THE OUTPUT RELATIONSHIP BETWEEN TAIWAN AND THE UNITED STATES: 1961-1987*

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摘　要

本文目的在於以各種方法實證台灣與美國之間的產出關係。全文分析主要根據新近發展的多變數時間數列計量方法 ── 向量自我迴歸（VAR），希望能夠藉此方法來探討台灣與美國之間實質國民生產毛額的因果與動態關係。除 VAR 方法外，亦利用交叉光譜分析來測度台灣與美國之間產出波動的相關性，更進一步利用移轉函數模型與移轉函數干擾模型，及實質商業循環理論來檢定台灣與美國之間實質國民生產毛額的因果關係。

VAR 模型顯示美國的產出干擾與台灣的產出干擾之間有密切的相關，美國的產出干擾在台灣產出的波動中扮演重要的角色。衝擊反應分析顯示美國產出干擾對台灣的產出具有持續、正面的效果與很強的彈性乘數效果，交叉光譜分析顯示台灣與美國之間的產出波動具有顯著的一致性，這表示台灣與美國之間的產出波動存在密切的相關。

雖然由 VAR 型無法發現美國與台灣的實質產出之間存在任何的因果關係，但 ARIMA 模型顯示美國與台灣的實質產出之間存在同時性的因果關係，即美國實質國民生產毛額的變動導致台灣實質國民生產毛額立即的波動。根據實質商業循環模型，吾人無法發現台灣與美國之產出的循環成分之間有任何顯著的相關，這隱含台灣的經濟波動乃因與美國的貿易連結而非與美國受到共同的外在衝擊所致。在世界經濟緊相結合的今日，貿易連結與共同外在衝擊應同時對一國的經濟波動扮演相當的角色。因此，進一步探討對美國出口在台灣經濟波動中所扮演的角色，將有助於吾人瞭解台灣經濟波動的原因與台灣和美國之間產出變動的因果關係。

Abstract

This paper presents an empirical analysis of the output relationship between Taiwan and the U. S. The analysis is based on an econometric technique recently developed for multivariate time series: vector autoregression (VAR). The purpose of this study is to

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examine the causal and dynamic relationship of real *GNP* between Taiwan and the U. S. In addition to the VAR approach, cross-spectral analysis is also used to measure the correlation of output movements between Taiwan and the U. S. The transfer function model, the transfer function-noise model, and the real business cycle theory are used to do further causality tests of the real *GNP* relationship between Taiwan and the U. S.

The VAR model shows that innovations in the U. S. output have a close correlation with innovations in Taiwan's output and they play an important role in Taiwan's output fluctuations at all time horizons. The impulse response analysis indicates that innovations in the U. S. output have persistent positive effect on Taiwan's output, and that they have a strong elasticity multiplier effect on Taiwan's output. The cross-spectral analysis show that there are significant coherences of output movements between Taiwan and the U. S. This indicates the existence of a close correlation of output fluctuations between Taiwan and the U. S.

Although the VAR model does not find the existence of any Granger causality between the U. S. real *GNP* and Taiwan's real *GNP*, the ARIMA model shows the existence of Granger instantaneous cansality between the U. S. real GNP and Taiwan's real *GNP*. A change in the U. S. real *GNP* causes Taiwan's real *GNP* to change immediately. According to the real business cycle model, we do not find any significant correlation of the cyclical components of output between Taiwan and the U. S. This implies that Taiwan's economic fluctuations are caused by trade links with the U. S. rather than by the common outside shocks with the U. S. In a closely integrated world economy, both trade links and common outside should play a role in a country's economic fluctuations. Further investigation of the role of Taiwan's exports to the U. S. in Taiwan's economic flutuations will help us understand the reasons of Taiwan's economic fluctuations and the causal relationship between Taiwan's and the U. S. outputs.

1. Introduction

For an open economy, the existence of internationally integrated goods and capital markets implies that a country's output fluctuations will be considerably influenced by fluctuations in other countries, especially the countries having a close trade or capital transaction relationship.[1]

The close trade relationship between Taiwan and the U. S. suggests that through the trade channel, both countries output should be integrated closely. Given the existence of integrated goods market, the fluctuations of U. S. output will be expected to spill over to Taiwan's small open economy through the transactions of goods. The U. S. output should play an important role in determining Taiwan's output level. In this paper we try to find some empirical evidences to support such a theoretical stance.

The U. S. economy plays a role of a locomotive in the world economy. Many studies have found that the U. S. business cycles tend to lead other industrialized

[1] The flexible exchanger rates cannot insulate a country from the foreign economic disturbances in theory (for example Fleming [14], Mundell [37], and Dornbusch [10]) and empirical evidences (for example, Swoboda [41]).

countries' business cycles [27, 28]. The close trade relationship between Taiwan and the U. S. makes it reasonable for us to expect that change in the U. S. output will cause Taiwan's output to change. Therefore, another major purpose of this paper is to find the causality relationship between Taiwan's output and the U. S. output, and to estimate the lead time of U. S. output fluctuations over Taiwan's output fluctuations.

If the hypothesis that changes in the U. S. output cause output fluctuations in Taiwan is accepted, then Taiwan's output fluctuations would mainly result from trade variation with the U. S. rather than from the common outside shocks. This hypothesis deviates from the real business cycle theory. The test whether Taiwan's output fluctuations were caused by the common outside shocks with the U. S. will provide us with further evidence from which to infer the Granger causality test of output changes between the two countries.

2. Output Linkage between Countries

For a two-country Keynesian model, the home country's output (or income) can be expressed mathematically as

$$Y = C_0 + cY + \bar{I} + \bar{G} + X - M_0 - mY. \tag{1}$$

Correspondingly, the foreign country's output can be expressed mathematically as

$$Y = C_0^* + c^*Y^* + \bar{I}^* + \bar{G}^* + X^* - M^*_0 - m^*Y^*, \tag{2}$$

where * represents the foreign country, Y is real GNP, C_0 and M_0 are autonomous real consumption and imports, $\bar{I}$ and $\bar{G}$ are exogenous real investment and government expenditure, c and m are parameters of marginal propensity of consumption and imports, respectively.

In a two-country model, one country's exports are the other country's imports. That is

$$X = M_0^* + m^*Y^*, \tag{3}$$

$$X^* = M_0 + mY. \tag{4}$$

Taking these exports and imports relationships into account and assuming that the home country is a small economy relative to the foreign country (hence it has no repercussion effect from the home country to the foreign country; the foreign income is an exogenous variable in determining the home equilibrium income), then the home country's equilibrium output can be written as

$$\tilde{Y} = \frac{C_0 + \bar{I} + \bar{G}\ M_0^* + m^*\tilde{Y}^* - M_0}{1 - c + m}, \tag{5}$$

where $\tilde{Y}$ and $\tilde{Y}^*$ are equilibrium real output of home country and foreign country respectively.

Equation (5) shows that the home equilibrium income depends in part on the foreign equilibrium income and its autonomous imports. The higher the foreign equilibrium income, the higher the home equilibrium income.

Assume C_0, $\bar{I}$, $\bar{G}$, M_0^*, and M_0 are constants, the dynamic income relationship between the home country and the foreign country is

$$\Delta Y = \alpha \Delta Y^*, \tag{6}$$

where Δ is first difference operator, $\alpha = \frac{m^*}{1-c+m} = \frac{m^*}{s+m}$, where s is a *parameter of the marginal propensity of savings,* α is the foreign income multiplier, which may be greater or less than one depending on the magnitude of m^*, s, and m. $\alpha = 1$, if $m^* = s + m$; $\alpha > 1$, if $m^* > s + m$; $\alpha < 1$, if $m^* < s + m$.

Equations (5) and (6) are the theoretical background for us to test the static and dynamic output relationships between Taiwan and the U. S.

3. Analytical Methodology

The main analytical methodology employed in this paper is a multivariate time series approach: vector autoregression (VAR). This approach has been popularized by Sims [40]. The analysis of the relationship between interdependent variables is traditionally done by the simultaneous structural equation models (or Cowles Foundation approach). In recent years, this approach is criticized on the following grounds:

(1) A priori restrictions. These involve arbitrary selection of which variables are to be included, which variables are to be treated as exogenous, and which functional form are to be used.

(2) Incredible identification. Possible exclusion of variables and misspecification of equations are always a problem. These problems become worse if the model includes variables of rational expectations [33, 40].

(3) Poor forecasting performance. Because of poor forecasting performance of the structural macroeconomic model, some economists, Litterman [31], for example, propose the use of alternative models for forecasting purposes.

(4) Unsuitable for policy analysis. One of the main purpose of the structural equation models is to evaluate the effect of changes in the exogenous (or policy) variables on the endogenous variables. But, as Lucas points out [36], if economic agents' expectations are rational, then the parameters of the structural macromodel will change as the economic policy changes. Hence, parameter estimates derived under old policies are inappropriate in simulating new policies.[2]

The VAR models are an alternative approach to circumvent these problems. It focuses on the reduced form of the particular system which is derived from what is essentially an unknown structural equation model.[3] In essence, this new approach seeks to reveal the qualitative, causal character of the underlying structural model (but it doesn't try to estimate structure), and to test whether the theories are supported by the data.

