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AGGREGATE DEMAND AND TECHNOLOGICAL CHANGES: A MACRO-ECONOMIC MODEL OF INDUCED INNOVATIONS

by
Uri Ben-Zion and Vernon W. Ruttan

Department of Agricultural and Applied Economics

University of Minnesota
Institute of Agriculture
St. Paul, Minnesota 55101

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The idea that technological progress can be regarded as an endogenous variable which is induced by the market demand for innovation rather than as an exogenous variable was suggested more than a decade ago by the path-breaking works of Fellner (1961), Griliches (1957) and Schmookler (1962).

Fellner has formulated a simple model which emphasizes the "adjustment mechanism which in market economics directs inventive activity into more or less labor-saving (less or more capital saving) channels, according to whether one or the other factors of production is getting relatively scarce on a macro-economic level", (Fellner, 1961).

Griliches has shown that the rate of acceptance of a technological innovation depends in part on the profit that the potential user expects to realize from a shift to the new technique.

Schmookler has analyzed the relationship between patents in railroads and other economic indicators such as output, gross capital formation and the real price of railroad shares. He concludes that "the major turning points in the various series usually come close together, with patents usually lagging behaind the economic indicators", (Schmookler, 1962).

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In this paper, we formulate a theoretical model to explain the relationship between the aggregate demand and the rate of technological change which was observed by Schmookler. We show that the value of input-saving technological change is higher in periods of growing demand than in periods of stable or falling demand. Following Griliches, we conclude that higher profitability would induce a higher rate of technological change and hence would lead to a positive relationship between the rate of technological progress and the changes in aggregate demand. One important assumption which we add to the analysis is that labor and capital are quasi-fixed factors of production, and their relevant marginal price is, therefore, not constant over time. In particular, the relevant marginal price is higher in a period of expansion and lower in a period of declining output.

In Section I, we justify the view that labor and capital are quasi-fixed factors of production. We use this approach to analyze the relationship between changes in the demand for a product and the choice of the optimal inputs by the producing firms.

In Section II, we present an aggregate model of the economy. We relate the gain from technological change to the fluctuation of the aggregate demand. We use the result to analyze the demand for technological change over the business cycle.

In Section III, we present an empirical version of the test procedures and then discuss the model in a specific form.

In Section IV, we discuss the available data for the United States for the period 1929-1969, which we have used in the empirical test. We then present the empirical results.

Finally, in Section V, we summarize the paper and discuss some possible theoretical and empirical extensions of our work.

I. Quasi-Fixed Factors of Production and the Choice of Inputs by Firms

In a simple price theory, factors of production are classified in a short run as fixed or variable factors.

Input which is purchased as flow, such as material, electricity, etc., is usually regarded as variable input. Factors of production which are purchased as stock, such as machinery, buildings, etc., are usually regarded as fixed input when the purchase of the durable factor is assumed to be irreversible.

Arrow (1968) has shown that the irreversibility of investment does affect the firm's choice of the optimal path of inputs to satisfy a given vector of output over time. This is because, in a time series context, irreversible input is a quasi-fixed input which is variable with respect to an increase in production and is fixed with respect to a decline in production[1].

In general, a factor of production is a quasi-fixed factor when the purchase of the durable factor is associated with an irreversible payment. We, therefore, do not have to assume that a quasi-fixed factor of production is necessarily a fixed factor in price theory terminology. We can consider, for example, a case in which there is a market for used capital,

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[1] If the asset is depreciable, the reduction in the input is limited by the rate of depreciation.

and a machine is defined as a quasi-fixed factor if there are transaction costs in the market for used machines, so that the market price is below the "net" value of the machine.

In the special case of no depreciation, the existence of transaction costs simply means that the purchase price of a new asset is lower than the price of "returned" (but otherwise equivalent) assets. Therefore, a firm is facing higher prices when it increases its stock of capital in a period of expansion than the "relevant return" price in a period of contraction[2].

Let K_0 be the stock for the quasi-fixed factor which the firm has on hand. For a level of input below K_0 the relevant cost per unit is P_1, which is the selling price of returned assets. For a level of input above K_0, the relevant price is P_0 which is the purchase price of a new unit. This is shown diagramatically in Figure 1.

