"DO BUSINESS CYCLES CAST LONG SHADOWS? SHORT-RUN PERSISTENCE AND ECONOMIC GROWTH"

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Do Business Cycles Cast Long Shadows? Short-run Persistence and Economic Growth

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Abstract.

This paper explores the links between short-run (cyclical) phenomena and the long-run technological trend of output. We show that there is a strong positive correlation between the degree of persistence of short-run fluctuations and the average growth rates in both cross-country and cross-industry data. We present an endogenous growth model with aggregate demand shocks that can account for this positive correlation. Although the shocks in the model are cyclical, they are able to generate persistent fluctuations through the effects that they have on technological progress. Persistence becomes a measure of the growth that is lost (or gained) during a recession (or a boom). Growth becomes a necessary condition for the shocks to be persistent and the degree of persistence is a function of the speed at which productivity increases. A key feature of the model is the cyclical behavior of those resources responsible for growth. We empirically verify this assumption by showing the procyclical behavior of R&D expenditures in the U.S., Germany and Japan.

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1. INTRODUCTION

Macroeconomists usually study long-term growth separately from short-term fluctuations. The business cycle literature studies deviations of output from a trend while the growth literature analyzes the slope of the trend. Traditionally these deviations were calculated from a deterministic trend, for example log-linear. Under this view, recessions are followed by recoveries that return the economy to its long-term trend.

Nelson and Plosser (1982) challenged the notion of a deterministic trend by showing that output follows a non-stationary process. Shocks are persistent in the sense that output does not return to a linear trend after being hit by a shock. Instead, output remains at a different level forever. This evidence has been used to support models in which productivity shocks are the main driving force of output fluctuations. Although one goal of these models is to integrate growth and fluctuations in the same framework, most of them treat technological progress as exogenous and analyze fluctuations as deviations from the steady-state solution of a neoclassical growth model.[1] This is, in fact, the same framework used by the literature following Nelson and Plosser (1982) which dealt with the issue of persistent fluctuations. From this framework they derived the identifying assumptions to distinguish demand (cyclical) shocks from technological (permanent) shocks.[2]

Our paper argues that analyzing business cycle fluctuations in models where technological progress is exogenous is misleading. To illustrate, Figure 1 presents a plot of a standard measure of the persistence of annual fluctuations in OECD countries against the average growth rate in the last 30 years.[3] There is a strong positive correlation between both variables. Countries that grow faster have at the same time more persistent fluctuations. By analyzing the persistence of output shocks with models that consider technological progress as exogenous, we are throwing all the underlying causal factors into an exogenous technological drift: we are leaving some vey interesting information out of the analysis.

We present an explanation for the correlation between growth and persistent fluctu-

[1] See Kydland and Prescott (1982) and Prescott (1986).

[2] See for example Campbell and Mankiw (1987), Shapiro and Watson (1988), Blanchard and Quah (1989), Cochrane (1992) and King, Plosser, Stock and Watson (1991).

[3] Data is annual from the Summers-Heston (1991) data set. Persistence is measured as the Cochrane (1989) ratio of variances with a window of 5 years.

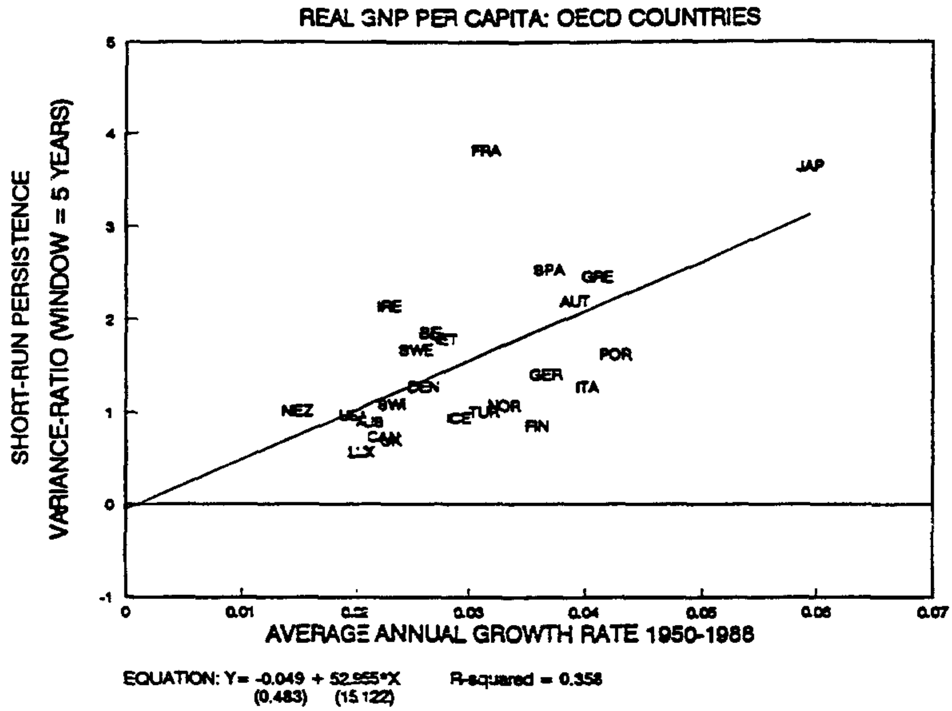

FIGURE 1

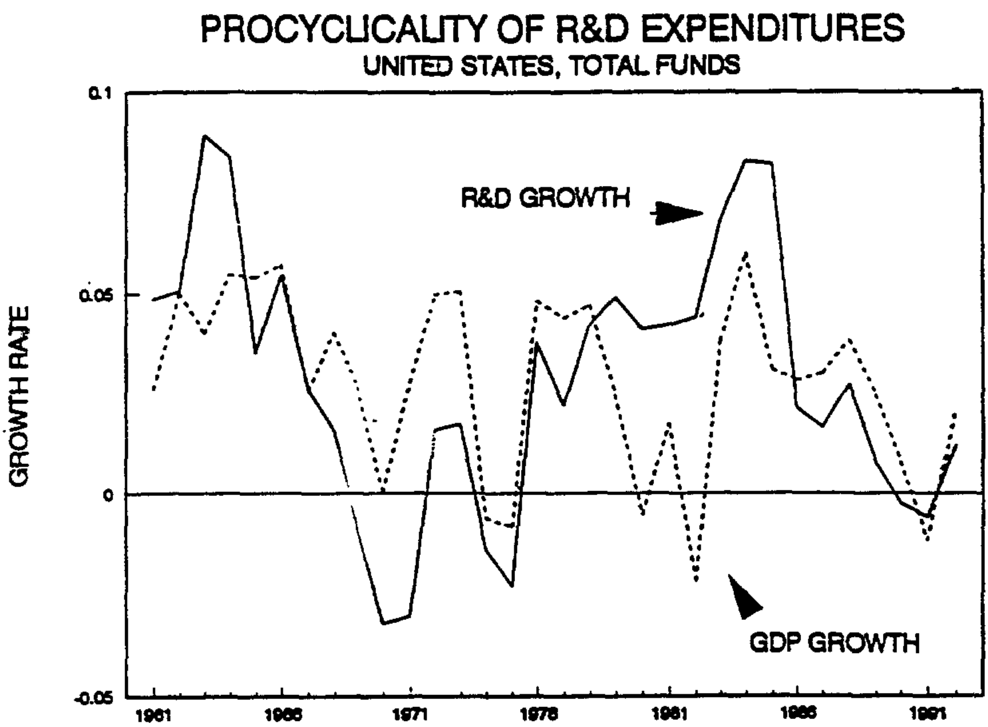

FIGURE 2

ations based on an alternative notion of persistence. In our model, persistence does not come from exogenous technological shocks. Instead, we think of persistence of shocks as a measure of the growth that is lost (gained) during a recession (boom). If during a recession the growth rate of technological progress is reduced, then after the effects of the recession vanish, output remains at a lower level forever. This is true regardless of the origin of the shock. Following this argument, suppose now that a typical recession transitorily reduces the rate of investment and the growth rate of productivity by some given percentage. Then, the permanent effects that a recession has on the level of output are much higher in a country like Japan that is growing at an average 6% than in a country like New Zealand that is growing at less than 2%. This was demonstrated in Figure 1.