The general VAR model takes the following form

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\begin{aligned}
Y_t &= A(L)Y_{t-1}+U_t, \\
A(L) &= A_0 + A_1L + A_2L^2 + \ldots, \\
E(U_t) &= 0, \\
E(U_tU_t') &= \Sigma, \\
E(U_tU_s') &= 0,\ t \neq s, \\
E(Y_tU_s') &= 0,\ t < s,
\end{aligned} \tag{7}
$$

[2] The Lucas criticism is that the models estimated are not structural. A change in the policy variable chagnes the coefficients but would not change a true structural model. In principle a structural model might allow for the change of parameters as the economic policy change. Therefore, a true structural model would be used for policy analysis.

[3] The reduced form model can be thought of as a rational for a particular kind of data summary. See Sims [39], p. 3.

where Y_t is a $n \times 1$ vector of variables, $A(L)$ is a $n \times n$ matrix of coefficients polynomial in the lag operator L, the roots of $A(L)$ are assumed to lie outside the unit circle. Σ is the $n \times n$ variance-covariance matrix for U_t, U_t is a $n \times 1$ vector of white noise, " ′ " denotes transpose, and E is the expectation operator.

The Wold decomposition theorem states that any stationary stochastic process may be written as a stochastic vector moving average (VMA) process, possibly of infinite order. The VAR model exists only if the corresponding VMA process is invertible. The VMA for Y_t in equation (7) has the form

$$\begin{aligned} Y_t &= B(L)U_t, \\ B(L) &= I - B_1L - B_2L^2 - \ldots, \\ E(U_t) &= 0, \\ E(U_tU_t') &= \Sigma, \\ E(U_tU_s') &= 0, \ t \neq s, \end{aligned} \tag{8}$$

where $B(L)$ is a $n \times n$ matrix of coefficients, I is a $n \times n$ identity matrix.

If the roots of the characteristic equation, $|B(L)| = 0$, lie outside the unit circle, Y_t is invertible and it may be written as a pure VAR model of the form

$$A^*(L)Y_t = U_t, \tag{9}$$

where $A^*(L) = B(L)^{-1}$, $A^*(L) = I - A_1L - A_2L^2 - \ldots.$

Equation (9) can be rewritten as equation (7), $Y_t = A(L)Y_{t-1} + U_t$. We just decide a prior which variables are to be included and do not need to impose any of prior restrictions for identifying the VAR model. The variables included in Y_t are decided by the specific economic theory.[4] All the variables in the VAR model are treated as endogenous, no variables are presumed to be exogenous. In the model, each of the variables is a function of the past lags of themselves and the past lags of all the remaining variables. Therefore, the system is an unrestricted reduced form of some unknown structural equation model. The number of lags in the system can be determined by the modified likelihood ratio test,[5] or by the Akaike information criterion.

Once the lag length is chosen, the VAR models is estimated by ordinary least

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[4] Cooley and LeRoy [6] criticize that VAR modeling is atheoretical, this critique may be unfair. Sims [39] rebuts this critique impressively.

[5] See Sims [40], pp. 17-18.

squares. Because in every quation the right-hand-side variables are lags of left-hand-side variables, estimating each equation separately by using ordinary least square (and these are maximum likelihood estimates) should produce consistent, asymptotically efficient estimates, and the residual will be a white noise.

Due to the possible existence of multicollinearity among the variables, the individual regression coefficients in the model do not mean much, and hence the hypothesis tests of coefficients are not based on the t-statistic of individual coefficients. *F* tests or modified likelihood ratio tests are used to test the joint statistical significance of the coefficients on a particular variable in the right-hand-side.

The estimation of the model will produce the matrix of contemporaneous correlation of innovations and the matrix of contemporaneous covariances of innovations. From the correlation matrix, we can find the degree of correlation and sign of change between innovations in the varibles. The covariance (or standard deviation) matrix enables us to conduct an innovation accounting analysis known as a dynamic analysis of the VAR model. This analysis is essentially a simulation of the accounting of the response of a particular variable to a contemporaneously uncorrelated innovation, or the responses of all the variables in system to a common set of innovations.

The innovation accounting is based on the equivalent moving average representation of a VAR model, which can be divided into the analysis of impulse response and decomposition of forecasting error variance. The dynamic economic implications can be derived from both analyses.

4. Testing of Output Relationship

4.1 Specification of VAR model

A quarterly time series data is used in our analysis. They are expressed in terms of logarithm and are seasonally adjusted.[6] Our VAR model used to test the output relationship between Taiwan and the U. S. is

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[6] The U.S. data are from Citibase which had been seasonally adjusted at annual rates. Taiwan's data are from *Quarterly National Income Statistics in Taiwan Area, the Republic of China (1961-1984)* (Taipei: DGBAS, June 1986), and *Quarterly National Economic Trend Taiwan Area, the Republic of China: Quarterly National Income Estimates* (Taipei: DGBAS, February 1988) respectively. Taiwan's data are seasonally adjusted with *TSP* package by the moving average method. We put emphasis on realizing the fluctuations of Taiwan's output, hence both Taiwan's real *GNP* and real industrial production are tested.

$$\begin{bmatrix} Y_t^* \\ Y_t \end{bmatrix} = \begin{bmatrix} A_{11}(L) & A_{12}(L) \\ A_{21}(L) & A_{22}(L) \end{bmatrix} \begin{bmatrix} Y_{t-1}^* \\ Y_{t-1} \end{bmatrix} + \begin{bmatrix} e_t^* \\ e_t \end{bmatrix},$$

where Y_t^* and Y_t stand for the U. S. and Taiwan's real *GNP* respectively, $A_{ij} = A_{ij0} + A_{ij1}L + A_{ij2}L^2 + \ldots + A_{ijp}L^p$ is the autoregressive coefficients, Y_{t-1}^* *and* Y_{t-1} stand for lag one of U. S. and Taiwan's real *GNP*, e_t^* *and* e_t are serially uncorrelated innovations of Y_t^* and Y_t respectively.

Taiwan is a small economy relative to the U. S. Between 1980 and 1987, the proportion of Taiwan's *GNP* to U. S. *GNP* on average was 1.65%, while the proportion of Taiwan's exports to the U. S. to the U. S. total imports on average was 4.02%.[7] It is appropriate to assume Taiwan is a small economy with respect to the U. S. Hence, in our VAR model the ordering is the U. S. real *GNP*-Taiwan's real *GNP*.

There are many different criteria used to determine an appropriate lag length for a VAR model. Among them the modified likelihood ratio statistic and the Akaike Information Criterion are two popular ones. For the modified likelihood statistic, the lag lengths were determined by testing successive set of restrictions. The shorter lag lengths was tested as restriction of the longer lag lengths, then the modified likelihood ratio statistics are used to determine the appropriate lag length.[8]

Our bivariate VAR model was initially estimated with lag lengths of six and eight, and the former specification was tested as restriction of the latter. The test statistic of modified likelihood ratio statistic is x^2 (8) = 16.99, the corresponding significance level is .03, the null hypothesis (no difference between six lag lengths and eight lag lengths) is rejected, the longer lag length therefore is used.

In order to test whether the eight lag lengths is appropriate or not, the model is further estimated with lag lengths of eight and ten. The test statistic of modified likelihood ratio statistic is $x^2(8)$ = 10.35, the corresponding significance level is .24, the null hypothesis is accepted and the shorter lag length is used. Therefore, the

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7 The proportions are calculated based on the data of *Quarterly National Economic Trends Taiwan Area, the Republic of China* (Taipei: DBGAS, August 1988).

8 By the Akaike Information Criterion to determine the lag length in the VAR model, see Hsiao [22] and Choudhri [5].

eight lag length is appropriate to this model.[9]

We focus on the specification with eight lags of the right-hand-variables and with equations containing constant and linear time trend terms.[10] We included a linear time trend in each VAR equation instead of using first difference to detrend the data. This can avoid the problem caused by the co-integration of variables in the VAR model. (By including a linear time trend instead of using the difference to detrend the data implies that we assume that the evolutions of variables in the VAR model follow a deterministic trend process. If the assumption is not true, it cannot avoid anything.)[11] Our model is an unrestricted VAR model and it is estimated by using version 3.01 of the Regression Analysis of Time Series (RATS) package.[12]

4.2 Hypothesis Test

The small economy assumption implies that the large country's (the U. S.) output can affect the small country's (Taiwan) output, not vice versa. In econometric sense, this means that the large country's output is exogenous to the small country's output, or the large country's output Granger-causes the small country's output. This hypothesis can be tested by *F*-tests of block of coefficients in the VAR equations.

Table 1 contains the *F*-statistics for the tests of the bivariate relationships. The *F*-statistics indicate that at the 20% significance level, the U. S. real *GNP* is strictly exogenous to Taiwan's real *GNP*, and Taiwan's real *GNP* is strictly exogenous to the U. S. real *GNP* too.[13] This means that output in Taiwan (the U. S.) is uncorrelated with the past output of U. S. (Taiwan). Hence, no evidence is found to support the

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[9] VAR model is a special case of vector autoregressive moving average (VARMA) model (see Tiao and Box [42]). The identification and estimation of VARMA model is much more difficult than VAR model. But, as the univariate model, the VARMA model and VAR model are convertible each other. A sufficient lag length VAR model is a good approximation of VARMA model.