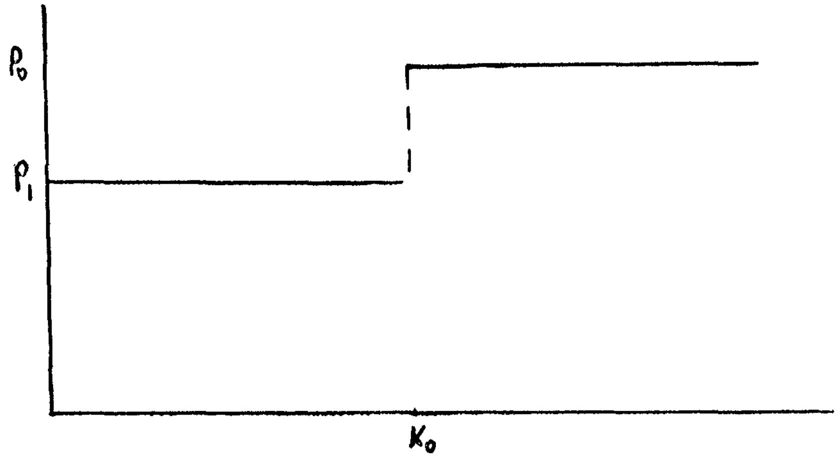

Figure 1: The relevant supply curve of a quasi-fixed factor.

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[2] Assuming that there is no change in the market purchase price of new assets over the relevant time horizon.

With regard to the firm's labor input, the "transaction cost" in the market takes the following forms:-

First, if one assumes hiring and firing costs, then there is a positive difference between the cost of hiring a new worker and the savings obtained by the firing of a given worker.

Second, Becker (1964) suggests that part of the human capital which can be obtained by the worker is "firm specific" and affects its marginal product only in the specific firm or job[3]. The cost of obtaining this specific human capital is shared by the firm and the worker. The wage rate of the individual is below the value of his marginal product in the firm but above the value of the marginal product which he can produce in an alternative firm. If the firm fires an employee, it loses the return on its share in the investment in the worker's specific human capital.

Oi (1962) developed this approach and emphasized the view that labor input is a quasi-fixed factor of production. The work of Oi was extended by Rosen (1968), Telser (1970) and Parsons (1972). Miller (1971) developed a model of the firm's demand for labor over time which took into account the specific investment in human capital. In his model, he developed an "inventory approach" to the demand for labor which "consists of a dichotomized (peak, off-peak) system of equations that attempts to capture the relevant differences in decision-making by firms during peak and off-peak periods in the production cycle", (page 279). The work of Miller is, therefore, the first work which relates the choice of inputs by firms to the fluctuations in the demand.

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[3] On the other hand, the general human capital is useful for work performed in all alternative firms.

In the following analysis, we shall assume that a firm has three inputs: labor L, Capital K and material M, which are combined in a production function of product X.

$$(1) \quad X = f(L,K,M)$$

The purchase price of the input and output are P_L^0, P_K^0, P_M^0, and P_X^0, which are assumed for simplicity to be constant over time[4]. Following our earlier discussion, we assume that labor and capital are quasi-fixed factors of production with the selling price of P_L^1 and P_K^1 respectively[5], where $P_L^1 < P_L^0$ and $P_K^1 < P_K^0$.

The analysis above suggests that firms face higher prices of labor and capital when they expand their output than the prices they face during a period of reduction in output. The marginal product of labor and capital will be P_L^1 and P_K^1 (respectively) in a period of falling demand and P_L^0 and P_K^0 in a period of rising demand[6]. In a period of falling demand the firm will evaluate the inputs, labor and capital, at their lower selling price, (P_L^1, P_K^1) while in a period of rising demand the firm will evaluate the quasi-fixed factors at their purchase prices, (P_L^0, P_K^0).

It should be noted that the recorded market prices are always the purchase prices P_L^0, P_K^0, in which "transactions" are made. The selling

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[4] If prices are rising in an inflationary process, this assumption implies that all prices of inputs and output change at the same rate, so that the "real prices" are constant.