This explanation relies on a procyclical response of those resources responsible for long-term growth. Capital expenditures are well-known to be procyclical. As Figure 2 shows, variables more directly related to technological progress, such as research and development expenditures, are also procyclical.[4]

This paper embeds the previous facts in an endogenous growth model where short-term fluctuations and long-term growth are not independent phenomena. We also present additional empirical evidence to support the main points of the model. The model represents an imperfectly competitive economy with aggregate demand externalities. The growth rate is determined by the amount of research done by firms. Optimal research depends on the expected profitability of innovations which is a function of aggregate demand. There are two types of results that stress the interdependence of fluctuations and growth. First, in a non-stochastic environment, there exists the possibility of multiple equilibria in growth rates caused by the aggregate demand externality. Equilibria with higher aggregate demand also have higher growth rates. Coordination failures lead to cyclical fluctuations that affect the speed at which technology is improved. Second, abstracting from the multiplicity of equilibria, exogenous aggregate demand shocks become persistent through the impact they have on research and productivity growth. Output does not revert to a linear trend after the effects of the demand shock die out.

This explanation for the persistence of output fluctuations has interesting impli-

[4] Figure 2 shows the procyclicality of *total* R&D expenditures. Other measures of R&D expenditures such as *industry-funded* R&D expenditures behave almost identically. Even if we decompose total expenditures into *basic* research and *applied* research, the behavior of both measures of R&D is clearly procyclical.

cations for several features of the business cycle. It is consistent with the time series evidence of output without relying on exogenous technological shocks. It does not require periods of technological regress to generate persistent contractions. Also, the model can explain the high persistence of identifiable demand shocks as compared to productivity shocks found in Campbell and Mankiw (1987) and D. Romer (1989).

We also present further empirical evidence that analyzes in detail the facts shown in Figures 1 and 2. R&D expenditures are shown to be procyclical even when we instrument with demand variables for output. Moreover, this procyclicality is corroborated with data from two other countries: Japan and Germany. Second, the strong positive correlation between long-run growth rates and the degree of persistence of short-term fluctuations of Figure 1 is also present in quarterly cross-sectoral data for industrial production in the U.S.

Several strands of the literature relate to this paper. Stadler (1986, 1990) shows how monetary shocks can generate a non-stationary process for output when growth is endogenous. Shleifer (1986) models the possibility of endogenous cycles arising from aggregate demand externalities. Cycles are crucial for growth because implementations of innovations require periods of higher demand. However, cycles have no long-run effect on growth because innovations are always implemented.[5] Our model endogenizes the flow of ideas and therefore allows us to establish richer conclusions about the effects of cycles in growth. Also by introducing exogenous shocks we follow a more conventional approach to business cycles. A third related line of research looks at the cleansing effects of recessions on productivity as a result of the lower opportunity cost of 'reorganizations' during downturns.[6]

Section 2 presents the model, characterizes the equilibrium and analyzes the connection between the short run and the long run. Section 3 provides empirical evidence and Section 4 concludes.

[5] Using a similar model, Murphy, Shleifer and Vishny (1989) provide a more static picture of the same result by emphasizing the importance of the size of the market in the presence of IRS technology. They show that there could be traps to development in the early phases of growth.

[6] See for example, Hall (1991), Galí and Hammour (1991), Caballero and Hammour (1992), DeLong (1990) and Saint-Paul (1993).

2. THE MODEL

2.1. Setup.

The model represents an imperfectly competitive economy with demand linkages across sectors as in Shleifer (1986) where technology is the outcome of an innovative process as in Aghion and Howitt (1992) or Grossman and Helpman (1991).[7]

The economy is characterized by a continuum of imperfectly competitive sectors uniformly distributed in the unit interval. There is a representative consumer that owns all claims to profits and maximizes the following utility function

$$U = \sum_{t=0}^{\infty} \beta^t \int_0^1 ln(x_{it})\ di$$

Where x_{it} represents consumption of good i at period t. This is a Cobb-Douglas utility function with equal shares defined for a continuum of goods. Assume that there is no storage so that total consumption must be equal to income every period.

$$\int_0^1 p_{it} x_{it}\, di = \Pi_t + W_t$$

Where Π_t and W_t represent profits and wages. From the first order condition of the consumer we get unit-elastic demand for every good so that the consumer spends the same amount on each good (let d_t be this amount). Given the normalization in the unit interval, this amount is equal to total expenditures (D_t) and income, $d_t = D_t = \Pi_t + W_t$.

The consumer inelastically supplies one unit of labor. There are two types of labor activities: production and research. Research activities require a higher skill and therefore a 'disutility' premium of v.

There is an innovative monopolist in each sector and a group of imitators. Innovations can be 'patented' only the period they are discovered so that they can be copied by the fringe of imitators next period. Assume that the research process is memoryless in the sense that the amount of effort to innovate today only affects the probability of finding an innovation today and not in future periods. When the monopolist uses r_t workers in research activity at period t, then it has a probability $\Phi(r_t)$ of finding

7 In Shleifer (1986) there is endogeneity in the process of implementing innovations but the long-run growth rate of the economy, measured by the flow of ideas, is exogenous.

an innovation. Where $0 < \Phi(\cdot) < 1$, $\Phi'(\cdot) > 0$ and $\Phi''(\cdot) < 0$. This innovation can be implemented in the same period.[8]

The production function of each monopolist is

$$y_t = A_t n_t^P$$

Where A_t indicates the technological level at time t and n_t^P is the amount of labor used for production. Innovations raise this technological parameter so that every time a monopolist innovates it improves its production function by γ, so that $A_t = \gamma A_{t-1}$ whenever there is innovation and $A_t = A_{t-1}$ when research fails.[9] Note that, although there is not capital in this model, A_t could represent the stock of capital or knowledge accumulated in a sector and the level of research could be the investment in this stock with uncertain returns.

Individual decision

Let's look first at the optimal policy of a monopolist in a single market, normalizing the wage of unskilled labor to one. The monopolist takes demand, summarized by y, as given. Now, if she has been successful and has achieved an improvement in her technology, the best thing to do is to price the good to keep all imitators out of the market. Given that the followers can use the 'next' available generation of technology, the monopolist should price at the marginal cost of the followers. If A_t is her technological level she should set a price equal to $p_t = (A_{t-1})^{-1}$. Given the specification of the innovative process, $p_t = (A_t)^{-1}\gamma$. This is optimal because if she charges more than $(A_t)^{-1}\gamma$, she loses all the market to the followers, and if she sets a lower price she receives the same revenue but at higher cost.

Given the optimal pricing policy of the 'successful' monopolist, we can compute her profits by noticing that the amount she sells is equal to $y_t = d_t A_{t-1}$ and the labor it requires to sell this amount is $n_t^p = d_t \gamma^{-1}$. Therefore, profits of a successful monopolist

[8] Allowing immediate implementation of innovations differs from the standard assumption where there is a lag between research and successful innovation. Introducing such a lag does not affect any of the results and, on the other hand, it unnecessarily complicates the model by introducing dynamics of implementation of the type shown in Shleifer (1986).

