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Macroeconomic Impacts of Endogenous Technical Progress

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ABSTRACT

This article uses rational expectations and a perfect competitive markets macroeconomic model with endogenous and exogenous technological changes. The model is used to derive reduced-form equations for the short-run process of output, price, and employment. Endogenous technological progress has a positive effect on output and employment and a negative impact on the aggregate price level. On the other hand, technological regress can explain stagflationary phenomena. In this model, active government intervention has nonneutral effects.

Introduction

This article analyzes the macroeconomic role of endogenous technological change. A conventional macroeconomic model with rational expectations and perfect competitive markets is employed to find reduced-form equations that characterize the process of aggregate output, aggregate price level, and aggregate employment. The model allows for both exogenous and endogenous technological changes.

Technology is defined as useful knowledge that is applied to the production process. Useful knowledge constitutes an improvement over the previous state of production. Technical progress is defined as technological change. For the purpose of this study, exogenous technical progress does not depend on economic variables such as profit and result from pure chance or intricate individual behavior.

On the other hand, endogenous technical progress does depend on economic variables and is the result of simple individual actions in pursuit of material rewards.[1] Scarce resources are devoted to the production of technologies by the private and the government sectors because technology is a nonrival and a partially excludable input.[2] Technology is defined as knowledge and it can not be exogenous to the functioning of the economic system.

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[1] Dosi [4, p. 1120] has stated that "private profit-seeking agents will plausibly allocate resources to the exploration and development of new products and new techniques of production if they know, or believe in, the existence of some sort of yet unexploited scientific and technical opportunities; if they expect that there will be a market for their new products and processes; and, finally, if they expect some economic benefit, net of the incurred costs, derived from the innovations."

[2] This classification of technology as a nonrival, partially excludable input has been suggested by Romer [15]. In other words, technology can be provided by both the private and the public sector. The model presented below allows public involvement in the "accumulation of technological knowledge."

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New knowledge (i.e., technical progress) requires research (usually called research and development), invention and innovation. It goes beyond the scope of this article to discuss the economics of technical progress. Comprehensive surveys and analyses are provided by Gomulka [6] and Kennedy and Thirlwall [7]. In this study, however, it is the innovation stage of technical progress that really matters. Invention is the creation of a new idea whereas innovation is the application of an invention to a production process.[3]

The idea of endogenous technology is not new but it has been only recently incorporated into macroeconomic analysis. Schmookler [19] was the first to argue, forcefully and persuasively, that technical progress is endogenous. Arrow [1], in, by now, a classical article, presented an endogenous theory of technical progress (changes in knowledge) and argued that learning is the "product of experience." According to Arrow, making technical progress endogenous would have practical policy implications, a point examined later in this paper. Eltis [5] modeled technical progress as an endogenous variable that depends on capital accumulation.[4] Eltis also argued that capital accumulation (aggregate sales of capital goods) depend on investment's share of national product and the level of employment. Capital accumulation promotes technical progress by increasing the productivity of labor. The model presented below makes the "accumulated technical progress" a function of both the productivity of labor and the level of employment.

Most of the above models emphasized the microeconomics of technical progress and the long-run economic implications. It is only very recently that endogenous technical progress has been used in macroeconomic models.[5] An exception was the model proposed by Uzawa [22], but it was developed to explain economic growth rather than cyclical variations.

There are two reasons for the recent macroeconomic preoccupation with technological change in general, and endogenous technological change, in particular. First, macroeconomic explanations of inflation, unemployment, and output growth were shattered in the 1970s and 1980s by the apparent failure of the dominant Keynesian School to explain the peaceful coexistence of high rates of inflation and unemployment. Second, once again, the theoretical weaknesses of the dominant macroeconomic school—the Keynesian School is based on shaky microeconomic foundations—were emphasized but, this time, there was a serious challenge coming from a new macroeconomic school, the real business cycle school.[6]

Can technological changes account for the short-run aggregate output and price variations that are consistent with the empirical evidence in the 1970s and in the 1980s? The real business cycle model made technological progress the *deux ex machina* to explain

[3] Chari and Hopenhayn [3] examined the determinants of transforming an invention (a new technology becomes available) into an innovation (the new technology has reached its peak use). This is called the diffusion of technology and, according to the two authors, it takes time. How fast technologies diffuse depends positively on (a) the rate of growth of output and (b) the rate of new inventions. One important implication of their model is that wages are higher in industries that apply the new technologies because people invest in technology-specific skills.

