The Relationship between Growth and Volatility under Alternative Shocks

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Abstract

This paper presents a simple stochastic endogenous growth model with multiple shocks – a preference shock and a learning shock. The model is used to predict alternative relationships between growth and volatility on the basis of the underlying impulse source of fluctuations.

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1. Introduction

The interactions between growth and business cycles have been studied intensively at both the empirical and theoretical levels. One of the main issues addressed is the relationship between long-run growth and short-run volatility.

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Empirically, many economists have tried to determine the sign of this relationship using cross-section, cross-country and time series data. However, the sign of this relationship remains ambiguous. Broadly speaking, two approaches have been followed. The first is the *ex-post* approach where volatility is measured by either the standard deviation or variance of the growth rate based on the historical data. For those analyses based on cross-country or cross-regional data, the correlation between the first and second moments of output growth is found sometimes to be positive (e.g., Grier and Tullock (1989) and Kormendi and Meguire (1985)), sometimes to be negative (e.g., Martin and Rogers (2000) and Ramey and Ramey (1995)) and sometimes to be zero (e.g., Dawson and Stephenson (1997)). For those studies based on individual countries time series, the correlation is positive and significant in Caporale and McKiernan (1996), but insignificant in Grier and Perry (2000) and Speight (1999). The second approach is the *ex ante* approach in which volatility is measured by the residuals from a forecast regression by distinguishing the unexpected part of volatility. Ramey and Ramey (1995) and Lensink et al. (1999) construct a measure of uncertainty as the residuals from a forecast regression of volatility, which they regard a closer measure of "uncertainty". Their results indicate a negative and significant relationship between growth and volatility across various samples of countries.

Modern stochastic endogenous growth theory enables to study the relationship between long-term growth and short-term volatility theoretically.[1] The studies in

[1] The theory is consistent with the argument of Nelson and Plosser (1982) which is macroeconomic time series are better characterised as non-stationary integrated processes rather than stationary processes around a deterministic trend. The key implication of this theory is that

this literature suggest that this relationship is ambiguous as well. This depends on the structure of the models considered, the assumptions made about the mechanisms responsible for endogenous technological change and the values of the parameters assumed. The models that follow Shumpeter (1942), where the mechanism is based on “creative destruction” show a positive relationship between growth and volatility. For example, in Aghion and Saint-Paul (1998a, b), productivity change is assumed to be the result of purposeful (internal) learning through deliberate actions which substitute for production activities.[2] Under such circumstances, the resources allocated to productivity improving activities are a convex function of the state of the economy and hence the average productivity increases as volatility increases. On the other hand, the models that follow Arrow (1962), where the mechanism of technological change takes the form “learning-by-doing” show that the relationship between growth and volatility tends often (but not always) to be negative. For example, in Martin and Rogers (1997, 2000), productivity change takes place through serendipitous (external) learning through non-deliberate actions which are complements to production activity. In this case, the factor through which expertise, knowledge and skills are acquired and disseminated is a concave function the shocks, so that increased volatility decreases growth.[3] By incorporating the above two conflicting mechanisms for endogenous technological change, Blackburn and Galindev (2003) shows that the

any shocks can have a permanent effect on output if it changes the amount on which productivity improvements depend. See Bean (1990), Fatas (2000), King et al. (1988), Jones et al. (1999) for permanent effects of temporary real shocks, and Stadler (1990), Pelloni (1997), Blackburn (1999) and Blackburn and Pelloni (2004) for permanent effects of temporary nominal shocks

[2] See also Caballero and Hammour (1994) for a related contribution on this subject.

[3] See Blackburn (1999) for a contrasting result in this approach.

relationship between growth and volatility is more likely to be positive (negative) if technological change is predominantly driven by internal (external) learning. In contrast to the above, some models in which knowledge is created under the assumption of learning-by-doing suggest alternative relationships between growth and volatility. According to De Hek (1999) and Smith (1996), the relationship between long-term growth and short-term cyclical volatility depends on the household's attitude towards risk as measured by the curvature of the utility function. Specifically, the more (less) risk-averse is an agent, the more likely it is that increased uncertainty will have a positive (negative) effect on long-run growth. Jones et al. (1999) considers the same issue in a different framework in which growth is the result of constant returns to reproducible factors – physical and human capital – that are purely rival (and not due to the accumulation of non-rival knowledge via learning-by-doing) and reaches the result the same as above. Blackburn and Pelloni (2004) investigates the correlation between the growth and volatility depends on the nature of the shocks under the assumption of an imperfect labour market. Long-run growth is positively correlated with the volatility of the real shocks and negatively correlated with the volatility of the nominal shocks.

