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MONETARY STABILIZATION POLICY DURING ECONOMIC CRISIS: CASE OF KOREA*

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The paper evaluates the effectiveness of high interest rate policy in stabilizing the exchange rate during the Korean crisis, based on a nonlinear impulse response function approach. We find that high interest rates induce depreciation for a very short period, followed by a substantial appreciation for an extensive period. In contrast, a low interest rate policy would appreciate the exchange rate only for a very short period but have little impact afterwards. Our empirical findings suggest that the IMF's interest rate policy in Korea contributed to the stabilization of the exchange rate.

JEL Classification: F310
Keywords: Crisis; High interest rate policy; Non-linear impulse response function

I. INTRODUCTION

When Korea was hit hard by the financial crisis in 1997, the IMF rescue program included a high interest rate policy for more than three months to stabilize the won/dollar exchange rate. The short-term inter-bank interest rate was raised to 30 percent on December 26, 1997 in response to the exchange rate plummeting from 900 to 2,000 Korean wons against the U.S. dollar. As the exchange rate stabilized, the short-term interest rate started to ease following the agreement between the Korean government and the IMF on February 7, 1998.

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Thereafter the interest rate was gradually lowered as the situation in the foreign exchange market improved. The interest rate fell below its pre-crisis level in the middle of 1998, and has remained low since then.

The high interest rate policy recommended by the IMF for the crisis-hit Asian countries has generated immense public and academic debates. Proponents of the policy such as Fischer (1998) suggested that the high interest rate policy helped stabilize exchange rates during the crisis. By restoring confidence and fostering needed corporate restructuring, the policy encouraged capital inflow to, or discouraged capital outflow from, countries in crisis, which subsequently strengthened their currencies. Opponents of the policy such as Furman and Stiglitz (1998) argued that the high interest rate policy destabilized exchange rates by raising corporate bankruptcies, which accelerated capital outflows.

The debate also stimulated an emerging literature seeking to empirically evaluate the efficacy of the high interest rate policy. The empirical evidence so far is mixed.[1] Some recent studies find that the high interest rate policy helped to stabilize exchange rates. For example, Dekle, Hsiao, and Wang (1998), using weekly Korean data, find that raising interest rates contributed to appreciation during the crisis period. Goldfajn and Gupta (1999), using monthly data for 80 countries for 1980-98, find evidence that high interest rates helped to stabilize exchange rates (see also Cho and West, 2001). On the other hand, Furman and Stiglitz (1998), using data for nine developing countries, suggest that high interest rates had a negative or little effect on foreign exchange stability. Goldfajn and Baig (1998), based on VAR analysis using daily data for crisis-hit Asian countries, find a positive correlation between real interest rates and exchange rates for Hong Kong, Indonesia and Malaysia, but a negative correlation for Korea and Thailand.

Surprisingly, the existing empirical studies yield a mixed result for Korea. The reason for the seemingly inconsistent results from previous studies may be because they do not allow for a nonlinear relationship between interest rates and foreign exchange rates. The purpose of this paper is to evaluate the high interest rate policy during the Korean crisis with a focus on nonlinear effects, in sharp contrast to previous studies. It is important to allow for nonlinearities for the following reasons.

First and most obviously, the relationship between interest rates and exchange rates may, in fact, have significant nonlinear characteristics (Bansal, 1997; Lahiri and Vegh, 1999; and Chung, 1998). For example, exchange rate movements may depend on whether the interest rate differential between two countries is large or small.

Second, there may be rich nonlinear dynamics in the time path of exchange rate responses to interest rate shocks stemming from the fact that the relation-

[1] There are also a few recent theoretical papers, including Lahiri and Vegh (2000) and Flood and Jeanne (2000).

ship between interest rates and exchange rates is affected by a number of other variables, including capital inflows and outflows, corporate bankruptcies, the current account balance, policy credibility, and risk premiums.

Third, the nonlinear model can facilitate the empirical analysis of whether a rise in interest rates has different effects than a fall, something that previous studies have not addressed. The examination of the asymmetric effects is important, particularly because the IMF's high interest rate policy had two phases: a rise in interest rates in the initial period followed by a cutback.

To take nonlinearities into account, we use semi-nonparametric (SNP) estimation, a nonlinear econometric methodology developed by Gallant and Tauchen (1989), followed by nonlinear impulse response analysis developed by Gallant, Rossi, and Tauchen (1993). By applying this methodology to Korean daily data, we compare the reactions of the conditional means of exchange rate changes to various interest rate shocks without relying on a specific parameterization of the mean and variance equations. Intuitively, the methodology can be regarded as an extension of linear impulse response function in VAR analysis to the nonlinear model. By analyzing nonlinearities, however, this model is able to detect potential asymmetries in the response of exchange rates to different types of interest rate shocks. It can also trace out the dynamic path of the exchange rate response, thereby providing a basis for assessing the short- and long-term effects of interest rate changes on the exchange rate.

We derive several important findings. First, the effect of the high interest rate policy on the won changes signs over time. A rise in the interest rate causes the exchange rate to depreciate over a very short period. But the increase in the interest rate induces the appreciation of the won after about four days, and the appreciation continues thereafter without substantial damping.

Second, the low interest rate policy induces a very short-run (less than five days) appreciation, but has no significant effects thereafter. A comparison between the high and low interest rate policies suggests a notable asymmetry in the exchange rate dynamics. Above all, the high interest rate policy induces a substantial appreciation over a long period, say more than thirty days, while the low interest rate policy has no impact on the exchange rate over the same period.

Third, the above results hold regardless of whether the interest rate is at the level of the pre-crisis period or the high interest rate period. This suggests that a further rise in the interest rate during the high interest rate period would have induced a further appreciation of the won, which may imply that the rise in interest rates recommended by the IMF during the Korean crisis was not excessive. It also suggests that a cut in the interest rate to the pre-crisis level could be achieved without causing depreciation.

These empirical findings suggest that the IMF's interest rate policy during the crisis contributed to the stabilization of the exchange rate. Our results also suggest that the rapid depreciation during the crisis was not temporary, which justifies the high interest rates in the initial period of crisis; and the asymmetric response suggests that a cut of the interest rate back to the pre-crisis level would not induce another serious exchange rate depreciation.

This paper is organized as follows. In the following sections, we discuss the empirical methodology, describe the data, and present the empirical results. We then evaluate the IMF's high interest rate policy and close with some concluding remarks.

Ⅱ. EMPIRICAL METHODOLOGY

In contrast with earlier studies, we adopt the semi-nonparametric (SNP) method proposed by Gallant and Tauchen (1989). The key motivation for choosing a nonparametric model is that it allows us to conduct nonlinear impulse response analysis of the underlying dynamics, including potential asymmetries in the dynamic effects of interest rate policy on the exchange rate.

2.1. SNP Estimation of the Conditional Density[2]

Let y_t be the observed data at time t with dimension M, which have a Markovian structure. Markovian structure means that the conditional density of y_t given the entire history (y_{t-1}, y_{t-2}, K) depends on L lags from the past. Denote the one-step ahead conditional density of y_t as $f(y_t \mid x_{t-1})$, where, $x_{t-1} = (y'_{t-L}, y'_{t+1-L}, K, y'_{t-1})'$, which is a vector of length $M \cdot L$. Given the history of y_t, one can then determine the conditional density of y_t, $f(y_t \mid x_{t-1})$, by choosing θ to minimize $s_n(\theta) \equiv -\frac{1}{n}\sum_{t=1}^{n} \log[f(y_t \mid x_{t-1}, \theta)]$ where n stands for the number of observations or by applying some conventional model selection criteria.

The SNP method is a semi-nonparametric density estimation based on an approximation of $f(y_t \mid x_{t-1})$ with Hermite series expansion. That is,[3]

$$f(y_t \mid x, \theta) \propto [P(z, x]^2 \cdot n_M(y \mid \mu_x, \Sigma),$$

where $P(z, x)$ is a polynomial in the standardized error $z = R^{-1}(y - \mu_x)$ and the past data x, $\Sigma = RR' =$(the variance and covariance matrix), $n_M(y \mid \mu_x, \Sigma) =$(Gaussian density), and μ_x is the linear conditional mean function of x_{t-1}, $\mu_x = b_0 + B \cdot x_{t-1}$. The constant of proportionality is $1/\int [P(z, x)]^2 \phi(z) dz$, which makes $f(\cdot)$ integrate to one. To achieve a unique

[2] See Gallant and Tauchen (1989) for more detail.

[3] For notational convenience, we use variables with and without time subscript "t" interchangeably.

representation, the constant term of the polynomial part is put to one.

When the density of z does not depend on x, it is a case of homogeneous innovations. When a multivariate polynomial of degree in z, K_z, is equal to zero, one gets $f(y \mid \theta) = n_M(y \mid \mu_x, \Sigma)$ exactly. When K_z is positive, one gets a Gaussian density whose shape is modified due to multiplication by a polynomial in the normalized error $z = R^{-1}(y - \mu_x)$. The shape modifications thus achieved are rich enough to accurately approximate densities from a large class that includes densities with fat, t-like tails, densities with tails that are thinner than Gaussian, and skewed densities (Gallant and Nychka, 1987). The tuning parameter K_z controls the extent to which the model deviates from normality.