[4] Eltis [5, p. 502] argues that "the rate of technical progress will be influenced by some aspect of an economy's investment activity. It may be influenced by the rate of growth of the capital stock, or the share of the National Product invested, or the period of time which the capital stock is replaced, or the accumulated sum of past investment. Technical progress will be endogenous to the processes analyzed by growth models rather than something which is exogenous to those processes in so far as the rate of technical progress depends upon investment."

[5] Macroeconomic models with endogenous technology are utilized in studies by Barro [2], King and Rebelo [8], Romer [14, 15], Stadler [20], Lucas [9], and Prescott and Boyd [16].

[6] For a nontechnical supportive review of the real business cycle approach see Plosser [12]. A critical review is given by Mankiw [11].

output fluctuations consistent with the empirical evidence on macroeconomic time series. According to this approach, aggregate production, consumption, and investment are random walks with a drift implying that there is no constant trend that can be exploited by policymakers. Permanent and temporary exogenous technological disturbances have effects that are not exploitable by policymakers. Mankiw [10, 11], argued that these conclusions are based on two key assumptions: (1) the economy experiences large and sudden technological changes and (2) all technological changes are exogenous.

The first assumption is not consistent with the empirical evidence which shows that technological progress at the innovation level is a gradual process.[7] The second assumption is really a thorny issue for the real business cycle models because they claim they "have an explicit and firm foundation in microeconomics." Technological change is introduced as an exogenous variable, however, even though there is a stream of writings, mainly by Arrow [1] and Eltis [5], which model technological progress as an endogenous economic process based on sound profit maximization motives.

This study attempts to contribute to this literature by presenting a simple theoretical macroeconomic model of rational expectations and perfect competitive markets assuming that some technological progress occurs as a gradual endogenous process. The model also allows for random technological disturbances. The model presented below is based on a model first developed by Stadler [20] but with one important addition: the government plays an active role in the "accumulation of technical knowledge."[8] This addition is necessary because the model is used not only to explain the determination of aggregate output, price level, and employment but, also to examine potential policy implications. Rational expectations models for policy analysis have been developed by Sargent [16] and Sargent and Wallace [17, 18].

This article is divided into five sections. The second section presents the model and derives equations for aggregate demand and aggregate supply. The third section finds reduced form equations for output, price and employment. The fourth section examines the policy implications of the model. The last section summarizes the arguments.

A Simple Macroeconomic Model

This section presents a simple aggregate demand and aggregate supply model with rational expectations and perfect competitive markets. The demand side is modelled with *ad hoc* relationships to simplify mathematical derivations. The supply side is the focus of the analysis and is modeled in a consistent way. By consistent, as opposed to *ad hoc,* we mean that objective functions and information sets are explicitly stated. Both the aggregate demand and the aggregate supply are specified as deviations from expected values.

AGGREGATE DEMAND

Following Sargent [16] and Sargent and Wallace [17, 18], the *ad hoc* structural aggregate demand equations are given by two behavioral relations and an equation describing the money supply role. All variables are in natural logarithms except the nominal interest rate (R). All coefficients are positive to facilitate interpretation. The three equations are:

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[7] Mankiw [11] has forcefully rejected this assumption along with the empirical evidence that allegedly supports it.

[8] There are other differences between the model presented here and Stadler's model. The model here is used to explain the short-run variations of output, employment, and price whereas Stadler's model is used to trace the long-run fluctuations of output and employment. Also, the aggregate demand in Stadler's model is restricted to the quantity theory of money. Here, an IS-LM framework with rational expectations is used where the quantity theory is a special case.

Aggregate demand equation (the IS curve):

$$Y_t = c_0 - c_1[R_t - (p^*_{t+1} - p_t)] + u_{1t} \tag{1}$$

Equation (1) is an IS log-linear relationship. The logarithm of real aggregate expenditures in period (t) denoted by (y_t) is negatively related to the real interest rate. The real rate of interest is equal to the nominal interest rate in period (t) minus the expected rate of inflation $(p^*_{t+1} - p_t)$. Expectations are formed rationally using all available information in the beginning of each period. For example, in period (t) economic agents form expectations using all available information up to this period.

Portfolio Balance Equation (the LM curve):

$$m_t = p_t + \mu_1 y_t - \mu_2 R_t + u_{2t} \tag{2}$$

Equation (2) summarizes the portfolio equilibrium between shares of money and bonds. It is assumed that equities are perfect substitutes for bonds. Demand for real balances $(m-p)$ is positively related to aggregate expenditures (y) and negatively related to the nominal interest rate. The quantity theory of money balances is nested in equation (2) as a special case when the income elasticity of the demand for money is equal to one and the nominal interest rate plays no role in the demand for money.

