Time Series Econometrics of Growth Models: A Guide for Applied Economists

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Abstract

This paper examines the use of specifications based on the endogenous and exogenous growth models for country specific growth policies. It is suggested that time series models based on the Solow (1956) exogenous growth model are useful and they can also be extended to capture the permanent growth effects some variables. Our empirical results, with data from Fiji, show that trade openness and human capital have significant and permanent growth effects. However, these growth effects are small and eventually converge over time.

JEL: E22, E23, F1, O11

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1. Introduction

There are numerous theoretical and empirical studies on the determinants of growth. Theoretical studies are classified into exogenous growth models and endogenous or new growth models. Empirical studies use either cross-section or time series techniques to estimate these theoretical models. Therefore, from an empirical perspective, there are four types of studies on growth. Firstly, cross-section studies based on the endogenous growth theories are the most prolific variety. Secondly, time series empirical works, based on the exogenous growth theory of Solow (1956) are the second most prolific type. However, many such time series studies give the wrong impression that their specifications are based on the endogenous growth theory. In fact these time series studies use the Solow model without an adequate awareness of its essence. In the Solow model what actually estimated with time series data are the long run Cobb-Douglas production functions and not the long run growth equations. This is so because in the Solow model the long run growth rate is determined by the rate of growth of technological progress (TFP) and its determinants are not known. Thirdly, cross section studies based on the exogenous growth theory are relatively few. The well-known works of Mankiw, Romer and Weil (1992) and its critiques belong to this category. Time series studies based on the endogenous growth theory are of four types viz., (a) Jones' (1995, 1997) calibration techniques to test the predictions of the endogenous growth model, (b) Similarly Kocherlakota and Mu Yi's (1996) use the VAR framework to test the predictions of the endogenous growth models, (c) Greiner, Semler and Gong's (2004) pioneering attempt to estimate the structural parameters of endogenous growth models with time series data and (d) several time series works in which the production function is augmented in an *ad hoc* manner with shift variables like human capital, openness of trade, aid, foreign direct investment and infrastructure expenditure etc. However, it is not clear from this last category whether the estimated long run equation actually is a production function or a growth equation although such studies incorrectly claim that it is the latter. This is important because cointegration techniques are used to estimate only the implied long run relationships in the levels of the variables and not in their growth rates. Furthermore, data with annual frequencies are too short to estimate long run growth equations. In the cross section studies this problem is overcome by using 10 or 20 year average values of the variables although shorter periods of 4 years are also used.

Given the four-fold classification and the fact that a significant effort is necessary to collect data and estimate alternative specifications, it is appropriate for the applied economists to ask which type of theoretical model (endogenous or exogenous?) and which type of data (cross section or time series?) delivers reliable and useable results for an understanding of country specific growth policies.

It may be said that many applied economists do not realize that econometric techniques are mainly tools to summarize data. Often an enormous amount of time is devoted to apply the latest econometric techniques and programmable software. However, as Smith (2000) has pointed out, it is important that applied economists pay adequate attention to the purpose of a study and interpretation of results; see also Rao (2006). There is no point in estimating a set of cross section regressions with a sample of a hundred countries if the purpose is to understand whether overseas development aid has any effect on the growth rate or level of output of Papua New Guinea or Kiribati. This is so because economic and production structures of these countries are vastly different from many in the sample of a large cross section study.

Hoover and Perenz (2005) have pointed out that there are more than 80 potential growth determinants to select for estimating cross section regressions although the theoretical underpinnings for selecting some of these growth determinants are not always clear. Similarly, Easterly, Levine and Roodman (2003), commenting on the quality of specifications in the cross section studies, have observed that “This literature has the usual limitations of choosing a specification without clear guidance from theory, which often means there are more plausible specifications than there are data points in the sample”. Therefore, it is not hard to select a small set of potential growth determinants, often highly trended, to estimate growth equations. It is not uncommon to see many *ad* *hoc* time series works which conclude, in no uncertain terms, that defense expenditure permanently boosts the growth rate or that aid has a permanent growth effects.[1]

Our paper is addressed to the applied economists, working on growth policies for a specific country. However, we do not downgrade the quality and purpose of theoretical and empirical works in the aforesaid four categories. Since many applied economists are mainly interested in policy, rather than in the methodological and theoretical controversies, it would be useful to develop a few pragmatic guidelines to save time and effort. In what follows, we assume that the average applied growth economist is interested in understanding the determinants of output and/or growth of a specific country or a small number of countries. His/her ultimate purpose is to explain to policy makers how the level of output and/or the growth rate can be increased in the short medium and long runs. Since country specific studies need time series data and time series estimation methods, there is no pint in discussing in this paper the relative merits of cross section and time series techniques. The reader may refer to Greiner et. al (2003) on the relevance of time series studies and Jones (1995) and Parente (2001) for the failure of endogenous growth theories to explain time series facts.

This paper is organized as follows. Section 2 discusses the controversy on the merits of the exogenous and endogenous growth theories. Section 3 is on the specification and estimation issues with time series data. Sections 4 and 5 discuss and present empirical results based on the endogenous and exogenous growth models, respectively. Section 5 concludes.

[1] Kocherlakota and Mu Yi (1996) have found that in the USA there is evidence only to support that non-defense structural investment expenditure has any permanent effect on output. Consequently, it is a bold assertion to state that defense expenditure has a permanent effect on the growth rates of some smaller countries.

2. Endogenous and Exogenous Growth

In the Solow (1956) growth model the long run equilibrium growth of output (in per worker terms) is determined by the rate of technical progress (TFP). However, the determinants of TFP are not known although its contribution to growth is as much as 50% in some advanced economies. The Solow (1956) growth model, therefore, is known as the exogenous growth model.

TFP is usually estimated as a residual from the growth accounting framework of Solow (1957) and also known as the Solow residual (SR). In our view SR is more like a measure of our ignorance of the determinants of growth rather than an estimate of the true TFP. An important feature of Solow (1956) model is its final conclusion that, in the long run, per worker income grows only at the rate at which TFP grows *(g)* and an increase in the investment ratio (ratio of investment to output) has no long run growth effects. Extensions to the Solow model, such as Mankiw, Romer and Weil (1992), MRW hereafter, essentially aim to reduce the size of the SR or our ignorance about the determinants of growth.