[10] After allowing for the lags, the estimated period is from 1963:2 to 1987:4.

[11] If variable in the VAR model are co-integrated, then the system will have an unit root and standard statistical analysis does not apply. Engle and Yoo [11] claim that when a set of variables exhibits co-integration, it is inappropriate for a forecasting VAR model including the variables in differences. Fuller [15] shows that differencing produces no gain in asymptotic efficiency in an autoregression, even if it is appropriate. Doan [9] says that in a VAR model, differencing throws information away while it produces almost no gain. In practice, there are different methods used to filter the data in the empirical VAR models.

[12] Contrast to unrestricted VAR model is restricted or Bayesian VAR model, which is developed by Litterman [31].

[13] In the VAR model, the definition of exogeneity is different from traditional simultaneous equations.

hypothesis that the U. S. real *GNP* Granger-causes Taiwan's real *GNP*.[14]

Although we cannot find the Granger causality relationship between Taiwan's real *GNP* and the U. S. real *GNP*, the innovations in both country's output variables do have a significant positive correlation. The correlation coefficient of innovations in real *GNP* of Taiwan and the U. S. is .31, which is significant at the .05% level.[15] This proves the existence of a close positive relationship between the output of Taiwan and the U. S.

Table 1: F-Tests of Block of Coefficients

Equation	Block of Coefficients	*F*-statistic	Significance Level
The U.S. Real *GNP*	The U.S. Real *GNP*	48.47	.00
	Taiwan's Real *GNP*	1.26	.28
Taiwan's Real *GNP*	The U.S. Real *GNP*	1.10	.37
	Taiwan's Real *GNP*	32.62	.00

Note: A low significance level means that the block of coefficients is significantly different from zero.

4.3 Dynamic Output Relationship

In the VAR model, the dynamic analysis is represented by the innovation

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[14] The decomposition of variance (Table 6) also cannot provide us a strong enough of evidence to suport the hypothesis that the U. S. real *GNP* Granger-causes Taiwan's real *GNP*. Litterman and Weiss [32] point out the problem of using the VAR model to test the causality between the variables. They say

> Interpretation of causal orderings as indicative of behavioral or structural relationships is a complicated and subtle issue. In general, when there are as many independent shocks to the system as there are variables, we would expect that each variable would have some incremental predictive power for each other variable, and thus no causal ordering would arise. Thus, failure to find a causal ordering would be compatible with many competing hypotheses, and as a result, we could not distinguish among the hypotheses.

[15] The test statistic for determining the existence of correlation is given by

$$t_{n-2} = \frac{r}{\sqrt{\frac{1-r^2}{n-2}}},$$

where t is t-statistic, n is sample size, r is the sample correlation coefficient.

accounting which is sensitive to the order of the variables in the VAR model (especially when the correlations of innovations between variables are high). In our model, the ordering of variables is: the U. S. real *GNP*-Taiwan's real *GNP*. This ordering embodies the small country assumption that innovations in the U. S. real *GNP* have immediate effects on Taiwan's real *GNP*. The following innovation accounting analysis is based on the standard deviations of innovations produced by estimation of the model (see Table 2).

Table 2: Standard Deviation of Innovations

Variable	The U. S. Real *GNP*	Taiwan's Real *GNP*
	.008426	.018974

The impulse response analysis is a simulated response of the moving average form of the VAR model to an orthogonalized, positive, one standard deviation shock in the model. The impulse responses of U. S. and Taiwan's real *GNP* to a positive, orthogonalized one-standard deviation shock in the U. S. real *GNP* and the impulse responses of U. S. and Taiwan's real *GNP* to a positive, orthogonalized one-standard deviation shock in Taiwan's real *GNP* are reported in Table 3 and depicted in Figure 1 to 4. The accumulated responses are reported in Table 4.

According to Table 3, 4, and Figure 1 to 4, we have the following findings:

(1) Innovations in the U. S. real *GNP* have more persistent effect on Taiwan's real *GNP* than on the U. S. real *GNP* itself. They generate the peak response on the U. S. real *GNP* (in the third period) more quickly than on Taiwan's real *GNP* (in the fifth period). But, the peak response of the latter (.01085) is larger than the former (.00999).

(2) All impulse responses of Taiwan's real *GNP* to a positive innovation in the U. S. real *GNP* are positive. This is consistent with the Keynesian theoretical hypothesis of output transmission between two countries. The responses of Taiwan's real *GNP* to a positive innovation in the U. S. real *GNP* are jagged. This implies that innovations in the U. S. output will cause Taiwan's output to fluctuate.

(3) Innovations in the U. S. real *GNP* cause larger responses on Taiwan's real *GNP* than on the U. S. real *GNP* itself. The maximum accumulated response of Taiwan's real *GNP* (.12313) is about 1.55 times the maximum accumulated response of U. S. real *GNP* (.07969) to a positive innovation in the U. S. real *GNP*. This is an impressive evidence to show the sensitivity of Taiwan's real *GNP* to innovations in the U. S. real *GNP*.

Table 3: Responses to One-Standard Deviation Shock in the U. S. and Taiwan's Real GNP

quarter	The U. S. *GNP* to Shock in the U. S. *GNP*	Taiwan's *GNP* to Shock in the U. S. *GNP*	The U. S. *GNP* to Shock in Taiwan's *GNP*	Taiwan's *GNP* to Shock in Taiwan's *GNP*
1	.00841	.00588	.00000	.01809
2	.00915	.00877	.00234	.01257
3	.00999*	.00756	.00288	.00928
4	.00900	.00712	.00373	.00995
5	.00854	.01085*	.00450*	.01890*
6	.00691	.01016	.00433	.01212
7	.00637	.00432	.00351	.00767
8	.00542	.00251	.00321	.00453
9	.00455	.00546	.00199	.01148
10	.00335	.00536	.00097	.00598
11	.00230	.00191	−.00005	.00173
12	.00145	.00171	−.00066	.00017
13	.00091	.00498	−.00140	.00717
14	.00050	.00578	−.00172	.00360
15	.00037	.00336	−.00205	.00115
16	.00040	.00326	−.00185	.00050
17	.00045	.00599	−.00183	.00669
18	.00042	.00649	−.00162	.00409
19	.00040	.00401	−.00151	.00183
20	.00038	.00333	−.00115	.00083
21	.00030	.00504	−.00109	.00563
22	.00013	.00501	−.00098	.00311
23	−.00007	.00258	−.00104	.00075
24	−.00024	.00171	−.00093	−.00045

*: The peak response to a positive innovation in the U. S. and Taiwan's real *GNP*.

(4) Innovations in Taiwan's real *GNP* have persistent effects on both of U. S. and Taiwan's real *GNP*. Its effect on the U. S. real *GNP* becomes negative from the eleventh period, but the accumulated responses of U. S. real *GNP* is still positive. Both the peak responses of U. S. and Taiwan's real *GNP* are in the fifth period, but Taiwan's peak response (.0189) is much larger than the U. S. peak response (.0045).

(5) Innovations in Taiwan's real *GNP* cause much larger responses on Taiwan's real *GNP* than on the U. S. real *GNP*. The maximum accumulated response of Taiwan's real *GNP* (.14782) is 5.39 times the maximum accumulated response of U. S. real *GNP* (.02745), and the accumulated response of U. S. real *GNP* in the twenty fourth period (.00956) is much smaller than Taiwan's accumulated responses. This is consistent with the hypothesis of the small country, that is small country's (Taiwan) output innovations cannot have or only have negligible effect on large country's (the U. S.) output.

A general way to measure the impact of innovations in the U. S. output on

Table 4: Accumulated Responses to One-Standard Deviation Shock in the U. S. and Taiwan's Real GNP

Quarter	The U.S. *GNP* to Shock in the U. S. *GNP*	Taiwan's *GNP* to Shock in the U. S. *GNP*	The U. S. *GNP* to Shock in Taiwan's *GNP*	Taiwan's *GNP* to Shock in Taian's *GNP*
1	.00841	.00588	.00000	.01809
2	.01756	.01465	.00234	.03066
3	.02755	.02220	.00522	.03994
4	.03655	.02932	.00895	.04988
5	.04509	.04017	.01345	.06879
6	.05200	.05032	.01778	.08091
7	.05837	.05464	.02129	.08858
8	.06379	.05715	.02450	.09311
9	.06833	.06261	.02648	.10460
10	.07168	.06797	.02745*	.11058
11	.07398	.06988	.02740	.11230
12	.07543	.07159	.02674	.11247
13	.07635	.07657	.02534	.11964
14	.07685	.08235	.02362	.12324
15	.07721	.08571	.02156	.12439
16	.07761	.08897	.01971	.12490
17	.07806	.09496	.01788	.13159
18	.07848	.10146	.01626	.13568
19	.07888	.10547	.01475	.13751
20	.07926	.10880	.01360	.13834
21	.07957	.11383	.01251	.14397
22	.07969*	.11884	.01152	.14708
23	.07962	.12142	.01048	.14782*
24	.07938	.12313*	.00956	.14737

*: The maximum accumulated response to a positive innovation in the U. S. and Taiwan's real *GNP*.