Money Supply Rule:

$$m_t = m_{t-1} + u_{3t} \tag{3}$$

Equation (3) is a money supply rule. Nominal money supply is a first-order autoregressive process with zero mean. It can be made to grow at a constant rate but would not add anything of substance to the model.

Substituting for R from equation (2) into equation (1) and solving for the log of price level (p) gives:

$$p_t = \frac{\mu_2 c_0}{c_1(1+\mu_2)} - \frac{\mu_2 + c_1\mu_1}{c_1(1+\mu_2)} y_t + \frac{1}{1+\mu_2} m_t + \frac{\mu_2}{1+\mu_2} p^*_{t+1}$$
$$+ \frac{\mu_2}{c_1(1+\mu_2)} u_{1t} - \frac{1}{1+\mu_2} u_{2t} \tag{4}$$

Applying the expectations operation in the above equation, we get the expected price level (notice that the expected value of the last term is equal to zero):

$$p^*_t = \frac{\mu_{2c} y_0}{c_1(1+\mu_2)} - \frac{\mu_2 + c_1\mu_1}{c_1(1+\mu_2)} y^*_t + \frac{1}{1+\mu_2} m^*_t + \frac{\mu_2}{1+\mu_2} p^*_{t+1} \tag{5}$$

Taking into consideration the money supply process and subtracting the expected price level from the actual price level, we get the following price deviation equation:

$$p_t - p^*_t = -\frac{\mu_2 + c_1\mu_1}{c_1(1+\mu_2)}(y_t - y^*_t) + U_t \tag{6}$$

where

$$U_t = \frac{1}{1+\mu_2}(u_{3t} - u_{2t}) + \frac{\mu_2}{c_1(1+\mu_2)} u_{1t} \tag{7}$$

Equation (6) is an aggregate demand relationship. Price variations around the mean are negatively related to variations of aggregate expenditures around the mean. A higher than expected price level reduces aggregate demand below its expected value.

Equation (6) is used in the next section to derive equations for the output process, the price process, and the employment process. To do so, it requires an aggregate supply function that is derived next.

AGGREGATE SUPPLY

The supply side consists of a number of small profit maximizing firms supplying a perfect competitive market. Money wages (W) are set in the beginning of the period and prices (P) are not realized until the working day is over and workers visit the market. Thus, workers form expectations about the price level in order to set the nominal wage rate in the beginning of the period. In this economy, production uses only labor and "accumulated technical knowledge" (Z). Adding capital stock is not necessary for the purposes of this paper. However, Z is a type of capital. In this economy there is no aggregation problem that can arise from extreme heterogeneity of labor and output. The supply side is characterized by the following equations:

Profit Equation:

$$V_t = E\sum_{j=1}^{n}\beta^j [Q_{t+j} - (W/P)_{t+j}L_{t+j}] \qquad 0<\beta<1 \tag{8}$$

Equation (8) gives the present value of expected current and future stream of profits. Profits are equal to output (Q) minus the labor cost, which is the only relevant cost.

Production Function:

$$Q_t = A(L_t)^\alpha (Z_t)^{1-\alpha}F_t \qquad 0<\alpha<1 \tag{9}$$

Output is produced according to a technical process described by equation (9). There are two inputs: (a) effective labor hours (L) used, and (b) accumulated technical knowledge (Z) given by equation (10). Output is subject to past and current stochastic disturbances captured by (F) to be specified later.

Accumulated Technical Knowledge:

$$Z_t = Z_{t-1}\,[(Q/L)_{t-1}]^\lambda\,(L_{t-1})^\gamma\,(G_t)^\delta \qquad 0<\lambda, \gamma<1 \text{ and } 0<\delta(1-\alpha)<1 \tag{10}$$

Equation (10) makes technological change a gradual endogenous economic process. The current level of technical knowledge is conditioned by previous levels of technical knowledge. As it has been mentioned in the introduction, the accumulated technical knowledge depends on three factors. First, it depends on the average product of labor attained in the previous period (Q/L) for reasons explained by Eltis [5] and further discussed by Stadler [20]. Second, it depends on the level of lagged employment because innovative knowledge is acquired by learning by doing, a point emphasized by Arrow [1]. Finally, the current level of accumulated technical knowledge depends on government assistance (G), which can be thought as training expenditures financed by printing new money.[9] This type of government intervention is necessary because individual firms can not exclude others from the use of accumulated technical knowledge, which in this case manifests itself as human capital, a point made by Romer [18]. No other type of government spending exists.

