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ACCOUNTING FOR TAIWAN GDP GROWTH: PARAMETRIC AND NONPARAMETRIC ESTIMATES

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ABSTRACT

The purpose of this paper is to study the impact of changes in prices of tradables on economic growth in a highly open economy, Taiwan. We do so by measuring productivity growth with both index number and parametric approaches, and identifying the sources of output growth using a methodology that allows the impacts of changes in the terms of trade to be accounted for. The results show that Taiwan's economic growth depends on inputs accumulation as well as technical progress with the terms-of-trade effect being negligible.

Key words and phrases: productivity change; SUR (Seemingly Unrelated Regressions); nonparametric approach; stochastic approach; terms of trade.

JEL classification: O30, C01, C14, C30 .

1. Introduction

Productivity is defined as output per unit of input. The study of productivity is intimately related to the study of economic growth as productivity increases induce an increase in output in perpetuity while this might not be true of input use. In fact, estimated aggregate supply elasticities have been known to be very small. It is shifts in this aggregate supply due to innovations that has reverted Malthusian predictions and in fact allowed higher standard of living.

Taiwan has been one of the fastest growing economies last century. During the same period, it became an open economy with high reliance on international trade. Economic theory is not clear about the impact from such a structural change in an economy, nor is it clear about the causality between trade and economic growth. Empirical analysis for a number of countries has confirmed a strong and positive association between trade and growth. In the Taiwanese case recent studies by Luh and Shih (2006), Sun and Chen (2005), Chang (2003), Färe, Grosskopf and Lee (2001), Dessus (1999), Fuess and Van Den Berg (1996) and Tallman and Wang (1994) among others, have investigated the nature of economic growth. Most of this work disregards the highly open nature of the Taiwanese economy and does not allow for possible effects derived from trade.

The purpose of this paper is to study the impact of changes in prices of tradables on economic growth in a highly open economy, Taiwan. We do so by measuring productivity growth, and identifying the sources of output growth using a methodology that allows the impacts of changes in the terms of trade to be accounted for.

Studies of total factor productivity (TFP) growth fall mostly within the following two categories¹:

- (1) Index numbers, the rate of change of an output index over an input index (Jorgenson and Griliches (1967)),
- (2) Econometric estimation of shifts in a production function (Tinbergen (1942), Solow (1957)) or a dual cost, revenue, or profit function (Kwon (1986), Kohli (1990)).

Both approaches are attempts at approximating the ‘Solow residual’, or that portion of output growth not accounted for by input growth. Most index number approaches are nonparametric and nonstochastic, with Tronquist type indexes calculated directly from the data. Most econometric approaches are parametric and stochastic and rely on the estimation of a Cobb-Douglas production function from which input contributions are isolated from productivity change². In this paper we propose the use of three approaches to the measurement of total factor productivity change and the corresponding

¹For a detailed review of this literature see Alston, Norton, and Pardey (1995).

²Most economy wide econometric studies have used Cobb-Douglas production functions. Flexible specifications of dual cost and profit functions are common at lower levels of disaggregation.

output growth decomposition, a parametric stochastic dual approach, a nonstochastic nonparametric index approach, and a parametric stochastic index approach that is a combination of the first two. After estimating productivity growth we proceed to decompose output growth incorporating the terms of trade effect.

Diewert and Morrison (1986), examine the need to incorporate a valuation adaptation to productivity growth measures in a small open economy with tradables and nontradables. Changes in the ratio of export prices to import prices not measured by a productivity indicator may be thought of similarly to a productivity increase. A favorable change in a country's terms of trade has a similar impact on domestic production than an innovation. Either an increase in technology or an increase (decrease) in the price of an exported (imported) good cause an exogenous change in the value of output which is potentially available based on the same levels of inputs and domestic prices. They propose a combined measure based on the standard productivity change approach net of a change in the price of tradable goods. The correction term is referred to as "the terms of trade change" and the measure itself as a "welfare" measure.

The purpose of this paper is to measure productivity growth in a small open economy, Taiwan, and to include in the growth decomposition the terms of trade effect. In doing so, interesting information about Taiwan's aggregate production technology is uncovered. Productivity growth estimates provide a Ricardian base for comparative advantage while from the econometric approach we obtain Rybczynski elasticities and Stolper-Samuelson elasticities which provide a resource base indicator of comparative advantage. We are also able to test predictions of the Hecksher-Ohlin model.

In section II, the basic model used to represent the economy is introduced and the alternative approaches to productivity measurement are presented. Section III describes alternative growth accounting procedures for a small open economy that include the terms of trade effect. Section IV describes the data and the results and section V has the conclusions.

2. Technical change and the GDP function

Technical change³ refers to an increase in output per unit of inputs and it is usually depicted as a shift up of the production function. In our study we choose to represent the aggregate production process of the economy by its dual, the restricted profit function. The restricted profit function, also known as the GDP function in the trade literature, has been extensively used to represent the aggregate technology of a small open economy (Diewert (1973), Kohli (1978), Dixit and Norman (1980)). In an open economy it is assumed that a country will maximize the returns from production given fixed resource endowments. If the economy is small, we can further assume that prices of tradables are given to reflect price-taking behavior.

The GDP function is defined as:

$$\Pi_t = \Pi(\mathbf{p}_t, \mathbf{x}_t, \mathbf{t}) \equiv \max_{\mathbf{y}_t} \{\mathbf{p}'_t \mathbf{y}_t : (\mathbf{y}_t, \mathbf{x}_t) \in T_t\} \quad (1)$$

where Π is GDP, \mathbf{p} is a vector of tradable and nontradable goods prices, \mathbf{x} is a vector of factor endowments, t is time and T_t is a well behaved production possibilities set at time t .

Equation (1) can be used to capture productivity change when additional revenues are obtained for given resources. In this study, three alternative methods are used to measure total factor productivity growth: an econometric approach, a nonparametric nonstochastic index approach, and a parametric stochastic index that combines the first two.

In the econometric approach it is necessary to specify an explicit functional form for the GDP function and to choose a variable that represents technical change so that

$$\Pi_t = f(\mathbf{p}, \mathbf{x}, t) + \epsilon_t \quad (2)$$

where ϵ_t is a random error and the shift in this function, $\frac{\partial \Pi}{\partial t}$, for given levels of inputs, is the measure of productivity change. We choose the translog form (Christensen, Jorgensen and Lau (1973)) given the desirable flexibility properties and its consistency with the Tronquist index that we use in an alternative approach. The translog function is a second-degree function in prices and fixed factors, it can be considered as a second-order approximation to any arbitrary function, it nests the widely used Cobb-Douglas form without constraining the value of elasticities.