The objective of this paper is to explain the lack of robust evidence on the relationship between growth and volatility by developing an analysis which derives an ambiguity of this relationship under the existence of alternative shocks – a preference shock and a learning shock. The analysis is based on a simple stochastic endogenous growth model with logarithmic preferences and learning-by-doing so as to produce closed-form solutions. I show that, depending on the nature of the shock, the relationship between growth and volatility may be either positive or negative. Specifically, if the volatility of the preference (learning) shock dominates, there would be a positive (negative) correlation between growth and volatility.

The paper is organised as follows. In section 2, the structure of the model is presented. In section 3, the model is solved. In section 4, the main results are established. In section 5, conclusions are drawn.

2. Model

I consider a discrete time (indexed by $t = 0,...\infty$) stochastic endogenous growth model in which there is a constant population (normalised to unity) of identical, infinitely-lived agents who are both producers and consumers of a single commodity. The instantaneous utility function of the representative agent depends on consumption and labour. I assume the following expected lifetime utility function

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \left[\gamma_t \log(C_t) - \lambda L_t^{\eta} \right], \beta \in (0,\ 1), \quad \lambda > 0, \quad \eta > 1 \tag{1}$$

where C_t denotes consumption and L_t denotes the fraction of time that the agent spends working. The term, $-\lambda L_t^{\eta}$, represents the disutility that the agent derives from working.[4] The linear case ($\eta = 1$) can be justified on the basis of indivisible labour and employment lotteries in the manner of Hansen (1985) and Rogerson (1988). The term γ_t is a positively-valued, and independently and identically distributed ($i.i.d.$) random variable with mean μ_γ and variance σ_γ^2 (a preference or taste, shock), which is one source of stochastic fluctuations in the economy.

At any point in time, t, the agent produces Y_t units of output by combining L_t units of labour and K_t units of capital in accordance with the following Cobb-Douglas technology,

$$Y_t = A(Z_t L_t)^\alpha K_t^{1-\alpha} \tag{2}$$

where the term, A, represents a productivity parameter and the term, Z_t, represents an index of knowledge which is freely available to all agents in the economy and which is acquired through serendipitous learning-by-investing. I assume that there is uncertainty about the return to knowledge creation, as in De Hek (1999). Specifically, $Z_t = \xi_t \bar{K}_t$ where $\bar{K}_t$ represents the total capital stock in the economy and ξ_t is a positively-valued, and independently and identically distributed ($i.i.d.$) random variable with mean μ_ξ and variance σ_ξ^2 (a learning shock) which is another source of stochastic fluctuations. The production function shows diminishing returns to capital at the agent level but constant returns to capital at the aggregate level through the externality effect of learning-by-doing.

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[4] The term $\eta \log(1 - L_t)$ could be used without affecting our main results. In addition, the alternative framework that the agent supplies one-unit of labour inelastically reaches some of our important results.

The model is completed by specifying the budget constraint of the agent. Assuming that capital fully depreciates within a period yields,

$$C_t + K_{t+1} = A(Z_t L_t)^{\alpha} K_t^{1-\alpha} . \tag{3}$$

3. Solving the Model

Given the above budget constraint, the agent maximises her expected lifetime utility in (1) subject to the budget constraint in (3) by choosing optimal policies over capital K_{t+1}, consumption C_t and labour L_t.