[9] The parameter γ is, obviously, higher than one. The model can be also interpreted in terms of improvements in quality as in Grossman and Helpman (1991) just by modifying the utility function to allow for differences in quality.

are

$$\pi_t = d_t - \frac{d_t}{\gamma} = \frac{\gamma - 1}{\gamma} d_t$$

The independence of profits from the current level of technology comes from the properties of the Cobb-Douglas utility function. For notational simplicity, define Γ as

$$\Gamma \equiv \frac{\gamma - 1}{\gamma}$$

Profits of a successful monopolist can be rewritten as $\pi_t = \Gamma\, d_t$.

The unsuccessful monopolist is not able to get any positive profits because the followers are just as productive and have the same marginal cost.

Next, we solve for the optimal amount of workers that the monopolist hires for research activities. Given the assumptions about the imitation process, the monopolist only cares about aggregate demand today. Let r_t be the amount of labor employed on research activities at time t. Then the following first-order condition holds,[10]

$$\Gamma\, \Phi'(r_t)\, d_t = (1 + v) \tag{2.1}$$

As the function $\Phi(\cdot)$ is concave, the second-order condition is satisfied. The connection between aggregate demand and growth is explicit in equation (2.1). The optimal amount of research at time t, for any given individual monopolist, is a function of d_t. An increase in the demand (as measured by d_t) that the monopolist faces, raises the optimal amount of labor that she devotes to research and therefore it affects the possibilities for growth. This is the crucial connection explored in the following sections. Next, we solve for the equilibrium of the whole economy.

General Equilibrium

Equation (2.1) characterizes the optimal behavior of an individual firm that takes aggregate demand as given. Now we look at the equilibrium of the whole economy and solve for d_t. From the normalization in the unit interval, $d_t = D_t$ and from the definition of D_t, $D_t = \Pi_t + W_t$. Denoting by R_t the total amount of labor devoted to research, aggregate wages are $W_t = (1 - R_t) + (1 + v)R_t$. Aggregate profits are equal to the proportion of successful monopolists in the population multiplied by their profits. As there is a continuum of sectors, the actual proportion of successful monopolists coincides

[10] Where it is assumed that firms maximize profits.

with the population mean so that a proportion $\Phi(R_t)$ is successful at period t, while the rest have zero profits. From here,

$$D_t = \Gamma\,\Phi(R_t)D_t - (1+v)R_t + (1-R_t) + (1+v)R_t = \Gamma\,\Phi(R_t)D_t + (1-R_t)$$

Thus,

$$D_t = \Big(1-\Gamma\,\Phi(R_t)\Big)^{-1}(1-R_t) \tag{2.2}$$

This equation together with the first-order condition of each monopolist characterize the equilibrium. Notice that we are looking at symmetric equilibria in which all monopolists employ the same number of skilled researchers. The research effort of each individual monopolist should satisfy

$$\Gamma\,\Phi'(r_t)\Big(1-\Gamma\,\Phi(R_t)\Big)^{-1}(1-R_t) = (1+v) \tag{2.3}$$

At any symmetric equilibria $r_t = R_t$ and the equilibrium is defined by an amount of research labor, R, that satisfies

$$\Gamma\,\Phi'(R)\Big(1-\Gamma\,\Phi(R)\Big)^{-1}(1-R) = (1+v) \tag{2.4}$$

The next sections focus on two variables, aggregate demand and the growth rate of output. Aggregate demand (D_t) determines the expected profitability of research.[11] Research determines the overall growth rate of output. Given the multisectoral structure of the model and the asymmetry in the timing of innovations, a measure of aggregate product needs to be defined. As expenditure shares are equal for all sectors, it is reasonable to give the same weight to each of the sectors. Then, the overall growth rate is the average of the growth rates of each sector and, thus, can be calculated as $\Phi(R)(\gamma-1)$. Apart from the function $\Phi(\cdot)$ and the parameter γ, the only variable that affects the growth rate is the amount of labor employed in research (R). This is the key variable that we look at when referring to the effect of shocks on the growth rate of the economy. Higher values of R imply higher growth.

The next two sections characterize the equilibrium of the model. First, we look at the strategic interactions among all sectors and show that there exists a form of strategic

[11] In this model, there is a one-to-one connection between demand and profitability of research. In a more general setup, this connection might not be so direct because the degree of competition can be a function of the level of demand.

complementarity in the level of research effort. Next we focus on the effects of 'short-run' shocks.

2.2. Characterization of Equilibria.

Symmetric equilibria are defined by an amount of labor that each monopolist hires for research activities. This amount determines the number of innovations that occur every period and, therefore, the growth rate. Let's look first at the strategic interactions between all the sectors to analyze the dependence of individual research effort on the total amount of research.

From equation (2.1) individual research depends positively on aggregate demand. From equation (2.2), aggregate research affects aggregate demand. The direction of this effect is not monotonic: there is a positive effect which works through the demand externality but there is also a negative effect which comes from the 'unproductiveness' (in terms of output) of the research workers. The next proposition establishes that, at least around any symmetric equilibria, there exists a positive relation between both variables.

PROPOSITION 1.- *At any symmetric equilibrium, the best response $r = r(R)$ is an increasing function.*

PROOF.- See appendix.

Proposition 1 establishes that around any equilibrium best response functions are upward sloping and therefore, individual research and aggregate research are strategic complements. When aggregate research is high, expected future demand is also high and, thus, individual research is more profitable. A straightforward extension of this proposition is the possibility of multiple equilibria. If the strategic interaction is strong enough, we can have more than one equilibria. The parameter v is an approximation for the degree of complementarity between aggregate and individual research.[12]

PROPOSITION 2.- *For v sufficiently high there exists an odd number of multiple equilibria.*

[12] This question is similar to the problem faced by Murphy, Shleifer and Vishny (1989). They find that if the demand externality comes only through profits then, best responses are flat around the equilibrium and, thus, there cannot be multiple equilibria. The introduction of a disutility of skilled labor makes the best response functions slope upwards. In fact, the slope of the best response function is positively related to this disutility. There is a more convincing argument to get around this problem, shown in Fatás and Metrick (1991), the introduction of intermediate inputs. We do not follow that approach here because it would unnecessarily complicate the model.

Growth rates and aggregate demand are positively correlated across equilibria.

PROOF.- See appendix.

Hence, the solution to the model presents an economy in which there might be more than one equilibria that are characterized by different growth rates. Equilibria with higher output growth rates also have higher levels of aggregate demand. This is a dynamic generalization of results of previous models with pecuniary externalities and shows how economies have to select among several possible equilibria that differ in their growth rates.

A straightforward implication of this proposition is the interpretation of recessions as equilibria characterized by low aggregate demand and low growth. Under this interpretation recessions are not only cyclical downturns but they also temporarily reduce the growth rate of productivity.[13] In this sense fluctuations are persistent because they permanently affect the level of output.

The next section presents a modified version of the model that introduces exogenous aggregate demand shocks. There is again a connection between aggregate demand and growth even in the presence of a unique equilibrium. For the remainder of the paper we, thus, abstract from the multiplicity of equilibria.[14]

2.3. Exogenous Short-run Shocks and Growth.

In equation (2.1) the equilibrium growth rate is a function of aggregate demand as measured by D_t. The causality that runs from D_t to R_t has to do with the relation between aggregate demand and profitability of innovations. In the model this connection is straightforward, lower aggregate demand affects the marginal profitability of an innovation and therefore reduces the optimal amount of research effort. This simple connection implies that any shock to aggregate demand affects the rate of innovation today and, thus, the productivity level forever.[15] In other words, any shock which affects aggregate demand, regardless of its origin and horizon, has permanent effects. As a corollary, a

[13] This interpretation, although in a model with technological externalities, is the one followed by Durlauf (1989) and Durlauf and Johnson (1992) where the lack of convergence among a subset of countries is given as evidence in favor of multiple equilibria models of growth.