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[9] Alternatively, G can be thought as public capital stock that has a positive effect on private sector output. A review of this literature and empirical evidence is given by Tatom [21]. In our model, the public capital elasticity of production is equal to $\delta\ (1 - \alpha)$.

Labor Supply:

$$L_t^s = e^{l_1}(W/P)^{l_2 t} \qquad 0 < l_2 < 1 \tag{11}$$

Finally, equation (11) gives the labor supply function. The supply of labor grows at a rate of l_1 and depends on real wages. The real wage rate elasticity of labor supply is less than one, a hypothesis that is consistent with empirical evidence.

At the aggregate level, maximization of (8) with respect to labor input subject to the production function constraint given by (9) results to the following labor demand equation, after some arithmetical manipulations and taking the natural logarithms (lowercase letters denote the natural logarithm of the uppercase letter variable):

$$l_t^d = \frac{\ln(A\alpha)}{(1-\alpha)} + \frac{(p_t - w_t)}{(1-\alpha)} + z_t + \frac{f_t}{(1-\alpha)} \tag{12}$$

The log of labor demand is a decreasing function of the log of the real wage rate $(w-p)$ and an increasing function of the log of the accumulated technical knowledge (z). The log of the disturbance factor F is defined by Stadler (20) as follows:

$$\ln(F_t) = f_t = f_{t-1} + \xi_t + \eta_t \tag{13}$$

where ξ_t and η_t can be thought as a permanent technological shock and a temporary productivity shock, respectively. Both are stochastic terms with zero mean and constant variance. f_{t-1} captures the accumulated past technological shocks.

In log form, the labor supply can be written as follows:

$$l_t^s = l_1 + l_2(w_t - p_t) \tag{14}$$

Nominal wages are set at a level where the expected labor demand equals the expected labor supply. In this case the nominal wage rate is set by the following function:

$$w_t = \frac{\ln(\alpha A) - (1-\alpha)l_1}{1 + l_2(1-\alpha)} + p_t^* + \frac{1-\alpha}{1 + l_2(1-\alpha)} z_t + \frac{1}{1 + l_2(1-\alpha)} f_{t-1} \tag{15}$$

Substituting the wage formation equation into equation (9) we get the aggregate employment equation:

$$l_t = \frac{\ln(\alpha A)l_2 + l_1}{1 + l_2(1-\alpha)} + \frac{1}{1-\alpha}(p_t - p_t^*) + \frac{(1-\alpha)l_2}{1 + l_2(1-\alpha)} z_t$$

$$- \frac{1}{(1-\alpha)[1 + l_2(1-\alpha)]} f_{t-1} + \frac{1}{1-\alpha} f_t \tag{16}$$

The log of the production function is:

$$q_t = \ln(A) + \alpha l_t + (1-\alpha)z_t + f_t \tag{17}$$

Substituting the employment equation into the above equation we get the aggregate supply equation:

$$q_t = \text{Co} + \frac{\alpha}{1-\alpha}(p_t - p_t^*) + \frac{(1-\alpha)(1 + l_2)}{1 + l_2(1-\alpha)} z_t + \frac{1 + l_2}{1 + l_2(1-\alpha)} f_{t-1}$$

$$+ \frac{1}{1-\alpha}(\xi_t + \eta_t) \tag{18}$$

The above supply equation is the core concept of the new classical model with rational expectations or as it is sometimes called, the Lucas type of aggregate supply. The Co is a combination of constant terms of the structural supply equations. The supply of output depends positvely on the difference between the actual price level and the expected price level. The supply of aggregate output depends not only on current and past stochastic technological disturbances but on the endogenous technological changes captured by the variable z, which has been defined as accumulated technical knowledge.

Output, Price, and Employment

The macroeconomic impact of endogenous technical change can be shown on the three important macroeconomic variables: output, price, and employment.