To approximate conditionally heterogeneous processes, one can apply as above, except letting each coefficient of the polynomial be a polynomial of degree K_x in x. Therefore, the shape of the density depends on x when K_x is positive. All moments, thus, can depend on x, and the density can approximate any form of conditional heteroskedasticity. The tuning parameter K_x controls the extent to which the model's deviations from normality vary with the history of the process.

To capture ARCH/GARCH properties common in most financial variables, one can modify the variance-covariance matrix to depend on the absolute values of the elements of the vectors $(y_{t-L_r} - \mu_{x_{t-1-L_r}}, K, y_{t-1} - \mu_{x_{t-2}})$. The variance-covariance matrix becomes:

$$\Sigma_{x_{t-1}} R_{x_{t-1}} R'_{x_{t-1}}$$

$$\text{vech}\,(R_{x_{t-1}}) = \rho_0 + \sum_{i=1}^{L_r} P_{(i)} \mid y_{t-1-L_{r+i}} \mid + \sum_{i=1}^{L_g} \text{diag}\,(G_{(i)}) R_{x_{t-2-L_g+i}}$$

where vech (R) denotes a vector of length $M(M+1)/2$ containing the elements of the upper triangle of R, ρ_0 is a vector of length $M(M+1)/2$, $P_{(1)}$ through $P_{(L_r)}$ are $M(M+1)/2$ by M coefficient matrices, $|y-\mu|$ denotes a vector containing the absolute values of $(y-\mu)$, and $G_{(1)}$ through $G_{(L_g)}$ are coefficient vectors with dimension of $M(M+1)/2$. The classical GARCH has $\Sigma_{x_{t-1}}$ expressed in terms of squared lagged residuals and lagged values of $\Sigma_{x_{t-1}}$. Therefore, the SNP version of GARCH is more akin to the suggestions made by Nelson (1991).

Large values of M can generate a large number of interactions such as cross product terms for even modest settings of degrees K_z and K_x. Accordingly, Gallant and Tauchen (1989) suggest two more additional tuning parameters, I_z and I_x, to filter out higher order interactions. $I_z = 0$ means no interactions are suppressed. $I_z=1$ means the highest-order interactions are suppressed, namely those of degree exceeding K_z-1. In general, a positive I_z means all interactions of order exceeding K_z-I_z are suppressed. Similarly, a positive I_x implies the suppression of all interactions of order exceeding K_x-I_x. The relationship between parameter setting and properties of the processes are summarized in Table 1.

[Table 1] Semi-Nonparametric Models

Parameter setting	Characterization of $\{y_t\}$
$L_\mu=0, L_g=0, L_r=0, L_p\geq 0, K_z=0, K_x=0$	iid Gaussian
$L_\mu>0, L_g>0, L_r=0, L_p\geq 0, K_z=0, K_x=0$	Gaussian VAR
$L_\mu=0, L_g>0, L_r=0, L_p\geq 0, K_z>0, K_x=0$	Non-Gaussian VAR with homogeneous innovations
$L_\mu>0, L_g>0, L_r>0, L_p\geq 0, K_z=0, K_x=0$	Gaussian GARCH
$L_\mu>0, L_g>0, L_r>0, L_p\geq 0, K_z>0, K_x=0$	Non-Gaussian ARCH with homogeneous innovations
$L_\mu>0, L_g>0, L_r>0, L_p\geq 0, K_z>0, K_x>0$	Full nonlinear non-Gaussian

Note: L_i's are the length for μ=(mean), g=(GARCH), r=(ARCH) and p=(polynomial part), and (K_z, K_z) are polynomial degrees in (z, x).

2.2. Impulse Response Analysis of Nonlinear Models[4]

In this subsection we describe strategies for eliciting the dynamics of the process $\{y_t\}$ as represented by $f(y \mid x)$. The analysis of impulse response functions developed by Sims (1980) has been widely used in the study of the dynamics of a linear process. The basic notion of an impulse response function under VAR analysis is to visualize the dynamic response of the system to a movement of an innovation that is a linear combination of iid innovations, u_t. In the general nonlinear case, however, there are various notions of an innovation, making it difficult to compute an impulse response function. However, if the impulse response function of the linear case is viewed as the perturbation of y_t instead of u_t, then the ideas from the linear VAR extend directly to the nonlinear case, as described in Gallant, Rossi, and Tauchen (1993).

On the assumption that the conditional density of the underlying process depends on at most L lags, the j-step ahead conditional mean profile given initial condition can be expressed by:

$$\hat{y}_j(x_0)=E(y_{t+j} \mid x_t=x_0)=\int y f^j(y \mid x_0)dy$$

[4] See Gallant, Rossi, and Tauchen (1993) for more detail.

where $f^j(y \mid x_0)$ denotes the j-step ahead conditional density

$$f^j(y \mid x_0) = \int \Lambda \int \left[\prod_{i=0}^{j-1} f(y_{i+1} \mid y_{i-L+1}, K, y_i) \right] dy_1 \Lambda\, dy_{j-1}$$

with $x_0 = (y'_{-L+1}, K, y'_0)'$. If x_0 is changed by $x^+ = x_0 + \delta$ or $x^- = x_0 - \delta$, for some vector value δ in the conditional density, the j-step ahead conditional mean profile becomes

$$\hat{y}_j(x^+) = E(y_{t+j} \mid x_t = x^+) \equiv \hat{y}_j^+$$

for $x^+ = (y'_{-L+1}, K, y'_0)' - (0, \Lambda, \delta') \equiv x_0 + \delta$, and

$$\hat{y}_j(x^-) = E(y_{t+j} \mid x_t = x^-) \equiv \hat{y}_j^-$$

for $x^- = (y'_{-L+1}, K, y'_0)' - (0, \Lambda, \delta') \equiv x_0 - \delta$, where $j = 1, \ldots, J$. In a similar vein, $\hat{y}_j(x_0)$ stands for a baseline, which means the dynamics of conditional means without any perturbation in conditional arguments. Accordingly, positive and negative impulse responses of the j-step conditional mean are $\{\hat{y}_j^+ - \hat{y}_j^0\}_{j=1}^J$ and $\{\hat{y}_j^- - \hat{y}_j^0\}_{j=1}^J$, respectively. These two terms provide a nonlinear impulse response function for shocks on the conditional mean of the system.

Analogously, we can measure the effects of perturbing conditional arguments on the j-step ahead conditional variance matrix. Define the $M \times M$ matrix as $\hat{v}_j(x_0) = E[\mathrm{Var}(y_{t+j} \mid x_{t+j-1}) \mid x_t = x_0)] = \int \Lambda \int \mathrm{Var}(y_j \mid y_{j-L-1}, K, y_{j-1}) \left[\prod_{i=0}^{j-1} f(y_{i+1} \mid y_{i-L+1}, K, y_i) \right] dy_1 \Lambda\, dy_{j-1}$ for, $j = 1, 2, K$, where $x_0 = (y'_{-L+1}, K, y'_0)'$. The positive and negative impulse responses of perturbations δ on the volatility are $\{\hat{v}_j^+ - \hat{v}_j^0\}_{j=1}^J$ and $\{\hat{v}_j^- - \hat{v}_j^0\}_{j=1}^J$, respectively.

Ⅲ. DATA

The data consist of the daily won/dollar spot exchange rate and the Korean and U.S. three-month CD rates from January 4, 1995 to September 30, 1998, totaling 897 observations. Both data sets are obtained from Bloomberg. We use daily observations since these are what policymakers watched most closely to formulate interest rate policy during the crisis period, and weekly or monthly data might not yield statistically reliable results given that the high interest rate period was so short.

In our empirical analysis, we divide the overall period into three sub-periods: the pre-crisis period from January 4, 1995 to November 30, 1997; the crisis period (or high interest rate period) from December 1, 1997 to March 31, 1998;[5] and the post high interest rate period from April 1, 1998 to September 30, 1998. The numbers of observations are 709, 76, and 112 for each period. This period anatomy allows us to analyze how the dynamics of interest rates evolved around the crisis. The average levels of the interest rate in each period are used as a baseline initial condition for impulse response function analysis as described in the next section.

We restrict the pre-crisis period to 1995 onward because of structural changes in the won/dollar exchange rate suggested by previous studies. Joo and Kim (1999), for example, argue that exchange rate movements were well explained by macroeconomic fundamentals after 1995, but not from 1990 to 1995. The timing of the structural break coincides with the Korean government's efforts to liberalize the capital account, such as easing limits on stock investment in non-state owned companies by foreigners from 10 percent to 12 percent and opening the market for non-guaranteed convertible bonds issued by small and mid-size companies. Furthermore, Standard & Poor's upgraded Korea's sovereign credit rating from A2 to A1 in May 1995, which resulted in net capital inflows, an expansionary monetary policy, and won depreciation.

The high interest rate policy (HIRP) period was chosen in accordance with the movement of historical data and previous studies. The beginning of this period coincides with December 3, 1997, the date that the Korean government and the IMF agreed on the first Letter of Intent for the IMF program. As is well known, Korean interest rates rose rapidly around early December 1997. The Korean government also made an upward adjustment of the ceiling on the interest rate from 25 percent to 40 percent, as noted in the Letter of Intent of December 22, 1997. The HIRP period in our analysis is also consistent with Furman and Stiglitz (1998), who suggested that the period of high interest rates in Korea was 113 days long, from December 2, 1997 to late March of 1998.

