What Happens When the Productivity Growth Trend Changes?: Modeling the Dynamics of the "New Economy"

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Abstract

Recent evidence of an increase in the trend rate of productivity growth inspires speculation about how a change in the underlying process of technological progress might be associated with adjustment dynamics. This paper considers such dynamics in the framework of a computable general equilibrium model that incorporates stochastic growth. Simulations of the model suggest that transition dynamics between steady state growth paths can have important implications for measuring productivity trends.

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The performance of the U.S. economy during the1990s has been universally hailed as stellar. The current expansion is close to surpassing the record for longevity, with strong output and employment growth continuing long past the point that most expansions run out of steam. More significantly, there are no apparent signs of emerging imbalances that might threaten to bring this favorable environment to an end. Inflation has remained subdued, capacity utilization has stayed relatively low, and despite the rapid growth of employment, wage pressures do not appear to be outstripping the pace of productivity growth.

It is plausible to conjecture that favorable supply shocks underlie the expansion of the 1990s. In a typical “real business cycle” (RBC) model, positive productivity shocks give rise to temporary expansions of output and factor demands, implying rising employment and investment.[1] In monetary extensions, real supply shocks are associated downward pressure on prices, and multi-country versions of this type of model suggest the emergence of a current account deficit as strong investment demand outstrips domestic saving.[2] These predictions are all suggestive of prominent features of the 1990s economy.

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[1] These features are highlighted in Kydland and Prescott (1982), Hansen (1985), King, Plosser and Rebelo (1988a,b), for example.

[2] One such simple monetary extensions (incorporating cash-in-advance constraints, for example) is Cooley and Hansen (1989). The effects of supply shocks on current account dynamics in two-country models is highlighted in Backus, Kehoe and Kydland (1994).

However, one distinctive aspect of the 1990s expansion is the popular perception that a fundamental change has taken place in the structure of the economy. "New paradigm" or "new economy" theories conjecture that rapid economic growth can continue unabated into the future. Put more concretely, there is a perception that the trend rates of productivity and potential output growth have increased. In a typical RBC models, the growth trend is exogenous and supply shocks give rise to temporary fluctuations. To examine the implications of changes in growth trends, a model of stochastic growth is required.[3]

In stochastic growth models, transition dynamics between steady-state growth paths can have important implications for short-term fluctuations Consequently, an examination of these dynamics might provide insight for the issue of identifying changes in underlying productivity trends, and for the understanding of the "new" economy in general. This paper describes such a model and proposes to compare its predictions with recent growth patterns in the U.S. economy.

Explanations for the emergence of the "new economy" are generally based on the idea that new technologies for information processing and communication are transforming the nature of the production process. This notion suggests that capital-embodied technological progress might be an important feature of the recent economic environment.[4] Consequently, the model examined in this paper includes technology growth of both the neutral and capital-embodied types. The structure of the model

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[3] Examples of stochastic growth in computable general equilibrium models include King, Plosser and Rebelo (1988b); and King and Rebelo (1993).

[4] This "embodiment hypothesis" has its roots in the work of Domar (1963) and Jorgenson (1966).

suggests an approach to distinguishing these growth processes in the data that is exploited for calibration and simulation.

The Model

The model is a modified version of a standard RBC framework that includes features of vintage-capital and embodied technological progress — as described by Greenwood, Hercowitz and Krusell (1998,1999) [hereafter, referred to as GHK].

Consumers (represented by a social planner) maximize logarithmic utility over consumption and leisure,

$$\max \sum_{t=0}^{\infty} \beta^t [\theta \ln(C_t) + (1-\theta) \ln(1-N_t)],$$

subject to an overall resource constraint with Cobb-Douglass production:

$$\begin{gathered} Y_t + B_t = C_t + I_t + a(I_t) + B_{t+1} / (1+r_t) \\ where\ Y_t = Z_t (H_t K_t)^a N_t^{1-\alpha} \end{gathered} \tag{1}$$

In equation 1, K_t , N_t, I_t and C_t represent capital, labor, investment and consumption, respectively. Z_t represents an index of total-factor, or neutral, productivity. A capital utilization index defines capital in effective units as $H_t K_t$. Equation 1 also includes a term $a(I_t)$ that represents investment adjustment costs.