The Euler equation for consumption and capital is

$$\frac{\gamma_t K_{t+1}}{C_t} = \beta(1-\alpha)E_t\left(\gamma_{t+1}\right) + \beta(1-\alpha)E_t\left(\frac{\gamma_{t+1}K_{t+2}}{C_{t+1}}\right). \tag{4}$$

The expression in (4) is a stochastic expectations difference equation which can be solved forwards in time by imposing the transversality condition $Lim_{\tau\to\infty}\beta^{\tau}(1-\alpha)^{\tau}E_t\left(\frac{\gamma_{t+\tau}K_{t+\tau+1}}{C_{t+\tau}}\right)=0$ and the fact that $E_{t+i}(\gamma_{t+i+1}) = \mu_{\gamma}$. This yields the following:

$$K_{t+1} = \frac{\beta(1-\alpha)\mu_{\gamma}}{1-\beta(1-\alpha)}\frac{C_t}{\gamma_t} . \tag{5}$$

Equation (5), together with the budget constraint, describes two stochastic equations for capital and consumption. These equations may be solved to obtain the following optimal decision rules for C_t and K_{t+1}:

$$C_t = \frac{(1-b)\gamma_t}{(1-b)\gamma_t + b\mu_{\gamma}} Y_t \equiv c(\gamma_t)Y_t \tag{6}$$

$$K_{t+1} = \frac{b\mu_\gamma}{(1-b)\gamma_t + b\mu_\gamma} Y_t \equiv k(\gamma_t) Y_t \tag{7}$$

where $b = \beta(1-\alpha)$. These expressions show that the equilibrium levels of consumption and capital are proportional to the level of output. These optimal policies imply that, for a given level of employment and given state of technology, consumption and capital depend on the realisations of current and expected future preference (demand) shocks. The effects of demand uncertainty on the optimal investment and consumption shares of output are stated in the following proposition.

Proposition 1. *(i) For a given level of output, an increase (decrease) in the current demand shock,* γ_t, *leads to more (less) consumption and less (more) capital investment. (ii) A mean-preserving spread in the probability distribution of the demand shock,* γ_t, *leads to lower average consumption and higher average investment.*

Part *(i)* of the Proposition follows from the fact that the function $k(\cdot)$ is decreasing in γ_t (i.e., $k'(\cdot) < 0$) and the function $c(\cdot)$ is increasing in γ_t (i.e., $c'(\cdot) > 0$). Naturally, a stronger preference for consumption (i.e., higher value of γ_t) leads the agent to consume more and to save less. Part *(ii)* of the Proposition reflects the fact that the function $k(\cdot)$ is convex in γ_t (i.e., $k'(\cdot) < 0$ and $k''(\cdot) > 0$) and the function $c(\cdot)$ is concave in γ_t (i.e., $c'(\cdot) > 0$ and $c''(\cdot) < 0$). The result is an example the well-known result of Rothschild and Stiglitz (1970) that the expected value of a concave (convex) function of a variable is decreased (increased) by a mean-preserving spread of that variable. The intuition for the result can be explained on the basis of precautionary saving behaviour: for a given level of employment, increased uncertainty about future consumption leads the agent to consume less and save more today due to a convex marginal utility of consumption.

The first order condition relating to labour choice is

$$L_t^{\eta} = \frac{\alpha \gamma_t Y_t}{\eta \lambda C_t} . \tag{8}$$

Substituting (6) into (8) gives the optimal decision rule for employment as

$$L_t = \left[\frac{\alpha \left[(1-b)\gamma_t + b\mu_{\gamma} \right]}{\eta \lambda (1-b)} \right]^{\frac{1}{\eta}} \equiv l(\gamma_t) . \tag{9}$$

The expression in (9) again shows that the equilibrium level of employment depends on the demand shock. The precise effect of this shock is stated in next proposition.

Proposition 2. *(i) An increase (decrease) in the current demand shock,* γ_t, *has a positive (negative) effect on employment. (ii) A mean-preserving spread in the probability distribution of the demand shock,* γ_t, *leads to lower average employment.*

Part *(i)* of the Proposition is proved by noting that the function $l(\cdot)$ is increasing in γ_t (i.e., $l'(\cdot) > 0$). Intuitively. A stronger preference for consumption motivates agents to work harder to produce more output. Part *(ii)* of the Proposition follows from the fact that the function $l(\cdot)$ is concave since $\eta > 1$ (i.e., $l'(\cdot) > 0$ and $l''(\cdot) < 0$). As before this may be explained on the basis of precautionary saving behaviour – greater uncertainty about future preferences reduces current consumption and raises current savings for a given level of income. A decrease in current consumption results in a decrease in employment. Given this, the preference shock has indirect level effects on consumption and investment through employment.