Taiwan's output is foreign income multiplier. In a small country model, the foreign income multiplier is determined by domestic marginal propensity of saving and imports, and foreign marginal propensity of imports (see equation (6)). Because different countries' income (or output) is measured by different monetary units, the "elasticity multiplier" rather than conventional multiplier is a more appropriate way to measure cross-country multiplier.

Deardorff and Stern [7] define elasticity multiplier as the percentage change in a country's *GNP* resulting from a spending shock equal to 1 percent of *GNP* in the initiating country. The impulse responses of Taiwan's real *GNP* to a positive innovation in the U. S. real *GNP* can be transformed into a measure of elasticity

Figure 1: Impulse Responses of the U. S. Real GNP to a Positive Shock in the U. S. Real GNP

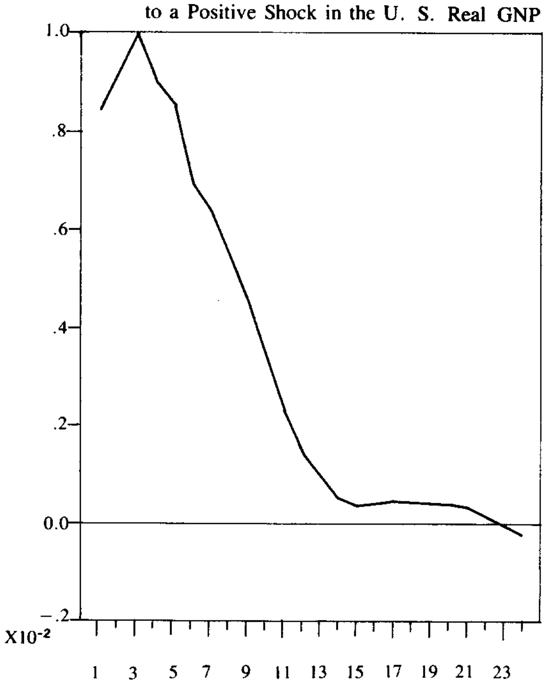


Figure 2: Impulse Response of Taiwan's Real GNP to a Positive Shock in the U. S. Real GNP

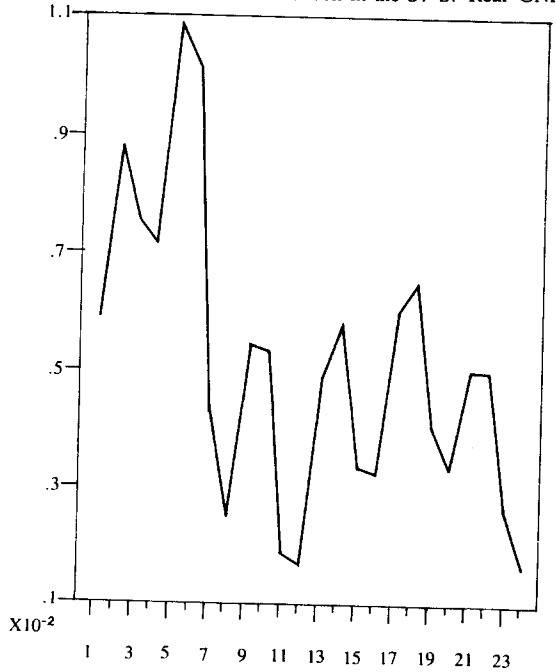


Figure 3: Impulse Response of the U. S. Real GNP to a Positive Shock in Taiwan's Real GNP

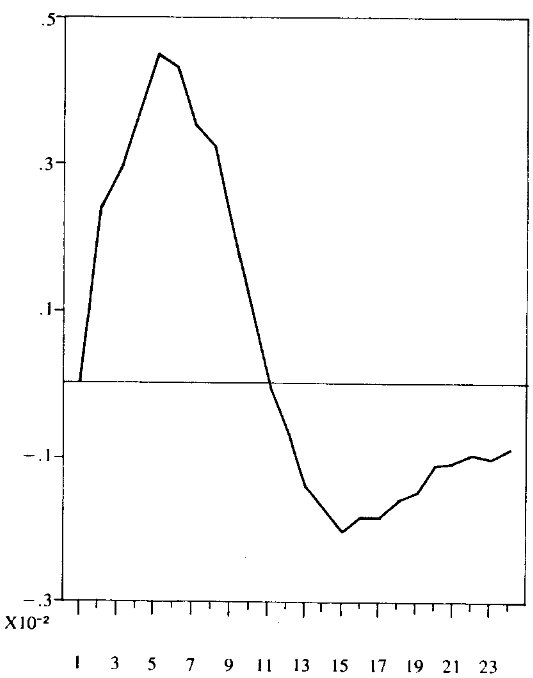
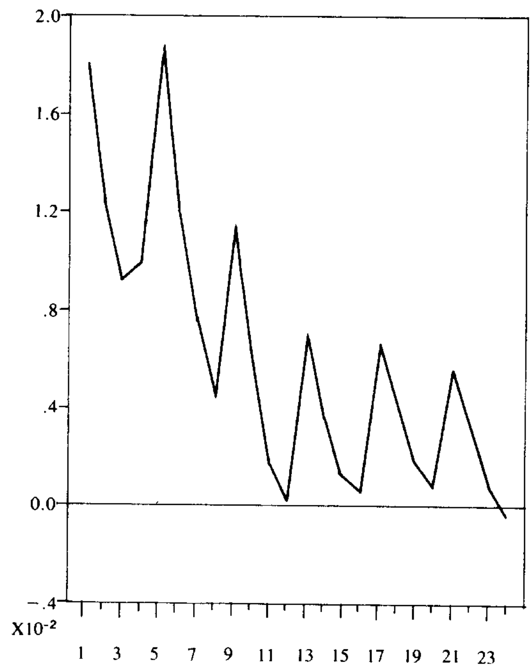


Figure 4: Impulse Responses of Taiwan's Real GNP to a Positive Shock in Taiwan's Real GNP



multiplier, it will give us a more concrete impression on the impact of innovations in the U. S. real *GNP* on Taiwan's real *GNP*.

The elasticity multiplier, denoted by η, is calculated by the impulse responses of Taiwan's real *GNP* to a positive innovation in the U. S. real *GNP* and is expressed mathematically as

$$\eta = \frac{\frac{D_1}{\sigma_1}}{\frac{D_2}{\sigma_2}},$$

where D_i are log deviations from trend, σ_i are standard deviations, 1 and 2 stand for Taiwan and the U. S. respectively. $\frac{D_i}{\sigma_i}$ are standard normal deviations. In this way we can solve the problems of positive relationship between the impulse response and the standard deviations of variables, and the variables measured in different units.

With this formula, we calculated that the elasticity multiplier produced by a positive innovation in the U. S. real *GNP* on Taiwan's real *GNP* is .82 (calculated by the peak response) or .66 (calculated by the average accumulated response from period one to twenty two).[16] The elasticity multipliers calculated by our approach are a total (or aggregate) multiplier effect of U. S. income on Taiwan's income in essence. In order to test the reasonability of our estimated elasticity multipliers, we compare our estimates with the elasticity multipliers estimated by different linkage models for income shock in the U. S. impacts on income in Japan, Germany, France, U. K., Italy, and Canada with two or three years of simulation (see Table 5). The linkage models reported by Helliwell and Padmore [20] are as follows: for LINK (a), Hickman [21]; for LINK (b), Filatov, Hickman and Klein [13]; for INTERLINK, OECD [38]; for EPA, Amano, et al. [1]; for METEOR and Naive, Deardorff and Stern [7]; for RDX2-MPS, Helliwell [19]; for MCM, Helliwell and Padmore [20]; for Fair, Fair [12]. Simulation period for LINK (a) was 1973-75; for LINK (b), 1979-82; for INTERLINK, 1978-80; for EPA, 1974-77; for RDX2-MPS, 1963-70; for MCM, 1975-78; for Fair, 1976I-77IV. It can be found that our estimates are compatible with the estimates of these models (especially with the estimate of Canada).

Another dynamic analysis is the decomposition of forecasting error variance, which is to calculate the percentage of the square of expected k-step-ahead forecasting

[16] The responses of U. S. real *GNP* become negative from the twenty third period, hence the accumulated response is from period one to twenty two.