³Technical change and productivity change are used as synonymous in this manuscript.

In the econometric approach a translog GDP function that has been augmented with a time trend as a proxy for technological innovation is estimated. This function is

$$\begin{aligned} \ln \Pi = & \alpha_0 + \sum_i \alpha_i \ln p_i + 1/2 \sum_i \sum_j \gamma_{ij} \ln p_i \ln p_j + \sum_h \beta_h \ln x_h + 1/2 \sum_h \sum_k \phi_{hk} \ln x_h \ln x_k \\ & + \sum_i \sum_h \delta_{ih} \ln p_i \ln x_h + \sum_i \delta_{iT} \ln p_i t + \sum_h \phi_{hT} \ln x_h t + \beta_T t + 1/2 \phi_{TT} t^2 \\ & i, j \in \{D, X, M\}; h, k \in \{L, K\} \end{aligned} \quad (3)$$

where there are two outputs, domestic consumption products (D) and exports (X), one variable input, import (M) (that could also be thought of as a negative output), two factor endowments, labor (L) and capital (K), and an index of technical change, t .

Using the derivative property of the GDP function, differentiation of (2) with respect to $\ln p_i$, yields (4), the shares in GDP of domestic output, of exports supplied and of imports demanded. Differentiation with respect to $\ln x_h$ yields (5), inverse factor demands expressed as shares of GDP (under perfectly competitive markets) :

$$S_i = \alpha_i + \sum_j \gamma_{ij} \ln p_j + \sum_h \delta_{ih} \ln x_h + \delta_{iT} t \quad i, j \in \{D, X, M\} \quad h, k \in \{L, K\} \quad (4)$$

$$S_h = \beta_h + \sum_k \phi_{hk} \ln x_k + \sum_i \delta_{ih} \ln p_i + \phi_{hT} t \quad i, j \in \{D, X, M\} \quad h, k \in \{L, K\} \quad (5)$$

Where $S_i \equiv p_i y_i / \Pi$ and $S_h \equiv w_h x_h / \Pi$ are the GDP shares and w_h is the price of factor h (or its marginal revenue).

The econometric estimate of productivity change is given by

$$\mu = \partial \ln \Pi / \partial t = \beta_T + \sum_i \delta_{iT} \ln p_i + \sum_h \phi_{hT} \ln x_h + \phi_{TT} t \quad i \in \{D, X, M\}; \quad h \in \{L, K\} \quad (6)$$

A positive μ indicates productivity increases.

This approach allows us to obtain information about the nature of technical change biases in addition to its rate and it also provides a more detailed description of the aggregate technology, both of them advantages over the index approach. Other parameters of interest describing the nature of technical change are the rate at which productivity grows and the output and input biases. The rate of change of total factor

productivity growth is given by

$$\frac{\partial^2 \ln \Pi}{\partial t^2} = \phi_{TT} \quad (7)$$

where a positive parameter indicates that the rate of technological change has increased over time. Output biases due to technical change can be obtained by looking at the share changes through time:

$$\frac{\partial S_i}{\partial t} = \delta_{it} \quad (8)$$

while input share changes indicate input biases

$$\frac{\partial S_h}{\partial t} = \phi_{ht} \quad (9)$$

A positive coefficient in (8) and (9) indicate that technological change has been *ith* output (negative for imports) producing or *hth* input using. For given resources, this implies an increase in the rental price of factor *h*. Due to the symmetry of the GDP function these parameters also indicate that an increase in the price of commodity *i* or in the endowment of factor *h* results in an increase in the rate of technological change. The latter concepts are represented by the price elasticities of technological change

$$E_{ii} = \partial \mu / \partial \ln p_i = \delta_{it} \text{ for all } i \in \{D, X, M\} \quad (10)$$

and the quantity elasticities of technological change

$$E_{ih} = \partial \mu / \partial \ln x_h = \phi_{ht} \text{ for } h \in \{L, K\} \quad (11)$$

Given our interest in the terms of trade effect on productivity it will be particularly important to focus on equation (10), which provides indication of the technical relationship between export and import prices, and technical change.

Other elasticities of interest are the time elasticities of output supplies

$$E_{it} = \partial \ln y_i / \partial t \text{ for all } i \in \{D, X, M\} \quad (12)$$

and the time elasticities of inverse input demands

$$E_{ht} = \partial \ln w_h / \partial t = \phi_{ht} \text{ for all } h \in \{L, K\} \quad (13)$$

They indicate the effect of technical change on the supply of domestic and tradables commodities and on factor rewards for a given set of prices and domestic factor endowments. Particular attention will be given to equation (12) given that it shows the relationship between exports and imports and technological change.

It is also possible to show that

$$\mu = \sum_i s_i E_{it} = \sum_h s_h E_{ht} \quad (14)$$

where the rate of technological change is a weighted average of the rate of increase in outputs or alternatively, of the rate of increase in factor payments through time. This suggests the following alternative measure of bias in technological change

$$\begin{aligned} \beta_i &= E_{it} - \mu, \quad i \in \{D, X, M\} \\ \beta_h &= E_{ht} - \mu, \quad h \in \{L, K\} \end{aligned} \quad (15)$$

If β_i is positive, technological change is biased in favor of output i . Similarly, a positive value of β_h indicates that it is input h using⁴.

In addition the econometric approach allows calculation of the supply elasticity for domestic production, the export supply elasticity and the import demand elasticity,

$$E_{ij} = \partial \ln y_i / \partial \ln p_j \quad i, j \in \{D, X, M\} \quad (16)$$

and of the inverse demand elasticity of capital and labor

$$E_{hk} = \partial \ln w_h / \partial \ln x_k \quad h, k \in \{L, K\} \quad (17)$$

This method also permits recovery of information about the effects of input growth on output supply, the Rybczynski elasticities (Kholi(1978, 1991, 1994)) even though our model does not exactly match Rybczynski's assumptions

$$E_{ih} = \partial \ln y_i / \partial \ln x_h \quad i \in \{D, X, M\} \quad h \in \{L, K\} \quad (18)$$

In the same vein, Stolper-Samuelson elasticities indicating the relationship between input and output prices are easily obtained

$$E_{hi} = \partial \ln w_h / \partial \ln p_i \quad i \in \{D, X, M\} \quad h \in \{L, K\} \quad (19)$$

⁴It is also possible to show that $E_{ti} = s_i \beta_i = \delta_{it}$ and $E_{th} = s_h \beta_h = \phi_{ht}$.