[5] For simplicity, we assume that P_L and P_K represent a price per unit of flow of labor and capital services.

[6] This also suggests that the firm will choose different combinations of quasi-fixed inputs and material in the different phases in the business cycles. In particular the firm will use lower ratios of quasi-fixed factors to the variable factor in periods of rising output than in a period of falling demand.

prices, P_L^1 and P_K^1, which are the relevant prices in periods of falling demand are not recorded or measured in the national income accounts[7].

II. Profitability of Technical Changes and the Aggregate Demand

Economic theory suggests a direct relationship between expected profitabilities of an investment and the level of investment. This relationship was extended by Schmookler with regard to firm incentive to invent; he emphasized that "the essential point is that the incentive to make an invention, like the incentive to produce any other goods, is affected by the access of expected return over expected costs", (Schmookler, 1962). Similar models of endogenous technical changes were developed and tested by Lucas (1967) and Rasmussen (1973)[8].

We assume that firm investment in research and development denoted by R is expected to reduce the levels of input needed for a given output X. The expected saving S from the investment R can be measured by the expected reduction in cost to produce a given output, X, as the result of the investment.

$$(2) \quad S = C(X) - C(X/R)$$

where C(X) is the minimum cost to produce output X with the given technology (R = 0), and C(X/R) is the expected minimum cost to produce X with an improved technology to be obtained by the investment R.

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[7] The idea that the measured market prices and observed profits may not be the appropriate variable from the firm's point of view in a period of falling demand was suggested more than a decade ago by Ruttan (1959).

[8] See also Binswanger (1974) for a rigorous formulation of this approach.

The savings in cost per unit of output is achieved by a reduction in inputs requirements per unit and can be written:-

$$(3)\quad S = X\left(\sum_{i=1}^{n} \Delta a_i P_{a_{it}}\right)$$

where Δa_i is the reduction of input a_i per unit of X and $P_{a_{it}}$ is the relevant price in which the input is evaluated[9].

In the particular case of three-factor inputs (1), we can write (3) as:-

$$(4)\quad S = X(\Delta m \cdot P_{Mt} + \Delta k \cdot P_{Kt} + \Delta l \cdot P_{Lt}) = X_t \cdot s_t$$

where M, K, and L are the inputs of material, capital and labor per unit of output at the level X_t, and it is the value of saving per unit of output. P_{Mt}, P_{Kt} and P_{Lt} are the prices in period t according to which the inputs saving is evaluated. In particular, in a period of rising demand the relevant prices of labor and capital are the purchase prices of input services P^o_K and P^o_L respectively, and the value of a given reduction of inputs per unit of output is given by:-

$$(5a)\quad S^o = \Delta m \cdot P_M + \Delta k \cdot P^o{}_K + \Delta l \cdot P^o{}_L .$$

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[9] Note that in general an investment in research and development R can be used to obtain alternative combinations of reduction in factor inputs per unit of output. In this case, the induced innovation approach suggests that it is optimal for the firm to choose the path of a technical change which will maximize the value of saving S. We assume that (Δa_i) in (3) are already chosen, such that the value of S is maximized for a given R.

While in a period of falling demand, the value of the saving per unit will be evaluated using the "selling price" of quasi-fixed inputs.

$$(5b) \quad S^1 = \Delta m \cdot P_M + \Delta k \cdot P^1_K + \Delta l \cdot P^1_L$$

Since the relevant prices of the quasi-fixed factors in periods of rising demand (P^o_K, P^o_L) are higher than the relevant prices in periods of falling demand (P^1_K, P^1_L), the value of saving from a technological change will be higher in a rising market than in a falling market. Also, since the price of the variable input is assumed to be constant over the "business cycle", it is relatively more expensive in a falling market than in a rising market. As a result, technological change may be biased toward material saving in a period of falling demand and toward saving of quasi-fixed factors in periods of rising demand.