Table 5: Elasticity Multipliers to Income Shock in the U. S. Estimated by the Different Linkage Models

Model	*Year**	U.S.	Japan	Germany	France	U. K.	Italy	Canada
LINK(a)	1	1.18	.13	.04	.02	.08	.08	.31
LINK(a)	2	1.87	.27	.08	.04	.21	.17	.56
LINK(a)	3	2.58	.40	.14	.06	.35	.31	.86
LINK(b)	1	1.60	.13	.13	.05	.08	.14	.53
LINK(b)	2	2.39	.20	.21	.06	.12	.21	.63
LINK(b)	3	2.73	1.22	.33	.07	.13	.26	.63
INTERLINK	2	1.52	.18	.20	.16	.21	.19	.59
INTERLINK	3	2.06	.34	.43	.34	.39	.39	.93
EPA	1	1.59	.11	.09	.07	.22	.06	.46
EPA	2	2.60	.33	.25	.27	.56	.20	.83
EPA	3	3.29	.53	.37	.44	.70	.34	1.41
METEOR	1	2.46	.22	.19	.12	.19	.15	.65
METEOR	2	2.86	.45	.43	.30	.45	.34	1.29
RDX2-MPS	2	2.03						−.15
RDX2-MPS	4	0.93						.28
Naive	Any	2.24	1.12	.07	.03	.10	.07	.65
MCM	1	1.98	.14	.16		.10		.34
MCM	2	1.90	.21	.32		.16		.54
MCM	3	1.43	.20	.38		.08		.61
Fair	1	1.43	.06	.05	.03	.07	.04	.18
Fair	2	1.39	.18	.19	.01	.21	.19	.55

Note: This table cites fro Helliwell and Padmore [20], p. 1117, Table 3.1. For the U. S., the elasticity multiplier is the conventional income multiplier. For the other countries, the elasticity multipliers are calculated as percentage change in income for a shock of 1 percent of income in the U. S. The abbreviations are U. S. = the United States, U. K. = the United Kingdom.

*: Simulation year.

error of a variable produced by a normalized, one standard deviation innovation in a certain variable.

Table 6 contains the decomposition of forecast error variance for the estimated VAR model. From this table we find that:

Table 6: Decomposition of Variances in the U. S. and Taiwan's Real GNP

(Unit: %)

Quarter	Standard Deviation (A), (ln)	The U. S. *GNP* (1)	The U. S. *GNP* (2)	Standard Deviation (B), (ln)	Taiwan's *GNP* (3)	Taiwan's *GNP* (4)
1	.008	100.00	.00	.019	9.54	90.46
2	.013	96.58	3.42	.024	18.68	81.32
3	.016	94.86	5.14	.027	22.78	77.22
4	.019	92.37	7.63	.030	24.65	75.35
5	.021	89.48	10.52	.037	24.69	75.31
6	.023	87.24	12.76	.040	27.25	72.75
7	.024	86.27	13.73	.041	27.11	72.89
8	.025	85.49	14.51	.041	27.05	72.95
9	.026	85.43	14.57	.043	26.31	73.69
10	.026	85.56	14.44	.044	26.91	73.09
11	.026	85.67	14.33	.044	27.01	72.99
12	.026	85.66	14.34	.044	27.12	72.88
13	.026	85.43	14.57	.045	27.32	72.68
14	.026	85.05	14.95	.046	28.32	71.68
15	.026	84.52	15.48	.046	28.69	71.31
16	.026	84.09	15.91	.046	29.05	70.95
17	.026	83.68	16.32	.047	29.62	70.38
18	.026	83.36	16.64	.047	30.72	69.28
19	.026	83.09	16.91	.048	31.17	68.83
20	.026	82.93	17.07	.048	31.50	68.50
21	.026	82.79	17.21	.048	31.81	68.19
22	.026	82.67	17.33	.049	32.41	67.59
23	.026	82.54	17.46	.049	32.59	67.41
24	.026	82.44	17.56	.049	32.67	67.33

Note (a): Standard Deviation (A) is the standard deviation of forecasting error of U. S. *GNP*, Standard Deviation (B) is the standard deviation of forecasting error of Taiwan's *GNP*.

Note (b): (1) and (2) are the percentage of forecast error variance t quarters ahead of U. S. *GNP* produced by a positive innovation of U. S. and Taiwan's *GNP* respectively; (3) and (4) are the percentage of forecast error variance t quarters ahead of Taiwan's *GNP* produced by a positive innovation of U. S. and Taiwan's *GNP* respectively.

(1) The variance in the U. S. real *GNP* mainly depends on own-innovations at all time horizons shown.

(2) The proportion of variance in Taiwan's real *GNP* accounted for by innovations in the U. S. real *GNP* is almost double of the proprotion of variance in the U. S. real *GNP* accounted for by innovations in Taiwan's real *GNP*.[17]
(3) Innovations in the U. S. real *GNP* immediately (from the third period) have a larger effect (more than 20%) on the fluctuations of Taiwan's real *GNP* and they account for the variance in Taiwan's real *GNP* reaches 32.67% in the twenty fourth period. This indicates that innovations in the U. S. real *GNP* play an important role in the fluctuations of Taiwan's real *GNP* at all time horizons shown.[18]

5. Cross-spectral Analysis

In this section we estimate cross-spectral densities in order to shed some light on the correlation of output movements between Taiwan and the U. S.

The cross-spectral analysis is used to measure the relationship between two stationary series to know the extent to which the variance in one series at frequency ω is correlated to the variance in the other series at frequency ω. Consequently, the cross-spectral analysis is particularly suited to the study of fluctuations of economic series since it determines how the variation of one economic series is affected by the fluctuations of the other economic series and what the frequency (period) of the cycle is.

In this study, we are not interested in the cross-spectral density itself (which is complex-valued) but the statistic derived from it: coherence. The coherence is analogous to the square of the correlation coefficient between two series (i.e., R^2 statistic) and is interpreted in a similar way. That is, the coherence indicates the proportion of the variance in one economic series that is accounted for by variation in the other series at some frequency (period). The larger coherence the more closely related are the two economic series.

The spectrum analysis needs the series to be stationary, and we know that most original economic series are not stationary, how to detrend the time series data is important to the spectrum analysis. The inappropriate detrending of the macroeconomic

[17] Of course, this has relations with the ordering of variables in the VAR model. We assume that our ordering is reasonable.

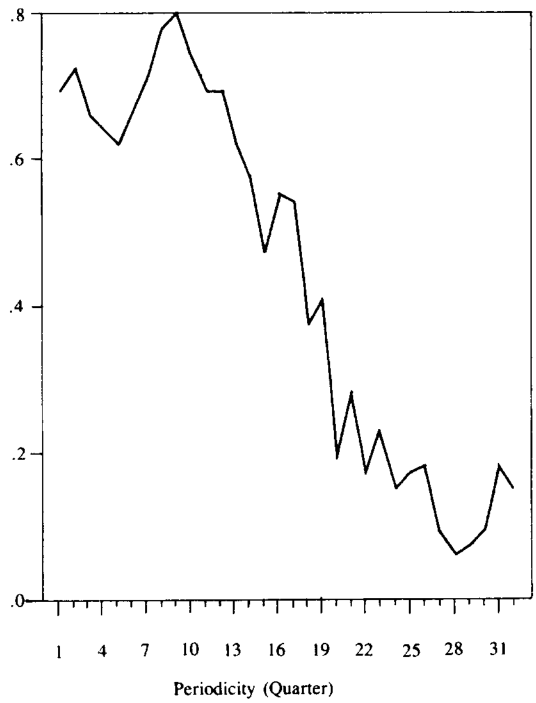
[18] In a real investment-real *GNP* two-variable VAR model, innovations in Taiwan's real investment at most account for 15.02% of variance in Taiwan's real *GNP* (see Hwang [23]). This highlights the importance of innovations in the U. S. real *GNP* in the fluctuations of Taiwan's real *GNP*.

time series will induce bias in the results. We ever tested and accepted the hypothesis that the evolutions of Taiwan and the U.S. log real *GNP* follow a stochastic trend process (see Hwang [24]). Therefore, it is appropriate to render both series stationary by differencing. The estimated coherences of first-difference log real *GNP* of Taiwan and the U. S. are tabulated in Table 7 and plotted in Figure 5.[19] The frequency band reported is from 1 to 32 quarters (periods), we think it is long enough to cover any duration of business cycles in the period from 1961 to 1987.[20]

We can test the hypothesis that coherence is zero by the statistic[21]

$$F_{2,4d} = \frac{4dK^2}{2(1-K^2)}, \tag{10}$$

Figure 5: Coherence of Real GNP between Taiwan and the U. S.



[19] Our estimate is computed on 107 observation (1961:2 to 1987:4), the cross-spectra are smoothed using a window width 11. This window takes a weighted moving average of the neighboring periodgram ordinates with weights summing to unity. We find that the choice of window type by a flat weighted average makes little difference with by a tent weight average.

[20] NBER minor cycles are about two to four years, major cycles are about eight years. Therefore, our reported periodicity is long enough to cover both NBER minor and major cycles.

[21] See Fuller [15], p. 315.

where K is the coherence, $d = (w-1)/2$ and w is the width of the spectral window. K is appropriately distributed as F-statistic with 2 and $4d$ $(d>0)$ degrees of freedom under the null hypothesis.

Solving for K in equation (10), the critical value for the coherence is .5086 (at the 5% significance level) or .6075 (at the 1% significance level). Table 7 shows that the coherences are significant in the frequency band corresponding to periodicities of 1 to 13 quarters (at the 1% significance level) or 1 to 17 quarters (at the 5% significance level). Figure 5 shows that the frequency band of output fluctuations centered around periodicities 7 to 12 quarters. These results suggest that output fluctuations in Taiwan and the U. S. are correlated closely in the business cycle frequency band. This is a significant piece of evidence to show the close output fluctuations (or growth cycle) relationship between Taiwan and the U. S.