In the accumulation equation, capital depreciation is a function of the utilization rate, with $\delta'(H_t)$, $\delta''(H_t) > 0$:[5]

$$K_{t+1} = [1 - \delta(H_t)]K_t + Q_t I_t \tag{2}$$

Improvements in the quality of new investment goods are represented by Q_t, a measure of the state of capital-embodied technology.

In equation 1, the opportunity for international borrowing and lending is introduced through B, which represents net foreign assets. Rather than fully specifying a rest-of-the-world economy, I take a more *ad hoc* approach of postulating a foreign bond supply function to close the model:

$$B_{t+1} = B_t^{\xi}(1 + r_t)^{\varepsilon} \tag{3}$$

where ε is the elasticity of the foreign bond supply with respect to the interest rate (differential) and $\xi<1$ is an autoregressive term on asset accumulation that assures that net foreign indebtedness doesn't diverge.[6]

Growth in the technology indices, Z_t and $Q_{t,}$, define the rate of aggregate economic growth. I assume that these technology variables can be decomposed into trend and cyclical components as $Z_{t+1} = X_{Z,t+1} z_{t+1}$ and $Q_{t+1} = X_{Q,t+1} q_{t+1}$, where $X_{i,t+1} = \gamma_{i,t} X_{i,t}$ with the γ_i , i=z,q, representing trend growth rates, and with z_t and q_t representing stationary cyclical components that capture temporary shocks to technology.

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[5] This approach to representing variable capital utilization is described in Greenwood, Hercowitz and Huffman (1988).

[6] This feature is introduced to assure stability (although a somewhat less restrictive assumption would suffice).

In their two papers, GHK(1998,1999) examine separately the implications of capital-embodied technical progress for long-term growth and cyclical fluctuations, finding that this type of technology can account for up to 60% of growth and 30% of fluctuations over the sample period 1954-1990. This paper examines the proposition that changes in the rate of technological progress–of either the neutral or embodied form–imply transition dynamics between steady-state paths that have important implications for both growth *and* cycles that might be important for understanding the "new economy" of the 1990s.

Methodology

The typical RBC approach to simulating a dynamic general equilibrium model begins with the assumption that cyclical components of productivity processes can be isolated from their trends in order to examine fluctuations separately from long-run growth. This often involves a transformation of variables that results in a stationary representation of the model in which underlying growth rates emerge as parameters. By treating these growth rates as being subject to exogenous shocks, it is possible to simulate a model in which growth rates are stochastic.

In the model examined in this paper, growth trends depend on both technology variables. With a stationary supply of labor (so that the model represents per-capita quantities), standard steady-state requirements imply that output, consumption and investment will grow at a common rate γ_y. The accumulation equation implies that $\gamma_k = \gamma_y \gamma_q$, and the production technology determines the relationship between output and productivity growth rates as:

$$\gamma_y = \gamma_z^{1/(1-\alpha)} \gamma_q^{\alpha/(1-\alpha)} \tag{4}$$

A stationary representation of the model can be derived by dividing each of the time-t variables by their respective growth factors, X_{it} . In the process or this transformation, the long-run growth rates emerge as parameters of the stationary problem. For example, representing transformed stationary variables by lower case letters, the capital accumulation becomes:[7]

$$\gamma_k k_{t+1} = [1 - \delta(H_t)]k_t + q_t i_t . \tag{2'}$$

Rather than treating growth rates as constant, it is fairly straightforward to treat the γ_{it} in the transformed problem as being subject to exogenous random shocks that initiate transition dynamics to a new steady-state growth path.[8] The growth rates of key model variables can be recovered from the simulation as the sum of the underlying growth trend, the deviations from that trend represented by the growth shocks themselves, and the growth fluctuations implied by the simulated dynamics of the stationary system.[9]

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[7] For general time-separable CRRA utility, the stationary transformation also involves a modification of the discount factor, β. This generalization would complicate the problem, but would not necessarily change the qualitative properties of dynamic simulations.

