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THE QUANTITATIVE IMPACT OF TAX POLICY  
ON INVESTMENT EXPENDITURES

by

Robert E. Hall and Dale W. Jorgenson

July, 1968

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I. Introduction

Tax policies for controlling investment expenditures by providing incentives or disincentives through tax credits and accelerated depreciation are now a permanent part of the fiscal policies of the United States and many other countries. However, the quantitative study of tax incentives has lagged far behind the study of policies which operate directly upon income. For example, the multiplier effect of the tax cut of 1964 has been estimated with some care; much less is known about the quantitative effect of the investment tax credit of 1962. In view of the many proposals now current to apply the tax incentive system in other sectors, notably low-cost housing, tax policies of this kind clearly call for extensive empirical study.

The effectiveness of tax policy in altering tax policy has been established in a qualitative sense by a number of authors; their argument can be stated in its essence as follows: If capital services cost less as a result of tax incentives, businessmen will employ more of them.<sup>1</sup> This

view is not free of ambiguities even at the qualitative level. For example, a reduction in the tax rate would appear to reduce the burden of the corporate income tax and to act as a stimulus to investment. But as Samuelson [39] has demonstrated, a reduction in the tax rate may make assets more attractive, less attractive, or equally attractive to the investor, depending on depreciation allowances for tax purposes. At a further remove a change in the tax rate may increase, decrease, or leave unchanged the cost of financial capital prevailing in the economy.<sup>2</sup> The effect of a reduction in taxes depends on the responsiveness of saving as well as that of investment to the proposed tax change.<sup>3</sup>

Even where the qualitative implications of a tax change can be clearly and unambiguously derived, the important questions for economic policy--how much investment? when will it occur?--are left unanswered. A stimulus to investment may have large effects or small. The resulting investment expenditures may take place immediately or may be spread over a considerable period of time. To determine the effects precisely a quantitative analysis of investment behavior is required. In two previous papers [18, 19] we have presented an econometric model designed for the specific purpose of studying the effects of tax policy on investment behavior. We have estimated the unknown parameters of this model from annual data on investment expenditures for the non-farm sector of the United States beginning with the year 1929. Given the empirical results, we have calculated the effects of tax policy on investment behavior in the post-war period. Specifically, we have studied the effects of the adoption

of accelerated depreciation in 1954, new lifetimes for depreciation in 1962, the investment tax credit in 1962 and its modification in 1964, and suspension of the investment tax credit in 1966-7.

The purpose of this paper is similar to that of our previous papers. We first re-estimate our econometric model of investment behavior, taking data that have become available since our earlier studies into account. We have revised our econometric technique to take account of recently developed methods of estimation. With these changes we obtain a new set of investment functions for the non-farm sector of the United States. We employ these investment functions to characterize the effects of the adoption of accelerated depreciation in 1954, the adoption of new lifetimes for depreciation and the investment tax credit in 1962, the tax cut of 1964, and the effects of suspension of the tax credit and accelerated depreciation for structures in 1966-7. As originally proposed, the suspension of 1966 was to extend over the period from October 1966 to December 1967; the suspension was lifted in March 1967. We calculate the effects of the suspension that actually took place and the hypothetical effects of a suspension through December 1967, as originally proposed.

The evolution of tax policies during the post-war period provides a broad range of experience for a quantitative study of the effects of tax policy on investment behavior. On the basis of our analysis of this experience, we conclude that tax policy has been highly effective in changing the level and timing of investment expenditures. Tax policy has also affected the composition of investment expenditures in the

non-farm sector. The adoption of accelerated methods for depreciation and the reduction in depreciation lifetimes for tax purposes have increased investment expenditures substantially. They have also resulted in a shift in the composition of investment away from equipment toward structures. The investment tax credit has been limited to equipment. The adoption of the investment tax credit has been a potent stimulus to the level of investment; the credit has also shifted the composition of investment toward equipment.

An econometric model of investment behavior has a decisive advantage over a purely qualitative analysis of the effects of tax policy as a basis for policy-making. At the same time our study has important limitations that must be made explicit at the outset. Our calculations are based on a partial equilibrium analysis of investment behavior. A general equilibrium analysis would be required to determine the full effects of a change in tax policy. We calculate the effects of tax policy on investment behavior given the level of investment goods prices, the cost of financial capital, and the level and price of output. Obviously, the results derived from a complete econometric model--incorporating our econometric model of investment and an explanation of investment goods prices, the cost of financial capital, and the level and price of output--could differ substantially. No econometric model of this scope is currently available so that such a general equilibrium analysis of tax policy, however desirable, is presently infeasible. For quantitative analysis we are forced to choose between an econometric model of

investment behavior that adequately reflects the direct effects of tax policy on investment and general equilibrium analysis based on the more traditional ad hoc explanations of investment behavior. This important gap in the study of macro-econometric models could be remedied by combining our model of investment behavior with an explanation of the supply of investment goods, the supply and demand for consumer goods, and the supply of saving.

## 2. Theory of investment behavior.

Our econometric model of investment behavior is based on the theory of optimal capital accumulation. This theory can be approached from two alternative and equivalent points of view.<sup>4</sup> First, the objective of the firm may be taken as the maximization of its market value. Given a recursive description of technology--output depending on the flow of current input and of capital services and capital depending on the level of investment and the past value of capital--maximization of the market value of the firm implies that the marginal product of each current input is equal to its real price and the marginal product of each capital service is equal to its real rental. In a second approach to the theory the objective of the firm is maximization of profit defined as the difference between current revenue and current outlay less the rental value of capital services. The rental price of capital services is determined from the condition of market equilibrium that equates the value of an asset and the sum of discounted values of all capital services from that asset. These two

alternative approaches lead to the same theory of the firm. We take maximization of profit as the objective of the firm and determine an appropriate price of capital services from the price of capital assets. Tax policy affects investment behavior through the price of capital services.