[14] See the appendix for the condition that needs to be imposed to ensure that there exists a unique equilibrium.

[15] To be more precise, we also need either that the shock is anticipated or that there is some persistence in the shocks received by aggregate demand. This point is clarified later.

technological shock that affects aggregate demand has its permanent effects amplified through the aggregate demand channel. To show these implications we follow two types of exercises. First, we introduce short-run dynamics in the model and show that during recessions the rate of innovation is lower. Second, we perturb the equilibrium with a specific technological shock. It is then shown that this shock has effects on research activity only because of an aggregate demand effect.

2.3.1. Aggregate Demand Shocks.

Given that our main concern is not the specific origin of the shocks but the dynamic behavior that they generate, we introduce exogenous aggregate demand shocks by simply postulating a random process for the unemployment rate.

As labor supply is normalized to 1, the unemployment rate is measured as $1-N$. Suppose that the employment rate, N, follows a simple two-state Markov process where it can take two values: low employment denoted by N_L and high employment denoted by N^L. The transition probabilities are defined by p_L and p_H and they represent the probability of remaining in the same state next period. Assume that they are both higher than 0.5 so that there is some persistence in both states. The stochastic process of the employment rate can be summarized as

$$N_t = \begin{cases} N_H \rightarrow N_{t+1} = \begin{cases} N_H & \text{with probability} \quad p_H \\ N_L & \text{with probability} \quad (1-p_H) \end{cases} \\ N_L \rightarrow N_{t+1} = \begin{cases} N_H & \text{with probability} \quad (1-p_L) \\ N_L & \text{with probability} \quad p_L \end{cases} \end{cases}$$

Given this process, it is natural to talk about the state N_L as a cyclical recession. To see why this is a valid interpretation, suppose that we did not allow for endogenous growth but assumed it to be exogenous. The trend would be growing at some exogenously given rate and the 'low-state' would be associated to lower temporary levels of output. After the effects of the shock disappeared, output would return to a linear trend.

The presence of endogenous growth changes the effects of this type of shocks. Output still does return to its trend but the trend is itself affected by the shocks. In other words, these shocks have permanent effects.

PROPOSITION 3.- *During recessions, the growth rate of productivity is lower. Shocks to the employment rate have permanent effects.*

PROOF.- See appendix.

The channel of transmission of these shocks to the trend is through demand. By looking at the individual solution for the optimal amount of research, we see that the first order condition (2.1) is not affected. However, from (2.2), aggregate demand is a function of the employment rate

$$D_t = \left(1 - \Gamma\,\Phi(R_t)\right)^{-1}(N_t - R_t)$$

Note also that given the strategic complementarity present around equilibrium, there is a 'multiplier' effect associated with the change in research labor that also operates through the demand externality.

Clearly, the effects that demand shocks have on research hinges upon the assumption that innovations are immediately implemented. However, this result is more general and also applies when there are lags between research and the implementation of innovations. This is true as long as the expected horizon of success for R&D overlaps with the last period where the effects of the demand shocks are felt. Also, there are some additional factors that could be introduced in the model to reinforce these effects. For example, cyclical shocks, by reducing firms' cash-flow, could cause a shift from long-run investment projects to high cash-flow short-run projects. Although the channel of transmission in this case is not demand, the optimal amount of research responds to business cycle fluctuations as in Proposition 3.

Proposition 3 summarizes the main idea of the paper. As long as recessions have consequences on the profitability of research, they will have permanent effects. Moreover, the stochastic properties of the business cycle are translated into the stochastic behavior of the trend. In this model, the trend is stochastic only because of the 'short-run' shocks that affect the economy. The same two-state Markov process that characterizes the cycle is present in the trend. If, for example, 'short-run' shocks were characterized by more general autorregresive process, the trend would also follow a similar autorregresive process.

Figure 3 graphically represents Proposition 3. The graph shows the permanent effects that employment shocks have on output. The evolution of output and productivity are graphed in response to a negative shock. There is a cyclical component of output that fades away. Output returns to the trend defined by productivity. However, in the long-run, output remains at a lower level because the shock also has effects on the creation of new technologies. The origin of these permanent effects is not a negative

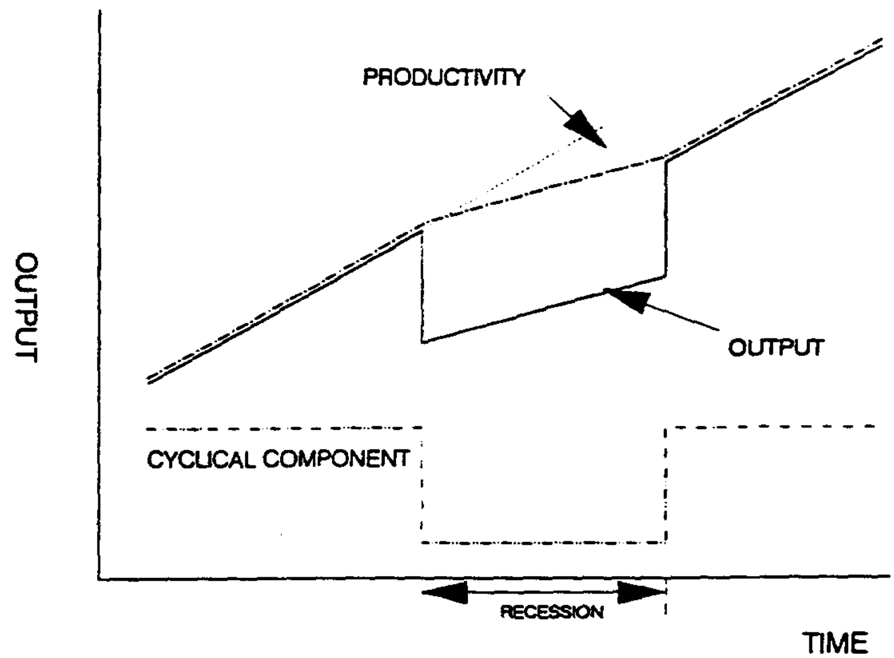

FIGURE 3

exogenous technology shock but the endogenous reaction of productivity growth. It is important to notice that growth is a necessary condition for employment shocks to be persistent. An economy with zero growth would have a stationary output series. This is in fact what the regression line of Figure 1 predicted.

Notice also that although in Figure 3 we have a persistent *negative* shock, productivity is always growing, there is no absolute technological regress. Under the alternative explanation to the persistence of this shock, namely a negative exogenous productivity shock, we would require some kind of technological regress.

2.3.2. Amplification of Technological Shocks.

The purpose of this exercise is to generalize the result of Proposition 3 to other type of shocks. We show that an exogenous technological shock (represented by a period of lower technological progress) is amplified through the aggregate demand channel. This effect can be considered a productivity multiplier in the sense that a true exogenous technological shock can see its effects on *productivity* amplified.

To introduce technological shocks let's assume the 'success function' $\Phi(\cdot)$ has an exogenous autonomous component, Φ_0 so that $\Phi = \Phi_0 + \Phi(r)$. Suppose there is a negative shock that temporarily reduces this autonomous component. This is a technological shock that affects the trend of the economy forever.[16] There is a first direct effect on the growth rate of the economy regardless of the amount of research effort. What happens to the equilibrium amount of research labor? By looking at the first order condition of each individual firm, a decrease in Φ_0 does not *directly* affect their optimal research. But there is an *indirect* effect that is working through the aggregate demand effect. We can rewrite aggregate demand in this case as

$$D_t = \left(1 - \Gamma\left(\Phi_0 + \Phi(R_t)\right)\right)^{-1}(1 - R_t)$$

Aggregate demand is affected by the decrease in Φ_0 and, thus, labor research is reduced in equilibrium. We, therefore, observe an effect that is only present because of the connection between aggregate demand and growth rates.