[8] King and Rebelo (1993) employ a very similar approach. Rather than considering the growth rates as stochastic directly, however, they evaluate changes in desired capital stock, and generate transition dynamics accordingly.

[9] The inclusion of stochastic growth rates in a log-linear approximation obviously introduces a potentially important source of approximation error. A full-blown second-moment evaluation dynamics would require more careful attention to this issue. For the purpose of simulating basic impulse-response functions and transition paths, however, the importance of approximation error can be evaluated against exact steady-state solutions. For the magnitude of growth changes examined in this paper, these errors are negligible.

Calibration

In calibrating the model, some of the underlying parameters are selected to be consistent with standard RBC calibrations based on long-run sample-means, while others are set in reference to more recent experience – particularly with respect to features of the model pertaining to the potential growth effects of new information processing technologies. Values for the key model parameters are listed in Table 1.

Capital's share of output, α, is set to 0.30, the preference parameter θ is selected so that the fraction of time spent working of 0.24, and the discount factor, β, is based on a real return to capital of 7%.[10] The steady-state capital depreciation rate, δ, is set to 6%, reflecting the 1960-98 average depreciation as a fraction of the net stock of nonresidential fixed private capital in the BEA's Fixed Reproducible Tangible Wealth estimates. As in Greenwood, Hercowitz and Huffman (1988), the form of the depreciation function is taken to be $\delta(H) = bh^{\omega}/\omega$. Given the calibration of a long-run value for δ, the model's steady-state efficiency conditions pin down the elasticity parameter, ω=2.39 .[11]

Investment adjustment costs are assumed take the form $a(i_t)=(\varphi/2)i_t^2$. It is convenient to normalize the cost parameter φ to be proportional to the steady-state value of capital, $\varphi = \Phi k/q)$, where Φ is the underlying constant of proportionality. This parameter is calibrated using information presented in Kiley (1999). Citing evidence from the Gartner Group – an information technology consulting firm – Kiley suggests that 4.2 percent of total revenue was devoted to IT budgets in 1998, and that 60% to 80% of

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[10] These values are generally consistent with GHK (1998,1999).

[11] In GHK (1998,1999), this parameter is selected directly, pinning down the tax rate on capital income. The reverse calibration approach is taken here, with the implicit assumption of no capital taxes..

those budgets represented the costs of training, support, and software. He associates these expenditures with adjustment costs of investment in computers. Since software expenses might be more suitably described as investment spending (and will be included as investment in forthcoming revisions to the NIPA), I choose a conservative estimate that about one-half of IT spending represents adjustment costs, about 2% of total output.

For the purposes of the demonstrations described in the next section, the baseline growth rate of capital-embodied technical progress is calibrated at 2.6%. This figure reflects average growth in the relative price of nondurables and services consumption to private fixed investment over the period 1980-1998 (as measured by the BEA's chain-weighted price indexes). GHK (1998, 1999) use the quality-adjusted series on PDE investment developed by Gordon (1990) in a similar relative price comparison to measure the quality improvement in capital equipment omitted by the National Income and Product Accounts (NIPA) over the period 1954-1990. Because the focus of this paper is on "new economy" technologies, I use a similar approach to capture the quality improvement that *is* now included in NIPA data, namely, the quality-adjustment for computer equipment that has been introduced to the accounts using hedonic price indexes.[12] Figure A illustrates the time-path of this measure of technology over recent decades.

The baseline growth rate of output (per capita) is set to 1.6%, approximately matching the growth of output per worker over the 1973-98 sample period.