Two objections to the theory of optimal capital accumulation as a basis for an econometric model of investment behavior must be discussed before we develop the theory in detail. First, a substantial body of data from surveys on business decision-making suggests that "marginalist" considerations such as the cost of capital and tax policy are irrelevant to the making of business decisions to invest. This evidence has been carefully analyzed by White [50], who concludes that the data from surveys are defective even by the standards of noneconometric empirical work and that no reliance can be placed on conclusions drawn from these data. A second objection is that previous attempts to analyze investment behavior on the basis of neoclassical theory have not been successful. This objection is valid so far as the first attempts to apply neoclassical theory are concerned. Negative results have been reported by Tinbergen, Roos, and Klein for models incorporating "marginalist" considerations.<sup>5</sup> However, an econometric model based on current formulations of the neoclassical theory provides an explanation of investment expenditures superior to that of its competitors--the flexible accelerator studied intensively by Eisner [11] or the combinations of capacity utilization, liquidity, and the rate of interest studied by Anderson [2] and by Meyer



and Glauber [33].<sup>6</sup> Further, the predictive performance of the neoclassical model is superior to that of models based on alternative theories of investment behavior.<sup>7</sup>

In addition to the direct support for the neoclassical theory from econometric studies of investment behavior, indirect support is provided by econometric studies of cost and production functions.<sup>8</sup> The evidence from these studies is overwhelmingly favorable to neoclassical theory. Current empirical research emphasizes such technical questions as the appropriate form for the production function and the statistical specification of econometric models of production. As an example, Nerlove [36] has recently surveyed a literature running to over forty references devoted solely to estimation of the elasticity of substitution. In this literature the neoclassical theory of the firm is taken as a point of departure. The purpose of the empirical research reviewed by Nerlove is to give more precise results within the framework provided by neoclassical theory.

We turn now to a detailed analysis of the relationship between tax policy and investment behavior. First, the objective of the firm is to maximize profit. Profit is defined in a special sense as the difference between current revenue and current outlay less the rental value of capital services. Letting  $p$  represent the price of output and  $Q$  its quantity,  $w$  the price of labor input and  $L$  its quantity,  $c$  the rental price of capital input and  $K$  its quantity, we define profit as follows:

$$(1) \quad P = pQ - wL - cK.$$

Profit is maximized at each point of time subject to a production function,

$$(2) \quad Q = F(L, K) .$$

Investment is the sum of changes in capital stock and of replacement. We assume that replacement is proportional to capital so that investment may be determined from the relationship,

$$(3) \quad I = \dot{K} + \delta K,$$

where  $\delta$  is the rate of replacement.

Necessary conditions for profit maximization are that the marginal product of current input is equal to its real price,

$$(4) \quad \frac{\partial F}{\partial L} = \frac{w}{p};$$

similarly, the marginal product of capital input is equal to its real rental,

$$(5) \quad \frac{\partial F}{\partial K} = \frac{c}{p} .$$

Second, the price of new capital goods, say  $q$ , must equal the present value of future rentals.<sup>9</sup> In the absence of direct taxation this relationship takes the form:

$$(6) \quad q(t) = \int_t^{\infty} e^{-r(s-t)} c(s) e^{-\delta(s-t)} ds$$

where  $r$  is the financial cost of capital,  $c$  is the rental price of capital input, and  $e^{-\delta(s-t)}$  is the quantity of capital input at time  $s$  resulting from the purchase of one unit of the capital asset at time  $t$ . If prices of new investment goods are expected to remain stationary, we obtain:<sup>10</sup>

$$(7) \quad c = q(r + \delta).$$

For the non-farm sector of the United States economy taxes are imposed on current revenue less outlay on current input and less certain deductions on capital account. As an approximation we represent taxation in the non-farm sector by the corporate income tax. We assume that business income is taxed at a constant marginal rate with deductions allowed for interest payments and for depreciation on capital assets. In addition a tax credit is allowed on the acquisition of new investment goods. Where the before tax rate of return, denoted  $\rho$ , reflects deductions of interest allowed for tax purposes, the relationship between the price of new capital goods and the present value of all future rentals and tax deductions becomes:

$$(8) \quad q(t) = \int_t^{\infty} e^{-(1-u)\rho(s-t)} [e^{-\delta(s-t)}(1-u)c(s) + uq(t)D(s-t)] ds + kq(t).$$

The rental value of capital services after taxes is  $(1-u)c$ , where  $u$  is the tax rate. The depreciation formula  $D(s-t)$  gives the depreciation allowance for tax purposes on an asset of age  $s-t$ . Note that

depreciation allowances depend on the price at which the asset is acquired  $q(t)$ , not the price of assets at the time depreciation is allowed as a charge against income  $q(s)$ . Finally, the tax credit is  $kq(t)$ , where  $k$  is the proportion of the value of the asset allowable as a credit against taxes; the tax credit is not deducted from the amount of depreciation to be claimed. This formulation is inappropriate to the tax credit for the years 1962 and 1963, prior to the repeal of the Long Amendment. Under this Amendment the tax credit was deducted from allowable depreciation so that:

$$(9) \quad q(t) = \int_t^{\infty} e^{-(1-u)\rho(s-t)} [e^{-\delta(s-t)} (1-u)c(s) + uq(t)(1-k)D(s-t)] ds + kq(t).$$