A straightforward implication of this result is that a technological shock that impacts aggregate demand through, for example, nominal rigidities or endogenous policy reaction, will also be amplified. The permanent effects that it leaves on the economy are a combination of the exogenous impact on the production function plus the endogenous reaction of technology. The oil shocks of the 70's and the contractionary monetary policy that followed them can be an example of this type of amplification.

3. EMPIRICAL ANALYSIS

In this section, we provide further evidence on the implications of Figures 1 and 2. We first present additional evidence on the procyclical behavior of R&D expenditures. We then show that the correlation between average growth rates and persistence of fluctuations of Figure 1 is also present in U.S. quarterly cross-industry data.

3.1. Cyclical Behavior of R&D Expenditures.

The model of Section 2 implies both productivity and innovative activity are procyclical. The literature amply documents that productivity is procyclical.[17] Here, we

[16] The shock is assumed to be temporary so that it has permanent effects on output level but not on its growth rate.

[17] For example, Durlauf (1989) shows that productivity is procyclical and cointegrated across sectors

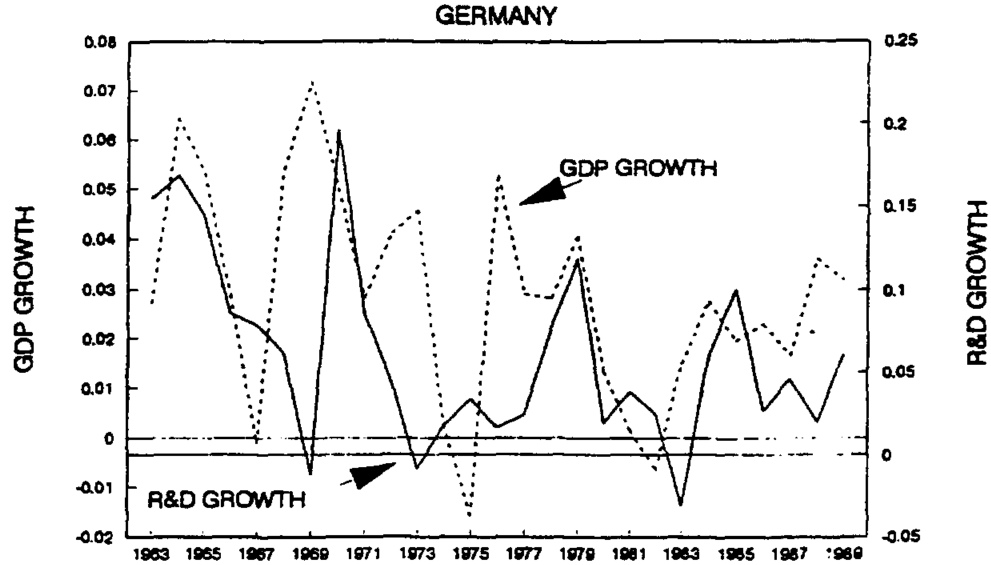

FIGURE 4

concentrate on an implication specific to this model: the procyclical behavior of the resources responsible for long-term growth. The allocation of these resources responds to output fluctuations. As long as their returns are constant, they are good approximations for the behavior of technological progress.

There is a long list of variables that are possible determinants of long-run growth: physical and human capital accumulation, introduction of new goods, learning by doing, research and development expenditures. The procyclical behavior of physical capital accumulation has been widely documented. The rest of the variables are generally very difficult to quantify with the exception of R&D expenditures. At the same time, R&D expenditures is the closest proxy for research in our model. Therefore, we look at the behavior of these expenditures as an approximation for all resources that are allocated to improve technology.[18]

and Bernanke and Parkinson (1991) discuss alternative theories of short-run procyclical productivity.

[18] The effect of R&D on total factor productivity (TFP) is an open area of research. By using R&D expenditures we are not assuming that it is solely responsible for TFP but rather that it is a representative measure of resources allocated to technological improvements.

The evidence shows a strong positive relation between output fluctuations and R&D expenditures. We already saw in Figure 2 how expenditures on R&D were clearly procyclical in the U.S. Figures 4 and 5 show procyclicality of R&D funds for Germany and Japan. Efforts to improve productivity are not neutral to business cycles.

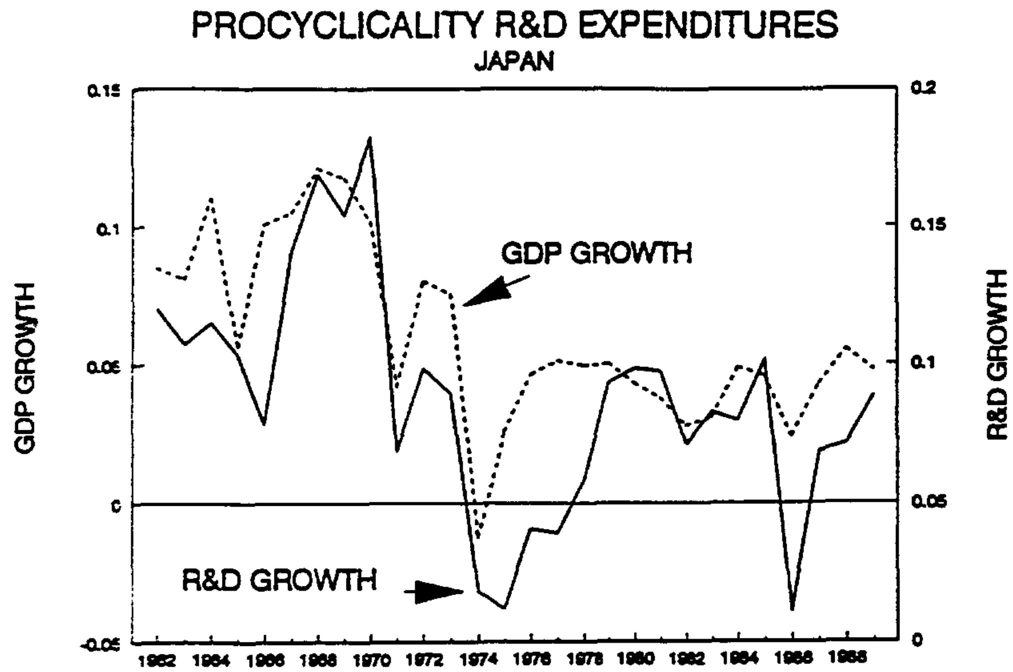

FIGURE 5

As a first approximation, we run a simple regression of the growth rate of R&D expenditures on the growth rate of output for Germany, Japan and the U.S.[19] Results are shown in rows [1] to [4] of Table 1. The estimates confirm the procyclicality of R&D expenditures. The coefficient on output growth lies in the range 0.7-1.0. Therefore, we find that innovative activity, measured by R&D expenditures, moves positively with output.

We also perform two additional tests in order to make explicit the origin of the positive correlation between output and R&D. First, and only for the U.S., we run

[19] In the case of Germany, a lag for output growth is added because the positive correlation occurs with a lag. Also, adding lags of R&D growth to the regressions does not affect the sign of the coefficients on output growth.

Table 1. Procyclicality of R&D expenditures Germany, Japan and U.S.

Equation: $\Delta rd_t = \alpha + \beta_0 \Delta y_t + \beta_1 \Delta y_{t-1} + \nu_t$

Country		β_0	β_1	R^2
Germany	[1]	0.73		0.08
		(0.50)		
	[2]	0.42	1.04	0.23
		(0.49)	(0.48)	
Japan	[3]	1.05		0.64
		(0.15)		
U.S.	[4]	0.75		0.22
		(0.24)		
U.S.	[5]	0.92		
(instruments)		(0.45)		

Sample: U.S.: 1962-92; Germany and Japan: 1962-89
Standard errors in parentheses.

the same regression but instrumenting for output with variables that capture demand shocks. Contemporaneous and lagged values of the growth rate of defense expenditures and of the monetary policy index constructed by Romer and Romer (1990) are used as instruments. Row [5] in Table 1 shows the results. The size and significance of the coefficient on output are essentially unchanged.