Let S_t be the potential saving from a technological change which is expected as a result of the firm's investment R_t in research and development. The firm will take the investment if the rate of return is above the firm's cost of capital. In other words, the investment is profitable if the present value of the expected savings exceeds the cost of investment.

$$(6) \quad \sum_{i=1}^{n} \frac{S_t^{t+i}}{(1+r)^t} > R_t$$

where S_t^{t+i} is the expected savings in period t+i as a result of the investment in new knowledge or technology made at period t. The expected savings in future period t+i is estimated at period t on the basis of information available at that period; r is the interest rate.

Assuming that the marginal productivity of investment is diminishing (similar to Keynes' marginal efficiency of capital), we predict a direct relationship between the level of investment in technological progress and the expected savings from the investment. In other words, firms will spend more on investment in technology if the expected rate of return from the investment is higher than in a period where the expected rate of return on the investment is lower.

The savings from a given investment and its rate of return will be higher if the firm predicts that the demand for its product will increase in future periods. The expected return of an investment in technology will be lower if the firm predicts a falling demand.

One common variable which affects the changes in the demand for a particular firm or industry is the changes in the aggregate demand, or the business cycle situation for the economy. A period of rising aggregate demand is not necessarily a period of rising demand for each particular firm. We assume, however that the higher the rate of increase in the aggregate demand, the higher the percentage of firms that expect and realize increase in the demand for their product. Similarly, for a falling aggregate demand, we would expect that the higher the rate of decline, the higher would be the percent of firms and industries which face a falling demand.

Aggregating over the firms, we can conclude that the larger the change in the aggregate demand, the higher is the expected return on technological investment and the level of investment. In other words, investment in technological progress will be higher in the rising phase of the business cycle and lower in the declining phase[10]. The relationship between aggregate investment in technological improvement and changes in aggregate demand can be written:-

$$(7) \quad R_t = f(D_{t-z}^{t+v}, D_{t-z}^{t+v+1}, D_{t-z}^{t+v+2}, \ldots D_{t-z}^{t+v+k})$$

where D_{t-z}^{t+v} represents the prediction made in period (t-z) with regard to changes in the aggregate demand in the future period t+v; z represents a lag between the date at which the investment appropriation was made and the date at which the actual investment takes place. v represents the lag between the actual investment and its result in terms of expected savings in cost due to technological change[11].

While (7) represents a simplified model of investment decision in a technological progress, it is not written in terms of observable variables. In particular, the expectations of firms' managers are not directly observable. However, one can assume that managers use current and past data to make their prediction with regard to future changes in the aggregate demand.

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[10] Our analysis was based on the assumption that market price of the output is constant (at least in terms of the prices of the purchased inputs). If the price of output rises with the business cycle, then this will strengthen the relationship between aggregate demand and investment in technical changes; see Barzel (1969) and especially Binswanger (1974) for a more detailed discussion.

[11] Studies of investment behavior by firms emphasize the lag betweeen investment decision and the actual "realized" investment (see Jorgenson (1963)). One would expect a similar lag in the realized investment in research and development.

$$(8) \quad D^{t+v+i}_{t-z} = f(E_{t-z}, E_{t-z-1} \dots E_{t-z-n})$$

where $E_{t-z} \dots E_{t-z-n}$ are a set of observable variables in the period (t-z) and earlier periods which firms use to predict the future trend of the aggregate demand.

Using (8) we can write the R_t as a function of observable variables which serve as business cycle indicators:-

$$(9) \quad R_t = f(E_{t-z} \dots E_{t-z-n}).$$

We assume that investments in a technological progress are realized in the future in terms of technological progress. We can view the index of technological progress TG in a given period as a distributed lag function of previous expenditures on technological progress.

$$(10) \quad (TG)_t = f(R_{t-z}, R_{t-z-1} \dots R_{t-z-j})$$

By substitution of (9) in (10), we can write the technological progress as a function of observed indicators which are regarded as proxy to the future direction of aggregate demand.

$$(11) \quad (TG)_t = f(E_{t-m}, E_{t-m-1} \dots E_{t-m})$$

The model can be tested empirically by using estimates of either (9) or (11). Since data on aggregate investment in a technological progress is not easily available, we concentrate the empirical work on a test of the later equation. In other words, in our empirical work, we will test the relationship between technological changes and variables which can be used as business cycle indicators.