Endogenous growth theories identify factors on which the Solow residual may depend. In other words, if we conduct a growth accounting exercise with an endogenous growth model, the SR, in principle, should become smaller. The endogenous growth theory has four strands; see Jones (1995). In Romer (1986) externalities cause TFP, in Lucas (1988) TFP depends on human capital, in Romer (1990) and Grossman and Helpman (1991a) creation of knowledge capital (through expenditure on R&D) improves TFP and finally in Barro (1991) public infrastructure investments can increase TFP.

Jones (1995, pp.495-496) points out that, based on these theories, Grossman and Helpman (1991a, 1991b) cite no fewer than ten potential determinants of long-run growth such as physical investment rate, human capital investment rate, export share, inward orientation, the strength of property rights, government consumption, population growth, and regulatory pressure etc. Permanent changes in these variables should lead to permanent changes in growth rates. The main theoretical contribution of the endogenous growth theory is to rationalize these permanent growth effects with an inter-temporal utility optimization model based on microeconomic foundations. In these models consumers determine how income is spent on current consumption and investment for future consumption. The more is the time preference rate and the higher is risk aversion, the less is invested and the less is future consumption. Generally consumers in the developing countries are expected to be more risk averse i.e., the elasticity of inter-temporal consumption substitution is low. Therefore, saving and investment rates are low in the developing countries.

Endogenous growth models not only explain how consumption and investment decisions are made but also how saving is allocated between investment in physical capital, human capital and R&D to increase the stock of knowledge. Therefore, these stock variables have their optimal evolutionary dynamics. However, unlike the diminishing returns on physical capital, returns from the stock of human capital may not decrease rapidly and returns R&D investments may never show diminishing returns because of the non-rivalrous nature of knowledge.

Therefore, in the long run equilibrium, when the rate of growth of physical capital (in per worker value) is zero, i.e., by definition $\Delta \ln k \rightarrow 0$, the rates of growth of the stocks of human capital and knowledge will be still positive. Similarly, the rate of growth of the stock of public infrastructure capital, because of its externalities, may continue to be positive in equilibrium. Consequently, the rate of growth of output depends on the rates of growth in these stocks.

The channels through higher export ratios, trade openness and improvements to the economic environment through institutional reforms and responsible macroeconomic policies are more indirect and influence the growth rate through various channels. For example, secure property rights may encourage higher investments in physical, human and knowledge capital. These effects are possible if institutional reforms decrease rent seeking practices and the risk aversion nature of consumers. Trade openness and higher export ratios may induce firms to become more competitive and adopt improved technologies. Furthermore, they may also impinge on growth through a variety of linkage effects. Thus the main difference between the endogenous and exogenous models is that the long run growth rate in the former could be influenced through a variety of appropriate policies including subsidies to encourage e.g., investments in R&D, education and health etc.

Therefore, the connection between the exogenous and endogenous growth models can be explained, in a simple way, with the following Cobb-Douglas production function augmented with knowledge capital *(NK)* as in the Romer (1990) and Grossman and Helpman (1991a) type of models. The augmented Cobb-Douglas production function with constant returns to capital and labour but with constant or increasing returns to knowledge capital is:

$$Y_t = C(NK)_t^{\gamma} K_t^{\alpha} L_t^{1-\alpha} \qquad (1)$$

where Y is output, NK is knowledge capital with $\gamma \geq 1$, K is physical capital and L is labour and C is an arbitrary constant. Taking the logs of the variables and expressing the variables in their first differences gives:

$$lnY_t = lnC + \gamma \ln NK_t + \alpha lnK_t + (1-\alpha) lnL_t \qquad (2)$$

Therefore

$$\Delta lnY_t = \gamma \Delta \ln NK_t + \alpha \Delta lnK_t + (1-\alpha) \Delta lnL_t \qquad (3)$$

The endogenous growth models argue that knowledge is non-rivalrous and it need not be subject to diminishing returns i.e., $\gamma \geq 1$. In the long run steady state equilibrium, the rate of growth of physical capital becomes zero. This is due to the diminishing marginal productivity of capital $(\alpha < 1)$. When the productivity of capital equals the rate of return on capital (which in turn equals to the rate of time preference and the real rate of interest), the rate of growth of per worker income equals the rate of growth of knowledge capital, i.e.,

$$\begin{aligned} \Delta lnY_t - \Delta lnL_t &= \gamma\Delta \ln NK_t + \alpha(\Delta lnK_t - \Delta lnL_t) \\ \Delta \ln y_t &= \gamma\Delta \ln NK_t + \alpha\Delta \ln k_t \\ \Delta \ln y^*_t &= \gamma\Delta \ln NK_t \quad \text{as } \Delta \ln k^*_t \to 0 \qquad (4) \end{aligned}$$

An asterisk indicates equilibrium value of the variable and lower case letters are in per worker units. Therefore, output growth continues as long as $\Delta NK > 0$.

The long run growth implications of the Solow exogenous growth model can be also derived from the above by reformulating the production function (1) by assuming that the stock of knowledge grows at a constant rate of g per period. The production function, therefore, is:

$$\begin{aligned} Y_t &= A_0 e^{gt} K_t^{\alpha} L_t^{1-\alpha} \qquad (1a) \\ \therefore lnY_t &= \ln A_0 + gt + \alpha lnK_t + (1-\alpha)lnL_t \qquad (2a) \\ \Delta lnY_t &= g + \alpha\Delta lnK_t + (1-\alpha)\Delta lnL_t \qquad (3a) \\ \Delta \ln y^*_t &= g \quad \text{as } \Delta \ln k^*_t \to 0 \qquad (4a) \end{aligned}$$

where, A_0 is the initial stock of knowledge which is assumed to grow at a rate of g per period. The main difference between the long run growth implications of these two models is that while in the endogenous growth models, the long run growth determinants are known, e.g., *NK*, in the Solow model TFP is simply assumed to evolve over time at a rate of g. This implies that whatever are the determinants of TFP in the exogenous growth model they are likely to be highly trended whereas in the endogenous model this is not the case and long run growth may be improved through appropriate policies.