There are two possible reasons to interpret the high coherence of output fluctuations (or growth cycle) between Taiwan and the U. S. One is the common response of Taiwan and the U. S. to the occurrence of common external shocks in both countries. Another possible reason is that the increase in trade flows between Taiwan and the U. S. have made Taiwan economy more integrated with the U. S. economy, Taiwan's output is hence more susceptible to the shocks in the U. S. output.

Table 7: Coherences of Real *GNP* between Taiwan and the U. S.

Periodicity 1-8 Quarters	.69	.72	.66	.64	.62	.67	.71	.78
Periodicity 9-16 Quarters	.80	.74	.69	.69	.62	.57	.47	.55
Periodicity 17-24 Quarters	.54	.37	.41	.19	.28	.17	.23	.15
Periodicity 25-32 Quarters	.17	.18	.09	.06	.07	.09	.18	.15

6. Test of Causality of Output Changes

In 4.2, the F-statistics of block of coefficients in the VAR model cannot give us evidence to support the hypothesis that the U. S. output is Granger-cause with respect to Taiwan's output. In this section, we use ARIMA model to do this test again.

Granger [16] defines the causality based entirely on the predictability of the variable: a variable x caused a variable y if the current y, y_t, can be better predicted by using all available information including past values of x than if the information excluding x had been used. That is, if

$$\sigma^2 \ (y_t \mid y_{t-i}, \ x_{t-i}) \ < \sigma^2 \ (y_t \mid y_{t-i}), \tag{11}$$

where y_{t-i} and x_{t-i}, $i \geq 1$, are past values of y and x respectively, and σ^2 is the variance of prediction error of y_t.

In the bivariate system, if series x contains information in past terms that help in the prediction of y_t, then x is said to cause y. If the current value of x, x_t, is included in the bivariate model that has better prediction of y_t than if it is not, then there is no time lag between x and y. We say that instantaneous causality of x to y occurs. Hence, the first step to test the causality in the bivariate system is to specify and estimate the univariate model of series y which contains only its own past information, then the bivariate model including the (current and) past information of y and x is specified and estimated. By comparing the accuracy of forecasting, if the bivariate model is better than the univariate model, x (instantaneously) Granger-causes y.

Box and Jenkins [3] suggest that the appropriate bivariate model (or transfer function-noise model) can be constructed by the following steps:

1. Prewhiten the input series, x, and specify an appropriate ARMA model

$$\phi_x(B)x_t = \ \theta_x(B)u_{xt}, \tag{12}$$

where u_x is normally distributed independent white noise term with zero mean and variance σ^2_{ux}, B is backward-shift operator, $\phi(B)$ and $\theta(B)$ are polynomials in B that satisfy the conditions for stationarity and invertibility.

2. Prewhiten the output series, y, and specify an appropriate ARMA model

$$\phi_y(B)y_t \ = \ \theta_y(B)u_{yt}, \tag{13}$$

where u_y is normally distributed and independent white noise term with zero mean and variance σ^2_{uy}.

3. Calculate the sample cross-correlations of the estimated residuals of $\hat{u}_x$ and $\hat{u}_y$.

4. Specify the bivariate (or transfer function) model based on the cross-correlations mentioned in 3

$$y_t = \frac{\omega(B)}{\delta(B)} x_t. \quad (14)$$

In practice, the output y might not follow the pattern of transfer function model exactly, even if the model was well specified. The presence of noises may corrupt the true relationship between output y and input x. Therefore, a model including noise which is independent of input x and which is additive to the effect of x may be more appropriate to represent the generating process of output y.[22] If the transfer function-noise model is to be constructed, we continue in the following steps:

5. Generate the noise series $\hat{n}$

$$\hat{n}_t = y_t - \frac{\omega(B)}{\delta(B)} x_t. \quad (14)$$

6. Specify an appropriate ARMA model for the noise series

$$\phi(B)\hat{n}_t = \theta(B)\epsilon_t' \cdot \quad (16)$$

where ϵ_t is normally distributed independent white nosie term with zero mean and variance σ_ϵ^2.

7. Specify the transfer function-noise model by combining the transfer function model and the noise model

$$y_t = \frac{\omega(B)}{\delta(B)} x_t + \frac{\theta(B)}{\phi(B)} \epsilon_t. \quad (17)$$

8. Estimate and diagnostically check the model. The model can be used to forecast the output variable, if it is specified appropriately.

The motivation of the bivariate (or transfer function-noise) model is that the innovation of u_{yt} in the univariate model is also the theoretical one-step-ahead prediction error made when forecasting y_t from its own past information.[23] If (current and) past information of the series x is useful in forecasting y_t, it is natural to consider whether or not the series x and u_y are related. If x and $u_{y(t+k)}$ are correlated for some positive k, then the forecast of y_t would be improved by taking account of this relationship.

[22] See Box and Jenkins [3], p. 362.
[23] See Box and Jenkins [3], p. 129.

In the two univariate time series system, the innovation of u_x is input or driving force to generate the output x, the innovation of u_y is input or driving force to generate the output y. The desire of relating the series x with u_y is to improve the forecasting of y_t. But, the distribution of cross-correlation estimator of u_x and u_y is simpler than x and y when x and y are independent.[24] Hence, combining the two univariate models for x and y with the identified model connecting u_x and u_y, a dynamic distributed lag model relating x to y can be identified.[25]

In order to test the Granger causality of outputs between Taiwan and the U. S., the first-difference log real *GNP* of these two countries, y_t and x_t, are used to construct the bivariate model and the transfer function-noise model. The steps are:

An ARMA (0, 2) model for x_t (the U. S. first-difference log real *GNP*) is[26]

$$\begin{aligned} x_t = \underset{(5.8)}{.008} + (1 + \underset{(2.2)}{.22}\, B + \underset{(2.2)}{.21}\, B^2)u_{xt}, \qquad (18) \\ DW = 1.97,\ Q(30) = 24.5, \end{aligned}$$

where the numbers in parentheses are *t*-statistics, *DW* is the Durbin-Watson statistic, and Q is the Q-statistic (or the Box-Pierce statistic), the number in parenthesis of Q is the degree of freedom.

An ARMA (3, 3) model for y_t (Taiwan's first-difference log real *GNP*) is[27]

$$\begin{aligned} (1 + \underset{(17.1)}{.90}B + \underset{(23.3)}{.91}B^2 + \underset{(17.5)}{.88}B^3)y_t = \underset{(14.1)}{.22} + (1 + \underset{(6.3)}{.67}B + \underset{(5.5)}{.58}B^2 + \underset{(5.2)}{.53}B^2)u_{yt}, \qquad (19) \\ DW = 1.78,\ Q\,(30) = 26.84. \end{aligned}$$

The cross-correlations of the residual in equation (18), $\hat{u}_x$, and the residual in equation (19), $\hat{u}_y$, are (from the U. S. to Taiwan):

lag 0-6	.28	.22	.10	.05	.09	−.03	−.17
lag 7-13	−.02	−.14	−.17	.14	.001	.09	.01
lag 14-20	.05	−.11	−.11	.04	.09	−.05	.002

[24] See haugh and Box [18].

[25] u_{yt} and $u_{x(t-\tau)}$ may have a low correlation for any lag τ, and yet the long-run relations between y and x are strong.

[26] The estimated period is from 1962:1 to 1987:4.

[27] The estimated period is from 1962:1 to 1987:4.

The bivariate (or transfer function) model is[28]

$$
\begin{array}{llllllll}
(1 + .27B & + .26B^2 & + .20B^2 & - .56B^4)y_t & = .02 + & (.51 & - .65B^6)x_t, & (20) \\
\quad (2.9) & (2.7) & (2.1) & (5.9) & & (7.2) & (2.6) \quad (3.4) &
\end{array}
$$

$DW = 1.83$, $Q(27) = 30.14$.

If the current value of x is excluded from the model, then the estimate of bivariate model is[29]

$$
\begin{array}{llllllll}
(1 + .24B & + .26B^2 & + .17B^3 & - .54B^4)y_t & = .02 + & (.51 & - .43B^6)x_t & (21) \\
\quad (2.5) & (2.6) & (1.7) & (5.5) & & (7.2) & (2.3) \quad (1.9) &
\end{array}
$$

$DW = 1.83$, $Q(27) = 26.72$.

By the residual of equation (20), we construct the following transfer function-noise model[30]

$$
\begin{array}{lllllll}
(1 + 1.02B & + .92\,B^2 & + .95 \quad B^3)y_t & = .02 +(.46 & + .35B & - .60B^6)x_t + & \\
\quad (22.4) & (18.4) & (21.6) \; (7.8) & (2.5) \quad (2.5) & (1.8) & (3.3) & \\
(1 + .80B & + .49B^2 & + .51B^3)\epsilon_t, & & & & (22) \\
\quad (7.1) & (3.3) & (4.4) & & & &
\end{array}
$$

$DW = 1.90$, $Q(27) = 23.42$.