The model developed in this section related technical changes to changes in aggregate demand through the use of the profit variable. The main implication is that the rate of technical change is higher in periods of rising demand than in periods of falling demand. This result, therefore, clarifies the relationship between the "timing of innovation" and economic factors and strengthens the view that the rate of technical changes is an induced endogenous variable.

The classical theory of induced innovation of Hicks, (1963) Fellner, (1961) Ahmad (1960) and others has suggested that in a given time period, innovations are biased toward input which becomes scarce and more expensive. In our model, we see that over-time, innovations are biased towards periods of rising aggregate demand where the primary factors are relatively scarce, and their relevant price is higher. This comparison between technological changes at a given point of time and the timing of a technological change which is in a time series context suggests that the model can be viewed as a clear extension of the classical theory of induced innovation[12].

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[12] A similar analogy in economic analysis is a substitution between two consumption goods x,y at a given point of time and the substitutuion of aggregate consumption (through savings) between two periods of time.

III. The Empirical Model

One important implication of the model developed in earlier section is the direct link between changes in the aggregate demand and technological changes. The link is based on the profitability or expected return of investment in technical progress. We show that the higher the expected change in the aggregate demand, the higher will be the expected return on investments in technical change in the level of investment.

We conclude that the realized technical change can be viewed as a distributed lag function of the actual (or expected) changes. In the aggregate demand, this relationship can be written as follows:-

$$(12) \quad \left(\frac{\Delta TG}{TG}\right)_t = \alpha_0 + \alpha_1\left(\frac{\Delta D}{D}\right)_{t-1} + \alpha_2\left(\frac{\Delta D}{D}\right)_{t-2} + \dots \alpha_k\left(\frac{\Delta D}{D}\right)_{t-k}$$

where $\left(\frac{\Delta TG}{TG}\right)_t$ is the relative change in the level of technology (or the rate of technical progress) in period t. $\left(\frac{\Delta D}{D}\right)_t$ is the percentage change in the aggregate demand in period t.

According to Equation (12), the rate of technological changes is given in the form of distributed lag function of the changes in output. The lag distribution of length k is determined by two types of lags:-

(a) The lag between the changes in the aggregate demand and the investment in technical progress.

(b) The lag between the investment in research and development and the realized technical change.

The second lag reflects the time which "elapses" between the actual investment in a technological change and the realized technical progress. This lag which depends on the "production process" of new technical knowledge may be a quiet variable since a breakthrough in research can come after a relatively short or relatively long period. For example, the rate of technical progress and the number of patents in year t may be either the "results" of investment made ten years ago or two years ago.

The high variability of the lag in patents was recognized by Schmookler (1962) and in his empirical work on patents he used a seven-year moving average of the annual patent series. Following a similar procedure, we assume that there is a trend in the level of technology in the economy and that the changes in the aggregate demand affect changes of the realized index of technological progress around the trend line. Thus, we write (12) in a "level" form as follows:-

$$(13) \quad L_n TG = \beta_o + \beta_1 t + \beta_2 L_n D + \sum_{i=0}^{k} \alpha_i \left(\frac{\Delta D}{D}\right)_{t-i}$$

where the time period t and the level of aggregate demand D represent the long run "trend line" while the changes in the aggregate demand $\left(\frac{\Delta D}{D}\right)_{t-k}$ represent the short run effect of deviation from the trend line. L_n represent the natural logarithm of the variable.

In order to estimate (13), we have to specify a measure of/the technological index as well as a measure of the aggregate demand. Technological change is usually measured as a residual of the change in output which is not explained by the changes in labor and capital inputs.

$$(14) \quad \left(\frac{\Delta TG}{TG}\right)_t = \left(\frac{\Delta X}{X}\right)_t - W_1\left(\frac{\Delta L}{L}\right) - W_2\left(\frac{\Delta K}{K}\right)_t$$

where $\left(\frac{\Delta X}{X}\right)_t$, $\left(\frac{\Delta L}{L}\right)_t$ and $\left(\frac{\Delta K}{K}\right)_t$ are the relative changes of output, labor input and capital input respectively. W_1 and W_2 are the shares of labor and capital in the total output[13].