The relative merits of the exogenous and endogenous growth models did not receive much attention until recently. It is generally assumed that the endogenous growth theories are superior because of their underlying optimization models are based on the microeconomic foundations, which in turn rationalize the inclusion of one or another variable in the empirical specifications.[2] However, theoretical criticisms have been leveled against endogenous growth models because the implied increasing returns in the production function is not consistent with the perfect competition assumptions. Therefore, it is necessary for these optimization model to assume that markets are imperfectly competitive. Such optimization models with imperfect markets are a difficult to solve and generally do not give unique equilibrium solutions. This is obvious from the debate on the Keynesian models based on micro foundations i.e., the new and neo Keynesian models. According some Keynesians there are now as many Keynesian models as the number of the new and neo Keynesians. Therefore, it is difficult to develop acceptable theoretical generalizations

Empirical reservations on the endogenous growth models are more frequent. It is well known that the MRW (1992) extension to the Solow model has considerably improved its fit to the cross section data of some 80 countries. Human capital augmented Solow model, with its simpler assumptions of competitive markets and constant returns, could explain as much as 80% of the variation in the growth rate, thus reducing SR significantly from about 50% to 20%.

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[2] The importance of the optimization framework, based on microeconomic foundations, can be explained as follows. It is not hard to imagine that the demand for a good depends on its price. Nevertheless, we need the constrained utility maximization framework not only to justify that price of a good is an important explanatory variable but also for insights into other important determinants of demand. Endogenous growth theory is important for this reason. In its absence, one can pick up, in an *ad hoc* manner, a handful of growth determinants to show that output growth depends on any set of arbitrary variables.

Other critiques of endogenous growth models are Jones (1995) and Parante (2003). Jones pointed that long run time series data do not corroborate the predictions of the endogenous growth models. Although expenditure on education and R&D and factors like trade openness are increasing in the advanced countries, there is no evidence that the growth rates in these economies are increasing proportionately. Jones (1995, p. 496) observed that lack of persistence in the growth rate can only be explained by "…either by some astonishing coincidence all of the movements in variables that can have permanent effects on growth rates have been offsetting, or the hallmark of the endogenous growth models, that permanent changes in policy variables have permanent effects on growth rates, is misleading".

Parante (2001) in a thought provoking paper *The Failure of Endogenous Growth* is critical of the empirical relevance of the endogenous growth models. He says that endogenous growth models do not explain why poor countries are not utilizing the existing stock of knowledge to improve their growth rates. What he means is that there are other factors and barriers resisting the exploitation of knowledge. This could be due to political power of certain vested interests. For example, historically, many trade unions have prevented the use of more efficient but less labour intensive technologies. In India bank workers have prevented the use of ICT for many years in the late 1980s. Parente gives some historical examples of such barriers. His criticisms complement Jones' criticisms and imply that endogenous growth models neither explain the growth experiences of the developed nor the developing countries.

Solow (2000, p. 153) observed that the popularity of the endogenous growth models is likely to decline. According to him

> "The second wave of runaway interest in growth theory—the endogenous growth literature sparked by Romer and Lucas in the 1980s, following the neoclassical wave of the 1950s and 1960s—appears to be dwindling to a modest flow of normal science. This is not a bad thing. The alluring prospect of a viable (predictive) endogenous growth theory does not seem to be a whole lot closer now than it was at the beginning of the wave."

In light these criticisms and observations we may say that endogenous growth models do not seem to have an unquestionable claim that they are better than exogenous or extended exogenous growth models to explain growth experiences of many countries.

3. Country Specific Time Series Models

In the country specific time series growth models proper specification and techniques of estimation are important. Given the aforesaid reservations about the relevance of endogenous growth models, the alternatives is specifications based on the Solow model and its extensions. However, many applied time series studies do not explicitly state how their specifications are derived.

An important issue, irrespective of which theory is used for the derivation of the specifications, is that annual periods are not long enough for the economy to reach equilibrium steady states. For example simulation results with the Sato (1963) closed form solution indicate that an economy may take more than 40 or 50 periods to converge to its long run equilibrium growth rate; see Rao (2006). Therefore, choice of the steady state specifications in equations (4) or (4a) are inappropriate for time series studies with annual frequencies because it is difficult to imagine that an economy reaches equilibrium within a year. This calls for the use of the non-steady state specifications in equations (3) and (3a). However, since many time series macro variables are likely to be non-stationary in their levels, specifications in the first difference forms of the variables in equations (3) and (3a) may yield unreliable and inefficient estimates because valuable information on the levels of these variables in equations (2) and (2a) is ignored.

Assuming that all the variables in a specification are I(1) in levels and I(0) in their first differences, the appropriate specifications based on the endogenous and exogenous growth theories, respectively, are as follows. For simplicity we assume that the growth enhancing variable in the endogenous growth model and the augmented Solow model is the stock of human capital *Z*. Furthermore, for convenience, we use specifications based on the general to specific approach (GETS) of Hendry. The endogenous and exogenous growth based specifications take the following forms.

Endogenous Growth

$$\Delta \ln y_t = -\lambda(\ln y_{t-1} - (a_0 C + \gamma \ln Z_{t-1} + \alpha \ln k_{t-1}))$$
$$\sum_{i=1}^{n1} m_i \Delta \ln y_{t-i} + \sum_{i=0}^{n2} n_i \Delta \ln Z_{t-i} + \sum_{i=0}^{n3} j_i \Delta \ln k_{t-i} + \varepsilon_{1t} \qquad (5)$$

Exogenous Growth (MRW Specification)

$$\Delta \ln Y_t = -\lambda(\ln Y_{t-1} - (a_0 C + gt + \alpha \ln K_{t-1} + \beta \ln Z_{t-1} + (1-\alpha-\beta)\ln L_{t-1}))$$
$$\sum_{i=1}^{n1} m_i \Delta \ln Y_{t-i} + \sum_{i=0}^{n2} n_i \Delta \ln Z_{t-i} + \sum_{i=0}^{n3} j_i \Delta \ln K_{t-i}$$
$$+ \sum_{i=0}^{n4} v_i \Delta \ln L_{t-i} + \varepsilon_{2t} \qquad (6)$$

where lower case variables are in per worker units and es are white noise errors. Equation (6) can also be given alternative specifications by multiplying capital and labour with indices of their quality as suggested by Caselli and Wilson (2003).