Proceeding as before we assume that the prices of new investment goods (and the rate of the investment tax credit) are expected to remain stationary. The relationship between the price of capital services  $c$  and the price of capital assets  $q$  becomes:

$$(10) \quad c = q[(1-u)\rho + \delta] \frac{1 - k - uz}{1 - u},$$

where:

$$(11) \quad z = \int_t^{\infty} e^{-(1-u)\rho(s-t)} D(s-t) ds,$$

may be interpreted as the present value of depreciation deductions totaling one dollar over the lifetime of the investment. If the tax credit is

deducted from allowable depreciation this relationship becomes:

$$(12) \quad c = q[(1-u)\rho + \delta] \frac{(1-k)(1-uz)}{1-u} .$$

Considering the impact of changes in the tax structure on the price of capital services, we see that an increase in the investment tax credit  $k$  will always reduce the price of capital services. Where the investment tax credit is deducted from allowable depreciation, this credit has precisely the effect of a direct subsidy to the purchase of investment goods.<sup>11</sup> Second, an increase in the present value of depreciation deductions  $z$ , resulting from a reduction in lifetimes of investment goods allowable for tax purposes or from the use of "accelerated" depreciation formulas, reduces the price of capital services.

The effect of a change in the tax rate  $u$  on the price of capital services depends on the effect of such a change on the rate of return. Holding the before-tax rate of return  $\rho$  constant, we find that a change in the tax rate is neutral in its effects on the price of capital services if the combined value of depreciation allowances and the investment tax credit is equal to the value of "economic" depreciation, where economic depreciation corresponds to:

$$(13) \quad D(s-t) = \delta e^{-\delta(s-t)} .$$

The present value of economic depreciation, say  $z^*$ , is:

$$(14) \quad z^* = \int_t^{\infty} e^{-(1-u)\rho(s-t)} \delta e^{-\delta(s-t)} ds ,$$

$$= \frac{\delta}{(1-u)\rho + \delta} .$$

Now, provided that:

$$k + uz = uz^*$$

we find:

$$c = q(\rho + \delta)$$

so that the price of capital services is unaffected by changes in the tax rate.<sup>12</sup> On the other hand, holding the after-tax rate of return, say  $r = (1-u)\rho$ , constant, we find that a change in the tax rate is neutral if the combined value of depreciation allowances and the investment tax credit is equal to the value of immediate expensing of assets; provided that:

$$k + uz = u$$

we find

$$c = q(r + \delta),$$

so that the price of capital services is unaffected by changes in the tax rate.<sup>13</sup>

We conclude that if the before-tax cost of capital is fixed, changes in the tax rate are neutral in their effects on the price of capital services when the combined effect of the investment tax credit and depreciation allowances for tax purposes is equivalent to economic depreciation. Second, holding the after-tax cost of capital constant, changes in the tax rate are neutral when the combined effect is equivalent to

immediate expensing of assets. Thus, the neutrality of changes in the tax rate depends on whether the burden of the tax is born by the firm (before-tax cost of capital constant) or shifted (after-tax cost of capital constant). The incidence of the corporate income tax has been the subject of much controversy. To resolve this controversy a general equilibrium analysis based on an econometric model including saving as well as investment is required.<sup>14</sup> We assume that the burden of the tax is born by the firm, that is, that the before-tax rate of return is unaffected by changes in the tax rate.

Prior to the Internal Revenue Act of 1954 essentially only one depreciation formula was permitted for tax purposes, the straight-line formula, with a constant stream of depreciation over the lifetime of the asset.

Denoting the lifetime by  $T$ , the straight-line depreciation formula is:

$$(15) \quad D(\tau) = \frac{1}{T}, \quad 0 \leq \tau \leq T,$$

where  $\tau = s-t$  is the age of the asset. The present value of depreciation deductions under the straight-line formula is:<sup>15</sup>

$$(16) \quad z = \frac{1}{(1-u)\rho T} [1 - e^{-(1-u)\rho T}]$$

Under the Internal Revenue Act of 1954 three depreciation formulas were allowed for tax purposes. As alternatives to the straight-line formula taxpayers were permitted to employ sum of the years' digits and declining balance formulas. These two formulas are known as "accelerated" methods of depreciation because they are associated with higher present values of depreciation deductions than the straight-line method for the

same lifetime and cost of capital. In the sum of the years' digits method the deduction for depreciation declines linearly over the lifetime of the asset, starting at twice the corresponding straight-line rate; the depreciation formula is:

$$(17) \quad D(\tau) = \frac{2(T - \tau)}{T^2} \quad 0 \leq \tau \leq T .$$

The present value of depreciation deductions under this formula is:<sup>16</sup>

$$(18) \quad z = \frac{2}{(1-u)\rho T} \left[ 1 - \frac{1}{(1-u)\rho T} (1 - e^{-(1-u)\rho T}) \right] .$$

In the declining balance method of depreciation the deduction declines exponentially over the lifetime of the asset starting at a fixed proportion of the straight-line rate. If this proportion, say  $\beta$ , is 2, the method is referred to as double declining balance; if the proportion is 1.5 the method is referred to as 150 percent declining balance. Tax provisions for depreciation under the declining balance method permit taxpayers to switch from declining balance to straight-line depreciation applied to the undepreciated balance at any point during the lifetime of the asset. Obviously, the switchover point that maximizes the present value of the depreciation deduction, say  $T^*$ , occurs where the flow of declining balance depreciation is equal to the flow of straight-line depreciation after the switch. The declining balance depreciation formula is:



$$(19) \quad D(\tau) = \begin{cases} \frac{\beta}{T} e^{-\frac{\beta}{T} \tau}, & 0 \leq \tau \leq T^*, \\ \frac{e^{-\frac{\beta}{T} T^*}}{T - T^*}, & T^* \leq \tau \leq T. \end{cases}$$