As the final date of the post-crisis (or post-HIRP) period we choose September 1998, given that the Korean government announced the completion of the first-stage restructuring in October 1998.[6] In the post-HIRP period, the Korean economy was still feeling the after-effects of the currency crisis and the interest rate was in a downward stabilization trend.[7]

The won/dollar exchange rate and the differential between the Korean and U.S. interest rates are illustrated in Table 2. The mean, standard deviation, and difference between the maximum value and the minimum value are largest during the HIRP period. In addition, the exchange rate distribution is skewed to

[5] We use the terminology "crisis period" and "high interest rate period" interchangeably throughout the paper.

[6] Of course, it is possible to include the data from October 1998 up until this day for our empirical analysis.

[7] Due to small number of observations during the crisis period, empirical analysis restrict to overall sample period rather than sub-period, such as high interest rate period, analysis.

the left during the HIRP period, while the interest rate differential in the same period is skewed to the right. This suggests that the interest rate had an upward trend whereas the exchange rate had an appreciation trend during the HIRP period. Further, during the post-HIRP period, both variables show different characteristics from a normal distribution.

For our empirical analysis, we focus on relation between the percentile change in the won/dollar spot exchange, denoted by *exch* ($=100\times\ln[s_t/s_{t-1}]$), and the differential between the Korean and U.S. interest rates, denoted by *int*, bearing the interest parity in mind.

[Table 2] Basic Statistics

	Mean	Max	Min	Std. Dev.	Skewness	Kurtosis
KRW/USD						
Whole Period	1038.4	1962.5	753.0	238.6	0.611	2.79
Pre-HIRP	814.5	915.0	753.0	49.2	0.608	1.91
HIRP	1360.5	1962.5	912.6	228.5	-0.311	2.82
Post-HIRP	1173.3	1389.0	1102.5	57.1	1.066	4.18
Interest Differential						
Whole Period	6.61	19.81	0.59	4.25	0.737	3.50
Pre-HIRP	7.79	11.16	4.73	1.27	0.207	2.71
HIRP	12.06	19.81	5.30	4.33	0.155	1.78
Post-HIRP	1.78	6.11	0.59	0.87	1.146	5.07

Notes: 1) The pre-HIRP period is between January 4, 1995 and November 30, 1997, the HIRP period between December 1, 1997 and March 31, 1998, and the post-HIRP period between April 1, 1998 and September 30, 1998.
2) The interest rate differential is between Korean and U.S. interest rates.

Ⅳ. MAIN EMPIRICAL RESULTS

The SNP estimation provides information regarding an appropriate statistical model describing the dynamics of the two variables, *exch* and *int*, reasonably well. Based on the estimated SNP specification, the impulse response analysis allows us to see the direction and duration of the effects that changes in the interest rate have on the exchange rate, more precisely on the percent change in the exchange rate.

We conduct the SNP estimation from January 4, 1995 to September 30, 1998 to capture the underlying dynamic structure over the full period since the high interest rate policy during the Korean crisis may have been adopted based on the past behavioral relation between interest rates and exchange rates. At the same time, if policymakers believed that high interest rates could lead to structural changes, they might have a forward looking perspective.[8]

Through the SNP estimation we can identify the parameters driving the dynamics of the model. Given that the SNP approach is based on a truncated Hermite series expansion, we need to determine the key parameters: the degrees of the polynomial (K_z, K_x) and the lag lengths of the mean, the GARCH and the polynomial part (L_μ, L_g, L_r, L_p). For this purpose, we use the Bayesian Information Criterion (BIC) as a selection strategy. Table 3 shows the objective surface for SNP estimation and the selected values for the parameters. From the table, we can see that $L_\mu=4$, $L_g=L_r=L_p=1$, $K_z=4$, $I_z=2$, $K_x=I_x=0$ are the most appropriate selection based on BIC. This suggests that the model has four lags in the linear autoregressive component, GARCH(1,1), and non-Gaussian error structure reflected by the fact that a polynomial of degree 4 in z is selected. In summary, the density is a GARCH model with a non-parametric error structure.

[Table 3] Bivariate SNP Estimation

L_u	L_g	L_r	L_p	K_z	I_z	K_x	I_x	P_θ	S_n	BIC
1	0	0	1	0	0	0	0	9	0.670	0.705
2	0	0	1	0	0	0	0	13	0.598	0.648
3	0	0	1	0	0	0	0	17	0.573	0.638
4	0	0	1	0	0	0	0	21	0.552	0.633
5	0	0	1	0	0	0	0	25	0.546	0.643
4	1	1	1	0	0	0	0	30	-0.911	-0.795
4	1	1	1	4	3	0	0	38	-1.094	-0.948
4	***1***	***1***	***1***	***4***	***2***	***0***	***0***	***39***	***-1.106***	***-0.956***
4	1	1	1	4	1	0	0	41	-1.111	-0.953
4	1	1	1	5	4	0	0	40	-1.097	-0.943
4	1	1	1	5	3	0	0	41	-1.098	-0.940
4	1	1	1	6	5	0	0	42	-1.098	-0.936
4	1	1	1	4	3	1	0	56	-1.130	-0.914
4	1	1	1	4	2	1	0	59	-1.135	-0.908
4	1	1	1	5	4	1	0	62	-1.129	-0.890
4	1	1	1	6	5	1	0	68	-1.136	-0.8742

Note: 1) L_is represent the lag length for (μ=(mean), g=(GARCH), r=(ARCH), and p =(polynomial part).
2) (K_z, K_z) are polynomial degrees in (z, x).
3) P_θ is the number of free parameters in the model.
4) S_n is the log likelihood value, and BIC stands for Bayesian Information Criterion.
4) Bold and italic characters denote the chosen empirical model based on the minimized BIC value.

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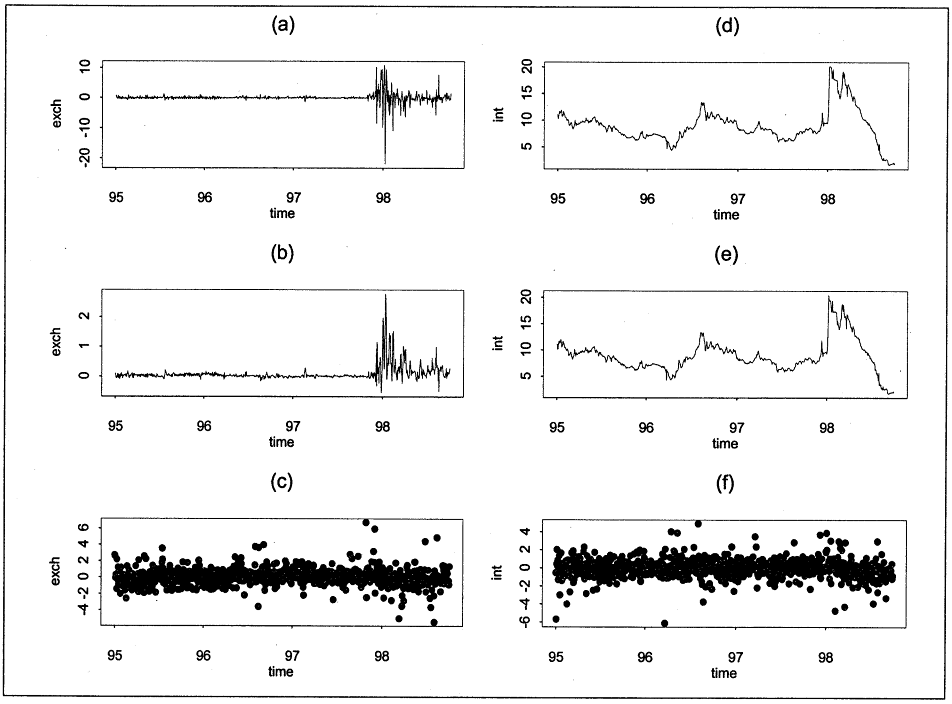
[8] Fischer (1998) suggests that the high interest rate policy would help restructure an economy as well as restore confidence.

Figure 1 presents information on the adequacy of the fit of the estimated model. A comparison of panels (a) and (d), which show the dynamic behavior of the raw data, and panels (b) and (e), which show the estimated one-step ahead conditional means, indicates that the estimated model does a good job of tracking the mean over the sample period. Panels (c) and (f) are scatter plots of the standardized residuals - the difference between the raw data and the estimated conditional mean - of each variable. The scatters are reasonably uniform in the vertical direction, suggesting a good fit.

[Figure 1] Dynamics of Raw Data and SNP Estimation



Note: Panel (a) is a plot of daily observations on the rate of change in the won/dollar exchange rates (*exch*) from January 4, 1995 to September 30, 1998, while panel (d) is a plot of the interest rate differential between Korea and the U.S. (*int*) during the same period. Panels (b) and (e) are plots of the SNP one-step ahead conditional mean for *exch* and *int*, respectively. Panels (c) and (f) are normalized residuals for *exch* and *int*, respectively.

Within the estimated SNP dynamic structure, we now carry out the analysis of nonlinear impulse response function to investigate the effect of interest rate policy in the pre-HIRP economic environment, when interest rates are lower than they are in the HIRP period. To flash this out, we empirically investigate how the exchange rate responds to both an upward and a downward adjustment of the interest rate from the average interest rate of the pre-HIRP period. The experiment is expected to provide information on which of the two policies, high and low interest rate policies, would have contributed more effectively to the stability of the exchange rate in the pre-crisis (or the pre-HIRP) economic environment.