Some features of these specifications are noteworthy. Firstly, these are the short term dynamic equations, incorporating the famous error correction adjustment process (ECM) of Phillips (1951). This adjustment process has been borrowed and used by other time series methods based on the cointegration techniques. Secondly, the dependent variable is the rate of change of output, giving the misleading impression that it is a kind of long run growth equation. Often many applied economists interpret these short run dynamic equations as growth equations and draw conclusions, e.g., aid has a certain impact on the rate of growth output. Thirdly, in these specifications what is estimated is the long run relationship in the levels of the variables of the production function. This can be clearly seen from the ECM where the cointegrating equation is normalized on output. Therefore, when the coefficient of Z is significant, we can say that Z affects the level of output in the long run and not necessarily the rate of growth of output. Fourthly, the specification must include the two basic conditioning variables viz., capital and labour. Many applications ignore these conditioning variables in their specifications. This would cause serious misspecification errors and yield unreliable effects for Z on output. Finally, there are differences in how an additional output enhancing shift variable like Z is introduced into the two types of models. In the endogenous growth specification, Z is simply added as if it is an intercept shift variable and its coefficient is unconstrained. In the exogenous growth specification, Z is also an intercept shift variable, but its coefficient is constrained to be less than unity implying that that there diminishing returns. But for these differences, they seem to be observationally equivalent. However, in deriving the steady state growth implications, there is a difference. In the endogenous growth equation, there is no time trend and in the steady state $\Delta \ln Z$ need not be zero and the rate of growth of per worker income equals the rate of growth of Z. In the specification based on the exogenous growth model, the steady state value of $\Delta \ln Z = 0$ and $\Delta \ln L = n$, and per worker income grows at the rate g which is exogenous. The implicit expectation in extending the Solow model is that if an adequate number of variables like Z are incorporated as shift variables into the production function, the coefficient of trend may become very small and even insignificant. If so, our measure of ignorance about the determinants of growth will become negligible. Thus the main difference between these two theoretical growth models, at least from an empirical perspective, is that while variables like Z have only permanent level effects on output in the exogenous growth models, such variables will have permanent growth effects in the endogenous growth models.

There seem to be problems with both types of specifications in equations (5) and (6). As Jones (1995) has pointed that, time series evidence is not consistent with the implications of the endogenous growth models. Although variables like Z have shown an upward trend, there is no such upward trend in the rate of growth of output. To overcome this limitation, one may introduce non-linear effects for Z. The following specification which abstracts from the ARDL variables for simplicity, illustrates such a modification.

Endogenous Growth

$$\Delta \ln y_t = -\lambda(\ln y_{t-1} - (a_0 C + \gamma_1 \ln Z_{t-1} + \gamma_2 (\ln Z_{t-1})^2 + \alpha \ln k_{t-1})) \tag{7}$$

For this equation to make sense $\gamma_2 < 0$ and $\gamma_1 > 0$, so that $\ln Z$ has its maximum effects on the level of output when $\ln Z = 0.5(\gamma_1 / \gamma_2)$. Z would have permanent and positive but declining growth effects until $\ln Z = 0.5(\gamma_1 / \gamma_2)$. These positive growth effects can only occur in the steady state, i.e., when $\Delta \ln k = 0$, if ΔlnZ>0. In the applied work, based on the endogenous growth models, it is generally assumed that $\Delta \ln Z > 0$ in the steady state and therefore Z has a permanent and decreasing growth effect until it reaches a critical value where $\ln Z = 0.5(\gamma_1 / \gamma_2)$.

Greiner et. Al. (2003) suggest that a trend variable, to capture the effects of other neglected (trended) variables, may be added to the endogenous models and this implies that

$$\Delta \ln y_t = -\lambda(\ln y_{t-1} - (a_0 C + gt + \gamma \ln Z_{t-1} + \alpha \ln k_{t-1})) \tag{8}$$

Equation (8) is observationally the same as the specification in (6) of the exogenous model. Furthermore, the steady state implications of the endogenous and exogenous growth models will be the same provided the steady state equilibrium is defined as the same in both models i.e., $\Delta \ln k = 0$ and $\Delta \ln Z \neq 0$. The only difference could be in the endogenous model γ need not be less than unity.

The way the Z variable is introduced into the Solow model retains its simplifying assumptions that there are constant returns and competitive markets. However, it becomes difficult to add additional shift variables into the Solow model unless such variables have a direct effect on the quality and productivity of labour and/or capital. For example, it is easy to include expenditure on health, the proportion of imported capital equipment and the age of capital stock etc., into the Solow model because they have implications for the measurement of these inputs. However, it is hard to add trade openness as a shift variable because it is not obvious how it can be introduced as a multiplicative variable with labour and/or capital or as an additional intercept shift variable.

In contrast it is easy to introduce such shift variables (with linear or non-linear effects) into the endogenous specification by simply treating *Z* as a vector of some potential shift variables. In fact such augmented specifications based on the endogenous growth model are popular in the applied work. However, in a number of such applications the two conditioning variables, capital and employment, are ignored. Although these studies make significant efforts to collect data on difficult to measure variables like political freedom, rule of law, institutional reforms and corruption etc., for which consistent time series data on an annual basis barely exist, they ignore the need to estimate data on the two basic inputs of the production function.[3] Since the two conditioning variables are ignored while estimating the growth effects of some selected variables, it may be said that such studies have limited use for policy due to misspecification biases.

Since the methodological and empirical criticisms on the endogenous growth models are not yet resolved satisfactorily, it is worth examining how the simpler and less controversial Solow model can be modified to estimate the effects of additional growth enhancing shift variables. We suggest the following empirical procedure.

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[3] This criticism is also applicable to the cross section studies where variables are averaged over shorter periods e.g., 4 years because it is difficult to imagine that an economy reaches its steady state in 4 years. See for example Burnside and Dollar (2000) where 4 year growth rates are used to capture the effects of aid on growth. When Easterly, Levine and Roodman (2003) have used 8 year growth rates the effect of aid on growth became insignificant.

In some time series studies there is awareness that what is estimated is the long run production function. However, often capital stock is proxied with the investment ratio. Fenny (2005), for example, in an elaborate study with 7 or 8 variables to analyze the effects of aid on the growth of output in Papua New Guinea, proxied capital and labour, respectively, with the investment ratio and a time trend, but their coefficients turned out to be negative. This is not to pillory this author and this study cited because it is one of a few systematic studies of this type.