We then run causality tests to identify the direction of the shocks that are causing the positive correlation between output and R&D. The question is whether this correlation originates in output and spreads to R&D as in the model of Section 2 or whether it comes from new technological opportunities that boost research and thereby increase output growth. Table 2 presents these tests.[20]

Table 2. Causality Tests.

	Country		
Variable	Germany	Japan	U.S.
Δy	0.403	0.650	0.638
Δrd	0.022	0.062	0.040

Sample: See Table 1

[20] The table reports the joint significance (p-value of the F-test) of the coefficients $\beta_1(L)$ and $\beta_2(L)$ on equations $\Delta y_t = \gamma_1 + \alpha_1(L)\Delta y_t + \beta_1(L)\Delta rd_t + \nu_t$ and $\Delta rd_t = \gamma_2 + \alpha_2(L)\Delta rd_t + \beta_2(L)\Delta y_t + \nu_t$. Two lags of each variable are included in each regression. We use R&D growth for the tests. Causality tests provide the same results if a detrended series is used. Moreover, unit root tests for R&D expenditures show that we cannot reject the presence of a unit root in any of the three countries at the 5% significance level.

The results show that, for the three countries, we cannot reject that output growth causes R&D growth but we can clearly reject that R&D growth causes output growth. This implies that, at least at the yearly frequency, shocks originating in R&D are not common. We conclude that the positive correlation between R&D and output originates in output shocks like the ones of our model.

In summary, R&D growth and output growth are positively correlated. Moreover, as in the model of Section 2, this correlation comes from output shocks that are translated into R&D and not the reverse. Also, the response of R&D to output fluctuations caused by identifiable demand shocks is practically identical to the response to a general shock.

3.2. Persistent Shocks: Exogenous Versus Endogenous Technology.

Business cycles have been traditionally measured as deviations of output from a deterministic trend (for example log-linear). Nelson and Plosser (1982) challenged this practice by showing that GNP was a non-stationary series and therefore shocks were not trend-reverting. They use this evidence to support the hypothesis that business cycles are driven by exogenous technological shocks. There is a large literature that develops and interprets this result. Most of this literature is built on the belief that productivity shocks do not have the frequency or magnitude required to explain output fluctuations.[21] These researchers accept the evidence about the persistence of GNP shocks and so attempt to measure the contribution of permanent shocks to GNP relative to the contribution to GNP of cyclical shocks. They all use the assumption that demand shocks (also referred to as cyclical shocks) are orthogonal to technological shocks.[22] Shocks that have permanent effects on output are identified as technological shocks while those that only have temporary effects are identified as demand shocks. An implicit assumption in these decompositions is that technological progress is exogenous.

The model of Section 2, by endogenizing growth, is able to explain the persistence of GNP shocks from a different perspective. The spirit of the model is closer to the old view of business cycles as movements of output around a trend. The difference is that now the trend reacts to business cycles. Recoveries are not strong enough to compensate

[21] The oil shocks of the 70's is probably the most accepted example of major technological shock but even in this case, it is difficult to explain why positive shocks, such as the decrease in oil prices during the mid-80's, do not have the contrary effect. See Shapiro and Watson (1988).

[22] This approach is the one followed by Campbell and Mankiw (1987), Shapiro and Watson (1988), Blanchard and Quah (1989) and King, Plosser, Stock and Watson (1991) among others.

for the growth that is lost during recessions. As Proposition 3 showed, when growth is endogenous the assumption of orthogonality between technological and cyclical shocks is not valid.[23] One can then interpret the persistence of GNP shocks as the negative repercussions that business cycles leave on the trend. The distinctive feature of this explanation is that aggregate demand shocks can be the main source of disturbances even if most shocks have permanent effects. Notice that a *transitory* response of the amount of resources allocated to growth has *permanent* effects on output. In other words, although output returns to its trend after the effects of the shock disappear, it does not return to a linear trend but to a trend that has also been affected by the shock. The advantage of this interpretation is twofold. First, permanent shocks can be caused by different phenomena and thus we do not have to restrict their origin to exogenous shifts in the production function.[24] Second, we can account for the persistence of negative shocks without requiring periods of absolute technological regress, productivity growth is temporarily lower during recessions but it never becomes negative.

An interesting implication unique to this explanation is that the persistence of output shocks is a function of the speed at which technology evolves. For example, in the model of Section 2.3, if the equilibrium growth rate of technology is zero, shocks are not persistent, output is a stationary variable. In general, given that persistence is a measure of how much growth has been lost (gained) during a recession (boom), the faster productivity grows the more persistent fluctuations are. One then expects that countries or sectors that grow faster will, at the same time, exhibit a higher degree of persistence.[25]

In Figure 1 we looked at differences in the degree of persistence across OECD countries and saw that they were positively correlated with the average growth rates for these countries. Now we do the same exercise for a different sample: two-digit U.S.

[23] In general, endogenizing growth can have non- trivial consequences for the analysis of shocks. As an example, under perfectly competitive endogenous-growth models such as the P.Romer 'Ak' model, shocks to the parameter A have 'super-permanent' effects on output. Super-permanent effects mean permanent effects on the growth rate of output. If this is the case, one expects *output growth* to be non-stationary. These conclusions are not so strong if we consider alternative models of endogenous growth, such as the one used here. In this model, shocks to the technological parameter of the production function do not permanently affect the growth rate of output.

[24] As D.Romer (1989) and Campbell and Mankiw (1987) show, identifiable demand shocks seem to be as persistent as other non-identified shocks.

[25] For this correlation to be true, growth has to respond proportionally to the cyclical shocks. This is true in the model of Section 2. For a more precise analysis of this issue and some calibrations see Fatás (1993).

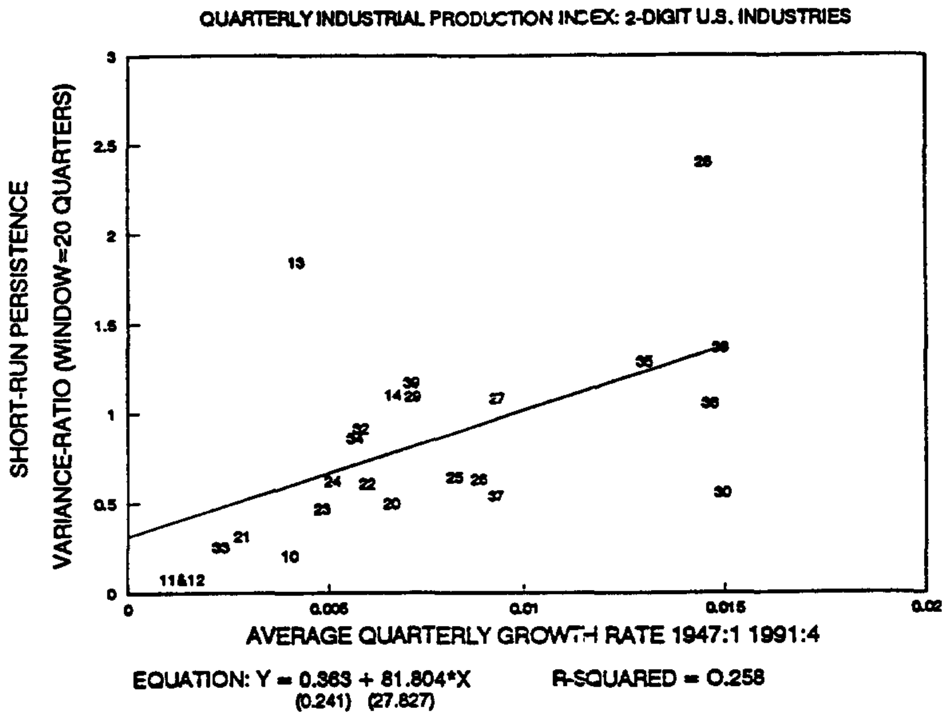

FIGURE 6

industries. We use the index of industrial production at a quarterly frequency. We use Cochrane's variance-ratio as a measure of persistence.[26] This ratio is calculated from the autocorrelations of the growth rate of the industrial production index using the formula