Since (14) defines technological change as a function of changes in output, it is inappropriate from an estimation point of view to use output as a measure of the aggregate demand in (13). Also, since firms will try to predict changes in the aggregate demand by using observable variables, we can choose exogenous variables which are used by firms to predict the level and changes in output. Those variables are regarded as proxy variables for predicting the direction of the aggregate demand.

Two variables which are used in the literature to explain and predict changes in the aggregate demand are the changes in money supply and the changes in the level of governemnt expenditure. These two variables are associated with the monetary and fiscal policy in the economy[14].

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[13] Since we use only a two factor model, the term output in this context refers to value added.

[14] See Andersen and Jordan (1968) for some discussion and test of the monetary and fiscal actions.

As a monetary variable we have used the level and changes of real money balances in the economy. The relationship between the monetary variables and aggregated demand is analyzed by Friedman (1971), Sims (1972) and others. These variables were also used in the recent work of Ben-Zion and Ruttan (1974)[15].

To analyze the effect of fiscal policy on the level and direction of the aggregate demand we use the level and changes in the level of government real expenditure on goods and services.

Finally, since the current level of a variable and the recent changes in the level of the variable are not independent, we have used the lag level of both real money balances and real government expenditures together with the recent rate of change of these variables. The final empirical version of the model is written as follows:-

$$(15)\quad L_n(TG)_t = \alpha_0 + \alpha_1 t + \alpha_2 \ln RMPC_{t-k} + \alpha_3 \ln RGPC_{t-k} + \sum_{t=0}^{k} R_i \left(\frac{\Delta M}{M}\right)_{t-i} + \sum_{t=0}^{k} \gamma_i \left(\frac{\Delta G}{G}\right)_{t-i}$$

where t is the time trend variable, RMPC is the level of real money balances per capita and RGPC is the real government expenditure per capita. $(\frac{\Delta M}{M})$ and $(\frac{\Delta G}{G})$ are the rates of change of the above variables. k is the number of periods of lags used in the regression. Since there is no specific theoretical value of k, we have used alternative values k = 1,2,3.

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[15] One can use the nominal money balances to explain nominal income. This has an advantage since money balances can be regarded as exogenous (see Sims (1972)). However, since nominal money supply affects both prices and real output, we use real money balances to approximate the effect on real output.

Equation (15) uses both the levels and rates of changes in monetary and fiscal variables as proxies for the level and changes in the aggregate demand, while earlier works (e.g. Andersen and Jordan (1968) suggest that monetary variables may be more significant; we have not incorporated any prior information with regard to this question.

VI. The Data and Results

The empirical model suggested in the earlier section was tested with U.S. yearly data for the period 1929-1969.

Technological changes in a period was calculated according to (14) as the difference between actual rate of growth of real output and the explained measure in output. Those were calculated by Christensen and Jorgenson (1972), who used three alternative combinations of inputs:-

(i) capital stock and the number of manhours;

(ii) capital stock and labor service (corrected for quality of labor);

(iii) capital services and labor services[16].

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[16] For detailed calculations of these corrected inputs, see Christensen and Jorgenson (1972).

The three alternative technical indices from the above alternative measures of inputs are denoted by TG_1, $TG_2$and TG_3 respectively.

Data on money supply is based on Friedman and Schwartz (1970)(for the period 1925-1968) and the survey of current business (1971)(for 1968-1969). The population is based on the National Income and Product accounts of the U.S. for the period 1929-1965 and in the survey of current business (1971) for the later years. As a price index we have used the implicit GNP deflator from Christensen and Jorgenson.

The results of the estimation of (15) which are corrected for the first order serial correlation are given in Table 1 for the alternative dependent variables, TG_1, TG_2, TG_3.[17] The results show that the level and rates of growth of real balances have a significant positive effect on technological changes. The variables associated with government expenditure are less significant and only current changes in government expenditure have a significant coefficient. The effect of the aggregate demand variables are somewhat stronger on the "raw" technological index TG_1 than on the corrected index TG_3.[18] In summary, however, the results support the predection of the model with regard to the relationship between changes in aggregate demand and technical progress.