Solving for the optimal switchover point, we obtain:

$$(20) \quad T^* = T \left( 1 - \frac{1}{\beta} \right).$$

The present value of depreciation under the declining balance method is:<sup>17</sup>

$$(21) \quad z = \frac{\frac{\beta}{T}}{(1-u)\rho + \frac{\beta}{T}} \left[ 1 - e^{-\left[ (1-u)\rho + \frac{\beta}{T} \right] T^*} \right] + \frac{e^{-\frac{\beta}{T} T^*}}{(1-u)\rho(T-T^*)} \left[ e^{-(1-u)\rho T^*} - e^{-(1-u)\rho T} \right].$$

For econometric implementation of a theory of investment behavior based on the neoclassical theory of optimal capital accumulation, we must choose an appropriate form for the production function. The choice of an appropriate functional form has been the subject of much empirical research. As we have already suggested, the focus of current research is the choice of an appropriate value for the elasticity of substitution.

Recently, this research has been surveyed by Griliches [16] and Nerlove [36]. The basic findings are summarized by Griliches as follows:

The studies based on cross-sectional data yield estimates which are on the whole not significantly different from unity. The time series studies report, on the average, substantially lower estimates. [16, p. 285]

In short, there is a basic conflict between estimates of the elasticity of substitution from cross section and from time series data.

A reconciliation of the disparate findings from cross sections and time series has been made by Griliches. The regression of output per head on the real wage (both in logarithms), employed by Arrow, Chenery, Minhas and Solow [4], is modified in three ways: (1) measures of labor quality are introduced into the regression, (2) regional dummy variables are introduced to take account of possible differentials in price of output and labor quality by region, (3) allowance is made for the possibility of serial correlation in the error term due to persistence of omitted variables.<sup>18</sup> The resulting cross section estimates of the elasticity of substitution are similar to previous estimates. Griliches observes that:

Only one of these  $\sigma$ 's [estimates of the elasticity of substitution] (out of 17) is significantly different from unity, and that one is above unity. [16, p. 292]

Allowing for serial correlation of the errors in successive years, Griliches obtains estimates for successive cross sections characterized as follows:

In general, all the estimated  $\sigma$ 's [estimates of the elasticity of substitution] are not very (statistically) different from unity, the significant deviations if anything occurring above unity rather than below it. [16, p. 292]

Griliches' general conclusion from these and additional estimates of the elasticity of substitution is the following:

I do not intend to argue that these results prove that the Cobb-Douglas [elasticity of substitution equal to unity] is the right form for the manufacturing production function, only that there is no strong evidence against it. Until better evidence appears, there is no reason to give it up as the maintained hypothesis. [16, p. 297]

On the basis of the results presented by Griliches and the work surveyed by Griliches and Nerlove we adopt the Cobb-Douglas production function as the appropriate functional form for our theory of investment behavior. This form was used in our earlier studies [18, 19].

If there is no lag in the completion of investment projects, the level of investment appropriate for optimal capital accumulation may be determined from the necessary conditions for maximization of profit. In the theory of investment behavior described below, we assume that the actual level of capital stock may differ from the optimal level. More specifically, we assume that given capital stock, the levels of output and current input are determined from the production function and the marginal productivity condition for current input. The desired level of capital is determined from the actual level of output, given the marginal productivity condition for capital input, while the actual level of capital is determined by past investment. Finally, we assume that time is

required for the completion of new investment projects. Projects are initiated at every point in time so that the actual level of capital plus the backlog of uncompleted projects is equal to the desired level of capital.

Now if the production function has Cobb-Douglas form, the marginal productivity condition for capital input may be written:

$$(22) \quad a \frac{Q}{K^*} = \frac{c}{p} ,$$

where  $a$  is the elasticity of output with respect to capital input and  $K^*$  is the desired level of capital. Solving for desired capital, we obtain:

$$(23) \quad K^* = a \frac{pQ}{c} .$$

To represent the theory of investment we let the proportion of investment projects initiated in time  $t$  and completed in period  $t + \tau$  be  $\mu_\tau$ . We assume that the sequence of proportions  $\{\mu_\tau\}$  depends only on the time elapsed between initiation of a project and its completion. We have assumed that new projects are initiated in each period until the backlog of uncompleted projects is equal to the difference between desired and actual capital. Under this assumption new investment starts in each period are equal to the change in desired capital stock. In every period the level of actual net investment is a weighted average of projects initiated in previous periods,

$$(24) \quad I_t - \delta K_t = \mu_0 [K_t^* - K_{t-1}^*] + \mu_1 [K_{t-1}^* - K_{t-2}^*] + \dots,$$

where  $I_t$  is gross investment and  $\delta K_t$  is replacement investment.

To make our notation more concise it is useful to use the lag operator  $S$ , defined as:

$$S x_t = x_{t-1},$$

for any sequence  $\{x_t\}$ . Using this notation, we may write the expression for the level of net investment given above more compactly, as follows:

$$(25) \quad I_t - \delta K_t = \mu(S) [K_t^* - K_{t-1}^*],$$

where:

$$(26) \quad \mu(S) = \mu_0 + \mu_1 S + \dots,$$

is a power series in the lag operator.