A more precise description of this experiment is as follows. Let $x_0=(y'_{L+1}, K, y'_0)'$ be a vector of the averages of *exch* and *int* during the pre-HIRP period. We can then see the effects of an increase in the interest rate differential on the dynamic path of *exch*, which is the rate of change of exchange rates, by changing the conditional arguments x_0 into $x_0^+=x_0+(0, \Lambda, \delta')'\equiv x+\delta$ where $\delta=(0, y_{int})'$, $y_{int}=\zeta\times$[average level of pre-HIRP interest rate differential], for ζ=0.1, 0.4, and 0.8. That is, we empirically analyze how increases of 10 percent, 40 percent, and 80 percent in the interest rate differential from the pre-HIRP average interest rate differential would affect the change in the exchange rate.[9] We can also easily see the effect on the exchange rate of a decrease in the interest rate differential by putting ζ=-0.1, -0.4, and -0.8.

Figure 2 shows the response of the rate of change in the exchange rate (*exch*), to each of the above-mentioned interest rate shocks on the pre-HIRP interest rate differential. From the experiment, we derive the following key findings, which hold regardless of the absolute size of the shock.

First, the effect of the high interest rate policy on the exchange rate changes sign over time. For a very short period, the conditional mean of *exch* stays above zero, suggesting that a rise in the interest rate causes the exchange rate to depreciate. After four days or so, however, the effect is reversed and the conditional mean becomes negative, which suggests that the increase in the interest rate induces an appreciation of the won. The appreciation effect of the HIRP shock is persistent without substantial damping.[10,11] The dynamic patterns of the exchange rate responses show a remarkable uniformity, especially about the timings of the reversal, regardless of the size of the shock.

Second, the low interest rate policy appreciates the exchange rate only for an extremely short period, but it has no significant effect afterwards. As seen in Figure 2, the low interest rate policy appreciates the won for less than five days. But the effect is almost nil thereafter, at least in terms of deviations from the baseline. This pattern also holds regardless of the size of the shock, with the timing of when the exchange rate effects vanish almost the same for

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[9] 80 percent in this case is the level necessary for the pre-crisis average interest rate to reach the maximum interest rate level during the HIRP period.

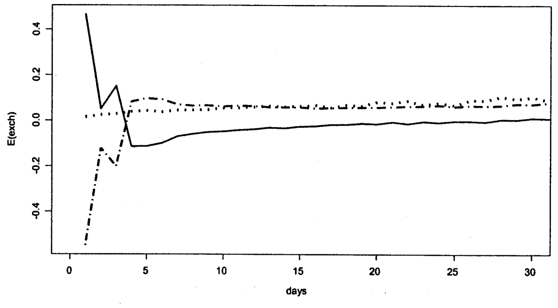
[10] In Figures 2 and 3, the chart for the impulse response function is drawn for 30 days, because the shape of the impulse response after 30 days is not much different from the one just before 30 days.

[11] Whether the effect of a shock is persistent or not would depend on the definition of persistency. The responses in the experiment, however, remain at substantial magnitudes, more than 10 percent of the total deviations from the baseline.

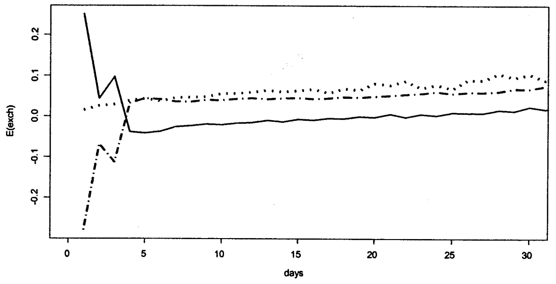
different sizes of the shock.

[Figure 2] Impulse Response Function of Changing Interest Rates in the Pre-HIRP Economic Environment

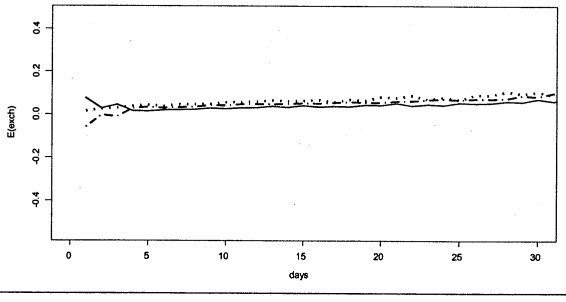
(i) 80 percent interest rate shock



(ii) 40 percent interest rate shock



(iii) 10 percent interest rate shock



Note: The y-axis is the conditional mean of *exch*, the percent change in the won/dollar exchange rate. The dotted line (······) indicates the baseline. The solid line (—) and the dashed line (- ·· - ·· ·) are the responses to a positive and negative shock to the interest rate, respectively.

A comparison between the two policy options, high interest rate policy and low interest rate policy, suggests a notable asymmetry in the exchange rate dynamics. The high interest rate policy induces a substantial appreciation over a long period, say more than thirty days, while the low interest rate policy may affect the exchange rate only over an extremely short period.

Now we look at the effect of interest rate policy on exchange rate dynamics during the HIRP period. More specifically, we examine how the exchange rate responds to an increase or a decrease in the interest rate from the average interest rate of the HIRP period. This experiment is expected to reveal some useful information on the appropriate policy prescription during the crisis period, particularly whether it would have been effective to further raise or cut the interest rate during that period.

In this experiment, we choose ± 0.1, ± 0.3 and ± 0.5 for the value of ζ, the percent increase or decrease in the interest rate differential from the average level during the crisis period. The maximum value for ζ, 0.5, is the ratio of the highest interest rate to the average interest rate during the HIRP period.

Figure 3 illustrates the effects on the exchange rate of shocks on the HIRP interest rate. The key results for the pre-HIRP period hold for the HIRP period. This suggests that a further rise in interest rates during the HIRP would have induced a further appreciation of the won. Thus, it would have been appropriate to continue to raise the interest rate during the HIRP period if policymakers had believed that the exchange rate would have continued to depreciate further. This suggests that the rise in the interest rate recommended by the IMF during the Korean crisis was not excessive.

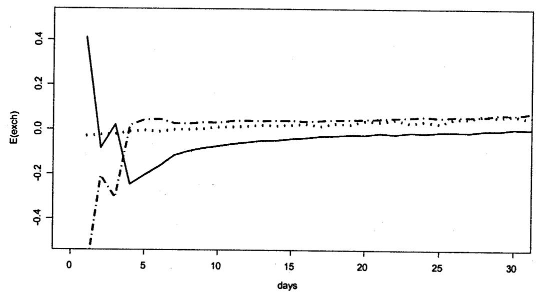
The results also suggest that a cut in interest rates below the level prevailing during the HIRP period would not have induced a significant depreciation over the three-month period.[12] This appears consistent with the fact that the exchange rate in Korea remained stable even after interest rates were cut back to the pre-crisis level.

The above findings shed new light on the literature on the efficacy of high interest rate policy. In particular, our empirical results may reconcile seemingly inconclusive and mutually inconsistent evidence suggested by the previous studies. Our results suggest that the reason why some empirical studies (for example, Goldfajn and Baig, 1998) using daily data find that the high interest rate policy has little or negative effect on the exchange rate may be because they do not allow for nonlinearities. In addition, our finding that the depreciation effect of the high interest rate policy is reversed after around four days suggests that if weekly or monthly data are used (as in Dekle et al, 1998; and Cho and West, 2001), the likelihood of having a positive effect would be higher.

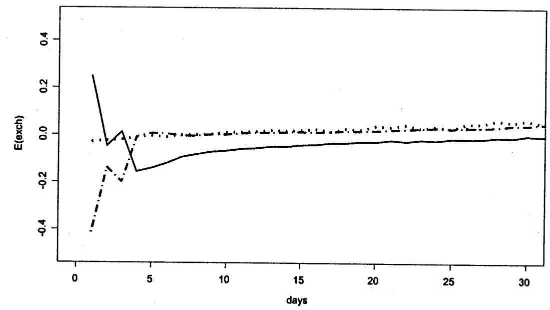
[12] The effect of a decrease in the interest rate seems to revert back to the baseline more slowly during the HIRP period than during the pre-HIRP period.

[Figure 3] Impulse Response Function of Changing Interest Rates with HIRP Economic Environment

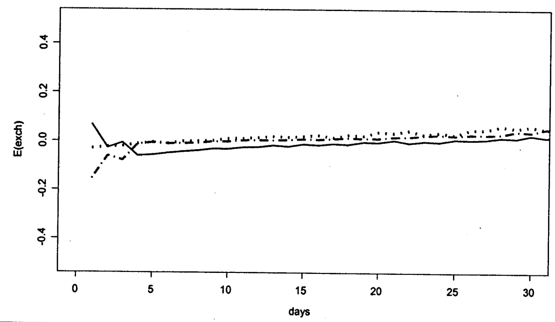
(i) 50 percent interest rate shock



(ii) 30 percent interest rate shock



(iii) 10 percent interest rate shock



Note: The y-axis is the conditional mean of *exch*, the percent change in the won/dollar exchange rate. The dotted line (······) indicates the baseline. The solid line (——) and the dashed line (- ·· - ·· ·) are the responses to a positive and negative shock to the interest rate, respectively.