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[12] Whelen (1999) also uses the BEA price and quantity measures of computer equipment to measure the importance of the embodiment hypothesis for growth accounting in the "new" economy.

A Demonstration

The specific experiments I conduct track increases in the trend growth rate of output and labor-productivity from 1.6% to 2.0%. The model is calibrated at an annual frequency, and the change in the growth trend is assumed to take place incrementally with a growth-rate increase of 0.1% in each of four years. This incremental-shock approach is taken to clearly separate the dynamic effects of growth shocks into realization and post-realization periods, and to represent the notion that the recognition of changes in a growth trend (if not the actual process itself) is likely to be a gradual process.

To capture the role of the underlying growth parameters as the determinants of long-run trends, I assume that changes in the growth trend are strictly permanent, i.e. the γ_{it}, $i=z,q$, follow random-walks,

$$\gamma_{it} = \gamma_{it-1} + e_{it} \tag{5}$$

and consider the model economy's response to the underlying shocks, e_{it}.[13] For each of the two types of growth shocks, the magnitudes of the underlying change is calibrated to generate a 0.4% increase in the growth rate of output and labor productivity (from equation 4).

Figure 1, showing the behavior of the capital stock following an increase in the growth of neutral technological change, highlights one key feature of the dynamics of this experiment. The textbook Solow growth model tells us that the optimal capital/labor ratio is inversely related to the growth rate of technological change. Figure 1 shows how this outcome is reflected in the transition dynamics from one steady state to another . The higher productivity-growth profile calls for a lower capital/labor ratio in the long run,

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[13] The magnitudes of each of the underlying shocks is adjusted to generate a 0.4% increase in the growth rate of output and labor productivity (from equation 4).

providing a depressing effect on investment and capital accumulation. On the other hand, the higher technology growth trend requires a higher growth rate for capital and investment in the long-run. Growth rates during the transition depend largely on which of these two effects dominate.

Figure 2 illustrates how consumption is affected. A large wealth effect and intertemporal substitution effects combine to raise consumption in the short run, while over time the decline in the capital/labor ratio pulls it below the new trend line extending from the point of the shock. This pattern implies an initial consumption boom a the same time that investment is depressed.

The growth paths of other key macroeconomic variables and ratios, shown Figure 3, illustrate more clearly the opposing forces of the higher long-run growth path and the transition dynamics to a lower capital/labor ratio. Investment growth declines sharply during the shock-realization period (reflecting *both* influences highlighted in Figures 1 and 2) then rebounds in the transition to the new steady state. The same wealth effects and intertemporal substitution effects that cause consumption to rise cause a decline in employment (due to a downward shift in the labor supply curve). Declining labor supply and investment demand during the transition imply lower output growth as well. The capital utilization rate dips slightly before rising permanently. The current account responds to the pattern of consumption growth, falling sharply during the shock-realization period as consumption growth surges and savings declines.[14]

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[14] The magnitude of the current account deficit implied by the model is quite small, representing only a small fraction of a percent of GDP. Because of the ad hoc method by which current account is introduced, it is probably a good thing that they have little effect on the model's overall dynamics.

Experiments to examine the sensitivity of the results (not reported here explicitly) demonstrate that some of the short-run implications of the model depend on the nature of preferences. When labor supply is modified to be infinitely elastic (eliminating the effects of labor supply shifts), the initial slowdown in output growth is eliminated. When the intertemporal substitution elasticity of consumption is assumed to be very low, the initial consumption surge is mitigated, and so is the slowdown of investment growth (highlighting the influence on investment demand of both the decline in desired capital and the positive wealth effect on consumption). Qualitative implications for other model variables are generally unaffected by these modifications.