These elasticities give us a notion of the importance of factor endowments on output supply and of the ease of transmission of output price changes into input price. They are used to test the predictions of both of these trade theories.

An alternative to the econometric approach to productivity measurement and decomposition is the exact index number approach introduced by Diewert and Morrison (1986). Index numbers deal with problems resulting from the necessity of approximating time derivatives by finite differences. This approach uses equation (1) to define an exact index of productivity growth:

$$R_t(\mathbf{p}, \mathbf{x}) \equiv \frac{\Pi_t(\mathbf{p}, \mathbf{x})}{\Pi_{t-1}(\mathbf{p}, \mathbf{x})} \quad (20)$$

that measures the percentage increase in output that can be produced by the period t technology set compared to the period $t - 1$ technology given \mathbf{p} and \mathbf{x} . If we assume that Π has a translog functional form, and we choose t and \mathbf{x} appropriately, R_t can be calculated as an implicit Tornquist index of outputs divided by a Tornquist index of inputs⁵. They show that

$$R_t = \frac{a}{bc} \quad (21)$$

where

$$\begin{aligned} a &\equiv \Gamma \equiv \frac{p_t y_t}{p_{t-1} y_{t-1}}, \\ \ln b &\equiv P \equiv \sum_{n=1}^N \frac{1}{2} \left[\frac{p_{nt} y_{nt}}{p_t y_t} + \frac{p_{nt-1} y_{nt-1}}{p_{t-1} y_{t-1}} \right] \ln \frac{p_{nt}}{p_{nt-1}} \end{aligned} \quad (22)$$

and

$$\ln c \equiv X \equiv \sum_{j=1}^M \frac{1}{2} \left[\frac{w_{jt} x_{jt}}{w_t x_t} + \frac{w_{jt-1} x_{jt-1}}{w_{t-1} x_{t-1}} \right] \ln \frac{x_{jt}}{x_{jt-1}} \quad (23)$$

with $\ln R_t = \ln a - P - X$ as an approximation to total factor productivity growth.

In a small open economy, the net output vector \mathbf{y} includes traded as well as domestic products and the total value change between periods t and $t - 1$ which includes all net outputs is given by ε . For productivity measurement, the effect of price changes is purged by dividing this value by equation (22) that includes the prices of all products, domestic and tradables. As noted by Diewert and Morrison, the output impact of an

⁵The Tronquist index is a superlative index and it is exact for a translog technology.

improvement in a country's terms of trade is conceptually similar to an improvement in its technology, since it enables the country to divert resources from the production of exports to the production of nontraded goods, while maintaining the same trade-balance position. Domestic output and absorption can increase without the need for any additional domestic resources. Similarly to productivity improvements, terms of trade improvements allow output produced with given levels of domestic resources to expand. Diewert and Morrison suggest that the output effects of the two changes be measured jointly and refer to it as a 'welfare change'. To include the terms of trade impact, the change in prices of exports and imports are not purged from the index, so they are not included in equation (22). This results in a measure that includes both, the productivity change R_t and the terms of trade effect A_t :

$$R_t(\mathbf{p}, \mathbf{x})A_t(\mathbf{p}, \mathbf{x}) \equiv \frac{\Pi_t(p_D, p_{Xt}, p_{Mt}, \mathbf{x})}{\Pi_{t-1}(p_D, p_{Xt-1}, p_{Mt-1}, \mathbf{x})} \quad (24)$$

and $A_t = d/e$ where

$$\begin{aligned} \ln d \equiv P_X &\equiv \sum_{i=1}^X \frac{1}{2} \left[\frac{p_{xt}^i y_{xt}^i}{p_t y_t} + \frac{p_{xt-1}^i y_{xt-1}^i}{p_{t-1} y_{t-1}} \right] \ln \frac{p_{xt}^i}{p_{xt-1}^i} \\ \ln e \equiv P_M &\equiv \sum_{i=1}^X \frac{1}{2} \left[\frac{p_{mt}^i y_{mt}^i}{p_t y_t} + \frac{p_{mt-1}^i y_{mt-1}^i}{p_{t-1} y_{t-1}} \right] \ln \frac{p_{mt}^i}{p_{mt-1}^i} \end{aligned} \quad (25)$$

or alternatively

$$A_t = \frac{\Pi_t(p_{Xt}, p_{Mt}, p_D, \mathbf{x})}{\Pi_t(p_{Xt-1}, p_{Mt-1}, p_D, \mathbf{x})} \quad (26)$$

Equation (26) differs from (24) in that the same period technology is evaluated at prices of tradables for different periods. This approach calculates the productivity index and the terms of trade index directly from data using equations (21) to (26). In practice, these indexes can be evaluated at prices (domestic prices for the terms of trade index) and factor endowments in the current period or in the previous period giving Laspeyres and Paasche productivity and terms of trade indexes respectively. In each case, we obtain Fisher indexes by calculating the geometric average of these two.

The third approach used in this paper to calculate productivity growth was suggested by Kohli as a hybrid between the econometric and the index number approach. It uses the same concept of equation (21) but instead of calculating the indexes directly

from data, it does so by using the predicted values of π from the estimation of (2). In this case the productivity index is

$$S_t(\mathbf{p}, \mathbf{x}) \equiv \frac{\hat{\Pi}_t(\mathbf{p}, \mathbf{x})}{\hat{\Pi}_{t-1}(\mathbf{p}, \mathbf{x})} \quad (27)$$

a ratio of predicted GDP values. S_t differs from R_t in equation (20) by a random error or unexplained residual U_t . In practice we substitute equation (3) into equation (27). Evaluation of equation (27) at period t prices and inputs provide a Laspeyres type index, while evaluation at $t - 1$ prices gives a Paasche index. In this paper we use the geometric average of the two that expressed in terms of the parameters of equation (3) in logs is

$$\ln S_{t,t-1} = 1/2 \sum \delta_{iT} \ln(p_{it}p_{it-1}) + 1/2 \sum \phi_{hT} \ln(x_{ht}x_{ht-1}) + \beta_T + 1/2\phi_{TT}(2t - 1),$$

for $i \in \{D, X, M\}$; $h \in \{L, K\}$

(28)