V. EVALUATION OF THE IMF's HIGH INTEREST RATE POLICY

Our empirical results provide some building blocks to assess whether the IMF's high interest rate policy prescription for Korea during the crisis was appropriate. The assessment would depend partly on how long the underlying trend of depreciation of the won against dollar would have continued. If the depreciation of the won had been very short-lived, less than five days or so, and small, then a low interest rate policy would have been a better policy option. If, however, the depreciation was expected to persist much longer, say one month, then a high interest rate policy would be more effective.

There is evidence that the sharp rise in the won/dollar rate would last for longer than a week, implying that the high interest rate policy was appropriate. In particular, the baseline movements in our impulse response analysis show a depreciation trend for at least a month (see Figures 2 and 3). This implies that our SNP estimation detected the realized depreciation trend of the won/dollar exchange rate during the pre-HIRP and HIRP periods, which coincide with observed data as shown in Figure 1.

Depreciation pressures lasting for an extended period may reflect the following circumstances at the onset of the crisis. First, there was no easy way to resolve the short-term external liabilities, which acted as a major cause of the currency crisis in Korea,[13] within a short period. This is obvious from the fact that it was three months after the eruption of the crisis before Korea could begin the debt rescheduling process of converting the US$20 billion short-term liabilities to long-term liabilities. Short-term debts continued to be called in despite financial assistance from the IMF beginning on December 3, 1997.

Second, it took a while for the once-depleted foreign reserves to be rebuilt. As domestic banks, faced with refusal of maturity extension by international creditor banks, were unable to raise funds in foreign currency on their own, the Bank of Korea provided them with contingency funds out of the foreign exchange reserves, which together with excessive foreign exchange market intervention led to the depletion of foreign exchange reserves. The massive re-accumulation of foreign exchange reserves that was obviously necessary to restore investor confidence would have taken more than just a couple of months.

Third, it is not easy for an economy to restore its credit ratings after they have been downgraded. During the crisis, international credit rating agencies quickly downgraded Korea's sovereign credit rating. For instance, Standard & Poor's downgraded Korea's credit rating by ten notches from October to December 1997, and Moody's downgraded six notches on three occasions. The rating of these agencies had an enormous impact on bond and stock investment in Korea, which in turn contributed to the devaluation of the Korean won.

[13] This factor is noted as the variable that best predicts the likelihood of a crisis in some empirical analysis. See Park and Choi (1998) and references therein.

Given the difficulty of restoring the credit rating back to its normal level, the depreciating trend of the won was likely to continue for some time.

In sum, our empirical results suggest that the IMF's recommendation of high interest rates was an effective policy for stabilizing the exchange rate. In particular, the asymmetric effects of policy alternatives suggest that raising the interest rate was appropriate at the onset of the crisis while devaluation pressures persisted; and that the subsequent cut in the interest rate was also effective, as the initial uncertainty dissipated.

Ⅵ. CONCLUSION

This study has evaluated the effectiveness of the high interest rate policy in stabilizing the exchange rate in Korea during the crisis. A nonlinear impulse response approach was adopted for a number of reasons. First, nonlinear model is more general and provides richer dynamics of exchange rate responses to an interest rate shock. In addition, nonlinear model provides a useful analytical tool to detect potential nonlinearities, particularly the asymmetric response of the exchange rate to an increase compared with a decrease in interest rates.

We found that the effect of the high interest rate policy on the exchange rate changes signs over time. A rise in the interest rate causes the exchange rate to depreciate only for four days or so. However, the increase in the interest rate induces the appreciation of the won afterwards, and the appreciation continues thereafter without substantial damping. We also found that the low interest rate policy appreciates the exchange rate only for an extremely short period, but has no significant effect afterwards. So there is a distinctive asymmetry in the exchange rate response to an interest rate shock. We also suggest that the mixed assessments of previous studies on the efficacy of high interest rate policy in Korea might have their root in the span of the data and the assumption of a linear relationship between interest rates and exchange rates.

Our empirical results also suggest that the IMF's high interest rate policy during the crisis, which was characterized by a sharp increase in interest rates at the onset of the crisis followed by a cutback after several months, was an effective policy prescription for exchange rate stabilization. If the sudden rise in the won/dollar rate was deemed extremely temporary (less than five days), then a low interest rate policy would have been more appropriate. Nevertheless, the economic situation at the time of crisis suggests that the rapid rise in the exchange rate was not temporary. Therefore, the high interest rate policy was appropriate in the situation. Our result also suggests that a cut of the interest rate back to the pre-crisis level would be achieved without another serious exchange rate depreciation, supporting for the policy of cutback of interest rates after several months. It is interesting as a future research to examine whether we get different results or policy implications by adding other economic variable to our analysis.

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CUMULATIVE TRADE AND ECONOMIC GROWTH IN THE EAST ASIAN COUNTRIES*

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There have been many empirical researches to find out the role of trade on economic growth. However, no attempt has been made to unravel the role of cumulative trade on economic growth. It could be presumed that the beneficial effects of trade will accumulate to affect the operation of economies to the future. We used cumulative trade augmented time index in our cost function framework to test whether cumulative trade contributed to the economic growth of the East Asian countries. We found that cumulative trade enhanced technical progress and played an important role in the economic growth of the East Asian countries. Cumulative trade also contributed to the East Asian countries' catching up the superior technologies of developed countries.

JEL Classification: C51, F10, O30, O53
Keywords: Cumulative trade, Technological progress, Economic Growth, Catch-up, East Asian countries.

Ⅰ. INTRODUCTION

The contribution of openness to economic growth has been explained in various ways. Trade promotes international competition which enhances production efficiency. Greater capacity utilization and economies of scale are the benefits of exports. Openness also allows greater specialization which generates higher productivity growth and openness to trade provides access to superior foreign technology embodied in imported inputs. Knowledge spillovers take place as commodity traders serve as a conduit for information flows. Grossman and Helpman (1991a) present a model which shows that cumulative volume of trade can cause technical progress to accelerate and the economy to grow faster.

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The favorable effects of trade are more relevant in less developed countries. Less developed countries can learn more than developed countries to catch up the technology gap.

There have been empirical researches to support those points. Among them: Feder (1983), Tyler (1981), and Kavousi (1984) showed that exports contribute to economic growth. Miller and Upadhyay (2000) report that openness and human capital contribute to TFP growth; the export-to-GDP ratio has a significant positive effect at the 1% level in the study of 83 countries for 1960-1989 period. Balassa (1985) found that exports accelerate growth from the study of 43 developing countries in the 1973-78 period. While those studies provided positive correlations between export expansion and output growth the study on the semi-industrialized countries by Esfahani (1991) attributes the positive export-GDP association to the contribution of exports to the reduction of import shortages. The study points out that exports in semi-industrialized countries are the main source of foreign exchange for the much needed imports of intermediate and capital goods. Weinhold and Rauch (1999) presented the evidence that specialization in manufacturing sector increases the rate of growth of manufacturing productivity in less developed countries. Anne Harrison (1995) provided a good survey and tested various openness measures to find that greater openness is associated with higher economic growth. Frankel et al. (1996) used gravity equation to find that openness (the share of trade to GDP) explains much of the growth of the East Asian countries, especially, in Singapore, Hong Kong, and Malaysia. Lawrence and Weinstein (1999) report that imports are more contributing than exports to the TFP growth of Japan and Korea.

However, those empirical researches are only on current trade not on cumulative trade.[1] The contributing effects of trade to economic growth will not vanish after contributing current economic growth but will continue to affect future economic growth. Those effects of trade will be accumulating; i.e., past levels of trade affect current growth. Learning will accumulate, enhanced competitiveness will affect future production, and acquired knowledge will be used next periods also. Catch-up effect might be present in doing so. Less developed countries will benefit more from trade. In this paper we used cumulative trade to test its role in technological progress and output growth in the seven East Asian countries (Korea, Japan, Taiwan, Singapore, Malaysia, Thailand, and Hong Kong). Those countries have been selected because they are trade-oriented fast-growing countries of the East Asian miracle, and thus, it is presumed that the spill-over and catch-up effects from trade are more noticeable than other countries. During 1968-1995 preiod they recorded 5.0% to 9.5% average annual output growth rate of non-agricultural sector as reported in Table 1. The high growth rate of output accompanied huge factor accumulation. The

[1] Grossman and Helpman presented theoretical framework using the cumulative trade as a variable in the function of the knowledge capital (Grossman and Helpman (1991a)).

growth rates of capital ranged from 7.5% to 13.1%. The growth rates of labor ranged from 4% to 6% except Japan and Hong Kong. In most of the countries trade grew more rapidly than the factors of production and output. All the countries except Japan recorded a trade growth rate of higher than 10%. The economic growth of the East Asian countries is also sustaining. The growth rates of output have not changed much, except Japan, in 1986-1995 period compared to previous periods as can be seen in Table 2. The growth rates of Korea, Taiwan, and Singapore in 1986-1995 are a little lower than in 1968-1975 by about 2%; however, the growth rates of Malaysia and Thailand are higher in 1986-1995 than in 1968-1975. The growth rates of total factor productivity (TFP) show improving or stable trends except Japan as can be seen in Table 3. The TFP growth rate of Japan has decreased recording 3.16% in 1968-1975 period, 1.46% in 1976-1985, and 1.0% in 1986-1995. The TFP growth rates of Malaysia and Hong Kong have not changed much but the controversial TFP growth rate of Singapore has improved much in the 1986-1995 period compared to the previous periods. The TFP growth rate of Singapore in the 1968-1975 period was -1.37%, -0.19% in 1976-1985, but shows huge surge of 3.74% in 1986-1995. Korea, Taiwan, and Thailand also show improving trends in TFP growth.[2]

[Table 1] Average Annual Growth Rates of Non-agricultural Output*, Labor, Capital, Trade, and TFP in Percentage for 1968-1995.