The discussion has so far neglected to mention the effects of the learning shock, ξ_t. As shown in (9), this shock has no effect on employment. This is due to the structure of the model which has been deliberately set up to yield closed-form solutions. In particular, the combination of logarithmic utility and Cobb-Douglas technology means that income and substitution effects of technology shock exactly cancel each other out so that employment is unaffected. This does not mean, however, that consumption and investment are independent of the shock, as is evident from (6) and (7). Since output is affected positively by the shock, then so too are consumption and investment.

4. Stochastic Endogenous Growth

I now turn to an explicit analysis of the relationship between growth and volatility. It is done so by solving for the growth rate of output which determines the growth rates of other non-stationary variables such as consumption and capital. These growth rates are endogenous and stochastic. The former property reflects the assumption of learning-by-investing according to which the aggregate stock of disembodied knowledge freely available to agents is approximated by the aggregate stock of capital: that is, $Z_{t+1} = \xi_{t+1} K_{t+1}$ in (2). As it has been seen, the stochastic nature of the growth rate is the result of the stochastic properties of productivity change, capital accumulation and employment. More significantly, I reach the result that both the average growth rate and the variance of output growth rate are functions of the variances of the shocks which imply a relationship between growth and volatility. These results are established as follows.

4.1. The Output Process

Substituting (7) and (9) into (2) yields the following expression for the actual growth rate of output between two consecutive periods:

$$\frac{Y_t}{Y_{t-1}} = A\xi_t^{\alpha} \left[\frac{\alpha\left[(1-b)\gamma_t + b\mu\right]}{\eta\lambda(1-b)} \right]^{\frac{\alpha}{\eta}} \frac{b\mu}{(1-b)\gamma_{t-1} + b\mu} \equiv y(\xi_t, \gamma_{t-1}, \gamma_t)\ . \tag{10}$$

Since output in each period depends on the state of the aggregate stock of knowledge and the level of employment in that period, the growth rate of output from one period to the next is a function of the demand shocks in both of those periods and the current learning shock. The effects of both demand and learning shocks can be explained on the basis of Propositions 1 and 2. A positive ξ_t shock has a direct positive effect on the growth rate (i.e., $y_1'(\cdot) > 0$). A positive last period demand shock, γ_{t-1}, has a negative effect on Y_t by reducing K_t and a positive effect on Y_{t-1} by increasing L_{t-1}, so that the growth rate of output decreases (i.e., $y_2'(\cdot) < 0$). A positive current demand shock, γ_t, has an instantaneous positive effect on the growth rate of output by virtue of the positive effect on L_t and hence Y_t (i.e., $y_3'(\cdot) > 0$).

Of more interest is the fact that the growth rate is a concave function of the learning shock, ξ_t (i.e., $y_{11}''(\cdot) < 0$), but, is either a concave or a convex function of the demand shock, γ_t, depending on the relative dominance of the investment and employment channels through which this shock affects output. These results suggest that a mean-preserving spread of the learning shock would cause a decrease in the average growth rate of output, whereas a mean-preserving spread of the demand shock could cause either an increase or a decrease in the average growth rate of output. The conflicting effects of the demand shock can be explained on the basis of the conflict between precautionary saving and employment behaviour. These two effects are reflected in the curvature properties of capital K_{t+1} in (7) and employment L_t in (9) respectively. On the one hand, increased volatility of the demand shock increases capital and decreases consumption for a given level of employment. This tends to increase growth. On the other hand, the fall in consumption decreases employment as well. This tends to reduce growth. If the latter effect was absent (e.g., if labour is supplied inelastically), then output growth would be unambiguously a convex function of the demand shock, implying that average growth would necessarily increase with a mean preserving spread of the shock. More generally, when labour is endogenous, the net effect depends on the parameter values of the model.