The predicted terms of trade index is calculated by replacing equation (3) into equation (26), expressing the index in terms of the parameters of the GDP function and obtaining a geometric average of the index evaluated at current and past prices. The parametric terms of trade index is

$$\ln A_{t,t-1} = 1/2 \sum \sum \gamma_{ij} (\ln p_{it} \ln p_{jt} - \ln p_{it-1} \ln p_{jt-1}) + \sum \ln(p_{it}/p_{it-1}) [\alpha_i + 1/2 \sum \gamma_{iD} \ln(p_{Dt}p_{Dt-1})$$

+ 1/2 \sum \delta_{ih} \ln(x_{ht}x_{ht-1}) + 1/2\delta_{iT}(2t - 1)] for $i, j \in \{X, M\}$ $h \in \{L, K\}$

(29)

3. Accounting for output growth in an open economy

Once productivity is measured, we proceed to investigate the sources of output growth. This exercise indicates the relative importance of resource expansion, versus technological change and terms of trade changes on the extraordinary output expansion of the Taiwanese economy during the 1968-1998 period. Since the work by Tinberger (1942), Solow (1958), and Jorgenson and Griliches (1967) it has become traditional to decompose output growth from a primal or output perspective as

$$\frac{\dot{y}}{y} = \sum_h s_h \frac{\dot{x}_h}{x_h} + r \quad (30)$$

where y represents output, \mathbf{x} is a vector of inputs, \mathbf{s} is a vector of input shares in total output value, r is productivity growth and a dot on the variables represent time derivatives. Equation (30) indicates that the rate of change in output can be attributed to the rate of change in inputs weighted by their respective shares plus the rate of productivity change. Similarly the dual or profit perspective indicates that profit changes could be decomposed into changes in variable prices, changes in resources and productivity changes in the following way⁶

$$\frac{\dot{\pi}}{\pi} = \sum_i s_i \frac{\dot{p}}{p} + \sum_h s_h \frac{\dot{x}}{x} + \mu. \quad (31)$$

In equation (31), price changes can be decomposed into changes in prices of tradables and nontradables. Dissagregating price changes so as to isolate changes in domestic prices from changes in terms of trade we obtain

$$\frac{\dot{\pi}}{\pi} = s_D \frac{\dot{p}_D}{p_D} + s_X \frac{\dot{p}_X}{p_X} + s_M \frac{\dot{p}_M}{p_M} + \sum_h s_h \frac{\dot{x}}{x} + \mu. \quad (32)$$

where the equivalent of Diewert and Morrison 'welfare' index in (26) is

$$s_X \frac{\dot{p}_X}{p_X} + s_M \frac{\dot{p}_M}{p_M} + \mu. \quad (33)$$

The decompositions in (31) and (32) can be calculated directly from data or from the econometric estimates of the translog GDP function using the predicted shares in equations (4) and (5).

Actual observations are also used to calculate the index equivalent of equation (32) consistent with our second approach for productivity measurement. In accordance to equations (21) and (24) changes in output values are decomposed, in the following way:

$$\Gamma_{t,t-1} = R_{t,t-1} \bullet A_{t,t-1} \bullet X_{Lt,t-1} \bullet X_{Kt,t-1} \bullet P_{Nt,t-1} \quad (34)$$

where $\Gamma_{t,t-1} \equiv \sum p_{it}y_{it} / \sum p_{it-1}y_{it-1}$ is one plus the rate of nominal GDP growth between period t and $t-1$, $R_{t,t-1}$ is the index of productivity in (20), $A_{t,t-1}$ is the terms of trade index (26), $X_{t,t-1}$ are Tronquist indexes of labor and capital growth, and $P_{Nt,t-1}$ is a Tronquist index of price changes of nontraded goods. If $P_{Nt,t-1}$, is not

⁶The primal and dual productivity measures are equivalent under constant returns to scale and perfectly competitive profit maximization.

included, we would have a decomposition of real GDP as opposed to nominal GDP. The combined effects of the first two terms, technical progress ($R_{t,t-1}$) and terms of trade change ($A_{t,t-1}$), is what Diewert and Morrison have termed a ‘welfare change index.’

As shown in the last section, these indexes can also be obtained from parameters of an estimated GDP function. When parametric indexes are calculated, value of output decomposition describes the same concept as $\Gamma_{t,t-1}$ but with random errors purged from the data as the indexes are calculated from econometric predictions instead of actual data. GDP decomposition in this case is

$$\pi_{t,t-1} = S_{t,t-1} A_{t,t-1} X_{Lt,t-1} X_{Kt,t-1} P_{Nt,t-1} \quad (35)$$

where $S_{t,t-1}$, now represents the contribution of technical progress to GDP growth as explained in (27). Since $\Gamma_{t,t-1}$ is calculated directly from observed data, and $\pi_{t,t-1}$ is predicted from the model estimated in (3), $\Gamma_{t,t-1}$ and $\pi_{t,t-1}$ will not be equal in general. The unexplained residual is

$$U_{t,t-1} \equiv \Gamma_{t,t-1} / \pi_{t,t-1} \quad (36)$$

From (35),(36) the observed GDP growth can be decomposed into the following components:

$$\Gamma_{t,t-1} = S_{t,t-1} \cdot U_{t,t-1} \cdot A_{t,t-1} \cdot X_{Lt,t-1} \cdot X_{Kt,t-1} \cdot P_{Nt,t-1} \quad (37)$$

In practice, all these indexes are obtained from the estimated parameters of the GDP function and can be written in the following way

$$\ln X_{ht,t-1} = \ln(x_{ht}/x_{ht-1})[\beta_h + 1/2 \sum \phi_{hk} \ln(x_{ht}x_{ht-1}) + 1/2 \sum \delta_{ih} \ln(p_{it}p_{it-1}) + 1/2\phi_{hT}(2t-1)]$$

$$i \in \{D, X, M\}; \quad h, k \in \{L, K\} \quad (38)$$

$$\ln P_{Nt,t-1} = 1/2\gamma_{DD}(\ln P_{Dt} \ln P_{Dt} - \ln P_{Dt-1} \ln P_{Dt-1}) + \ln(p_{Dt}/p_{Dt-1})[\alpha_D + 1/2 \sum \gamma_{Dm} \ln(p_{mt}p_{mt-1}) + 1/2 \sum \delta_{Dh} \ln(x_{ht}x_{ht-1}) + 1/2\delta_{DT}(2t-1)]$$

$$m \in \{X, M\}; \quad h \in \{L, K\} \quad (39)$$

Equations (8), (9), (38) and (39) are replaced into equation (35) to obtain this parametric index decomposition of GDP growth.