Firstly, such additional variables can be introduced, in their first differences, as additional ARDL terms into equation (6). If a number of these lagged first differences are significant, it is an indication that they may also have a permanent level or growth effect. Secondly, it seems relatively less complicated to test if these variables have any permanent growth effects. The weakness of the exogenous growth model is that it is not clear how it can be extended to capture permanent growth effects of some growth inducing variables. If the endogenous growth theories are seen as rationalizations that certain variables and policies have permanent growth effects, the rate of growth in the exogenous model can be made, at least from an empirical perspective, a function of the growth variables identified in the endogenous growth models. For this purpose, the production function in (1a) can be modified as follows.[4]

$$Y_t = A_0 e^{[g_1 + g_2 Z]t} K_t^{\alpha} L_t^{1-\alpha} \qquad (9)$$

where, for simplicity, g is now assumed a function of a growth promoting shift variable *Z* and also some unknown trended variables proxied with time. The *Z* variable could be variables like trade openness or aid etc., or a vector of some growth improving variables. The implications of this modification are as follows.

$$lnY_t = \ln A_0 + (g_1 + g_2 Z_t)t + \alpha lnK_t + (1-\alpha) lnL_t \qquad (10)$$

$$\Delta lnY_t = [g_1 + g_2(\Delta Z_t t + Z_t)] + \alpha \Delta lnK_t + (1-\alpha)\Delta lnL_t \qquad (11)$$

$$\Delta \ln y_t = [g_1 + g_2(\Delta Z_t t + Z] + \alpha \Delta \ln k_t \qquad (12)$$

$$\Delta \ln y^* = g_1 + g_2 Z \quad \text{as } \Delta \ln k_t \text{ and } \Delta Z \to 0 \qquad (13)$$

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[4] A similar interest was shown by Senhadji (2000) in the determinants of the level of TFP, but not its growth rate. However, he has used cross country data where the level of TFP relative to its level in the US was explained with initial conditions (ratio of initial level of TFP to the US level), external shocks, macroeconomic environment, the trade regime, and political stability. Favorable external environment, good macroeconomic management, social harmony and political stability are all associated with higher levels of TFP.

Let *Z* be trade openness. The above implies that in the long run equilibrium growth rate in the more open countries will be higher. There seems to be ample empirical evidence from cross section empirical work to support this implication. Furthermore, it is also easy to extend this to allow for non-linear effects. For example consider the following non-linear variant of our approach.

$$Y_t = A_0 e^{\left[a_1 - \frac{a_2}{Z}\right]t} K_t^{\alpha} L_t^{1-\alpha} \qquad (14)$$

If *Z* is R&D expenditure, equation (14) implies that growth rate will not perpetually increase with ever increasing R&D expenditure. In our empirical work we found that this non-linear specification is very useful to capture the growth effects of openness and human capital in a developing country like Fiji.

A major problem with these extensions to the exogenous growth model is that if several trended variables are selected in place of a single *Z* variable, co-linearity between the variables will be accentuated because they are multiplied with the trend variable. In such instance the principal component of the variables could be used. This can be done after testing for the growth effects of some selected variables, one at a time, so that variables that have insignificant growth effects can be ignored.

4. Empirical Results with Endogenous Model

For illustration we shall estimate the effects of trade openness on the growth of output in Fiji. First, we estimate a baseline specification of output using data for the period 1972-2002. Definitions of the variables and data sources are in the Appendix. This baseline specification is the same as in equation (5) but without the *Z* variable. Estimates with the non-linear two-stage instrumental variable method (NL2SLS-IV) of this equation is in column 1 of Table-1. The dummy variable *COUP* captures the effects of political coups

TABLE-1
Endogenous Growth Specifications
Dependent Variable $\Delta \ln y$ (1972-2002)

	1	**2**	**3** TRADE	**4** HKI	**5** TRADE & HKI
INTERCEPT	-3.328 [0.00]	-3.255 [0.00]	-3.035 [0.00]	-3.296 [0.00]	-3.162 [0.00]
λ	-1.081 [0.00] (4.164)	-1.379 [0.00] (9.878)*	-1.276 [0.00] (8.824)*	-1.394 [0.00] (10.164)*	-1.322 [0.00] (14.289)*
T	0.006 [0.00]	0.006 [0.00]	0.005 [0.03]		
$\ln TRADE_{t-1}$			0.160 [0.07]		0.089 [0.00]
$\ln HKI_{t-1}$				0.219 [0.00]	0.161 [0.00]
$\ln k_{t-1}$	0.221 [0.00]	0.230 [0.00]	0.255 [0.00]	0.205 [0.00]	0.232 (c)
$\Delta \ln k_{t-1}$	0.413 [0.00]	0.460 [0.00]	0.496 [0.00]	0.631 [0.00]	0.601 [0.00]
$\Delta \ln HKI_{t-1}$				0.385 [0.00]	0.282 [0.02]
$COUP$	-0.0265 [0.01]	-0.010 [0.00]	-0.0383 [0.40]	-0.028 [0.02]	-0.019 [0.13]
$DUM95$		0.046 [0.00]	0.034 [0.01]	0.045 [0.00]	0.041 [0.00]
$\bar{R}^2$	0.704	0.763	0.729	0.702	0.719
Sargan's χ^2	6.54 [0.257]	5.763 [0.330]	4.051 [0.774]	3.075 [0.878]	2.586 [0.921]
SEE	0.032	0.029	0.031	0.032	0.032
$\chi^2(sc)$	0.812 [0.367]	0.201 [0.654]	0.063 [0.801]	0.792 [0.374]	0.947 [0.331]
$\chi^2(ff)$	0.000 [0.992]	0.104 [0.747]	0.626 [0.429]	0.295 [0.587]	0.007 [0.935]
$\chi^2(n)$	1.038 [0.595]	0.862 [0.650]	0.339 [0.844]	0.129 [0.938]	1.292 [0.524]

Notes: p-values (White adjusted) are in the square brackets. t-ratio for the adjustment coefficient ? is shown in the brackets. Rejection of the null hypothesis of no cointegration at the 5% level is denoted with an asterisk. Critical values are from Ericsson and MacKinnon (2002).

in Fiji. A variant of this equation, with an additional shift dummy, is in column 2. *DUM95* captures the effects of the tax incentives given to boost investment and exports from 1995. These two equations are well determined and all the coefficients are significant. Their summary Chi-square test statistics indicate that there is no serial correlation, functional form misspecification and non-normality in the distribution of the residuals. Sargan's Chi-square test is insignificant at the 5% level indicating that our choice of instruments is appropriate.[5]

These two equations give close estimates and imply that the share of profit income is about 23% of the GDP which is a plausible estimate for Fiji where unions are strong and government is the major employer. We prefer the equation in column 2 as our baseline equation because the Ericsson and MacKinnon (2002) cointegration test shows that there is cointegration between the levels of the variables at the 5% level of significance. The estimated rate of growth of TFP is indeed very small at about 0.5% and close to the value of 0.7% from the growth accounting exercise with stylized values for factor shares.[6] The average rate of growth of total output during the sample period in Fiji was 3%, implying that about 85% of Fiji's growth was due to factor accumulation.