To summarize, investment in period  $t$  depends on the capital stock at the beginning of the period and changes in the desired level of capital in previous periods. The form of the relationship depends on the form of the distributed lag function and the rate of replacement. The desired level of capital depends on the level of output, the price of output, and the rental price of capital input. Tax policy affects investment behavior through the rental price of capital input. This price depends

on the price of investment goods, the cost of capital, the tax rate, the formulas for calculating depreciation allowances for tax purposes, and the level of the investment tax credit. A change in tax policy changes the rental price of capital input. This results in a change in the desired level of capital stock. An increase in desired capital stock generates net investment; if the price of capital input and the other determinants of desired capital remain constant net investment declines to zero as capital stock approaches its desired level. The change in tax policy continues to affect gross investment through replacement requirements for a permanently larger capital stock.

### 3. Econometrics of investment behavior.

Our theory of investment behavior implies a distributed lag relationship between net investment and changes in the desired level of capital. To implement this theory econometrically we must impose restrictions on the sequence of coefficients  $\{\mu_\tau\}$ . In previous studies we have employed the restriction that this sequence has a rational generating function. With this restriction the power series  $\mu(S)$  may be represented as the ratio of two polynomials in the lag operator, that is, a rational function of the lag operator,

$$(27) \quad \mu(S) = \frac{\gamma(S)}{\omega(S)} .$$

The resulting rational distributed lag function may be written as a mixed moving average and autoregressive scheme in changes in the desired level

of capital and net investment.<sup>19</sup> Second, we must add a random component to the distributed lag function, obtaining,

$$(28) \quad \omega(S) [I_t - \delta K_t] = \gamma(S) [K_t^* - K_{t-1}^*] + \epsilon_t,$$

where  $\epsilon_t$  is a random error in the distributed lag function. Finally, we must choose an appropriate specification for the stochastic component  $\epsilon_t$ . In previous studies we have assumed that the random component is distributed independently and identically over time. In this study we retain these features of our previous specification. In addition we employ further restrictions on the sequence of coefficients  $\{\mu_r\}$  in order to economize on the number of parameters to be estimated.

We assume first that the distributed lag function may be represented as a finite moving average with an autoregressive error, that is,

$$(29) \quad I_t - \delta K_t = \beta(S) [K_t^* - K_{t-1}^*] + v_t,$$

where  $\beta(S)$  is a polynomial in the lag operator and  $v_t$  is an autoregressive error. Since we assume that  $v_t$  is generated by an autoregressive scheme, we have:

$$(30) \quad \omega(S) v_t = \epsilon_t,$$

where  $\omega(S)$  is a polynomial in the lag operator and  $\epsilon_t$  is distributed independently and identically over time. Multiplying both sides of the distributed lag function by the polynomial  $\omega(S)$ , we obtain an

alternative form at the distributed lag function,

$$\begin{aligned}
 (31) \quad \omega(S) [I_t - \delta K_t] &= \omega(S) \beta(S) [K_t^* - K_{t-1}^*] = \omega(S) v_t, \\
 &= \omega(S) \beta(S) [K_t^* - K_{t-1}^*] + \epsilon_t,
 \end{aligned}$$

which is a rational distributed lag function with independently and identically distributed error term, the specification employed in our earlier studies.

Using our representation of the power series  $\mu(S)$  as the ratio of two polynomials in the lag operator, we may write:

$$\omega(S) = \omega(S),$$

$$\gamma(S) = \omega(S) \beta(S).$$

The rational distributed lag function employed in our earlier studies is now further restricted in that the polynomial  $\gamma(S)$  is the product of two polynomials, one of them  $\omega(S)$ , the denominator of the original representation of the power series  $\mu(S)$ . If this restriction is valid, it may be used to reduce the number of parameters to be estimated. Further, the implied estimator of the power series  $\mu(S)$  reduces to an estimator of the polynomial  $\beta(S)$ , since:



$$\begin{aligned}
 \mu(S) &= \frac{\gamma(S)}{\omega(S)} , \\
 &= \frac{\omega(S) \beta(S)}{\omega(S)} , \\
 &= \beta(S) .
 \end{aligned}$$

This restriction overcomes a possible objection to an unconstrained estimator of the parameters of the power series  $\mu(S)$  for a rational distributed lag function. In some circumstances relatively small variations in the coefficients of the numerator of the power series may give rise to large variations in the coefficients of the power series itself, as Griliches [15] has suggested. Under the restriction we have proposed the estimator of the coefficients of the power series  $\mu(S)$  is independent of the estimator of the coefficients of the numerator  $\omega(S)$ .

As an example, if there are five terms in the original polynomial in the lag operator  $\beta(S)$ , the distributed lag function becomes:

$$(32) \quad I_t - \delta K_t = \sum_{\tau=0}^4 \beta_{\tau} [K_{t-\tau}^* - K_{t-\tau-1}^*] + v_t .$$

If, further, the order of the polynomial  $\omega(S)$  is unity, that is, the disturbance has only first-order autocorrelation, we may multiply both sides of the distributed lag function by  $\omega(S) = 1 + \omega_1 S$  to obtain:

$$\begin{aligned}
(33) \quad & [I_t - \delta K_t] + \omega_1 [I_{t-1} - \delta K_{t-1}] \\
& = \beta_0 [K_t^* - K_{t-1}^*] + \sum_{\tau=0}^3 (\omega_1 \beta_\tau + \beta_{\tau+1}) [K_{t-\tau-1}^* - K_{t-\tau-2}^*] \\
& \quad + \omega_1 \beta_4 [K_{t-5}^* - K_{t-6}^*] + \epsilon_t, \\
& = \sum_{\tau=0}^5 \gamma_\tau [K_{t-\tau}^* - K_{t-\tau-1}^*] + \epsilon_t.
\end{aligned}$$