4. Data

To estimate (3) we need data on nominal GDP, output shares, prices and factor supplies. For capital, only the capital formation is available from original data. To estimate the initial capital stock, available data on gross fixed capital formation of investment at constant prices is used. First, we assume a steady-state relation $\bar{I} = (g + \delta)K^*$, where \bar{I} is the steady state level of investment, g is the rate of growth of real investment (and capital), δ is the rate of depreciation and K^* is the steady-state capital stock. Second, we estimate the growth rate g by a detrending regression model, $\ln I = a + bt$ where t is just the time trend and the coefficient of t is the growth rate of real investment. Third, we assume a rate of depreciation of 5 percent. We then estimate the initial capital stock in the first period of the sample from the steady-state relation. By adding investment during the previous period and deducting depreciation at an assumed rate of 5 percent per year we can rebuild the capital stock series. Capital revenue is defined as national income from property.⁷

Due to lack of working hours information, we take the published total labor force as the labor stock. Labor income is defined as the compensation of employees. The prices of domestic sales, export output and imports are GDP deflator indexes. Domestic sales include consumer expenditures, investment and government purchases.

The data used in this paper are annual series drawn primarily from the Taiwan Statistical Data Book, and the Quarterly National Economic Trends Taiwan Area, the Republic of China. The full sample period is 1967 to 1998.

5 Results

5.1 Econometric estimates

To estimate the SUR system ((3),(4),(5)) we first assume that the error vectors are independently distributed with a multivariate normal distribution with zero means and covariance matrix Ω . We then utilize the iterative Zellner procedure from version 8 of

⁷Crego, A., D. Larson, R. Butzer, and Y. Mundlak (1999) have constructed a capital stock series for Taiwan for the period 1967-1992, shorter than the one in this study. Their 1967 and 1992 estimates are very similar to ours.

Shazam (White 1997) to obtain the maximum likelihood estimates for those parameters.

To fit the properties of a restricted profit function, homogeneity in prices is required. Constant return to scale was the first hypothesis to be tested and imposed in estimation given that it was not rejected. The equations were estimated with the following symmetry and homogeneity restrictions:

$$\begin{aligned} \sum_i \alpha_i = 1; \sum_j \alpha_{ij} = 0; \sum_h \beta_h = 1; \sum_k \phi_{hk} = 0; \gamma_{ij} = \gamma_{ji}; \phi_{hk} = \phi_{kh}; \sum_h \delta_{ih} = 0; \\ \sum_i \delta_{ih} = 0; \sum_i \delta_{iT} = 0; \sum_h \phi_{hT} = 0 \end{aligned} \quad (40)$$

Since the input shares as well as the output shares add up to unity, the import share and the capital share equations were left out. Because we are using a maximum likelihood procedure, the estimates are independent of the equation deleted.

The parameters estimated are shown in table 1. The table contains 28 parameters, 10 of them are significant at the 5% level, 2 of them are significant at the 10% level. In addition to the properties of symmetry and homogeneity, the GDP function is convex in prices. In this estimation convexity in prices is violated. This is not uncommon when using flexible functional forms, in particular a translog.

Before accounting for economic growth we use the estimated parameters to examine the implied price, quantity and time elasticities in equations (10) to (19).

The estimated elasticities are shown in table 2 for a selected number of years. The own price elasticities are in 2.I. The domestic supply own price elasticity has oscillated between 0.31 to 0.35 in 1968- 1998. The own price elasticities of exports are negative reflecting the lack of convexity mentioned. Own price import demand elasticities in most years were negative ranging from -0.47 to -0.16. The next six rows in Table 2.I show cross price elasticities. Imports are substitutes for domestic sales and complements for exports.

Inverse input price elasticities are shown in section 2.II. Own price elasticity for both inputs are negative, as expected, with the derived demand for capital evolving to be more inelastic than the derived demand of labor during the period of analysis.

Rybczynski elasticities, showing how output supply changes due to an increase in resources are in section 2.III. We find that increases in capital intensity have favored

exports and imports much more than domestic sales, with this intensity decreasing over time.

Stolper-Samuelson elasticities in section 2.IV indicate ease of transmission of output price changes into input price changes. They show that an improvement in terms of trade will pass through as increases in price of both labor and capital.

As to the response of outputs and inputs to technical change (sections 2.V and 2.VI) we find that technological change has been biased for exports relative to imports and domestic sales, and has increased the price of capital more rapidly than the price of labor. In section 2.VII we find that increases in the price of exports accelerates technological change while the contrary is true for prices of imports and nontradables. We also see in 2.VIII that the rate of technological change is decreasing in capital and increasing in labor.

The last row of Table 2 presents the evolution of productivity change for the Taiwanese economy, obtained as explained in equation (6). We see that this rate has evolved from 0.53% to 8.5%.

Table 1 Parameters of Translog GDP function for Taiwan (1968-1998)

α_0	1.0457 (0.3473)	ϕ_{ll}	-0.1108 (-1.3224)
α_d	1.0436 (3.9997)**	δ_{dl}	-0.0245 (-0.5914)
α_x	-0.0859 (-0.089)	δ_{dk}	0.0246 (1.1321)
α_m	0.0422 (0.0378)	δ_{xl}	-0.0345 (1.1473)
β_l	-0.0332 (-0.0217)	δ_{xk}	0.0346 (0.5013)
β_k	1.0303 (2.9311)**	δ_{ml}	0.0590 (3.6445)**
γ_{dx}	-0.4921 (-8.6105)**	δ_{mk}	-0.0592 (-0.48)
γ_{dm}	0.1412 (1.7573)*	δ_{dt}	-0.0084 (1.5546)
γ_{xm}	0.4027 (4.6640)**	δ_{xt}	0.0140 (2.2011)**
γ_{dd}	0.3509 (4.1757)**	δ_{mt}	-0.0056 (-1.3913)
γ_{xx}	0.0894 (0.9755)**	ϕ_{lt}	0.0032 (0.4256)
γ_{mm}	-0.5439 (-5.1972)**	ϕ_{kt}	-0.0032 (-0.9279)
ϕ_{lk}	0.1109 (1.8906)*	β_t	0.0102 (0.2432)
ϕ_{kk}	-0.1108 (-15.26)**	ϕ_{tt}	0.0030 (6.1856)**
LL	198.73		
R^2	0.9823		

Number in parentheses are t-values, “**” indicates significant at 5% level, “*” indicates significant at 10% level.