The above results indicate that there is some scope for increasing the growth rate in both the short and long runs. The short run growth rate can be increased by increasing factor accumulation i.e., by increasing the investment ratio. This policy option should not be underestimated. Simulations with the Sato (1963) closed form solution showed that these short run growth effects last for more than a decade.[7] However, to increase the long run

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[5] We have used the lagged values of the variables as instruments. In addition an intercept and trend are also included.

[6] These growth accounting results in Rao, Sharma, Singh and Lata (2006).

[7] The Sato closed form solution for the level of output in the Solow (1956) model is

$$Y_t = A_0 e^{gt} L_0 e^{nt} \left[\frac{s}{n+g+\sigma} (1 - e^{(1-\lambda t)}) + \left(\frac{Y_0}{A_0}\right)^{[(1-\alpha)/\alpha]} e^{-\lambda t} \right]^{\frac{\alpha}{1-\alpha}}$$

growth rate, it is necessary to formulate policies to increase the rate of growth of TFP. For this purpose we first estimate the specifications based on the endogenous growth model from equation (5) and identify the extent to which openness of trade and human capital contribute to the long run growth rate.

We first estimated this equation with the trade openness variable. Although there is no trend in equation (5), trend is included, following Greiner *et. al* (2003), to captures the effects of other missing variables in the equation. These estimates are in column 3 of Table-1 and are impressive since all the summary statistics are satisfactory. However, the coefficient of the openness variable ($\ln TRADE$) is significant only at the 7% level. This equation implies that a 10% increase in trade openness permanently contributes 1.6% to the growth rate. Since the coefficient of the trend variable remained significant at 0.0046, which is only marginally less than its value of 0.0055 in the baseline equation in column 2, there may be some other potential growth inducing variables the effects of which might have been captured by trend.

We have added to the openness variable, two other potential growth inducing variable viz., an index of human capital and life expectancy. While the coefficient of human capital was positive and significant, the coefficient of life expectancy was negative and insignificant. Therefore, we have re-estimated this equation first with human capital (*lnHKI*) and then with both human capital and openness. In the latter equation the coefficients of *lnTRADE* and *COUP* were not significant even at the 10% level. This is partly due to the high correlation of 0.881 between *lnTRADE* and *lnHKI*. In order to gain some efficiency, we have re-estimated this equation by constraining the coefficient of capital is 0.232, which was its estimated value in the unconstrained equation. Estimates

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where Y is output, s is investment ratio, A_0 is the stock of knowledge at the beginning of the period, L_0 is employment at the beginning of the period, a is the exponent of capital in the Cobb-Douglas production function with constant returns (see footnote 1), $\lambda = (1-\alpha)(n+g+\delta)$, n is growth of employment, g is growth rate of technical progress, s is the rate of depreciation of capital and $t = 0 \cdots t$ is time. Simulations with the closed form solutions are in Rao, Sharma, Singh and Lata (2006).

with human capital and trade openness and human capital are in column 4 and 5, respectively, of Table-1.

Both equations are well determined and all the coefficients, except *COUP* in column 5 (significant at only 13% level) are significant at the 5% level. The Ericsson and MacKinnon (2003) test indicates that there is cointegration at the 5% level in both equations. The Chi-square test statistics indicate that there is no serial correlation, functional form misspecification and non-normality in the distribution of the residuals. Sargan's Chi-square test is insignificant at the 5% level indicating that our choice of instruments is appropriate.

Comparison of the equations with only one growth inducing variable, of columns 3 and 4 with the equation with two growth inducing variables in column 5 shows that the growth effects of trade openness and human capital index seem to be over-estimated when only one of these variables is included in the specification. Due to the high correlation between these two variables, inclusion of only one variable may be partly capturing the effects of the other missing variable. Estimates in column 5, where the coefficient of capital is constrained at 0.232 to its value in the unconstrained equation show that the permanent growth effects of openness has decreased from 0.160 in column 3 to about 0.09 in column 5. Similarly, the permanent growth effects of human capital have also declined from 0.219 in column 4 to 0.161 in column 5. Human capital also has a one time high short run growth effect of 0.282. However, it is doubtful if this estimate is reliable because $\Delta \ln HKI_{t-1}$ may be capturing the dynamic effects of some other missing variables. In both equations of columns 4 and 5 the coefficient of trend was insignificant and therefore these equations are estimated without the trend variable. Due to co-linearity between trade openness and human capital, it is hard to say that their individual growth effects are accurately captured by the equation in column 5. Nevertheless, their coefficients give some indication that the growth effects of human capital are almost twice the growth effects of trade openness.[8] This equation implies that a 10% increase in

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[8] The restriction could not be rejected by the Wald test. The computed test statistic with the p-value in the square brackets is $?^2(1) = 0.0244$ [0.876].

both openness and human capital will permanently increase the growth rate by 2.5% and this effect seems to be rather on a high side.

5. Empirical Results with the Extended Exogenous Model

Estimates with the extended specification, based on the endogenous growth model, are in Table-2. In column 1, human capital index is introduced into the production function as in the MRW (1992) model, with the constraint that there are constant returns to capital per worker and the index of human capital. Although its summary Chi-square statistics are insignificant at the 5% level indicating the tests on the residuals are satisfactory, the coefficient of trend is high and negative at -0.022. Furthermore, the adjusted R^2 of this equation is low at 0.299 and the Ericsson and MacKinnon (2003) cointegration test shows that there is no cointegration between the levels of the variables.