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[17] The results in Tables 1 and 2 were corrected for the first order serial correlation using Cochran-Orcutt iteration procedure.

[18] This was expected since the "raw index" is also affected by the "rate of utilization of input", a rate which depends on part of the changes in aggregate demand.

The date on the rate of change in monetary and fiscal variables indicate a significant correlation between the monetary and fiscal for a given period. Therefore, we have estimated (14) using separately and determinatively monetary variables and fiscal variables as proxies for the changes in aggregate demand.

Using the fiscal and monetary variables separately we have also extended the length of the lag from 3 to 7 years. The long lag is based on our assumption of the long and variable lag between the derived demand for invention and its realization in the form of technical progress. The results of the estimation corrected for serial correlation are given in Tables 2 and 3. Table 2 presents the results for monetary variables and Table 3 presents the results for fiscal variables.

The results indicate that both monetary and fiscal variables seem to have strong influence on the rate of technical change and the length of the lag between the changes in aggregate demand and technical progress is quite long.

Table 1

THE RELATIONSHIP BETWEEN INDICES OF TECHNICAL CHANGE AND MONETARY AND FISCAL VARIABLES[1]

Dependent Variable / Independent Variable	TG_1	TG_2	TG_3
CONSTANT	$0.886x10^{-1}$ (32.17)	$0.882x10^{-1}$ (30.33)	$0.862x10^{-1}$ (30.66)
TIME	$0.173x10^{-3}$ (14.84)	$0.211x10^{-3}$ (17.70)	$0.265x10^{-3}$ (22.07)
$\ln RMPC_{t-4}$	$0.245x10^{-2}$ (4.41)	$0.238x10^{-2}$ (4.11)	$0.220x10^{-2}$ (3.54)
$\ln RGPC_{t-4}$	$0.158x10^{-4}$ (0.06)	$0.377x10^{-4}$ (-0.148)	$0.156x10^{-4}$ (-0.06)
DM0[2]	$0.356x10^{-2}$ (3.80)	$0.340x10^{-2}$ (3.72)	$0.268x10^{-2}$ (2.72)
DM1	$0.481x10^{-2}$ (5.12)	$0.474x10^{-2}$ (5.12)	$0.376x10^{-2}$ (3.80)
DM2	$0.224x10^{-2}$ (2.16)	$0.212x10^{-2}$ (2.13)	$0.124x10^{-2}$ (1.15)
DM3	$0.340x10^{-2}$ (2.85)	$0.333x10^{-2}$ (2.81)	$0.124x10^{-2}$ (2.06)
DG0[3]	$0.285x10^{-3}$ (2.69)	$0.29\ x10^{-3}$ (2.87)	$0.226x10^{-3}$ (2.00)
DG1	$0.457x10^{-4}$ (0.312)	$0.39\ x10^{-4}$ (0.27)	$0.505x10^{-4}$ (0.0327)
DG2	$-0.881x10^{-5}$ (0.05)	$-0.484x10^{-4}$ (-0.26)	$-0.731x10^{-4}$ (-0.38)
DG3	$0.170x10^{-3}$ (0.778)	$0.115x10^{-3}$ (0.52)	$0.129x10^{-3}$ (0.56)
R^2	0.9961	0.997	0.997
DW	1.939	2.1151	2.183

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[1] "t" values of coefficients are given in parenthesis.

[2] DM0, ..., DM3 denote $(\frac{\Delta M}{M})_t \ldots (\frac{\Delta M}{M})_{t-3}$

[3] DG0, ..., DG3 denote $(\frac{\Delta G}{G})_t \ldots (\frac{\Delta G}{G})_{t-3}$

