteriorating macroeconomic conditions during the early part of 1997, including a deterioration of the already shaky position of the financial sector which, subsequently, became increasingly loan shy, and there was increased anticipation of a rise in the rate of inflation. Further chaebol bankruptcies throughout the year, including that of the Kia motor group in July 1997, as well as increasing concern over the country's ability to service its short term debts, further compounded the uncertainty and proved to be a drag on private consumption spending.

The endogenous structural break for Gc is found to have occurred in the fourth quarter of 1993. This can be potentially explained by the fact that GDP growth declined sharply in 1992 and 1993 primarily due to a significant slowdown in investment and consumption expenditure, as part of a stabilization policy that also included a sharp decline in government consumption expenditure to reduce inflationary pressure in the economy. By 1994 there was a modest recovery in government consumption expenditure.

The endogenous structural break for GFCF is found to have occurred in the second quarter of 1994. This corresponds to the start of a boom in construction, equipment and domestic infrastructure investment which remained strong throughout the rest of 1994 and peaked in early 1995. Thereafter, a prolonged period of steady decline, with some exceptions, in the annual growth of GFCF until the first quarter of 1998 is apparent.

The endogenous structural break for X is found to have occurred in the first quarter of 1985. The economic stabilization measures of the early 1980s, introduced by the authoritarian government of President Chun Doo Hwan, focusing upon economic stabilization and liberalization, began to produce results by the mid 1980s. Inflation decreased, the economy recovered its competitiveness, productivity and growth. Export growth began to take-off at this point such that by 1986 the nation experienced its first current account surplus in its modern history.

The endogenous structural break for IM is found to have occurred in the second quarter of 1994. During the early 1990s the country sustained high export growth, however this rapid growth of exports occurred in conjunction with an equally rapid

growth of imports. Imports grew most noticeably over the period 1994-95, fuelled by increased imports of capital goods (32.5 per cent), industrial materials (32.6 per cent) and consumer goods (27.8 per cent). Substantial imports of machinery and equipment were apparent for the economy and seen as essential for the expansion and upgrading of productive capacity. The government's expansionary economic policy, domestic market opening to foreign competition, liberalization of foreign capital inflows, the construction and investment boom and rising private consumption expenditure at this time all contributed to buoyant import demand.

The endogenous structural break for CPI is found to have occurred in the first quarter of 1996. Consumer price inflation was generally on a downward trend during the period of the 1990s, from relatively high rates in 1990 and 1991, with the exception of 1994. Price stability, however, became the government's primary focus during 1996. Stable agricultural prices, increased competition from imports and subdued consumption spending contributed to low inflation particularly in the second half of 1996. The decline in inflation was also facilitated by excess capacity arising from the equipment and investment boom of 1994-95 and by a softening of global demand in 1996.

In the case of Ms the endogenous structural break is found to occur in the first quarter of 1997. Macroeconomic conditions deteriorated in early 1997 arising from labour unrest due to the proposed introduction of new legislation making worker lay-offs easier, in conjunction with restrictions on union activities. In the same quarter, 23 January 1997, the Hanbo debacle occurred. Korea's second biggest steel company imploded under a US$5.9 billion debt, which took out its entire parent group the then fourteenth largest Korean conglomerate. The Bank of Korea swiftly injected 6 trillion won (US$7 billion) in liquidity to prevent a possible chain reaction of other corporate bankruptcies which would then have a deleterious effect on the financial sector.

Finally, the variable ER is found to have an endogenous structural break in the first quarter of 1991. This is somewhat surprising, particularly given the traumatic developments in the financial sector and the exchange rate in the third and fourth quarters of 1997. However, during the early part of the 1990s the won did experience a continual depreciation against the US dollar. The strong growth of the economy in 1990 and 1991, arising primarily from the boom in the construction sector, resulted in an overheating of the economy, rapid growth of private consumption and investment spending, rapid expansion of imports, industrial materials and consumer goods in particular, and inevitable trade and current account blow-outs. This contributed to the weakening of the currency from 716.4 won per US dollar in 1990 to 760.8 won per US dollar by 1991.

While the results presented and discussed in this section show some interesting differences between Perron's Innovational Outlier and Additive Outlier methodologies, which are the most advanced methodologies for the examination of structural breaks in non-stationary time series, it is important to note that these tests are unable to detect the presence of multiple structural breaks. Therefore, the possibility exists that other potentially significant breaks occurred during the period of analysis. Only the most significant of these are detected through Perron's methodologies.

5. Summary and Concluding Remarks

The Korean economy has experienced intermittent periods of economic turbulence, with the likelihood of resulting structural breaks, during its prolonged period of economic growth and development since the early 1960s. The most recent and obvious of these being the effects arising from the Asian financial crisis of 1997, the tech wreck of 2000-01 and the credit card bubble of 2001-02. The existence of such structural breaks means that tests for non-stationarity of Korean macroeconomic data, particularly using the conventional ADF test, may result in model misspecification and coefficient bias unless such breaks are robustly and correctly identified.

Quarterly time series data for the Korean economy, covering the period 1980Q1-2005Q1, was used to determine the most important years for the occurrence of structural breaks for key macroeconomic variables. In doing so the paper compared and contrasted tests for stationarity using the traditional ADF test procedure with that of the IO (which assumes a gradual change in the intercept and/or slope) and AO (which assumes instantaneous changes in intercept) model approaches, where the latter two both endogenously determine the timing of structural breaks. The empirical results presented showed that the conventional ADF unit root test and AO model provided no evidence against the null hypothesis of unit roots in any of the series under investigation. However, the IO model, which takes into account the gradual effects of potential structural breaks in the series, found that two of the variables examined are stationary. This finding is also consistent with empirical results derivable using the Zivot-Andrews procedure. This indicates that considerable care must be taken when conducting unit root tests on data that has a high likelihood of being subject to structural breaks, as in the case of macroeconomic data for Korea.

While the IO and AO approaches used in this study are the most advanced methods to endogenously detect for significant structural breaks, they are unable to identify multiple structural breaks. As Ben-David and Papell (1997) note, tests that allow for multiple structural breaks, such as Bai and Perron (2003), are restricted to stationary and non-trending data which is not the case for the variables under investigation in this research. Although this paper has shed some light on the major structural breaks in Korean macroeconomic data, and possible explanations and factors behind these, future research should give more attention to the issue of multiple structural breaks, especially when dealing with long-term time series data.

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