Estimates with the trade openness variable, in linear and non-linear forms are in columns 2 and 3, respectively, of Table-2. Compared to the MRW specification with human capital, there are significant improvements in these equations. Their summary Chi-square statistics are insignificant at the 5% level and the Ericsson and MacKinnon test shows that there is cointegration between the levels of the variables. All the coefficients, except *COUP*, are significant at the 5% level. The coefficient of *COUP* is significant at the 10% level in column 2 but insignificant in the non-linear specification in column 3. The linear specification implies that trade openness has a small but a significant permanent growth effect on output. A 10% increase in trade openness improves growth rate by 0.02% and this is much less than the growth rate of 1.6% implied by the endogenous model. The non-linear version of this equation implies that these growth effects taper off as the openness variable increases. The adjusted R^2 of these two equations are close at 0.75 and much higher than 0.299 in the MRW specification.

TABLE-2

Exogenous Growth Specifications
Dependent Variable $\Delta \ln y$ (1972-2002)

	1 MRW equation	**2** Trade Liner effect	**3** Trade Non-liner	**4** **HKI** Liner	**5** **Trade & HKI** With PC1(L)	**6** **Trade & HKI** With PC1(NL)
INTERCEPT	-3.290 [0.00]	-3.118 [0.00]	-2.957 [0.00]	-3.070 [0.00]	-3.164 [0.00]	-3.014 [0.00]
λ	-0.914 [0.02] (3.45)	-1.431 [0.00] (11.22)*	-1.354 [0.00] (12.60)*	-1.448 [0.00] (11.00)*	-1.447 [0.00] (10.50)*	-1.426 [0.00] (10.76)*
T	-0.022 [0.00]	0.005 [0.02]	0.013 [0.00]	0.004 [0.00]	0.005 [0.01]	0.014 [0.00]
$\ln TRADE_{t-1} \times T$		0.002 [0.05]				
$(\ln TRADE_{t-1})^{-1} \times T$			-0.008 [0.04]			
$\ln HKI_{t-1}$	0.778 (Constrained)			0.004 [0.00]		
$\ln PC_{t-1} \times T$					0.002 [0.08]	
$(\ln PC_{t-1})^{-1} \times T$						-0.009 [0.03]
$\ln k_{t-1}$	0.222 [0.00]	0.243 [0.00]	0.282 [0.00]	0.255 [0.00]	0.230 [0.00]	0.266 [0.00]
$\Delta \ln k_{t-1}$	0.823 [0.00]	0.460 [0.00]	0.452 [0.00]	0.531 [0.00]	0.522 [0.00]	0.641 [0.00]
$\Delta \ln HKI_{t-1}$	0.610 [0.02]			0.192 [0.00]		
$\Delta \ln PC_t$					0.241 [0.00]	0.286 [0.00]
$COUP$	-0.039 [0.01]	-0.020 [0.09]	-0.010 [0.37]	-0.030 [0.00]	-0.034 [0.00]	-0.040 [0.01]
$DUM95$	0.028 [0.00]	0.043 [0.00]	0.039 [0.01]	0.044 [0.00]	0.043 [0.00]	0.041 [0.00]
$\bar{R}^2$	0.299	0.778	0.751	0.784	0.808	0.782
Sargan's χ^2	6.010 [0.538]	6.864 [0.551]	4.565 [0.803]	5.874 [0.661]	6.249 [0.696]	4.122 [0.766]
SEE	0.050	0.028	0.030	0.028	0.026	0.028
$\chi^2(sc)$	1.646 [0.199]	0.008 [0.930]	0.300 [0.584]	0.236 [0.627]	1.203 [0.273]	0.048 [0.827]
$\chi^2(ff)$	1.042 [0.307]	0.000 [0.992]	0.216 [0.642]	0.005 [0.942]	0.008 [0.929]	0.209 [0.647]
$\chi^2(n)$	0.414 [0.813]	0.726 [0.696]	0.005 [0.998]	0.971 [0.324]	1.594 [0.451]	0.615 [0.266]

Notes: p-values (White adjusted) are in the square brackets. t-ratio for the adjustment coefficient ? is shown in the brackets. Rejection of the null hypothesis of no cointegration at the 5% level is denoted with an asterisk. Critical values are from Ericsson and MacKinnon (2002).

When the growth effects of human capital with the linear specification are estimated the coefficients of trend and $lnHKI_{t-1}$ were very close, but both were insignificant even at the 10% level. The estimates of these two coefficients were 0.0034 and 0.0037 respectively. Therefore, this equation is re-estimated with the constraint that these two coefficients are equal and the constrained estimate is given in column 4 in Table-2. This equation implies that a 10% increase in the human capital index will have a small but significant permanent growth effect of 0.04% on output. While the growth affect of human capital is twice of trade openness, it is much less than the 2.2% effect implied by the equation of the endogenous growth model.

In the non-linear version with human capital, the coefficient of $(1/lnHKI_{t-1})$ was insignificant even at the 10% level. A constrained estimate where the coefficient of capital was set at its value in the unconstrained equation did not improve the significance of the non-linear term. Therefore, it is not possible to test if the growth effects of human capital eventually taper off. This is not important because the growth effects of human capital are very small.[9]

When both human capital and trade variables are included in a linear form, the coefficient of neither was significant and the coefficient of human capital was negative. This may be due to co-linearity which is accentuated because both variables are now multiplied with trend. Therefore, we have used the first principal component (ln*PC*) of these two variables to estimate their joint growth effects. Estimates with the linear and non-linear versions with *lnPC* are, respectively, in columns 5 and 6 of Table-2. All the coefficients, except that of $\ln PC_{t-1} \times T$ in column 5 (significant at 10% level), are significant at the 5% level. The summary Chi-square statistics in both equations are insignificant at the 5% level. The Sargan Chi-square test validates the choice of instrumental variables and the Ericsson and MacKinnon test shows that the variables in their levels are cointegrated.. The adjusted R^2 of both equations are high at 0.808 and 0.782 respectively. Thus these

[9] When *HKI* is used instead of its log value, the constrained estimate of this equation where the coefficient of capital is set to its value in the unconstrained equation implied that these growth effects of 0.004 taper off and converges to 0.009.

two equations are well determined. The linear equation in column 5 implies that a 10% increase in *PC* will permanently increase the growth rate of output by 0.02%. Although these growth effects are small, it should be noted that they are significant. The non-linear equation in column 6 implies that as *lnPC* increases, its growth effects eventually converge to 1.3%. In 2002, $\ln PC = 1.6334$. The linear equation implies that human capital and trade openness have added about 0.296% to the 2002 growth rate of 1.6% in output per worker which is about 18%.[10] The balance of the growth rate was due to factor accumulation and the short run effects of changes in capital per worker and *lnP*C.