Growth Rates of	Countries						
	Korea	Japan	Taiwan	Singapore	Malaysia	Thailand	Hong Kong
Output	9.5	5.0	9.0	8.8	8.2	8.4	7.1
Labor	5.1	1.1	4.2	4.0	5.1	6.1	1.7
Capital	13.1	8.0	10.9	12.2	9.0	8.8	7.5
Trade	14.5	6.7	12.4	10.7	10.0	10.1	10.1
TFP	1.99	1.78	3.14	0.88	1.23	1.08	2.87

* In Singapore and Hong Kong output is GDP including agricultural sector.

[Table 2] Average Annual Growth rates of Non-agricultural Output for Three Subperiods.

Subperiods	Countries						
	Korea	Japan	Taiwan	Singapore	Malaysia	Thailand	Hong Kong
1968-1975	11.7	8.3	9.9	10.8	6.7	7.3	6.7
1976-1985	8.3	4.3	9.5	7.0	9.1	7.7	8.2
1986-1995	9.0	3.0	7.9	8.9	8.5	10.0	6.3

[2] For other measures of TFP growth rates refer to Young(1995), Collins(1996), Sarel(1997), Hsieh(1999), and Iwata *et al.*(2003) among others. The authors except Young report that TFP growth played more important role in the output growth of East Asian countries than Young's result.

[Table 3] Average Annual Growth rates of TFP for Three Subperiods for Non-agricultural Sector

Subperiods	Countries						
	Korea	Japan	Taiwan	Singapore	Malaysia	Thailand	Hong Kong
1968-1975	2.65	3.16	1.04	-1.37	1.24	-0.04	3.13
1976-1985	0.06	1.46	3.84	-0.19	1.24	0.79	2.85
1986-1995	3.40	1.00	4.11	3.74	1.20	2.24	2.67

To find out the effect of cumulative trade to economic growth we use a translog cost function for those economies. We will test whether cumulative trade contributes to technological progress by estimating the cost function. The estimated cost function will also give the elasticities of labor, capital, output, and cumulative trade to let us know the relative contribution of the factors to the growth of the economies.

Ⅱ. THE MODEL

As mentioned above current trade will affect future economic growth for some time. However, it could be presumed that the effect of trade to the future would diminish as time goes by. Thus we use perpetual inventory method to measure the cumulative trade by applying depreciation rates. Thus,

$$Q(t) = (1-\delta)Q(t-1) + T_r(t-1) \tag{1}$$

where $Q(t)$ is cumulative trade at time t, δ is its depreciation rate, and T_r is the volume of trade which is exports plus imports. Various depreciation rates have been applied to derive the stocks for this study. When the depreciation rate is 1.0 the cumulative trade is just the one period lag of trade. The cumulative trade has been divided by GDP. We assume that cumulative trade contributes to technological progress,[3] and thus the index of technological progress is augmented by cumulative trade such that:

$$T = A\exp(\gamma_Q Q^*)\exp(t),^4 \tag{2}$$

where T is the index of technological progress augmented by technical progress, A is a constant, Q^* is the cumulative trade divided by GDP, t is the index of exogenous technical change represented by a time trend. We employed a translog cost function to analyze the economies such that:

[3] Grossman and Helpman specified that knowledge capital is a function of cumulative trade and cumulative amount of domestic research.

[4] This specification is applied from the specification of the commodity augmentation factors. See Boskin and Lau(1992)

$$\begin{aligned}\ln C = {} & \alpha_0 + \alpha_L \ln W_L + \alpha_K \ln W_K + \alpha_Y \ln Y + \alpha_T \ln T + 0.5\alpha_{LL}(\ln W_L)^2 \\ & + \alpha_{LK} \ln W_L \ln W_K + \alpha_{LY} \ln W_L \ln Y + \alpha_{LT}(\ln W_L)\ln T \\ & + 0.5\alpha_{KK}(\ln W_K)^2 + \alpha_{KY} \ln W_K \ln Y + \alpha_{KT}(\ln W_K)\ln T \\ & + 0.5\alpha_{YY}(\ln Y)^2 + \alpha_{YT}(\ln Y)(\ln T) + 0.5\alpha_{TT}(\ln T)^2\end{aligned} \tag{3}$$

where C is the total cost of labor and capital for non-agricultural sector, W_L is the wage rate, W_K is the rental rate of capital, Y is the output of non-agricultural sector, and $\ln T = \ln A + \gamma_Q Q^* + t$, where Q^* is cumulative trade divided by non-agricultural output. $\ln T$ is the cumulative trade augmented index of technological progress, which means that cumulative trade contributes to technological progress when γ_Q is positive. After substituting $\ln T = \ln A + \gamma_Q Q^* + t$ and normalizing by the price of capital under the assumption of linear homogeneity in prices,[5] Equation (3) becomes

$$\begin{aligned}\ln(C/W_K) = {} & \alpha_0^* + \alpha_L^* \ln(W_L/W_K) + \alpha_Y^* \ln Y + \alpha_T^* \gamma_Q Q^* + \alpha_T^* t \\ & + 0.5\alpha_{LL}^* \ln(W_L/W_K))^2 + \alpha_{LY}^* \ln(W_L/W_K)\ln Y \\ & + \alpha_{LT}^* \gamma_Q \ln(W_L/W_K) Q^* + \alpha_{LT}^* \ln(W_L/W_K) t \\ & + 0.5\alpha_{YY}^*(\ln Y)^2 + \alpha_{YT}^* \gamma_Q (\ln Y) Q^* + \alpha_{YT}^*(\ln Y) t \\ & + 0.5\alpha_{TT}^* \gamma_Q^2 Q^{*2} + \alpha_{TT}^* \gamma_Q Q^* t + 0.5\alpha_{TT}^* t^2\end{aligned} \tag{4}$$

This is a variable cost function with the variable inputs of capital and labor and a fixed input of cumulative trade. From Equation (4) a labor share equation from Shepard's Lemma and a revenue share equation under the assumption of perfectly competitive output markets can be obtained as follows.

$$S_L = \alpha_L^* + \alpha_{LL}^* \ln(W_L/W_K) + \alpha_{LY}^* \ln Y + \alpha_{LT}^* \gamma_Q Q^* + \alpha_{LT}^* t \tag{5}$$

$$S_Y = \alpha_Y^* + \alpha_{LY}^* \ln(W_L/W_K) + \alpha_{YY}^* \ln Y + \alpha_{YT}^* \gamma_Q Q^* + \alpha_{YT}^* t \tag{6}$$

where S_L and S_Y are the cost shares of labor and output, respectively. Capital share can be obtained as $1 - S_L$. Our specification does not impose a priori constant returns to scale; thus, the cost elasticity of output needs not be one. The cost function should be concave in factor prices, accordingly, the Hessian matrix of second partial derivatives with respect to factor prices should be

[5] This assumption amounts to restricting the parameters such that: $\alpha_K = 1 - \alpha_L$, $\alpha_{KK} = -\alpha_{LK}$, $\alpha_{LK} = -\alpha_{LL}$, $\alpha_{KY} = -\alpha_{LY}$, $\alpha_{KT} = -\alpha_{LT}$

negative semi-definite. If the cumulative trade is contributing to technical progress γ_Q will have plus sign and the elasticity $\partial \ln C / \partial \ln Q^*$ will be negative in the variable cost function.

Ⅲ. DATA AND ESTIMATION METHOD

Estimation is implemented for the group of seven East Asian economies (Korea, Japan, Taiwan, Singapore, Malaysia, Thailand, and Hong Kong). Except Singapore and Hong Kong,[6] only non-agricultural sectors are considered. The output(Y) is obtained by excluding agriculture from total GDP categorized by kind of activity. Non-agricultural indirect taxes are subtracted from and subsidies are added to output(Y). Non-agricultural indirect taxes are obtained by multiplying total indirect taxes to the share of non-agricultural GDP to total GDP. Non-residential and non-agricultural capital stock is used for the capital (K). We generate four categories of capital stock separately (non-residential buildings, other construction, transportation equipment, machinery and other equipment)[7] and add them up to form capital (K). The perpetual inventory method is used to derive each categorized capital stock. Base year capital is calculated using the formula $K_{i0} = I_{i0}/(m_i + \delta_i)$, $i = 1, 2, 3, 4$ where K_{i0} is the base year stock of the ith categorized capital, I_{i0} is the gross fixed capital formation of the ith category excluding agriculture, m_i is the growth rate of I_{i0} for the first ten years, δ_i is the depreciation rate of each category. The depreciation rates for non-residential buildings, other construction, transportation equipment, machinery and other equipment are 0.0304, 0.03024, 0.2079, and 0.1376, respectively. These values are derived by taking unweighted average of the depreciation rates of asset types from the table of Jorgenson and Yun (1990). The depreciation rate of total capital stock is the weighted average of the depreciation rates of categorized capital stocks. Rental price of capital(W_K) is $P_I(r - inf + \delta)$ where P_I is the price of non-agricultural fixed capital formation, r is the nominal interest rate, and inf is the inflation rate of P_I. We average the real interest rates of the sample period. Labor is total man hours worked in the non-agricultural sector. Total man-hours are calculated by multiplying total non-agricultural employment and average weekly hours and 50. Total labor cost is compensation of employees in non-agricultural sector times TM_N/EMP_N where TM_N is total non-agricultural employment and EMP_N is employees in the non-agricultural sector. Unit cost of labor (W_L) is obtained by dividing the compensation of employees by total man-hours worked in non-agricultural sector and normalizing it to the base year 1985. PPP values for

[6] GDP including agricultural sector is considered for Singapore and Hong Kong.