Table 2

THE RELATIONSHIP BETWEEN PRODUCTIVITY INDICES AND MONETARY VARIABLES

Dependent Variable Independent Variable	TG_1	TG_2	TG_3
C	0.8878×10^{-1} (72.73)	0.8769×10^{-1} (75.29)	0.8673×10^{-1} (100.68)
TIME	0.1696×10^{-3} (38.81)	0.2047×10^{-3} (49.07)	0.2599×10^{-3} (86.36)
$\ln RMPC_{t-8}$	0.2486×10^{-2} (14.22)	0.2286×10^{-2} (13.70)	0.2084×10^{-2} (16.92)
DM0	0.4748×10^{-2} (6.80)	0.4484×10^{-2} (6.74)	0.3904×10^{-2} (6.29)
DM1	0.4523×10^{-2} (6.34)	0.4172×10^{-2} (6.15)	0.3205×10^{-2} (4.64)
DM2	0.2565×10^{-2} (3.48)	0.2323×10^{-2} (3.31)	0.1424×10^{-2} (1.96)
DM3	0.3251×10^{-2} (4.57)	0.2896×10^{-2} (4.28)	0.2741×10^{-2} (3.91)
DM4	0.1218×10^{-2} (2.15)	0.9544×10^{-3} (1.77)	0.9658×10^{-4} (0.16)
DM5	0.2180×10^{-2} (14.01)	0.1935×10^{-2} (13.02)	0.2087×10^{-2} (13.78)
DM6	0.2392×10^{-2} (14.35)	0.2156×10^{-2} (13.54)	0.1983×10^{-2} (16.68)
DM7	0.2523×10^{-2} (14.90)	0.2298×10^{-2} (14.22)	0.2132×10^{-2} (18.03)
R^2	0.9959	0.9971	0.9985
S.W.	1.7248	1.7579	1.9421

Table 3

THE RELATIONSHIP BETWEEN PRODUCTIVITY INDICES AND FISCAL VARIABLES

Dependent Variable Independent Variable	TG_1	TG_2	TG_3
C	$0.7677x10^{-1}$ (76.13)	$0.7670x10^{-1}$ (86.27)	$0.7629x10^{-1}$ (85.87)
TIME	$0.1383x10^{-3}$ (11.12)	$0.1762x10^{-3}$ (16.36)	$0.2423x10^{-3}$ (22.55)
$lnRGPL_{t-7}$	$0.1029x10^{-2}$ (5.56)	$0.9521x10^{-3}$ (5.85)	$0.7839x10^{-3}$ (4.82)
DGO	$0.4704x10^{-3}$ (3.11)	$0.4813x10^{-3}$ (3.43)	$0.3502x10^{-3}$ (2.48)
DG1	$0.6617x10^{-3}$ (5.00)	$0.6156x10^{-3}$ (5.02)	$0.5162x10^{-3}$ (4.20)
DG2	$0.7328x10^{-3}$ (5.09)	$0.6651x10^{-3}$ (5.04)	$0.5114x10^{-3}$ (3.86)
DG3	$0.1024x10^{-2}$ (6.86)	$0.9393x10^{-3}$ (6.89)	$0.7859x10^{-3}$ (5.75)
DG4	$0.9825x10^{-3}$ (6.84)	$0.9017x10^{-3}$ (7.02)	$0.7537x10^{-3}$ (5.87)
DG5	$0.9729x10^{-3}$ (6.22)	$0.8771x10^{-3}$ (6.27)	0.7106^{-3} (5.08)
DG6	$0.1014x10^{-2}$ (6.08)	$0.9163x10^{-3}$ (6.16)	$0.7515x10^{-3}$ (5.05)
DG7	$0.1022x10^{-2}$ (5.78)	$0.9360x10^{-3}$ (5.98)	$0.7693x10^{-3}$ (4.91)
R^2	0.9900	0.9933	0.9957
D.W.	1.4577	1.5320	1.4749

Summary and Conclusion

The model developed in this paper emphasizes the relationship between aggregate demand and technological change. This model formally derives the relationship between the aggregate demand and investment in technical change as was suggested by Schmookler. The empirical results for the U.S., support the implications of the model. The lags between aggregate demand and technical changes seems to be rather long. One implication which was not tested directly is the effect of aggregate demand on the choice of input and the bias in the technological changes.

Also, the approach that labor and capital are quasi-fixed factors of production may yield some important implications with regard to the firm's demand for factor of production and the firm's investment decision. We hope that additional research will shed more light on these important questions.

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