Comparisons between the equations based on the endogenous and exogenous growth theories give the impression that the explanatory powers of both types of equations are close. However, when the two equations that capture the growth effects of both human capital and trade openness are compared, the adjusted R^2 of 0.808 of the equation based on the exogenous growth model in Table-2 is 40% higher than 0.702 of the equation based on the endogenous growth model.[11] The non-nested hypothesis tests showed that the Akaike Information Criterion and Schwarz Bayesian Criterion favour the equation based on the exogenous growth model.[12] Furthermore, it is hard to accept the implication of the equation based on the endogenous growth model that that a 10% increase in human capital and trade openness will increase the growth rate of output permanently by 2.5%. In contrast, the equation based on the exogenous growth model implies a permanent growth effect of only 0.3% and this effect eventually converges to 1.3% when both variables increase; see footnote 11. These findings are also consistent with Jones' (1995) findings that there is no evidence for persistent increases in the growth rate of output in the USA and OECD countries. The growth rate of output in Fiji also did not show any

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[10] This is computed as $(0.0052823+0.0022624\times1.6334)\times 33=0.296$.

[11] The equation based on the endogenous growth model is re-estimated with *lnPC* replacing human capital and trade variables. However its adjusted R^2 has declined to 0.620.

[12] Six other non-nested hypothesis test statistics viz., *N, NT, W, J, JA* and the encompassing tests rejected the endogenous growth based equation in column 5 of Table-1 against the exogenous growth based equation. However, these non-nested hypothesis tests are conducted by re-estimating these two equations with OLS and the adjusted R^2 of both equations are close to their values with the NL2SLS-IV method.

upward trend. In Fiji the growth rate of output (per worker) during our sample period is only 0.8% . A rolling regression, with a window of 5 years, showed that the coefficient of trend ($ß_1$) in the regression $\ln y = \beta_1 + \beta_2 T$ showed a mild downward trend. Therefore, it is unlikely that the high growth effects implied by the endogenous growth model have been experienced by Fiji. Therefore, we may say that the augmented equations based on the exogenous growth theory seem to be appropriate for explaining Fiji's growth rate.

5. Summary and Conclusion

In this paper we have looked at the econometrics of growth from the perspective of applied economists. Applied economists are mainly interested in country specific growth policies instead of theoretical and methodological issues in growth economics. We have suggested that for country specific growth policies time series studies are more appropriate than a large number of cross section econometric studies. Therefore, applied economists have a choice between using specifications based on the endogenous and exogenous of econometric growth. After briefly considering arguments of Jones (1995), Parente (2001) and the observations by Solow (2000) which prefer the exogenous growth model, we have extended the specification of this model to capture the permanent growth effects of growth inducing variables like openness of the economy and human capital. Our empirical results with data from Fiji clearly favour the augmented specifications based on the exogenous growth theory. Our findings thus lend support to the arguments by Jones (1995), Parente (2001) and Solow (2000).

We have noted that many country specific time series studies fail to realize that what actually estimated with the time series econometric techniques is the long run Cobb-Douglas production function and not the long run growth equation. This is irrespective of whether ones specification is based on the endogenous or exogenous growth theory. Therefore omitting the key variables of the production function viz., capital and labour from the specifications—which many in fact many do—gives unreliable growth effects of the determinants of growth. For example, when $\ln k$ and $\Delta \ln k$ are removed from equation 5 in Table2, the growth effects $\ln PC$ became negative and the coefficient of trend increased by more than fivefold from 0.005 to 0.027 and the adjusted R^2 has declined from 0.808 to 0.459. Needless to say these weaknesses and unreliable results are due to misspecification errors. To conserve space this estimate is not reported in Table-2.

There are, however, some limitations in this study. First, we have used data from one country only. Second, we have selected only two variables (out of a large number potential growth improving variables) viz., trade openness and human capital to analyze their effects on growth. Third, did not use alternative time series techniques. Needless to say these limitations somewhat restrict the scope for generalizing without further investigations the conclusions of this study. This study should be seen, therefore, as exploratory and suggestive of a framework and methodology for further studies in the applied work on country specific growth policies.

Data Appendix

Y is the real gross domestic product in 1990 prices.

L is employment in the informal and formal sectors.

K is capital stock, estimated with the perpetual inventory methods with the assumption that the depreciation rate is 4%. The initial capital stock estimate used for 1970 is F$1446.225 million is from Fiji's 8th Economic Development Plan. Investment data used to compute K includes investment in private and public corporate sectors.

HKI is constructed as the product of two index numbers viz., life expectancy in years (**LE**) and the education index, both set to unity in 1970. The education index number is constructed as follows. The proportion of enrollments to population of primary, secondary and university enrollments is used to estimate the education levels of the employed workers. Workers with no formal education are given a weight of one. Workers with primary, secondary and tertiary education are given weights of 1.134, 1.244 and 1.312 respectively. The aggregated series is converted into an index number. The weights selected reflect the earnings differences and these are from Barro and Lee (1993).

TRADE is the ratio of exports plus imports to GDP.

COUP is one in 1987, 1988 and 1989 and zero in all other periods.

DUM95 is one in 1995, 1996, 2001. In all other periods it is zero.

Per worker income (**y**) and per worker capital (**k**) are estimated by dividing **Y** and **K** with **L**.

Sources of Data

1. Output, employment and investment data are, respectively, from the IFS CD-ROM 2003, and the Reserve Bank of Fiji Quarterly Review (various issues).

2. Enrollments data are from the Financial Reports for the Ministry of Education (various issues) and from the Planning and Development Office of the University of the South Pacific.

3. Total population data are from Key Statistics, June 2005 issue.

4. Life expectancy data are from the World Bank Indicators CD-Rom, 2004.

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