The Q-statistic of equations (19), (20), (21), and (22) shows that these models are well specified. Hence, these models can be used to do the post sample dynamic forecasting (i. e., the forecasting uses only information through 1982). The post sample forecasting for the period 1983:1 through 1987:4 by the univariate model, the bivariate model, and the transfer function-noise model are listed in Table 8.[31]

---

[28] According to the cross-correlations of the residuals, the maximum lag is set to ten, then we drop the coefficient which t-statistic is insignificant. By this way, we reach equation (20). The estimated period is from 1963:3 to 1987:4.

[29] The estimation is by *OLS*, the estimated period is from 1963:4 to 1987:4.

[30] The estimated period is from 1963:1 to 1987:4.

[31] All models are fitted from 1963:4 to 1982:4, then to do the post sample dynamic forecastings from 1983:1 to 1987:4. The forecasting of bivariate model in Figure is the one included the current value of x.

Table 8: Forecastings of Change in Taiwan's log Real *GNP*

Period	Actual Value	Univariate Model	Bivariate Model (included x_t)	Bivariate Model (excluded x_t)	Transfer Function-Noise Model
1983:1	.0052	.0082	−.0024	.0024	.0129
1983:2	.0406	.0513	.0735	.0582	.0611
1983:3	.0771	.0320	.0637	.0530	.0632
1983:4	−.0323	−.0026	−.0002	−.0011	.0002
1984:1	.0309	.0141	.0293	.0183	.0354
1984:2	.0373	.0450	.0616	.0595	.0487
1984:3	.0617	.0304	.0357	.0365	.0405
1984:4	−.0545	.0028	−.0102	−.0079	−.0086
1985:1	.0170	.0156	.0136	.0115	.0162
1985:2	.0223	.0402	.0380	.0432	.0259
1985:3	.0525	.0291	.0220	.0236	.0302
1985:4	−.0380	.0071	.0027	.0031	.0024
1986:1	.0523	.0168	.0177	.0200	.0180
1986:2	.0274	.0364	.0357	.0408	.0276
1986:3	.0697	.0280	.0259	.0203	.0339
1986:4	−.0061	.0104	.0094	.0073	.0082
1987:1	.0206	.0178	.0190	.0200	.0180
1987:2	.0284	.0335	.0449	.0375	.0374
1987:3	.0778	.0270	.0330	.0319	.0383
1987:4	−.0511	.0131	.0194	.0173	.0188

In order to test the existence of Granger causality, the mean square of forecasting error *(MSFE)* for the univariate model, the bivariate (or transfer function) model, and the transfer function-noise model are calculated, they are .001032, .000956 (both bivariate models), and .000789 respectively. By comparing with the *MSFE* of the univariate model, the reduction of *MSFE* of the bivariate model is 7.4%, the reduction of *MSFE* of the transfer function-noise model is 23.6%.

According to the forecasting performances of these four models, we find that change in the U. S. real *GNP* contains information useful for improving the forecasting of Taiwan's real *GNP*. This may imply that the change in the U. S. real *GNP* causes the change in Taiwan's real *GNP* in the sense of Granger (instantaneous) causality.[32]

[32] Layton [30] constructs a bivariate model which makes the post sample mean square of forecasting error reduce 7.5%, and he concludes that the U. S. growth cycle is causal to the Australian growth cycle. Our finding of Granger instantaneous causality by the ARIMA model is consistent with the result of VAR model which does not include the current U. S. real *GNP* in the model.

The *MSFE* of both bivariate models is 7.4% less than the *MSFE* of univariate model. Is this reduction in *MSFE* significant? We can use the Granger and Newbold approach to test this significance indirectly.[33] Granger and Newbold test the difference in the variance of two white noise series by investigating the correlation of the sum and of the difference of the two series. Assuming the residual of Taiwan's real *GNP* in the univariate model (or equation (19)) is e_u, in the bivariate model (or equations (20) and (21)) is e_t, then if the correlation between $(e_u - e_t)$ and $(e_u + e_t)$ is positive, then $var(e_t)$ is smaller than $var(e_u)$. If the correlation is significantly different from zero, then $var(e_t)$ is significantly different from $var(e_u)$. Equivalently, we can regress $(e_u - e_t)$ on $(e_u + e_t)$, the coefficient of $(e_u + e_t)$ is nothing but an adjusted correlation coefficient between $(e_u - e_t)$ and $(e_u + e_t)$. If the coefficient of $(e_u + e_t)$ is positive and significantly different from zero, then $var(e_t)$ is significantly smaller than $var(e_u)$. Both test statistics for the significance are *t*-statistics.

By using residuals of equations (19), (20), and (21), we can calculate that the correlation between $(e_u - e_t)$ and $(e_u + e_t)$. The results are .197 (by the residual of equations (19) and (20)) and .08 (by the residual of equations (19) and (21)), the former is significant at the 5% level. The regression of $(e_u - e_t)$ on $(e_u + e_t)$ by the residual of equations (19) and (20) is (estimated by *OLS*)

$$\underset{}{(e_u - e_t)} = \underset{(.17)}{.0002} + \underset{(1.96)}{.064}\ (e_u + e_t), \tag{23}$$

where the numbers in parentheses are *t*-statistics.

The regression of $(e_u - e_t)$ on $(e_u + e_t)$ by the residual of equations (19) and (21) is (estimated by *OLS*)

$$(e_u - e_t) = \underset{(.22)}{.0002} + \underset{(.79)}{.02}\ (e_u + e_t). \tag{24}$$

In equation (23), the coefficient of $(e_u + e_t)$ is positive and significant at the 5% level. Both correlation and coefficient of regression indicate that the variance of residual in the bivariate model included the current value of x is significantly smaller than the variance of residual in the univariate model. Therefore, we can conclude that the change in the U. S. real *GNP* instantaneously Granger-causes the change in Taiwan's real *GNP*.[34]

[33] See Granger and Newbold [17], p. 279.

[34] Kang [25] ever used this approach to test the causality between the industrial production and the leading indicator of the U. S.

The estimated bivariate model and transfer function-noise model consistently indicate that change in the U. S. real *GNP* significantly influences (by the *t*-statistic) change in Taiwan's real *GNP*. Moreover, the current and past of U. S. real *GNP* contain information useful to help predict Taiwan's real *GNP*, this indicates the existence of Granger instantaneous causality, there is no time delay between change in the U. S. real *GNP* and change in Taiwan's real *GNP*.

7. Further Test of Causality of Output Changes

There are different propositions about the sources of economic fluctuations. According to Keynesians, the source of economic fluctuations is aggregate demand. Monetarists however believe that the source of economic fluctuations is money supply. In recent years, Kydland and Prescott [29], Long and Plosser [34], and King and Plosser [26] had used the neoclassical model to reinterpret the business cycle. Their approach is referred as the "real business cycle model." Because these models focus on the self-interested response of economic agents to productivity innovations, the business cycles arise as a consequence of the intertemporal optimizing behavior of economic agent. Hence, only the shocks to technology have the effects on the fluctuations of economy.

An important characteristic of business cycles is that outputs in different sectors tend to move together. The real business cycle model explains that such a comovement of outputs among different sectors is caused solely from the optimal production decisions and the change of production technology. It may or may not come from the common outside shocks or shocks that are correlated across sectors. The observed output comovement of different sector does not logically mean the presence of a common outside shock.

A simple approach in distinguishing whether the shocks are common or industry specific is by the analysis of the correlation matrix of output innovations.[35] If the correlation matrix of output innovations have large off-diagonal elements, the major source of fluctuations in outputs is caused by common outside shocks. On the other hand, if the off-diagonal elements of the correlation matrix are approximately zero, the major source of fluctuations of outputs is industry specific.[36]

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[35] See Long and Plosser [34, 35].

[36] This is necessary but not sufficient condition for the fluctuations of outputs are industry specific. There may be a small common innovation that turns out to be important. For example, the output of industry i, denoted by x_{it}, can be represented as: $x_{it} = \bar{x}_i + e_{ct} + e_{it} + a_1 e_{i(t-1)} + a_2 e_{i(t-2)} + \ldots + b_1 e_{c(t-1)} + b_2 e_{c(t-2)} + \ldots$, where $\bar{x}_i$ is mean output of industry i, e_i is innovation for industry i, e_c is innovation common to industries. Even $var(e_{it}) > var(e_{ct})$, but if $b's$ are much larger than $a's$, then it is possible that common shocks account for most of long-run variation of x_{it}.

Long and Plosser's real business cycle model can be extended to an open economy in order to analyze the world business cycle.[37] The traditional international economic theory (such as Fleming-Mundell model [14, 37]) propose that the international transmission of economic fluctuations is via the channel of goods trade or capital flow. But, according to the real business cycle theory, the international economic fluctuations are caused by the common outside shocks that lead to output comovement of different countries. On the other hand, if international economic fluctuations are transmitted by the trade channel, then the (current and) lagged foreign outputs can help predict current output of trade partner country, that is, the Granger (instantaneous) causality will exist among countries' outputs.[38]

In order to test the robustness of the Granger instantaneous causality between the output changes in both Taiwan and the U. S., we calculated the correlation matrix of cyclical components of real *GNP* between Taiwan and the U. S.[39] The

Our finding is different from Dellas' finding [8]. He finds that for the U. S., Japan, Germany, and the U. K., any country's output is uncorrelated with the past output of the other countries, and all correlations of output innovations across these countries are significant at the 5% confidence level. Dellas' finding is based on the assumption that the evolution of real *GNP* is a deterministic trend process and the cyclical component is derived by the residual of the regression on the linear time trend and its square. This approach is inappropriate if the evolution of real *GNP* is a stochastic trend rather than a deterministic trend process.