Figure 4 illustrates the growth patterns of key variables following a shock to the growth rate of capital-embodied technology. Many of the general features of the model economy's responses to a neutral technological growth shock carry over to this case, but the patterns are augmented by the expected quality improvement in future capital that is implied by this type of shock. For example, the initial drop in investment growth is larger: With ever more productive capital equipment expected to become available in the future, the decline in the desired capital stock is enhanced by the incentive to replace existing capital. Similarly, the capital utilization rate (and hence the depreciation rate) increases more than in the case of the neutral technology growth shock. Stronger intertemporal substitution effects cause the temporary surge in consumption and leisure similarly to be larger. The more rapid decline of investment also results in an initial increase in the current account balance, followed by a sharp decline when investment spending picks up to take advantage of higher-quality capital available after the shock.

The implications of these growth patterns for labor productivity are illustrated in Figure 5. Two features of Figure 5 are particularly relevant to the issue of identifying changes in the trend growth rate of technological progress. First, the response to either shock is a surge in productivity growth during the shock-realization period, potentially serving as an indicator of the realization of a trend change. On the other hand, post-shock transition dynamics are characterized by a very gradual rise in labor productivity. This is particularly true in the case of an increase in capital-embodied technological progress, where the process of replacing vintage capital with newer, more productive capital creates a very slow process of transition to the new steady-state growth path.

Concluding Remarks and Future Extensions

The model simulations presented in this paper suggest that transition dynamics between steady-state growth paths can have important implications for both trends and fluctuations in aggregate economic variables. Most relevant for the issue of assessing the emergence of the "new economy" is the observation that an increase in the trend rate of capital-embodied technical change gives rise to a very gradual acceleration in measured labor productivity. This consideration can greatly complicate the task of empirically identifying changes in trend growth rates.

To be more rigorous about testing the empirical significance of the theoretical dynamics considered here, it would be desirable to take the model to the data. Figure 6 illustrates a direction that such a test might take. Figure 6 shows the measure of capital-embodied technological change suggested in this paper (the price of investment goods relative to consumption goods) along with a series representing neutral technological progress (as measured by Solow residuals). As highlighted by the trend lines identified by using a Hodrick-Prescott filter, changes in trend have been important for both of these measures of technology. If we take the deviations from trend to represent stationary disturbances (as in RBC models) and changes in the growth rate of the HP-trends to represent stochastic growth shocks, it is possible to construct a simulation experiment in which we can assess the explanatory power of each of these types of shocks for reproducing growth patterns actually observed in the data. Such an exercise is planned as the next logical step in the development of this research.

In the absence of evidence to support the importance of the dynamics considered here, the dynamic implications of the model should at least serve as a cautionary note regarding the identification of changing technological growth trends. Nevertheless, the analysis in this paper can be interpreted as supporting the conclusions of recent studies of productivity trends. In particular, the model's implications are generally consistent with the following hypotheses: First, there is some evidence of rising trend growth rates in recent years. Second, these increases are not easily identified, and have thus far been concentrated in the information technology sector. Finally, even though there is still considerable uncertainty about the outlook for growth in productivity and output, there is good reason to believe that the continuing adaptation and integration of new technologies into the economy's aggregate production potential bodes well for the future.

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Table 1: Calibrated Parameter Values

Parameter	*Description*	*Calibrated Value*
α	Capital share of output	0.30
θ	Consumption share of utility	0.26
β	Discount rate	0.95
δ	Steady-state depreciation rate	0.06
ω	Depreciation Elasticity	2.39
φ	Adjustment cost parameter	1.0
γ_q	Growth rate of embodied technology	1.026
γ_y	Growth rate of output	1.016