$$\hat{V}^k = 1 + 2\sum_{j=1}^{k-1}(1 - j/k)\,\hat{\rho}_j$$

where $\hat{\rho}_j$ is the jth autocorrelation of the growth rate of production. We again choose a window (k) of 5 years (20 quarters in this case).[27] Figure 6 show a plot of this measure against average growth rates for each industry. There is again a strong positive correlation between both variables. Sectors that grow faster exhibit more persistent fluctuations. Moreover, the intercept of a linear regression again goes roughly through the origin.[28] This implies that countries or sectors with average growth rates close to

[26] See Cochrane (1988) and Campbell and Mankiw (1988) for an extended analysis of the interpretation and construction of this measure.

[27] Results are similar for higher k.

[28] The null of hypothesis of the intercept being equal to zero cannot be rejected in any of the two

zero have a variance-ratio equal to zero and, hence, a stationary output series. This is a key prediction of the model of Section 2.3.

This evidence points towards an important role for growth-related variables in explaining the origin of the persistence of output fluctuations. The interpretation pursued by this paper is that the process of growth is temporarily affected by business cycles. Shocks that are driving fluctuations at the business cycle frequency have an impact on technological progress. These results are consistent with the model of Section 2 where aggregate demand shocks are the only source of fluctuations. However, the correlations shown in both figures can also be reconciled with models where the source of uncertainty is not demand shocks. In that sense, an endogenous growth model with transitory technological shocks like the one presented in King, Plosser and Rebelo (1988b) could possible generate the same positive correlation.[29]

4. CONCLUSIONS

This paper explores the links between short-run (cyclical) phenomena and the long-run technological trend of output. We show that there is a strong positive correlation between the degree of persistence of short-run fluctuations and the average growth rates in both cross-country and cross-industry data. Countries or sectors that grow faster have more persistent fluctuations.

We present an endogenous growth model with aggregate demand shocks that can account for this positive correlation. Although the shocks in the model are cyclical, they are able to generate persistent fluctuations through the effects that they have on technological progress. Persistence becomes a measure of the growth that is lost (or gained) during a recession (or a boom). This establishes a link between growth and persistent fluctuations. Growth becomes a necessary condition for the shocks to be persistent and the degree of persistence is a function of the speed at which productivity increases. Faster productivity growth leads to more persistent fluctuations.

A key feature of the model is the cyclical behavior of those resources responsible for growth. We empirically verify this assumption by looking at the procyclical behavior

samples.

[29] One could also argue that higher technological progress generates more persistent exogenous technological shifts. This would imply that the underlying source of cyclical fluctuations is substantially different across countries. One would therefore expect significant differences in the characteristics of business cycle across countries. This issue is not addressed in this paper.

of R&D expenditures. R&D expenditures are shown to be procyclical in the U.S., Germany and Japan. This positive correlation is robust to the use of demand variables as instruments for output.

The model has interesting implications for the notions of trend and cycle. The common interpretation of the time series of output is based on two components: a trend (possibly stochastic) and cyclical movements around it. The trend is only affected by *exogenous* changes in the production function and the deviations from the trend consist of the cyclical effect of any shock that hits the economy. In our model technology is not independent of cyclical fluctuations. Cyclical shocks are spread and amplified through demand linkages across sectors and they affect the profitability of innovations. The technological trend, represented by the endogenous process of technological improvements, is therefore affected by the shocks. Hence, after these effects vanish, output remains permanently higher or lower. In other words, 'cyclical' shocks have permanent effects. Therefore, the fact that shocks are persistent is not informative about the origin of the shocks. Persistence is a measure of how much long-term growth has been lost or gained after a shock; it is a measure of the long-run consequences that business cycles have on output.

The advantage of our explanation is that we can account for the documented persistence of GNP with a model in which aggregate demand shocks are the only source of uncertainty. These shocks become persistent through the reaction of technological progress. Moreover this explanation is consistent with the documented correlation between short-run persistence and long-run growth.

5. APPENDIX

For notational simplicity, time subscripts irrelevant to the proof are dropped from their variables.

PROOF OF PROPOSITION 1.- The best response of each individual firm is implicitly defined by the first order condition

$$\Gamma \Phi'(r) D = (1 + v) \tag{P.1}$$

and the equation for aggregate demand

$$D(R) = \left(1 - \Gamma \Phi(R)\right)^{-1} (1 - R) \tag{P.2}$$

We can rewrite both equations together as

$$\Gamma \Phi'(r) \left(1 - \Gamma \Phi(R)\right)^{-1} (1 - R) = (1 + v) \tag{P.3}$$

From here, using the implicit function theorem we can get

$$\frac{\partial r}{\partial R} = -\frac{\Phi'(r)\, \Gamma (\partial D(R)/\partial R)}{\Phi''(r) \Gamma \beta\, D(R)} = -\frac{\Phi'(r)\, (\partial D(R)/\partial R)}{\Phi''(r)\, D(R)} \tag{P.4}$$

From $(P.2)$

$$\frac{\partial D(R)}{\partial R} = \frac{\left(-(1 - \Gamma \Phi(R)\right)^{-1} + \Phi'(R) \Gamma (1 - R)}{\left(1 - \Gamma \Phi(R)\right)^{2}} \tag{P.5}$$

Given that we are only concerned with the value of this derivative around an equilibrium we can use the first order condition $(P.3)$ and simplify this expression to

$$\frac{\partial D(R)}{\partial R} = \frac{\left((1 + v) - 1\right)(1 - R)}{D \left(1 - \Gamma \Phi(R)\right)^{2}} = \frac{v}{1 - \Gamma \Phi(R)} \tag{P.6}$$

This expression is always positive. Therefore using equation $(P.4)$ and given that $\Phi''(\cdot) < 0$ we can conclude that

$$\frac{\partial r}{\partial R} > 0$$

PROOF OF PROPOSITION 2.- To prove there exists a possibility of multiple equilibria we need to show that around an equilibrium the slope of the best response function is greater than one (See Cooper and John (1988) for a precise proof of this statement). The slope is defined by equations $(P.4)$ and $(P.6)$.

$$\frac{\partial r}{\partial R} = -\frac{\Phi'(r)\, v}{\Phi''(r)\, (1 - R)} \tag{P.7}$$

The value of this expression depends on the parameter v. If v is equal to 0 then the best response function is flat around an equilibrium. As v gets higher the slope gets higher. Depending on the value of the parameters, this expression can be greater than one. If this is the case, then there is an odd number, higher than one, of equilibria. They are characterized by different levels of innovative activity and, thus, different growth rates. Moreover, the higher the growth rate the higher aggregate demand, D. This is straightforward from the first order condition of an individual firm.

Given that, for the rest of the paper we abstract from the possibility of multiple equilibria, we impose the following condition for the equilibrium value of R

$$v\,\Phi'(R) < -\Phi''(R)\,(1-R) \tag{P.8}$$

This condition ensures that there are no multiple equilibria.