We have succeeded in obtaining satisfactory specifications of the distributed lag function between net investment and changes in the desired level of capital using polynomials  $\omega(S)$  of low order. However, we have had to employ as many as five terms in the polynomial  $\beta(S)$  to obtain a satisfactory specification. In order to economize further on the number of parameters to be estimated we have employed an approximation due essentially to Mrs. Almon [1]. We have assumed that the polynomial in the lag operator  $\beta(S)$  has coefficients generated by a polynomial in the lag itself,

$$(34) \quad \beta_\tau = \pi_0 + \pi_1 \tau + \dots + \pi_k \tau^k;$$

of course, to make this an approximation at all, the order of the approximating polynomial must be less than the order of the polynomial in the lag operator.

Continuing our example: If the order of the approximating polynomial is two and there are five terms in the original polynomial in the lag operator  $\beta(S)$ , the distributed lag function becomes:

$$\begin{aligned}
 (35) \quad I_t - \delta K_t &= \sum_{\tau=0}^4 \beta_{\tau} [K_{t-\tau}^* - K_{t-\tau-1}^*] + v_t \\
 &= \sum_{\tau=0}^4 (\pi_0 + \pi_1 \tau + \pi_2 \tau^2) [K_{t-\tau}^* - K_{t-\tau-1}^*] + v_t, \\
 &= \sum_{\sigma=0}^2 \pi_{\sigma} \sum_{\tau=0}^4 \tau^{\sigma} [K_{t-\tau}^* - K_{t-\tau-1}^*] + v_t.
 \end{aligned}$$

On transformation this function becomes:

$$\begin{aligned}
 (36) \quad [I_t - \delta K_t] + \omega_1 [I_{t-1} - \delta K_{t-1}] \\
 &= \sum_{\sigma=0}^2 \pi_{\sigma} \sum_{\tau=0}^4 \tau^{\sigma} [K_{t-\tau}^* - K_{t-\tau-1}^*] \\
 &\quad + \omega_1 \sum_{\sigma=0}^2 \pi_{\sigma} \sum_{\tau=0}^4 \tau^{\sigma} [K_{t-\tau-1}^* - K_{t-\tau-2}^*] \\
 &\quad + \epsilon_t.
 \end{aligned}$$

In this distributed lag function there are only four unknown parameters

--  $\pi_0$ ,  $\pi_1$ ,  $\pi_2$  and  $\omega_1$ .

To estimate the unknown parameters of a rational distributed lag function with independently and identically distributed error term  $\epsilon_t$  we may employ ordinary least squares. The resulting estimator is consistent; its asymptotic distribution may be characterized in precisely the same way as in our previous studies.<sup>20</sup>

Provided that the restrictions on the coefficients we have proposed are valid, it is useful to take these restrictions into account in estimating the unknown parameters of the distributed lag function. First, approximation of the coefficients of the polynomial in the lag operator  $\beta(S)$  by a polynomial in the lag itself results in restrictions that are linear in the unknown parameters  $\{\beta_\tau\}$ . We use these restrictions to eliminate the parameters  $\{\beta_\tau\}$  and express the distributed lag function in terms of the parameters  $\{\pi_\sigma\}$ . The constrained distributed lag function is still linear in the unknown parameters so that ordinary least squares may be applied directly. Secondly, generation of a rational distributed lag function by autoregressive transformation of a finite moving average results in a distributed lag function that is non-linear in its parameters. To estimate such a function we may employ a two-stage least squares procedure due to Durbin [10]. This procedure begins with an ordinary least squares estimator applied to the unconstrained rational distributed lag function. The second stage is to estimate the parameters of the moving average  $\{\beta_\tau\}$  by applying least squares to the dependent and independent variables transformed in accord with the original autoregressive scheme. Parameters of the scheme  $\{\omega_\tau\}$  are set equal to their first-round

estimates. This procedure results in estimates of the parameters  $\{\beta_\tau, \omega_\tau\}$  that are asymptotically efficient.<sup>21</sup> Of course, this procedure can be re-iterated; it is easily seen to converge on successive iterations to the maximum likelihood estimator of the distributed lag function.

Reverting to our example, Durbin's two-stage procedure may be characterized as follows: First, we estimate the parameters of the rational distributed lag function without constraints--  $\omega_1, \gamma_0 \dots \gamma_5$  --by ordinary least squares. Second, we apply least squares to the relationship:

$$(37) \quad [I_t - \delta K_t] + \hat{\omega}_1 [I_{t-1} - \delta K_{t-1}] \\ = \sum_{\sigma=0}^2 \pi_\sigma \sum_{\tau=0}^4 \tau^\sigma \{ [K_{t-\tau}^* - K_{t-\tau-1}^*] + \hat{\omega}_1 [K_{t-\tau-1}^* - K_{t-\tau-2}^*] \} + \hat{\epsilon}_t,$$

where  $\hat{\omega}_1$  is the first-round estimator of the autocorrelation parameter,  $\omega_1$ , and  $\hat{\epsilon}_t$  is the error in the distributed lag function plus the error in the first stage estimator  $\hat{\omega}_1$  times the corresponding variables and parameters. Since the first stage estimator is consistent, the error in this estimator does not affect the asymptotic properties of the estimator of the remaining parameters--  $\pi_0, \pi_1$ , and  $\pi_2$ .