Figure A
Investment-Specific Technological Change

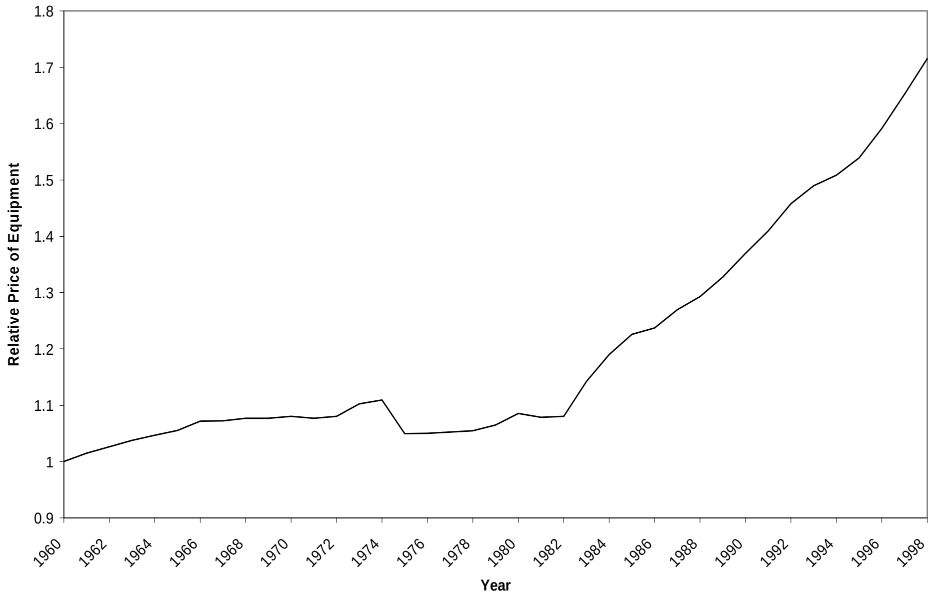

Figure 1

Response of Capital to a Neutral Productivity-Growth Shock

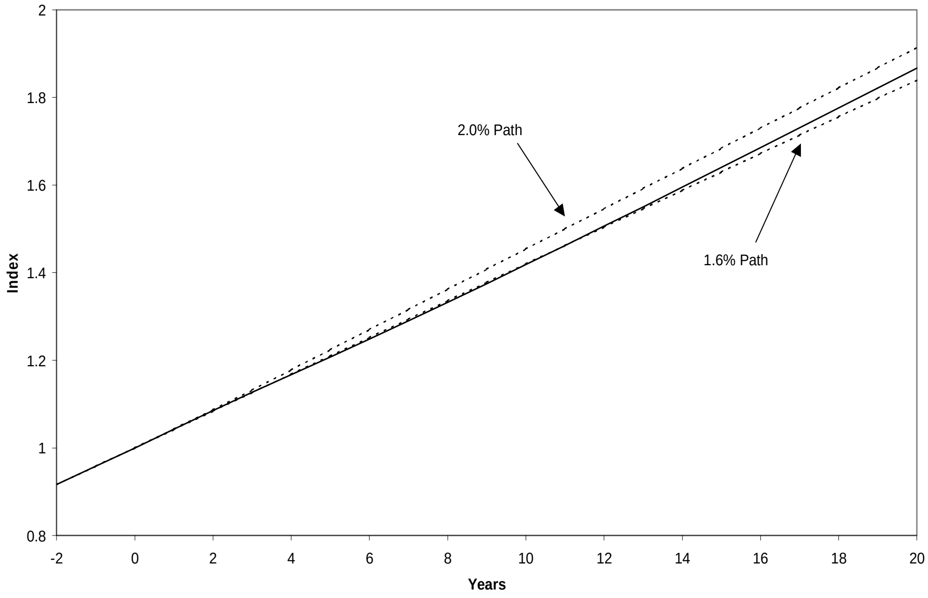

Figure 2
Response of Consumption to a Neutral Productivity-Growth Shock