PROOF OF PROPOSITION 3.- The equilibrium value of R is defined by

$$\Phi'(R)\,D(R,N) = (1+v)\,\Gamma^{-1} \tag{P.9}$$

where $D(R,N)$ represents aggregate demand and is given by

$$D(R,N) = \left(1-\Gamma\,\Phi(R)\right)^{-1}(N-R) \tag{P.10}$$

We need to show that the equilibrium value of R increases when the employment rate (N) goes up. From (P.9),

$$\frac{dR}{dN} = -\frac{\Phi'(R)\left(\partial D(R,N)/\partial N\right)}{\Phi'(R)\left(\partial D(R,N)/\partial R\right) + \Phi''(R)\,D(R,N)} \tag{P.11}$$

From (P.10) one can compute both partial derivatives and evaluate them at the equilibrium to obtain

$$\partial D(R,N)/\partial N = \frac{D(R,N)}{N-R} \tag{P.12}$$

and

$$\partial D(R,N)/\partial R = D(R,N)\,\frac{v}{N-R} \tag{P.13}$$

Using these expressions in (P.11) and simplifying terms we get

$$\frac{dR}{dN} = \frac{(-\Phi''(R))\,(N-R)}{\Phi'(R)} - v$$

This expression is always positive by condition (P.8). Therefore,

$$\frac{dR}{dN} > 0$$

DATA SOURCES

Output, *U.S.*: Real Gross Domestic Product from Citibase. Quarterly data seasonally adjusted, annualized by averaging over quarters within a year. *German* and *Japanese* real Gross Domestic Product from Table 6-1 of *Science and Engineering Indicators-1991*, published by National Science Board.

Sectoral Industrial Production: Monthly index of industrial production for 2-digit industrial sectors averaged within a quarter. Data from *Federal Reserve Bulletin* published by the Federal Reserve Board at Washington.

Research and Development: U.S. R&D expenditures from Table B-2 of *National patterns of R&D Resources, 1992*, published by National Science Foundation; *German* and *Japanese* R&D expenditures from Table 4-26 from *Science and Engineering Indicators-1991*, published by National Science Board.

6. REFERENCES

AGHION, PHILIPPE AND PETER HOWITT (1992). "A Model of Growth Through Creative Destruction." *Econometrica.* **60(2).**

BARRO, ROBERT (1986). Comments to "Real Business Cycles." *NBER Macroeconomics Annual.*

BERNANKE, BEN S. AND MARTIN L. PARKINSON (1991). "Procyclical Labor Productivity and Competing Theories of the Business Cycle: Some Evidence from Interwar U.S. Manufacturing Industries." *Journal of Political Economy.* **99, 3.**

BLANCHARD, OLIVIER AND DANNY QUAH (1989). "The Dynamic Effects of Aggregate Supply Demand Disturbances." *American Economic Review* **79.**

CABALLERO, RICARDO AND MOHAMAD L. HAMMOUR (1992) "The Cleansing Effect of Recessions." NBER Working Paper No. **3922.**

CAMPBELL, JOHN Y. AND N. GREGORY MANKIW (1987). "Permanent and Transitory Components in Macroeconomic Fluctuations." *American Economic Review Proceedings.*

COCHRANE, JOHN H. (1988). "How Big is the Random Walk in GNP." *Journal of Political Economy.* **96, 5.**

COCHRANE, JOHN H. (1992) "Univariate vs Multivariate Forecasts of GNP Growth and Stock Returns: Evidence and Implications for the Persistence of Shocks, Detrending Methods and Tests of the Permanent Income Hypothesis." NBER Working Paper No. 3427.

COOPER, RUSELL AND ANDREW JOHN (1988). "Coordinating Coordination Failures in Keynesian Models." *Quarterly Journal of Economics.* **103**

DE LONG, BRADFORD J. (1990) "Liquidation Cycles: Old Fashioned Real Business Cycle Theory and the Great Depression." NBER Working Paper No. **3546.**

DICKENS, WILLIAM T. (1982). "The Productivity Crisis, Secular or Cyclical?" *Economic Letters* **9.**

DURLAUF, STEVEN N. (1989). "Output Persistence, Economic Structure, and the Choice of Stabilization Policy." *Brooking Papers on Economic Activity*, Fall. **2.**

DURLAUF, STEVEN N. AND PAUL A. JOHNSON (1992). "Local Versus Global Convergence Across National Economies." NBER Working Paper No **3996.**

FATÁS, ANTONIO (1993). "Persistence and Growth. Demand vs. Technology Shocks in an Endogenous Growth Model." Mimeo, Harvard University.

FATÁS, ANTONIO AND ANDREW METRICK (1991). "No News Can Be Good News: Irreversible Investment and Strategic Interaction." Mimeo, Harvard University.

FISCHER, STANLEY (1991). "Growth, Macroeconomics and Development." NBER Working Paper No. **3702**.

HALL, ROBERT (1991). "Recessions as Reorganizations." NBER Macro Annual Conference. March.

GALÍ, JORDI AND MOHAMAD L. HAMMOUR (1991). "Long-Run Effects of Business Cycles." Mimeo, Columbia University.

GRILICHES, ZVI (1989). "Patents: Recent Trends and Puzzles." *Brooking Papers on Economic Activity*, Annual.

GROSSMAN, GENE M. AND ELHANAN HELPMAN (1991). *Innovation and Growth in the Global Economy.* MIT Press.

KING, ROBERT G., CHARLES I. PLOSSER AND SERGIO T. REBELO (1988a). "Production, Growth and Business Cycles, I. The Basic Neoclassical Model." *Journal of Monetary Economics.* **21**.

KING, ROBERT G., CHARLES I. PLOSSER AND SERGIO T. REBELO (1988b). "Production, Growth and Business Cycles, II. New Directions." *Journal of Monetary Economics.* **21**.

KYDLAND, FINN. E. AND EDWARD C. PRESCOTT (1982). "Time to Build and Aggregate Fluctuations." *Econometrica.* **50, 6**.

MANKIW, GREGORY N. (1988). "Imperfect Competition and the Keynesian Cross." *Economic Letters.* **26, 1**.

MURPHY, KEVIN, ANDREI SHLEIFER AND ROBERT W. VISHNY (1989). "Industrialization and the Big Push." *Journal of Political Economy.* **97, 5**.

NELSON, CHARLES AND CHARLES PLOSSER (1982). "Trends and Random Walks in Macroeconomic Time Series." *Journal of Monetary Economics* **10**.

ROMER, CHRISTINA AND DAVID H. ROMER (1990). "New Evidence on the Monetary Transmission Mechanism." *Brooking Papers on Economic Activity*, Spring, **1**.

ROMER, DAVID H. (1989). Comments to "Output Persistence, Economic Structure, and the Choice of Stabilization Policy." *Brooking Papers on Economic Activity*, Fall, 2.

ROMER, PAUL M. (1989). "Crazy Explanations for the Productivity Slowdown." *NBER Macroeconomics Annual.*

SAINT-PAUL, GILLES. (1994) "Productivity Growth and the Structure of the Business Cycle" *European Economic Review* **37, 4.**

SHAPIRO, MATTHEW AND MARK WATSON. (1988) "Sources of Business Cycle Fluctuations." *NBER Macroeconomics Annual.*

SHLEIFER, ANDREI (1986). "Implementation Cycles." *Journal of Political Economy.* **94, 6.**

STADLER, GEORGE W. (1986). "Real Versus Monetary business cycle theory and the statistical characteristics of output fluctuations." *Economic Letters.* **22.**

——— (1990). "Business Cycles Models with Endogenous Technology." *American Economic Review.* 4, Sept.

SUMMERS, ROBERT AND ALAN HESTON. (1991). "The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950- 1988." *Quarterly Jornal of Economics.* **106, 2.**