4.2. Growth and Volatility

Given (10), together with the first and second order moments of the shocks - i.e., $\{\mu_\xi, \mu_\gamma\}$ and $\{\sigma_\xi^2, \sigma_\gamma^2\}$, the mean and variance of output growth may be approximated as follows:

$$Mean\left(\frac{Y_t}{Y_{t-1}}\right) = y(\mu_\xi, \mu_\gamma) + \frac{1}{2} y_{11}(\mu_\xi, \mu_\gamma)\sigma_\xi^2 + \frac{1}{2}\left[y_{22}(\mu_\xi, \mu_\gamma) + y_{33}(\mu_\xi, \mu_\gamma)\right]\sigma_\gamma^2 \quad (11)$$

$$Var\left(\frac{Y_t}{Y_{t-1}}\right) = \left[y_1(\mu_\xi, \mu_\gamma)\right]^2 \sigma_\xi^2 + \left\{\left[y_2(\mu_\xi, \mu_\gamma)\right]^2 + \left[y_3(\mu_\xi, \mu_\gamma)\right]^2\right\}\sigma_\gamma^2 . \quad (12)$$

These expressions show that, in general, an increase in the variance of any of the shocks causes an increase in $Var(Y_t/Y_{t-1})$, but either an increase or a decrease in $Mean(Y_t/Y_{t-1})$. From the above discussion, one might presume that an increase in the variance of the learning shock, σ_ξ^2, would cause an unambiguous decrease in $Mean(Y_t/Y_{t-1})$,[5] while an increase in the variance of the demand shock, σ_γ^2, might cause either an increase or a decrease in $Mean(Y_t/Y_{t-1})$ depending on

[5] It is straightforward to prove that $y_{11}(\mu_\xi, \mu_\gamma) < 0$.

variations in precautionary savings and employment.[6] In the present framework, it is found that the precautionary savings channel dominates; that is $y_{22}(\mu_\xi, \mu_\gamma) > y_{33}(\mu_\xi, \mu_\gamma)$. I demonstrate this since $|2| > |\alpha/\eta[\alpha/\eta - 1]|$ for any $0 < \alpha < 1$ and $\eta > 1$. Therefore Z_t and $y(\cdot)$ turn out to be convex functions of the demand shock. Thus $Mean(Y_t/Y_{t-1})$ is a decreasing function of σ_ξ^2 but an increasing function of σ_γ^2 so the model generates an ambiguous correlation between long-run (secular) growth and short-run (cyclical) volatility.

The model predicts that the correlation between $Mean(Y_t/Y_{t-1})$ and $Var(Y_t/Y_{t-1})$ is more likely to be positive (negative) if demand (learning) shocks dominate - i.e., $f(\cdot) = [y_{11}(\mu_\xi, \mu_\gamma)]\sigma_\xi^2 + [y_{22}(\mu_\xi, \mu_\gamma) + y_{33}(\mu_\xi, \mu_\gamma)]\sigma_\gamma^2 > 0$ (< 0). Some tedious calculus and algebra reveal that

$$f(\cdot) = \left\{ \alpha(\alpha - 1)\frac{\sigma_\xi^2}{\mu_\xi^2} + (1-b)^2 \left[2 + \frac{\alpha}{\eta}\left(\frac{\alpha}{\eta} - 1\right)\right] \frac{\sigma_\gamma^2}{\mu_\gamma^2} \right\}. \tag{13}$$

As we can see, this expression depends on the variances of both shocks and the model's structural parameters. Evidently, $f(\cdot) < 0$ if $\sigma_\gamma^2 = 0$, but $f(\cdot) > 0$ if $\sigma_\xi^2 = 0$. More generally, the sign of $f(\cdot)$, and therefore the correlation between growth and volatility, depends on the relative variances of learning and demand shocks (together with other parameters). A positive correlation ($f(\cdot) > 0$) is more likely for relatively high values of σ_γ^2 and low values of σ_ξ^2, while a negative

[6] These effects are reflected in the terms $y_{22}(\mu_\xi, \mu_\gamma) > 0$ and $y_{33}(\mu_\xi, \mu_\gamma) < 0$ respectively.

correlation ($f(\cdot)<0$) is more likely for relatively low values of σ_γ^2 and high values of σ_ξ^2.

5. Conclusion

The relationship between cyclical volatility and secular growth has been studied by using a simple stochastic endogenous growth model with learning-by-investing and alternative shocks – preference and learning shocks. Under these alternative shocks, the model delivers alternative relationships between growth and volatility which contradicts the normal presumption that models with learning-by-doing predict a singularly negative correlation. Specifically, preference shocks tend to produce a positive relationship, while learning shocks tend to produce a negative relationship. These results may help to explain the lack of robust evidence on the relationship between growth and volatility.

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