Table 2 Estimated Elasticities

		1968	1973	1978	1983	1988	1993	1998
(I)	Edd	0.3307	0.3219	0.3251	0.3249	0.3313	0.3473	0.3134
	Exx	-0.4020	-0.3805	-0.3383	-0.3000	-0.3237	-0.3328	-0.2639
	Emm	0.8090	0.2480	-0.1611	-0.3732	-0.2863	-0.3226	-0.4731
	Edx	-0.2114	-0.1251	-0.0405	0.0187	-0.0115	-0.0133	0.0593
	Exd	-0.6897	-0.3055	-0.0823	0.0338	-0.0226	-0.0275	0.0956
	Edm	-0.1167	-0.1941	-0.2818	-0.3407	-0.3168	-0.3309	-0.3695
	Emd	0.4306	0.5413	0.6302	0.6696	0.6640	0.6958	0.6685
	Exm	1.0943	0.6888	0.4234	0.2692	0.3493	0.3634	0.1714
	Emx	-1.2370	-0.7866	-0.4663	-0.2934	-0.3747	-0.3701	-0.1922
(II)	Ell	-0.7052	-0.6295	-0.5470	-0.4715	-0.4360	-0.3785	-0.3175
	Elk	0.7045	0.6288	0.5463	0.4708	0.4353	0.3778	0.3168
	Ekl	0.7389	0.8224	0.9289	1.0471	1.1130	1.2420	1.4301
	Ekk	-0.7396	-0.8231	-0.9294	-1.0475	-1.1135	-1.2425	-1.4304
(III)	Edl	0.4861	0.5405	0.6036	0.6637	0.6929	0.7415	0.7919
	Edk	0.0521	0.0596	0.0693	0.0828	0.0903	0.1062	0.1444
	Exl	-0.1508	-0.0131	0.1313	0.2724	0.3363	0.4411	0.5791
	Exk	0.6042	0.5215	0.4432	0.3750	0.3507	0.3049	0.2405
	Eml	0.2867	0.3937	0.4916	0.5683	0.5906	0.6413	0.7044
	Emk	0.7123	0.6054	0.5075	0.4309	0.4085	0.3578	0.2947
(IV)	Eld	0.9205	0.9109	0.9204	0.9234	0.9352	0.9625	0.9102
	Ekd	1.0188	1.0110	1.0259	1.0383	1.0569	1.1000	1.0759
	Elx	0.2293	0.3297	0.4176	0.4818	0.4481	0.4365	0.5405
	Ekx	0.3677	0.4706	0.5659	0.6435	0.6193	0.6300	0.7737
	Elm	-0.1472	-0.2379	-0.3352	-0.4023	-0.3803	-0.3958	-0.4475
	Ekm	-0.3836	-0.4784	-0.5884	-0.6783	-0.6725	-0.7261	-0.8453
(V)	Edt	-0.0031	0.0102	0.0229	0.0358	0.0492	0.0618	0.0763
	Ext	0.0193	0.0326	0.0453	0.0582	0.0716	0.0842	0.0987
	Emt	-0.0003	0.0130	0.0257	0.0386	0.0520	0.0646	0.0791
(VI)	Elt	0.0084	0.0218	0.0344	0.0473	0.0607	0.0733	0.0878
	Ekt	0.0021	0.0155	0.0281	0.0410	0.0544	0.0670	0.0815
(VII)	Etd	-0.0084	-0.0084	-0.0084	-0.0084	-0.0084	-0.0084	-0.0084
	Etx	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140
	Etm	-0.0056	-0.0056	-0.0056	-0.0056	-0.0056	-0.0056	-0.0056
(VIII)	Etl	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032
	Etk	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032
(IX)	μ	0.0053	0.0186	0.0313	0.0442	0.0576	0.0702	0.0847

5.2 Nonstochastic indexes

Table 3 shows the index number estimates obtained from equation (21)-(24), with geometric averages shown in the bottom row. For the period 1968-1998 the average nominal GDP growth rate is 14.17%. Decomposing this nominal economic growth rate into five components, we identify technical change growing at an average 2.9% annual growth rate. This estimate is higher⁸ than that estimated by Young (1995) 2.6% (1966-1990); Liang and Jorgenson(1998) 2.33-2.7%; Fuess and Van den Berg (1996) 2.21-2.44%; Dessus(1999) 2.26% respectively. By dividing $\Gamma_{t,t-1}$ by $P_{Nt,t-1}$, we obtain an annual rate of real net output growth of 8.44%. Technical change then accounts for approximately 35% of real net output growth. Capital accumulation is estimated to be the biggest contributor to growth of output, 41%, as it grew at an annual rate of 3.35%. Labor has also been an important contributor accounting for 25% of this growth while growing at an annual rate of 2.1%. The terms-of-trade have been marginal in contributing to this growth as the evolution in the third column of Table 3 indicates. A graphical representation of this decomposition of economic growth is shown in Figure 1. In this figure we see that capital accumulation has been the most important source of economic growth followed by technological progress.

Looking at individual effects in Table 3 we see that besides the oil crisis years, 1973-1974 and 1979-1981, the domestic price change was mostly smaller than 4% and volatile. The terms of trade effects were half positive and half negative. The growth rates of capital diminished as well as the growth rate of labor. The technical change index oscillated between 2.7% and 7.5% before 1973. After 1973, we see lower rates except for the period 1983-1989.

⁸It may be due to differences in approach, period of analysis and variable sources as these authors estimate this rate from Solow residuals derived from a Cobb-Douglas production function.