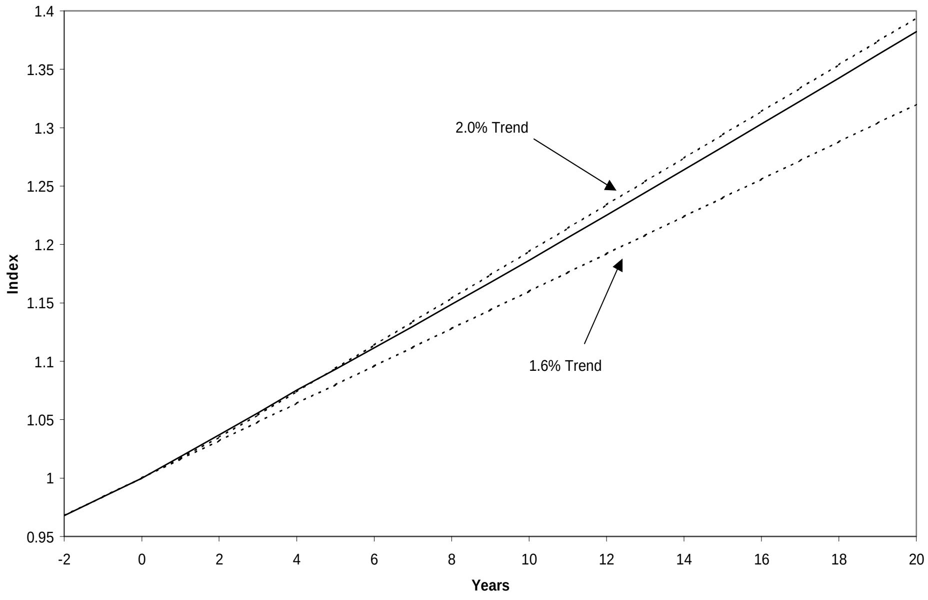

Figure 3
Simulation Results -- Responses to a Higher Neutral Technology Growth Rate

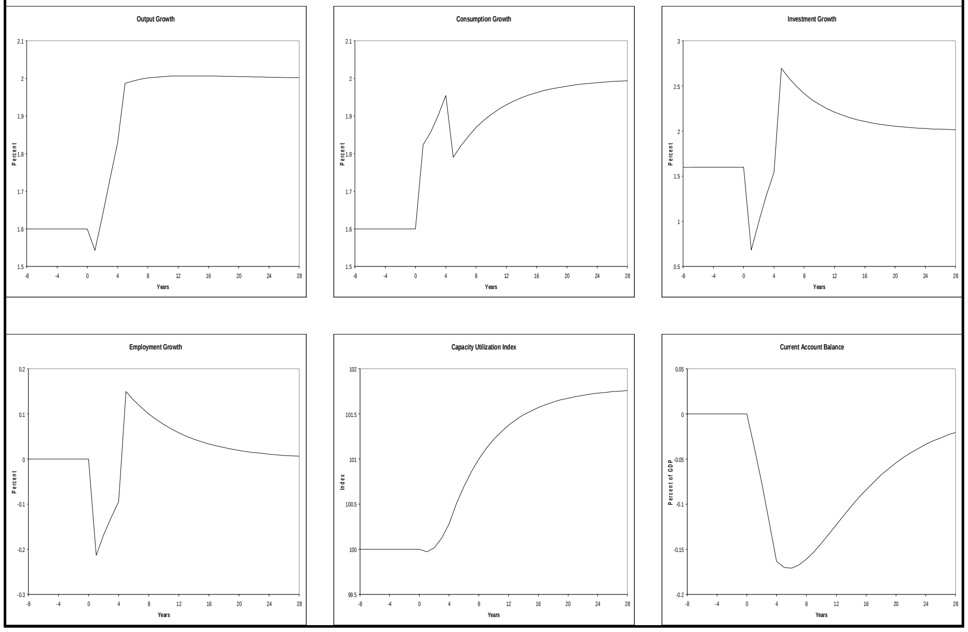

Figure 4
Simulation Results -- Responses to a Higher Embodied Technology Growth Rate