In addition to the difference of derivation of the cyclical components, we believe that the economic relationship between Taiwan and the U. S. may be different from

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37 See Dellas [8], and Cantor and Mark [4].

38 By the contemporaneous correlation matrix, Dellas finds that the comovements of output among advanced industrial countries (the U. S., Japan, Germany, and the U. K.) are caused by the common outside shocks rather than trade links.

39 We have tested and accepted the hypothesis that the evolutions of Taiwan and U. S. real *GNP* follow a stochastic trend process. Therefore, the cyclical components are derived by the ARIMA model as Beveridge and Nelson [2]. The ARIMA model for U. S. real *GNP* is an ARMA (0, 2) model:

$$x_t = \underset{(6.61)}{.008} + \underset{(2.3)}{.223}\, u_{x,t-1} + \underset{(2.3)}{.219}\, u_{x,t-2} + u_{x,t},$$

$DW = 1.96$, $Q(30) = 24.2$, where x_t is the U. S. first-difference log real *GNP*, u_x is white noise of x, the numbers in parentheses are t-statistics. The ARIMA model for Taiwan's real *GNP* is an ARMA (0, 4) model:

$$y_t = \underset{(3.4)}{.0215} - \underset{(1.3)}{.113}\, v_{y,t-1} + \underset{(.71)}{.058} v_{y,t-2} + \underset{(3.2)}{.275}\, v_{y,t-3} + \underset{(5.5)}{.566}\, v_{y,t-4} + \underset{(5.1)}{.055}\, v_{s,t-4} + \underset{(5.4)}{.516}\, v_{s,t-8} + v_{y,t},$$

$DW = 2.10$, $Q(30) = 29.86$, where y_t is Taiwan's first-difference log real *GNP*, v_y is white noise of y, v_s is white noise of seasonal component.

the economic relationship between the U. S. and Japan, Germany, and the U. K. First, the economic structure is very different between Taiwan and the U. S. The former is a developing semi-industrial country, the latter is an advanced industrial country. The economic structures of the U. S., Japan, Germany, and the U. K. are similar, all of them are developed industrial countries.

Second, the trade links between these industrial countries are much more interdependent (or highly integrated) than the trade links between Taiwan and the U. S. That is, Taiwan is very dependent on the U. S. market, but the importance of Taiwan's market to the U. S. is negligible. Table 9 shows that in the period from 1979 to 1985, average 41% and 23.2% of Taiwan's exports and imports relied on the U. S. market, but only 2.2% and 3.5% of U. S. exports and imports came from Taiwan. The difference in the relative importance of U. S. market to Taiwan and Taiwan's market to the U. S. is striking. On the other hand, we can find more interdependent bilateral trade relationships between the U. S. and Japan, Germany, and the U. K. For Japan, 29.3% of exports were to and 18.8% of imports were from the U. S., at the same time it absorbed 10.1% of U. S. exports and supplied 13.6% of U. S. imports. For Germany, 7.6% of exports were to and 6.6% of imports were from the U. S., at the same time it absorbed 4.5% of U. S. exports and supplied 5% of U. S. imports. For the U. K., 12.6% of exports were to and 11.6% of imports were from the U. S., at the same time it absorbed 5.4% of U. S. exports and supplied 4.5% of U. S. imports. Clearly, the bilateral trade relationship between Taiwan and the U. S. and Japan, the U. K., Germany and the U. S. are very different.

Third, Taiwan's economy is much more open than these industrial developed countries. For example, Taiwan's openness is 7.97 times that of the U. S., 4.27 times that of Japan, 2.86 times that of Germany, and 2.67 times that of the U. K. (measured by proportion of exports to *GNP*); or 5.41 times that of the U. S., 4.18 times that of Japan, 2.06 times that of Germany, and 2.57 times that of the U. K. (measured by proportion of imports to *GNP*) (see Table 9). Therefore foreign trade plays a more important role in Taiwan's economic activity than in the other developed countries.

In reality, under close integration of goods and capital markets between countries, any country's economic fluctuations are possibly caused by both trade links and common outside shocks with other countries. But, the relative importance of trade links and common outside shocks in economic fluctuations may be different across countries at different times and situations.[40] Based on the above reasons, we believe that at most of the time the trade links with the U. S. play a more important role than the common outside shocks with the U. S. in Taiwan's economic fluctuations. By checking the role of Taiwan's exports to the U. S. in Taiwan's economic

Table 9: Openness and Trade Flow with the U. S. —— 1979-1985

Unit: %

	(1) Openness by Exports	(2) Openness by Imports	(3) Exports to the U. S.	(4) Imports from the U. S.	(5) The U. S. Exports to	(6) The U. S. Imports from
The U. S.	6.7	8.8				
Taiwan	53.4	47.6	41.0	23.2	2.2	3.5
Japan	12.5	11.4	29.3	18.8	10.1	13.6
Germany	25.9	23.5	7.6	6.6	4.5	5.0
The U.K.	20.8	22.3	12.6	11.6	5.4	4.5

Note (a): The numbers are average values for the period from 1979 to 1985.
Note (b): (1) is openness measured by a country's total exports divided by its *GNP;* (2) is openness measured by a country's total imports divided by its *GNP;* (3) is a country's exports to the U. S. divided by its total exports; (4) is a country's imports from the U. S. divided by its total imports; (5) is exports of the U. S. to country i divided by the U. S. total exports; (6) is imports of the U. S. from country i divided by the U. S. total imports.
Sources: The data are from *Directions of Trade Statistics Yearbook* (Washington D. C.: IMF, 1986) and *Quarterly National Economic Trends Taiwan Area, the Republic of China* (Taipei: DGBAS, August 1988).

fluctuations, we can identify whether Taiwan's economic fluctuations are mainly caused by the trade links or by the common outside shocks with the U. S.

8. Conclusion

In this paper, we use the recently developed econometric method —— the VAR approach —— to investigate the output (real *GNP*) relationship between Taiwan and the U. S. The *F*-statistics of block of coefficients in our VAR model does not show the evidence to support the hypothesis that the U. S. output Granger-causes Taiwan's output, but the correlation coefficient does indicate the existence of a significant positive relationship between the two countries' output.

[40] The common outside shocks may play a more important role than the trade links in a country's economic fluctuations when worldwide shocks are dominant (for example oil crises). But, when country-specific shocks are dominant, the trade links rather than common outside shocks may play a more important role in a country's economic fluctuations.

The impulses response analysis shows that innovations in the U. S. output have innovations in the U. S. output have more persistent effect on Taiwan's output than on the U. S. output. To a positive innovation in the U. S. output, the peak response of Taiwan's output is about 1.086 times the peak response of U. S. output; the maximum accumulated response of Taiwan's output is about 1.55 times the maximum accumulated response of U. S. output.

According to the impulse response of Taiwan's real *GNP* to a positive innovation in the U. S. real *GNP*, we calculate that the elasticity multiplier of U. S. real *GNP* on Taiwan's real *GNP* is .82 or .66. It is compatible with the elasticity multiplier of U. S. income shock impacts on other countries' income estimated by different large-scale linkage models with two or three years of simulation. All of these evidences show that innovations in the U. S. output have big effect on Taiwan's output change.

The variance decomposition analysis shows that from the third period, the proportion of Taiwan's output variance accounted for by the U. S. output innovations exceeds 20%, reaching 32.67% in the twenty fourth period. This indicates that the U. S. output innovations play an important role in Taiwan's output fluctuations at all time horizons shown.

The cross-spectral analysis shows that the coherences of real *GNP* between Taiwan and the U. S. are significant in the frequency band corresponding to periodicities of 1 to 13 quarters (at the 1% significance level) or 1 to 17 quarters (at the 5% significance level). This gives us a strong evidence for the existence of close correlation of putput movements (or growth cycle) between Taiwan and the U. S.

Although we cannot find the evidence to support the hypothesis that the U. S. output Granger-causes Taiwan's output in the VAR model, trough the construction of the bivariate model and transfer function-noise model, we find that the current and past values of U. S. real *GNP* contain useful information to help predict Taiwan's real *GNP*. In the Granger sense of instantaneous causality, this means that change in the U. S. real *GNP* causes Taiwan's real *GNP* to change immediately. There is no time lag between a change in the U. S. real *GNP* and a change in Taiwan's real GNP.

According to the real business cycle model, we find that correlation coefficient of cyclical components of real *GNP* between Taiwan and the U. S. is insignificant. This give us further evidence to support the argument that Taiwan's economic fluctuations are caused by the trade links rather than by the common outside shocks with the U. S. Further study of the role play by Taiwan's exports to the U. S.

in Taiwan's economic fluctuations is needed to confirm this hypothesis.

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