To test the validity of the two constraints we have proposed, we begin with the unconstrained least squares estimator of the unknown parameters of the distributed lag function. This is the first stage in Durbin's two-stage estimator. We then impose the constraints, obtaining an estimator satisfying the restrictions that  $\gamma(S) = \omega(S)\beta(S)$  and that  $\beta(S)$  has coefficients that may be approximated by a polynomial in the lag

itself. A test statistic that is asymptotically equivalent to a likelihood ratio test is the following: Divide the difference between the sums of squared residuals associated with the constrained and unconstrained estimators, say  $e_0'e_0$  and  $e_1'e_1$ , respectively, by the difference between the number of parameters to be estimated without constraints, say  $k_1$ , and the number to be estimated with constraints taken into account, say  $k_0$ . Finally, divide this ratio by the sum of squared residuals associated with the unconstrained estimator, divided by the number of observations, say  $n$ , less the number of parameters to be estimated. The resulting statistic,

$$(38) \quad F = \frac{(e_0'e_0 - e_1'e_1)/(k_1 - k_0)}{e_1'e_1 / (n - k_1)},$$

is asymptotically equivalent to the statistic associated with the likelihood ratio test of this hypothesis. In the example we have outlined above there are seven unknown parameters in the unconstrained distributed lag function so that  $k_1 = 7$ . In the constrained estimator there are only four, so that  $k_0 = 4$ . We should note that accepting the null hypothesis at conventional levels of significance is not in itself justification for imposing the constraints; it is merely an indication that there is no strong evidence contradicting the constraints.

#### 4. Estimates of the parameters of the investment functions.

We have fitted the econometric model of investment behavior outlined in previous sections to data on investment expenditures based on the 1966 Capital Goods Study of the Office of Business Economics (OBE).<sup>22</sup> These data were adjusted by Gordon [13] to take account of the role of government-owned capital used in private production. Data are available for structures and equipment separately for both manufacturing and non-farm, non-manufacturing sectors of the U. S. economy for the years 1929-65. The data are derived by allocating commodity flow data on gross private domestic investment from the national product accounts among sectors of destination. The investment data used in this study differ from those employed in our earlier studies in two ways: (1) They reflect revisions in commodity flow estimates of gross private domestic investment resulting from recent revisions of the U. S. National Income and Product Accounts [44]. (2) They incorporate estimates of government-owned capital and some other minor adjustments made by Gordon.

Published price indexes for gross private domestic investment are biased because they are based in part on the price of inputs to the capital goods industries rather than the price of output. To overcome this bias we used the Bureau of Public Roads price index for structures in our previous studies. We have replaced this index for structures by an index constructed by Gordon, based on price indexes for the output of structures from the 1966 Capital Goods Study. In our previous study we replaced the implicit deflator for producers' durables by a deflator for consumers' durables. The

bias in the producers' durables price index is not very substantial in any case;<sup>23</sup> to avoid a possible bias resulting from differences in the cyclical behavior of consumers' and producers' price indexes, we have decided not to attempt to correct the bias in the producers' durables price index. Accordingly, we employ the implicit deflator for producers' durables from the national product accounts in this study. All price indexes are taken to be equal to unity in 1965.

Capital stock for equipment and structures in both industry groupings is obtained from the recursion relation,

$$K_t = I_{t-1} + (1-\delta)K_{t-1}$$

where  $I_t$  is investment in period  $t$ , derived as outlined above, and  $\delta$  is the rate of replacement, taken to be 2.5 times the inverse of the Bulletin F [45] lifetime. The values of  $\delta$  are the same as those employed in our previous studies:

|  |        |
|--|--------|
| Manufacturing equipment                | 0.1471 |
| Manufacturing structures               | 0.0625 |
| Non-farm, non-manufacturing equipment  | 0.1923 |
| Non-farm, non-manufacturing structures | 0.0694 |

Initial values for capital stock in 1929 were estimated by cumulating net investment over the whole period for which data are available for each asset.



The desired level of capital stock depends on the value of output. As a measure of output we have used gross value added at factor cost, defined as gross product originating in each industry less indirect business taxes. For the years 1929 to 1946 these data are identical to those of our previous studies. For the years 1947 to 1965 data were obtained from the OBE study of gross product originating in each sector.<sup>24</sup>

The desired level of capital also depends on the rental price for capital services. Through 1953 the rental price is that appropriate to straight-line depreciation. Since 1954 the rental price is that appropriate to sum of the years' digits depreciation.<sup>25</sup> From October 1966 to March 1967 the appropriate rental price for structures is that for 150 percent declining balance depreciation. Other methods of accelerated depreciation were suspended during this period. The investment tax credit was introduced in 1962 at a rate nominally equal to 7 percent of the value of investment in equipment. In practice certain limitations on the applicability of the investment tax credit reduce its effective rate to 6 percent for manufacturing equipment and 5.8 percent for non-farm, non-manufacturing equipment.<sup>26</sup> For 1962 and 1963 the base for depreciation was reduced by the amount of the tax credit; after 1964 the base for depreciation is not reduced by the amount of the credit. From October 1966 to March 1967 the investment tax credit was suspended.