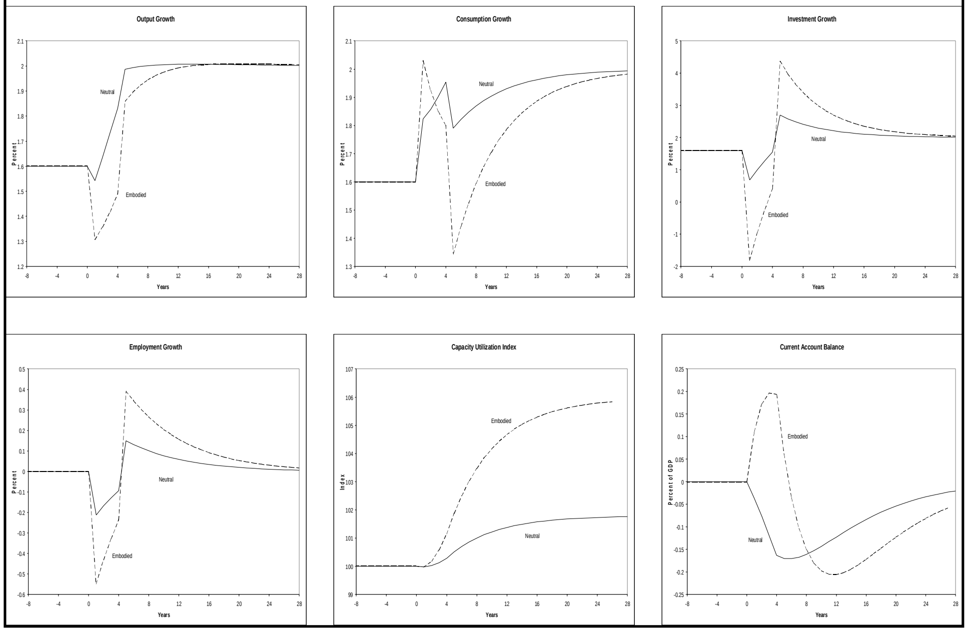

Figure 5
Responses of Productivity Growth to Higher Technology Growth

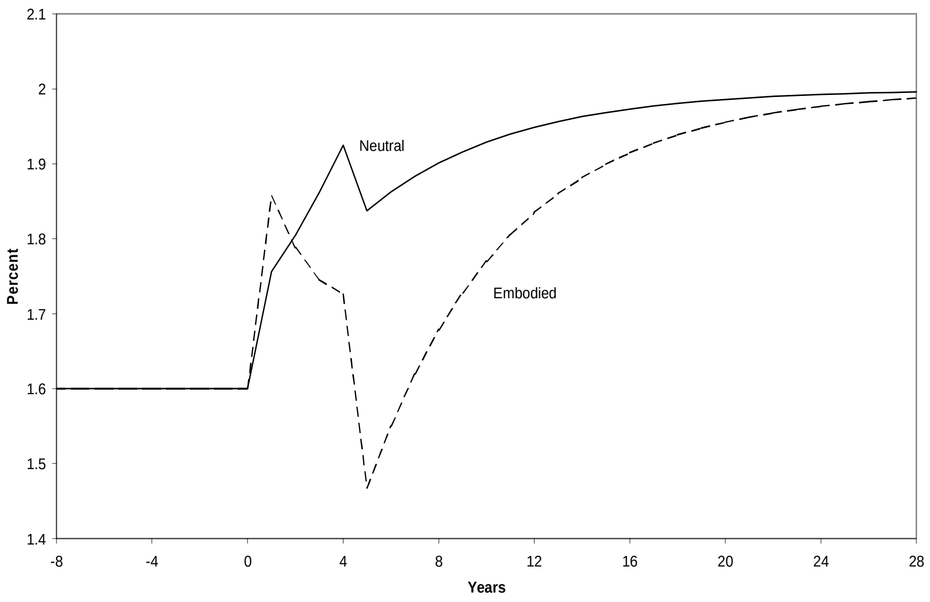

Figure 6:

Q and Z

(Logged, with HP-Trend Lines)