AGGREGATE OUTPUT

We reproduce below equations (6) and (18), which give the aggregate demand and the aggregate supply functions, respectively:

$$p_t - p_t^* = -\frac{m_2 + y_1 m_1}{y_1(1 + m_2)}(y_t - y_t^*) + U_t$$

$$q_t = \text{Co} + \frac{\alpha}{1 - \alpha}(p_t - p_t^*) + \frac{(1 - \alpha)(1 + l_2)}{1 + l_2(1 - \alpha)} z_t + \frac{1 + l_2}{1 + l_2(1 - \alpha)} f_{t-1}$$
$$+ \frac{1}{1 - \alpha}(\xi_t + \eta_t)$$

Equilibrium at the aggregate level requires that aggregate demand is equal to the aggregate supply ($y_t = q_t$) and, also, that expected aggregate demand is equal to expected aggregate supply ($y_t^* = q_t^*$). Taking the expected output from the second equation and substituting it into the first equation we get the price deviation as a function of actual q. Substituting this into the supply equation and solving for q results to the following equation that describes the output process:

$$q_t = Co + \frac{(1 - \alpha)(1 + l_2)}{1 + l_2(1 - \alpha)} z_t + \frac{1 + l_2}{1 + l_2(1 - \alpha)} \text{f}_{t-1}$$
$$+ \frac{\text{y}_1(1 + m_2)}{y_1(1 + m_2)(1 - \alpha) + \alpha(m_2 + y_1 m_1)}(\xi_t + \eta_t) + C_1 U_t \qquad (19)$$

The parameter C_1 is a combination of supply and demand parameters of the structural equations. Equilibrium output depends on both endogenous technological change captured by the variable (z) and the technological shocks (temporary and permanent) captured by the stochastic parameters (ξ) and (η).

AGGREGATE PRICE

The derivation of the equation for the price process is more complicated because the price level in period (t) depends on the expected price level in period (t + 1). Below we reproduce the price equation (equation 4):

$$p_t = \frac{\mu_2 c_0}{c_1(1 + \mu_2)} + \frac{\mu_2 + c_1\mu_1}{c_1(1 + \mu_2)} y_t + \frac{1}{1 + \mu_2} m_t + \frac{\mu_2}{1 + \mu_2} p_{t+1}^* + \frac{\mu_2}{c_1(1 + \mu_2)} u_{1t}$$
$$- \frac{1}{1 + \mu_2} u_{2t}$$

Following a procedure discussed in Sargent [16, Appendix A] we can find, by shifting forward the above price equation and taking expectations, the following expression for the expected price in period $(t+1)$:

$$p^*_{t+1} = B_0 m_t - B_1 z_t - B_2 f_{t-1} \tag{20}$$

In order to derive the above equation we used (1) the money supply rule from equation (3), (2) the expected output calculated from equation (18), and (3) the fact that z and f can be written as autoregressive processes. Here, the B's depend on the parameters of the structural equations. Substituting equation (20) and (19) into equation (4) and solving for (p) gives the following equation that describes the aggregate price process:

$$P_t = H_0 - H_1 z_t - H_2 f_{t-1} + H_3 m_t - \frac{(\mu_2 + c_1\mu_1)}{c_1(1 + \mu_2)(1 - \alpha) + \alpha(\mu_2 + c_1\mu_1)}(\xi_t + \eta_t) \tag{21}$$

The H coefficients depend on the parameters of the structural equations and the B's. Ho includes the u's. Endogenous and exogenous technical changes have a negative impact on the price level. Money supply has a positive impact on the price level.

AGGREGATE EMPLOYMENT

The equation for aggregate employment was derived in the previous section as equation (16). Substituting from equation (21) for the actual and the expected price level and after some arithmetical manipulations we obtain:

$$\begin{aligned} l_t = L_0 &+ \frac{c_1(1 + \mu_2) - (\mu_2 + c_1\mu_1)}{c_1(1 + \mu_2)(1 - \alpha) + \alpha(\mu_2 + c_1\mu_1)}(\xi_t + \eta_t) + \frac{(1 - \alpha)l_2}{1 + l_2(1 - \alpha)} z_t \\ &+ \frac{l_2(1 - \alpha)}{(1 - \alpha) + l_2(1 - \alpha)^2} f_{t-1} \end{aligned} \tag{22}$$

The employment process depends on both the exogenous and the endogenous technical progress. Lo depends on constant terms and u's.

Equations (19), (21), and (22) describe the behavior of the macroeconomy when there exists both endogenous and exogenous technical progress. The question asked is what is the macroeconomic impact of technological changes? From the three equations the following observations can be made.