[7] This classification is in accordance with the definitions and classifications in the United Nations Systems of National Accounts (SNA).

1985 from Summers and Heston (1991) are used to convert data to US dollars. The sources of the data can be found in the Data Appendix.

For estimation purposes stochastic disturbance terms are added to Equation (4) through (6). We assume that the disturbances ε_{ti}'s are first order autoregressive such that: $\varepsilon_{ti} = \rho\varepsilon_{ti-1} + \mu_t$ and μ_t is distributed i.i.d. over time. We apply $\rho = 0.85$ for all the three estimation equations. α_0, α_L, α_K, α_Y, and α_t are estimated individually for each country applying dummy variables, and the other parameters are estimated jointly using the 3SLS estimation procedure. The instrumental variables for the estimation are country dummies, all exogenous variables and their squares lagged one and two periods, and time and its square. Heteroscedacity is taken care of using White's method. The sample period of the data for estimation is 1968-1995.

Ⅳ. ESTIMATION RESULTS

The cost function and the share equations of (4)-(6) are estimated by using cumulative trade derived under different depreciation rates. The results are summarized in Table 4. The estimated coefficient of cumulative trade is significant under the depreciation rates of 0.3-1.0. Especially, the estimated coefficient of cumulative trade under the depreciation rates of 0.5-0.9 is significant at 1% level. From the experiments it can be seen that cumulative trade is contributing to technical progress. The estimated cost functions for the seven East Asian Countries met curvature conditions at all data points for all the models.

[Table 4] Estimates of γ_Q under various Depreciation Rates. The Standard Errors are in the Parentheses.

	Depreciation Rate									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
γ_Q	-0.144	0.714	1.211*	1.704*	2.138**	2.464**	2.657**	2.708**	2.616**	2.401*
	(0.270)	(0.402)	(0.542)	(0.678)	(0.799)	(0.898)	(0.970)	(1.012)	(1.020)	(0.994)

* Significant at 5 % level
** Significant at 1 % level

We present estimation results for the model of the cumulative trade under depreciation rate of 0.5.[8] R^2's for the cost function, the labor share equation, and the revenue share equation are .99, .98, and .94, and the Durbin-Watson statistics are 1.71, 1.83, and 1.88, respectively. Estimated parameters and standard errors are reported in Table 5. Country dummy numbers from 1 to 7 represent

[8] Estimation results for the models of depreciation rates of 0.6 and 0.7 are robust except that some t-values for the elasticities deteriorate a little.

Korea, Japan, Taiwan, Singapore, Malaysia, Thailand, and Hong Kong respectively.

[Table 5] Estimated Parameters and Standard Errors for the seven East Asian Countries. The depreciation rate of the cumulative trade is 0.5.

Parameter	Estimate	Standard Error
γ_Q	2.13819	.799885
α_{01}^*	2.02449	.813861
α_{02}^*	1.59392	.849134
α_{03}^*	.068665	.459833
α_{04}^*	-1.38509	.754963
α_{05}^*	-1.19119	.585695
α_{06}^*	-.517029	.455448
α_{07}^*	-2.10642	.725986
α_{L1}^*	.660337	.086585
α_{L2}^*	-.055752	.049493
α_{L3}^*	.043470	.017832
α_{L4}^*	-.212176E-02	.059292
α_{L5}^*	-.052238	.032959
α_{L6}^*	-.121283	.021043
α_{L7}^*	.074373	.031666
α_{Y1}^*	.410479	.354078
α_{Y2}^*	-.470172	.192474
α_{Y3}^*	.041003	.092242
α_{Y4}^*	.724043	.242299
α_{Y5}^*	.534667	.146724
α_{Y6}^*	.098765	.092916
α_{Y7}^*	.606710	.162378
α_{T1}^*	.681652E-02	.026717
α_{T2}^*	.058384	.017178
α_{T3}^*	-.640857E-02	.989511E-02
α_{T4}^*	-.034398	.016284
α_{T5}^*	-.030876	.013678
α_{T6}^*	.980053E-02	.011092
α_{T7}^*	-.021940	.014069
α_{LL}^*	.074003	.020874
α_{YY}^*	.190973	.090660
α_{TT}^*	.130918E-02	.588474E-03
α_{LY}^*	.014259	.022896
α_{LT}^*	-.491640E-02	.137607E-02
α_{YT}^*	-.013183	.600403E-02
Equation	R2	DW
Cost	0.999	1.718
Labor Share	0.985	1.835
Revenue Share	0.943	1.886

The elasticities of output, labor, cumulative trade, and technical progress calculated from the estimated model of depreciation rate 0.5 are reported in Table 6. Those elasticities are from the calculation of $\partial \ln C/\partial \ln Y$, $\partial \ln C/\partial \ln W_L$, $\partial \ln C/\partial \ln Q^*$, and $\partial \ln C/\partial t$. The elasticity of capital can be obtained as $1-\partial \ln C/\partial \ln W_L$ due to the assumption of linear homogeneity in prices. Since the estimated elasticities are the functions of the estimated parameters we also present an estimate for the standard errors of the elasticities at the sample means of the inputs. All of the elasticities for all the countries are statistically significant except the elasticity of cumulative trade in Japan, which is significant at 10% level. The elasticity of cumulative trade is highest in Singapore, Hong Kong, and Malaysia while it is lowest in Japan. Table 7 also reports relative contributions of labor, capital, cumulative trade, and technical progress.[9] The relative contribution of cumulative trade to output growth is

[Table 6] Elasticity of Output, Labor, Cumulative Trade, and Technical Progress in Percentage, Annual Average of 1968-1995 when the Depreciation Rate of the Cumulative Trade is 0.5. (Figures in the parentheses are standard errors calculated at respective sample means of the inputs)

	Elasticity of			
	Output	Labor	Cumulative Trade	Technical Progress
Korea	1.069 (0.070)	0.768 (0.011)	-0.107 (0.044)	-0.0382 (0.0064)
Japan	1.074 (0.039)	0.774 (0.005)	-0.014 (0.009)	-0.0143 (0.0050)
Taiwan	0.998 (0.032)	0.782 (0.007)	-0.144 (0.055)	-0.0355 (0.0063)
Singapore	1.308 (0.037)	0.687 (0.011)	-0.418 (0.134)	-0.0351 (0.0066)
Malaysia	1.365 (0.049)	0.699 (0.014)	-0.303 (0.117)	-0.0520 (0.0102)
Thailand	1.108 (0.066)	0.636 (0.021)	-0.068 (0.033)	-0.0239 (0.0090)
Hong Kong	1.459 (0.066)	0.813 (0.007)	-0.328 (0.117)	-0.0436 (0.0097)

[9] Relative contributions of labor, capital, cumulative trade, and technical progress are calculated such as:

$RC_L=(1/\sigma)(1/(1-(1/\partial \ln C/\partial \ln Q_M^*))(\partial \ln C/\partial \ln W_L)\Delta L\times 100,$

$RC_K=(1/\sigma)(1/(1-(1/\partial \ln C/\partial \ln Q_M^*))(\partial \ln C/\partial \ln W_K)\Delta K\times 100,$

$RC_{Q*}=(1/\sigma)(1/(1-(1/\partial \ln C/\partial \ln Q^*))(-\partial \ln C/\partial \ln Q^*)\Delta Q^*\times 100,$

$RC_t=(1/\sigma)(1/(1-(1/\partial \ln C/\partial \ln Q^*))(\partial \ln C/\partial t)\times 100,$

where RC_L, RC_K, RC_{Q*}, and RC_t are relative contribution of labor, capital, cumulative trade, and technical progress in percentage, respectively. σ is the returns to scale which is calculated as $(1-(1/\partial \ln C/\partial \ln Q^*))/(\partial \ln C/\partial \ln Y)$, and ΔL, ΔK^*, and ΔQ^* are the annual growth rates of labor, capital, and cumulative trade, respectively. See Prucha and Nadiri (1991) for the detail.

[Table 7] Relative Contribution of Labor, Cumulative trade, Technical Progress in Percentage, Average of 1969-1995. The depreciation rate of the cumulative trade is 0.5.

	Relative Contribution of			
	Labor	Capital	Cumulative Trade	Technical Progress
Korea	35	27	4	34
Japan	21	43	1	35
Taiwan	34	25	5	36
Singapore	25	34	8	32
Malaysia	30	23	3	44
Thailand	40	33	2	25
Hong Kong	17	17	13	53

highest in Hong Kong and Singapore recording 13% and 8%, respectively. In Taiwan and Korea cumulative trade contributes 5% and 4% to output growth, respectively. The relative contribution of cumulative trade is very small in Japan and Thailand recording only 1% and 2% respectively. The contribution of cumulative trade is much lower than the other sources of output growth in most of the countries. Technical progress is a very important source of output growth in the East Asian countries. It is the most important source of growth in Hong Kong, Malaysia, and Taiwan and the second most important source of growth in Korea, Japan, and Singapore.