Table 3 Taiwan GDP Growth Accounting (1968-1998)-
Nonstochastic, nonparametric indexes

Year	$R_{t,t-1}$	$A_{t,t-1}$	$X_{Lt,t-1}$	$X_{Kt,t-1}$	$P_{Nt,t-1}$	$\Gamma_{t,t-1}$
1968	1.0265	1.0024	1.0265	1.0343	1.0665	1.1652
1969	1.0383	1.0091	1.0158	1.0390	1.0477	1.1586
1970	1.0501	0.9947	1.0280	1.0386	1.0331	1.1522
1971	1.0754	0.9928	1.0231	1.0397	1.0237	1.1626
1972	1.0691	0.9988	1.0303	1.0455	1.0424	1.1991
1973	1.0309	0.9889	1.0477	1.0498	1.1576	1.2980
1974	0.9173	0.9612	1.0187	1.0485	1.4217	1.3391
1975	1.0003	1.0126	1.0130	1.0464	0.9993	1.0729
1976	1.0706	1.0135	1.0266	1.0486	1.0276	1.2002
1977	1.0245	0.9963	1.0432	1.0416	1.0560	1.1714
1978	1.0691	0.9815	1.0354	1.0381	1.0605	1.1961
1979	0.9969	1.0077	1.0246	1.0389	1.1277	1.2060
1980	1.0174	0.9665	1.0197	1.0380	1.1979	1.2469
1981	1.0194	0.9949	1.0161	1.0373	1.1130	1.1897
1982	0.9954	1.0129	1.0142	1.0328	1.0140	1.0711
1983	1.0372	1.0046	1.0237	1.0289	1.0070	1.1053
1984	1.0593	1.0040	1.0246	1.0240	0.9999	1.1157
1985	1.0211	1.0034	1.0124	1.0231	0.9949	1.0558
1986	1.0777	1.0163	1.0270	1.0195	1.0065	1.1542
1987	1.0701	0.9929	1.0278	1.0218	1.0160	1.1337
1988	1.0300	0.9940	1.0121	1.0264	1.0234	1.0884
1989	1.0352	0.9975	1.0145	1.0283	1.0378	1.1180
1990	1.0148	1.0012	1.0077	1.0297	1.0373	1.0935
1991	1.0293	1.0034	1.0164	1.0279	1.0352	1.1169
1992	1.0215	1.0037	1.0184	1.0274	1.0342	1.1095
1993	1.0206	1.0027	1.0121	1.0296	1.0320	1.1006
1994	1.0169	0.9927	1.0172	1.0294	1.0269	1.0855
1995	1.0198	0.9881	1.0109	1.0276	1.0325	1.0809
1996	1.0220	1.0107	1.0068	1.0266	1.0162	1.0850
1997	1.0258	1.0084	1.0160	1.0252	1.0093	1.0874
1998	1.0125	1.0116	1.0132	1.0269	1.0226	1.0898
1968-1998	1.0290	0.9989	1.0207	1.0335	1.0528	1.1417

$R_{t,t-1}$: index of technological change (equation (20)~(23));

$A_{t,t-1}$: terms-of trade adjustment index (equation (26));

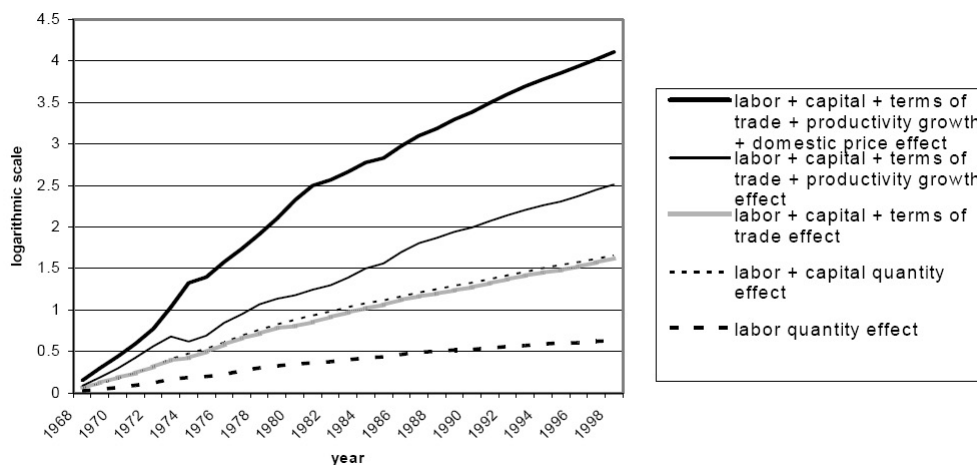
$X_{Lt,t-1}$: labor quantity effect (equation (23));

$X_{Kt,t-1}$: capital quantity effect (equation (23));

$P_{Nt,t-1}$: nontraded good price effect (equation (22));

$\Gamma_{t,t-1}$: nominal GDP growth index (equation (34)).

Figure 1 Accounting for Taiwanese Nominal GDP Growth–Nonstochastic indexes



labor quantity effect ($X_{Lt,t-1}$)

capital quantity effect ($X_{Kt,t-1}$)

terms-of-trade adjustment index ($A_{t,t-1}$)

index of technological change or productivity growth ($R_{t,t-1}$)

nontraded good price effect ($P_{Nt,t-1}$)

nominal GDP growth index ($\Gamma_{t,t-1}$)

5.3 Stochastic Indexes

Using estimated parameters and equations (26)-(32) we can alternatively decompose Taiwan's nominal GDP growth into the same six components in section 2, the difference being the presence of an unexplained residual component. The results are shown in Table 4. Results are similar to what we obtained from the nonstochastic index number approach, with a minor increase in the role of technological innovation still technical change and capital growth account for most of the economic growth and the terms of trade effect seems insignificant. The graphical decomposition for nominal and real economic growth showing the contributions is in Figure 2.

6 Conclusion and Suggestion

Our results show that big part of Taiwan's economic growth was based on input accumulation. Although both inputs show important contributions, it is capital the one with a bigger role. This result though does not diminish the role of technical progress in that evolution. Technical change accounted for a third of real GDP growth of the Taiwanese economy during the period 1968-1998. This estimate is higher than that of several other authors.

This work adds to the literature the impact of changes in the terms-of-trade as a potential factor in explaining the evolution of output growth in a highly open economy as Taiwan's. It does so by presenting three different estimates of this effect along with that of input accumulation and innovations. Our estimates indicate that, given relatively stable terms-of-trade, its impact in explaining GDP growth of the Taiwanese economy has been insignificant relative to that of capital accumulation and technological change.