First, endogenous technological change affects all three macroeconomic variables (output, inflation, employment). It has a positive effect on aggregate output and aggregate employment and a negative impact on the price level. Thus, it is possible to explain the *coexistence* and *persistence* of inflation and unemployment (low levels of employment) as situations of technical regress.[10] A reduction in the accumulated technical knowledge can explain the stagflationary phenomena of the 1980s. The fact that knowledge accumulates, stagflation tends to persist. This can be seen from equation (10) where the current level of (z) depends on past values of (z).

Second, the endogenous technology elasticity of output is greater than the endogenous technology elasticity of employment. In numbers, a 10% increase in technological progress and assuming that $\alpha = 0.7$ and $l_2 = 0.4$, then employment will increase by only 1.1%, whereas output will increase by 3.75%. Employment does not increase by

[10] The term technical regress refers to the innovation stage, that is, the stage of application of new useful knowledge. Thus, technical regress can occur when, for whatever reasons, a second best innovation is applied. The oil shock and the effect it had on the "knowledge" can be considered a technical regress.

as much because an increase in the accumulated technical knowledge reduces prices and for a given nominal wage it increases the real wage rate, which lowers employment of labor.

Third, contrary to monetarist and rational expectations claims, inflationary pressures can start from the "real" sector of the economy. A technical regress creates current and future inflation without any change in the money supply rule.

Fourth, exogenous technological changes have the same qualitative macroeconomic impacts as the endogenous technological change but in quantitative terms the impact is not the same. The elasticities of the exogenous technological shocks depend on both demand and supply coefficients of the structural equations.

Fifth, in an economy characterized by the quantity theory of money ($\mu_1 = 1$ and $\mu_2 = 0$), the elasticity of exogenous technological changes of output and price is equal to one but it is zero for employment. If the income elasticity of money demand is less than one, however, then the employment effect is positive.

Sixth, all three processes described by equations (19), (21), and (22) are nonstationary because they depend on the accumulated exogenous technological shocks captured by the variable (f_{t-1}).

Policy Implications

In this model government intervention can occur on the demand side of the economy by setting the money supply rule and on the supply side of setting the level of assistance to accumulated technical knowledge.

From equations (19), (21), and (22) it can be seen that systematic monetary policy has no real effect. It only increases the price level. Thus, the neutrality of money is preserved. The coefficients (Co) and (Lo) depend on money "surprises," that is, the disturbance term u_{3t}. A monetary shock affects both output and employment in the same period. In the absence of endogenous technology the monetary shock will dissipate. With endogenous technology, a monetary shock in one given period increases the current and the future output and employment levels. Thus, in this sense, money is nonneutral even in a rational expectations model without resulting to assumptions of price and wage stickiness.

The supply side policy can be analyzed by looking at equation (10), reproduced below:

$$Z_t = Z_{t-1}\,[(Q/L)_{t-1}]^{\lambda}\,(L_{t-1})^{\gamma}\,(G_t)^{\delta} \qquad 0<\lambda,\ \gamma<1 \text{ and } 0<\delta(1-\alpha)<1$$

In logarithms the above equation can be written as follows:

$$z_t = z_{t-1} + \lambda q_{t-1} + (\gamma-\lambda)l_{t-1} + \delta g_t \tag{23}$$

Equation (23) can be solved backwards, which gives the expression below[11]:

$$z_t = \lambda\Sigma q_{t-j} + (\gamma-\lambda)\Sigma l_{t-j} + \delta\Sigma g_{t-j+1} \tag{24}$$

The above expression can be substituted into equations (19), (21), and (22) to find the output, price, and employment as functions of (g). Government spending on the supply side has a direct positive effect on current output and current price level and a negative effect on current price level. This type of government spending tends to persist, however. It is the accumulated government spending on technical knowledge that matters.

[11] A terminal condition is imposed that in period $(t-n)$ accumulated technical knowledge is zero.

Conclusions

This study presented a model with rational expectations and perfect competitive markets to examine the macroeconomic impact of exogenous and endogenous technological changes. The latter is measured as accumulated technical knowledge that depends on all past levels of output, all past levels of employment, and all past levels of government technological spending. Two main conclusions can summarize this study.

First, the effect of endogenous technical progress is different from the effect of exogenous technical progress. The first can explain both the nature and the persistence of macroreconomic phenomena such as stagflation. The impact of exogenous shocks is very sensitive to the structural equations of the demand side.

Second, the policy implications are different from the conventional classical macroeconomic models. In particular, government intervention is nonneutral and it accumulates overtime. Thus, optimal government intervention requires one to take into consideration not only the current macroeconomic impacts but, also, the future impact on output, price, and employment.

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