Ⅴ. THE CATCH-UP MODEL

If cumulative trade helps a country, which is technologically lagged behind, catch up the leader the following form of technology index can be considered.

$$T^* = \gamma_Q Q^* + \gamma_C((Y_{Jt} - Y_{it})/Y_{it})Q^* + t \qquad (7)$$

where Y_{Jt} is the per capita non-agricultural GDP of Japan at time t and Y_{it} is the per capita non-agricultural GDP of country i at time t. $\gamma_Q Q^*$ represents the contribution of cumulative trade to technical progress and $\gamma_C((Y_{Jt} - Yit)/Y_{it})Q^*$ represents the catch-up factor. Equation (7) can be written as

$$T^* = (\gamma_Q - \gamma_C)Q^* + \gamma_C((Y_{Jt}/Y_{it})Q^* + t \qquad (8)$$[10]

Equation (8) is substituted to Equations (4), (5), and (6) for catch-up model and they are estimated using 3SLS estimation procedure. We applied $\rho = 0.8$ for all the three equations. The instrument variables are same as the non-catch-up model except that the log of population lagged one period is added

[10] Equation (7) and (8) are due to Benhabib and Spiegel (1994).

for the catch-up model. Table 8 reports the estimates and standard errors of γ_Q and γ_C for different depreciation rates for the catch-up model. Both of the coefficients γ_Q and γ_C of cumulative trade are statistically significant at 1% level under the depreciation rates of 0.2, 0.3. We report the estimation results for the catch-up model under the depreciation rate of 0.2.[11] R^2's for cost function, labor share equation, and revenue share equation are .998, .984, and .945, and the Durbin-Watson statistics are 1.486, 1.741, and 1.706, respectively. The estimated parameters and standard errors are reported in Table 9. Country dummy numbers from 1 to 7 represent Korea, Japan, Taiwan, Singapore, Malaysia, Thailand, and Hong Kong respectively.

[Table 8] Estimates of γ_Q and γ_C for Different Depreciation Rates for Catch-up Model. The standard errors are in the parentheses.

	Depreciation Rate				
	0.1	0.2	0.3	0.4	0.5
γ_Q	-7.002(8.789)	1.397(0.500)**	1.737(0.618)**	1.462(0.606)**	1.771(0.731)*
γ_C	-16.221(23.295)	1.412(0.465)**	1.992(0.641)**	0.503(0.486)	0.641(0.564)
	Depreciation Rate				
	0.6	0.7	0.8	0.9	1.0
γ_Q	2.021(0.858)*	2.191(0.976)*	2.269(1.076)*	2.256(1.148)*	2.181(1.888)
γ_C	0.737(0.648)	0.798(0.743)	0.805(0.849)	0.725(0.960)	0.514(1.065)

* significant at 5 % level
** significant at 1 % level

Table 10 and Table 11 show the elasticities and relative contributions for the catch-up model when the depreciation rate is 0.2. Most of the elasticities are statistically significant at 5% level; however, the elasticities of cumulative trade for Malaysia, Thailand, and Japan are significant at 11.5%, 13.4%, and 16.7% levels, respectively and the rate of technical change for Japan is significant at 12.7% level. The elasticities of cumulative trade and technical change are highest in Singapore recording -.93 followed by Malaysia with -.76. The elasticity of cumulative trade for Japan is close to zero. The estimates for the rate of technical progress range from 0.86 percent per annum in Japan to 4.03 percent in Singapore.[12] The average rate of technical change for Malaysia, Thailand, and Hong Kong is high at 3.49, 3.23, and 2.98 percent, respectively. The relative

[11] The model of depreciation rate of 0.3 gives more insignificant elasitisities than the model of depreciation rate of 0.2.

[12] The rates for Singapore, Malaysia, and Thailand are relatively high compared to previous researches; however, Iwata *et al.*(2003) also reported high rates. Their TFP growth estimates for Singapore, Malaysia, and Thailand are 3.9, 3.4, and 3.4 percent, respectively.

[Table 9] Estimated Parameters and Standard Errors of Catch-Up model for the seven East Asian Countries. The depreciation rate of the cumulative trade is 0.2.

Parameter	Estimate	Standard Error
γ_Q	1.39706	.500939
γ_C	1.41236	.465972
α_{01}^*	-.282929	.757932
α_{02}^*	2.95544	.693613
α_{03}^*	.177701	.363483
α_{04}^*	-1.25601	.694338
α_{05}^*	-1.87362	.760474
α_{06}^*	-.458728	.582623
α_{07}^*	-1.63225	.504286
α_{L1}^*	.748441	.073201
α_{L2}^*	-.102728	.037697
α_{L3}^*	.049157	.012589
α_{L4}^*	.031016	.049201
α_{L5}^*	.013774	.027822
α_{L6}^*	-.066876	.018454
α_{L7}^*	.047438	.028002
α_{Y1}^*	.595091	.260514
α_{Y2}^*	-.696055	.151791
α_{Y3}^*	.065032	.058391
α_{Y4}^*	.883935	.171922
α_{Y5}^*	.719701	.108282
α_{Y6}^*	.237001	.069486
α_{Y7}^*	.541784	.102025
α_{T1}^*	.121998	.025527
α_{T2}^*	.048660	.016202
α_{T3}^*	-.012011	.011856
α_{T4}^*	-.042336	.021564
α_{T5}^*	-.019382	.020837
α_{T6}^*	-.010392	.017138
α_{T7}^*	-.024878	.014951
α_{LL}^*	.099168	.018856
α_{YY}^*	.222061	.063354
α_{TT}^*	-.129362E-02	.798493E-03
α_{LY}^*	.841299E-02	.018920
α_{LT}^*	-.726389E-02	.118244E-02
α_{YT}^*	-.020133	.487104E-02
Equation	R2	DW
Cost	0.998	1.486
Labor Share	0.984	1.741
Revenue Share	0.945	1.706

contribution of cumulative trade is highest in Hong Kong contributing 23% of GDP growth and Singapore is the next at 17% followed by Malaysia at 11%. It is only 1% in Japan, and 4% and 5% in Korea and Taiwan, respectively. Cumulative trade is contributing more than labor or capital to GDP growth of Hong Kong. Comparing Table 11 with Table 7 we can see that the relative contributions of cumulative trade for the catch-up model and the non-catch-up model are the same in Korea, Japan, and Taiwan but much higher for the catch-up model in other countries. However, much is left for technical progress. The technical progress is an important source of economic growth for all the countries contributing more than 20% to output growth. The technical progress is the most important source of economic growth for Hong Kong and Singapore contributing 40% of output growth in Hong Kong and 32% in Singapore. In Japan, Malaysia, and Thailand technical progress is the second most important source of economic growth. Labor is the most important source of economic growth in Korea and Taiwan while capital is the most important source of economic growth in Japan. Capital is the second most important source of economic growth in Korea, Singapore, and Taiwan.[13]

[Table 10] Cost Elasticities. Annual Average of 1968-1995 for Catch-up Model with Depreciation rate of 0.2. (Figures in the parentheses are standard errors calculated at respective sample means of the inputs)

	Elasticity of			
	Output	Labor	Cumulative Trade	Technical Progress
Korea	1.120 (0.046)	0.782 (0.007)	-0.216 (0.080)	-0.0184 (0.0060)
Japan	1.107 (0.030)	0.784 (0.004)	-0.018 (0.009)	-0.0086 (0.0056)
Taiwan	1.038 (0.022)	0.792 (0.005)	-0.258 (0.009)	-0.0215 (0.0079)
Singapore	1.302 (0.030)	0.687 (0.009)	-0.926 (0.326)	-0.0403 (0.0092)
Malaysia	1.342 (0.042)	0.709 (0.012)	-0.756 (0.478)	-0.0349 (0.0154)
Thailand	1.132 (0.043)	0.648 (0.014)	-0.530 (0.331)	-0.0323 (0.0151)
Hong Kong	1.455 (0.046)	0.820 (0.007)	-0.332 (0.128)	-0.0298 (0.0108)

[13] Iwata *et al.*(2003) also reports small contribution of capital to ouput growth. They attribute 44-47% of ouputput growth to TFP growth, which is higher than our estimation of the contribution of technical progress but they do not consider cumulative trade.

[Table 11

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DATA APPENDIX

The variables of GDP by economic activity, Gross Fixed Capital Formation and its categories, and Compensation of Employees are taken largely from the Yearbook of National Account Statistics of UN (YNAS) because the YNAS carries all three variables together and provides well-organized and standardized data. Some data for recent years are obtained from the statistical yearbooks of each country and Statistical Yearbooks of Asia and Pacific. Data for Taiwan are collected from National Income in Taiwan Area, and the data for Hong Kong are collected from Estimate of GDP, Hong Kong. Data for compensation of Employees of total economy and agriculture are only partly available in some countries. Thus, they are interpolated. Lending rate is used for the interest rate in calculating the rental rate of capital. Lending rate is collected from International Financial Statistics. The prices of GDP and Gross Fixed Capital Formation are obtained by dividing current values by constant values and normalizing them with the base year 1985. Total employment, classified into status and economic activity, and average weekly hours worked in non-agricultural sectors, are taken mostly from the Yearbook of Labor Statistics. Some unavailable data for some countries are interpolated.

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