Table 4 Taiwan GDP growth accounting-Indexes using parametric estimates (1968-1998) (annual rates and geometric averages)

Year	$S_{t,t-1}$	$U_{t,t-1}$	$A_{t,t-1}$	$X_{Lt,t-1}$	$X_{Kt,t-1}$	$P_{Nt,t-1}$	$\Gamma_{t,t-1}$
1968	1.00413	1.01750	1.00247	1.02471	1.04505	1.06234	1.16519
1969	1.00677	1.02177	1.01046	1.01436	1.05134	1.04516	1.15857
1970	1.00950	1.03164	0.99586	1.02527	1.05027	1.03170	1.15220
1971	1.01212	1.05278	0.99420	1.02094	1.05067	1.02308	1.16257
1972	1.01487	1.04441	0.99953	1.02771	1.05653	1.04237	1.19909
1973	1.01758	1.00409	0.99102	1.04525	1.05780	1.15943	1.29804
1974	1.01977	0.88978	0.98307	1.01821	1.05395	1.39892	1.33911
1975	1.02274	1.16111	1.00657	1.01263	1.05142	0.84305	1.07292
1976	1.02560	0.87722	1.01571	1.02533	1.05491	1.21430	1.20022
1977	1.02787	0.99257	0.99780	1.04117	1.04698	1.05559	1.17138
1978	1.03057	1.03264	0.98281	1.03412	1.04201	1.06133	1.19615
1979	1.03334	0.96217	1.00940	1.02399	1.04192	1.12629	1.20597
1980	1.03587	0.97755	0.97697	1.01920	1.04078	1.18817	1.24687
1981	1.03809	0.97995	0.99731	1.01563	1.04033	1.10986	1.18971
1982	1.04400	0.75119	1.28460	1.01379	1.03570	1.01253	1.07105
1983	1.04695	1.26098	0.78895	1.02338	1.03035	1.00640	1.10528
1984	1.04672	1.01169	1.00426	1.02480	1.02389	0.99987	1.11575
1985	1.04977	0.97276	1.00444	1.01275	1.02203	0.99446	1.05578
1986	1.05280	1.01441	1.02517	1.02838	1.01765	1.00731	1.15417
1987	1.05554	1.00319	1.00166	1.03000	1.01873	1.01870	1.13375
1988	1.05802	0.97264	0.99538	1.01328	1.02174	1.02632	1.08840
1989	1.06047	0.97505	0.99945	1.01591	1.02314	1.04077	1.11797
1990	1.06303	0.95817	1.00012	1.00838	1.02426	1.03930	1.09348
1991	1.06578	0.96775	1.00361	1.01778	1.02279	1.03655	1.11694
1992	1.06836	0.95712	1.00533	1.02004	1.02197	1.03536	1.10954
1993	1.07112	0.95819	1.00214	1.01344	1.02247	1.03265	1.10057
1994	1.07411	0.95331	0.99140	1.01948	1.02102	1.02722	1.08545
1995	1.07707	0.95512	0.98629	1.01253	1.01880	1.03269	1.08085
1996	1.08011	0.95279	1.01207	1.00793	1.01690	1.01631	1.08495
1997	1.08325	0.95255	1.00950	1.01929	1.01472	1.00931	1.08741
1998	1.08659	0.93840	1.01416	1.01641	1.01451	1.02203	1.08980
1968-1998	1.04431	0.98374	1.00097	1.02081	1.03392	1.05191	1.14166

$S_{t,t-1}$: index of technological change, secular component (equation (28));

$U_{t,t-1}$: index of technological change, unexplained component (equation(35)~(36));

$A_{t,t-1}$: terms-of trade adjustment index (equation (29));

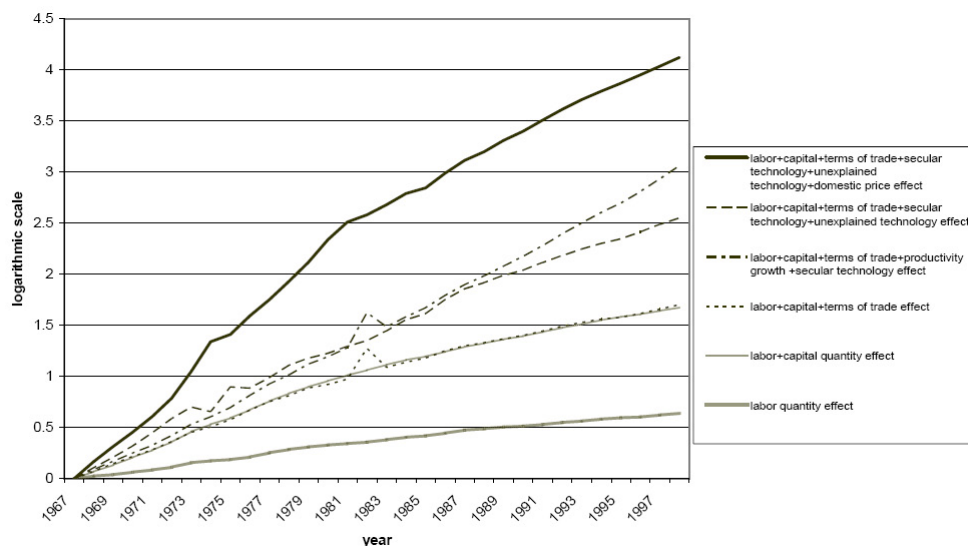
$X_{Lt,t-1}$: labor quantity effect (equation(38));

$X_{Kt,t-1}$: capital quantity effect (equation (38));

$P_{Nt,t-1}$: nontraded good price effect (equation (39));

$\Gamma_{t,t-1}$: nominal GDP growth index(calculated from observed data).

Figure 2 Accounting for nominal GDP growth in Taiwan—Indexes using parametric estimates



labor quantity effect ($X_{Lt,t-1}$);

capital quantity effect ($X_{Kt,t-1}$);

terms-of trade adjustment index ($A_{t,t-1}$);

index of technological change, secular component ($S_{t,t-1}$);

index of technological change, unexplained component ($U_{t,t-1}$);

nontraded good price effect ($P_{Nt,t-1}$);

nominal GDP growth index ($\Gamma_{t,t-1}$).

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