The rental price of capital services also depends on the tax rate  $u$ , the after-tax rate of return  $r$ , the investment goods price  $q$ , the rate of replacement  $\delta$ , and the lifetime of capital goods allowable for

tax purposes. We took the tax rate to be the statutory rate prevailing during most of each year. We did not allow for excess profits taxes during the middle thirties or the Korean War. For all years we took the rate of return before taxes  $\rho$  to be constant at 20 percent. This value is higher than the value of 14 percent used in our previous studies. The higher value is consistent with the results of Jorgenson and Griliches [23]. Under our assumption of a constant before-tax rate of return the after-tax rate  $r = (1-u)\rho$  varies with the tax rate. The investment goods price is the same as that used to deflate investment expenditures in current prices and the rate of replacement is the same as that used to calculate capital stock. Estimates of lifetimes of assets allowable for tax purposes were obtained from a special Treasury Study [46]. These estimates are the same as those employed in our previous studies:

| Period  | Equipment | Structures |
|---------|-----------|------------|
| 1929-54 | 17.5      | 27.8       |
| 1955    | 16.3      | 25.3       |
| 1956-61 | 15.1      | 22.8       |
| 1962-5  | 13.1      | 22.8       |

New estimates of these lifetimes for recent years would require that the special Treasury study be updated.

In the previous section we described a statistical technique for fitting our econometric model to data on investment expenditures. In summary this technique is based on the application of least squares in two

stages. First, we fit an unconstrained rational distributed lag function to data on net investment and changes in the desired level of capital for each class of asset for each sector. The independent variables include lagged values of net investment and current and lagged changes in the desired level of capital. We have chosen the polynomial in the lag operator  $\beta(S)$  to be of fourth order and the polynomial  $\omega(S)$  to be of first order, so that one lagged value of net investment and current and five lagged changes in desired capital are included among the independent variables. The results of the first stage regressions for the period 1935 to 1940 and 1954 to 1965 are presented in Table 1. The coefficient  $-\hat{\omega}_1$  is associated with lagged values of net investment and is an estimate of the autocorrelation of the disturbances. The coefficients  $-\hat{\alpha}\gamma_0 \dots \hat{\alpha}\gamma_5$  are associated with changes in the ratio of the value of output to the rental price of capital services.

Measures of goodness of fit of the first-stage regressions are also given in Table 1. Goodness of fit is measured in two ways: the ratio of the explained sum of squares to the total sum of squares for gross investment,  $R_I^2$ ; the ratio of the explained sum of squares to the total sum of squares for net investment,  $R_N^2$ . While net investment is the dependent variable in the regression, gross investment is the variable of primary interest for policy considerations. The standard error of estimate,  $s$ , corrected for degrees of freedom, is also presented for each of the regressions. Autocorrelation of errors has already been taken into account in the generation of the distributed lag

Table 1. Fitted Investment Functions, 1935-40 and 1954-65, First Stage Results.

| Asset Class                         | $\hat{\omega}_1$   | $\alpha\gamma_0$ | $\alpha\gamma_1$ | $\alpha\gamma_2$  | $\alpha\gamma_3$  | $\alpha\gamma_4$  | $\alpha\gamma_5$  | $R_N^2$ | $R_I^2$ | s     | d     |
|-------------------------------------|--------------------|------------------|------------------|-------------------|-------------------|-------------------|-------------------|---------|---------|-------|-------|
| Mfg.<br>Equipment                   | -.4753<br>(.2276)  | .0123<br>(.0052) | .0190<br>(.0057) | .0071<br>(.0079)  | .0034<br>(.0075)  | -.0001<br>(.0069) | .0015<br>(.0057)  | .801    | .969    | .658  | 2.277 |
| Mfg.<br>Structures                  | -.6109<br>(.3255)  | .0036<br>(.0042) | .0055<br>(.0040) | .0030<br>(.0045)  | .0035<br>(.0048)  | -.0015<br>(.0046) | .0001<br>(.0043)  | .524    | .815    | .585  | 1.447 |
| Non-farm,<br>Non-mfg.<br>Equipment  | .0916<br>(.3319)   | .0317<br>(.0117) | .0389<br>(.0198) | .0229<br>(.0163)  | .0143<br>(.0138)  | .0054<br>(.0132)  | .0202<br>(.0133)  | .820    | .965    | 1.255 | 1.837 |
| Non-farm,<br>Non-mfg.<br>Structures | -1.0065<br>(.0953) | .0057<br>(.0037) | .0082<br>(.0040) | -.0010<br>(.0044) | -.0025<br>(.0039) | -.0029<br>(.0039) | -.0046<br>(.0038) | .987    | .967    | .531  | 1.931 |

function underlying our econometric model. A test for autocorrelation may be performed by combining the first stage results with results from the second stage. For completeness we present the Durbin-Watson ratio  $d$  for each regression. Of course, the usual test for autocorrelation based on this ratio is biased toward randomness.<sup>27</sup>

Actual and fitted values of net investment from the first stage regressions are plotted in Figures 1-4. The overall goodness of fit is superior to that of our previous investment functions for 1931-41 and 1950-63 except for manufacturing structures. This improvement is mainly due to the change in time period and to revisions of the basic investment data; however, it is also partly due to the change in our specification of the distributed lag function. We have added three lagged changes in desired capital, which improves the results to some extent.

The second stage of our statistical procedure is to transform all variables in accord with the estimated autoregressive scheme of the errors from the first stage. Second, we approximate the polynomial in the lag operator  $\beta(S)$  by a polynomial in the lag itself. We have chosen a second degree polynomial for this purpose so the lag function is a parabola. The dependent variable is now net investment plus  $\hat{\omega}_1$  times lagged net investment while the independent variables are weighted sums of changes in desired capital plus  $\hat{\omega}_1$  times the corresponding lagged value. The weights depend on the lags. The derived estimates of the parameters --  $\alpha\beta_0 \dots \alpha\beta_4$  -- are presented in Table 2. Measures of goodness of fit similar to those presented for the unconstrained distributed lag functions

Figure 1. Actual and fitted net investment, first stage regressions, manufacturing equipment. Solid line is actual net investment and broken line is fitted net investment.

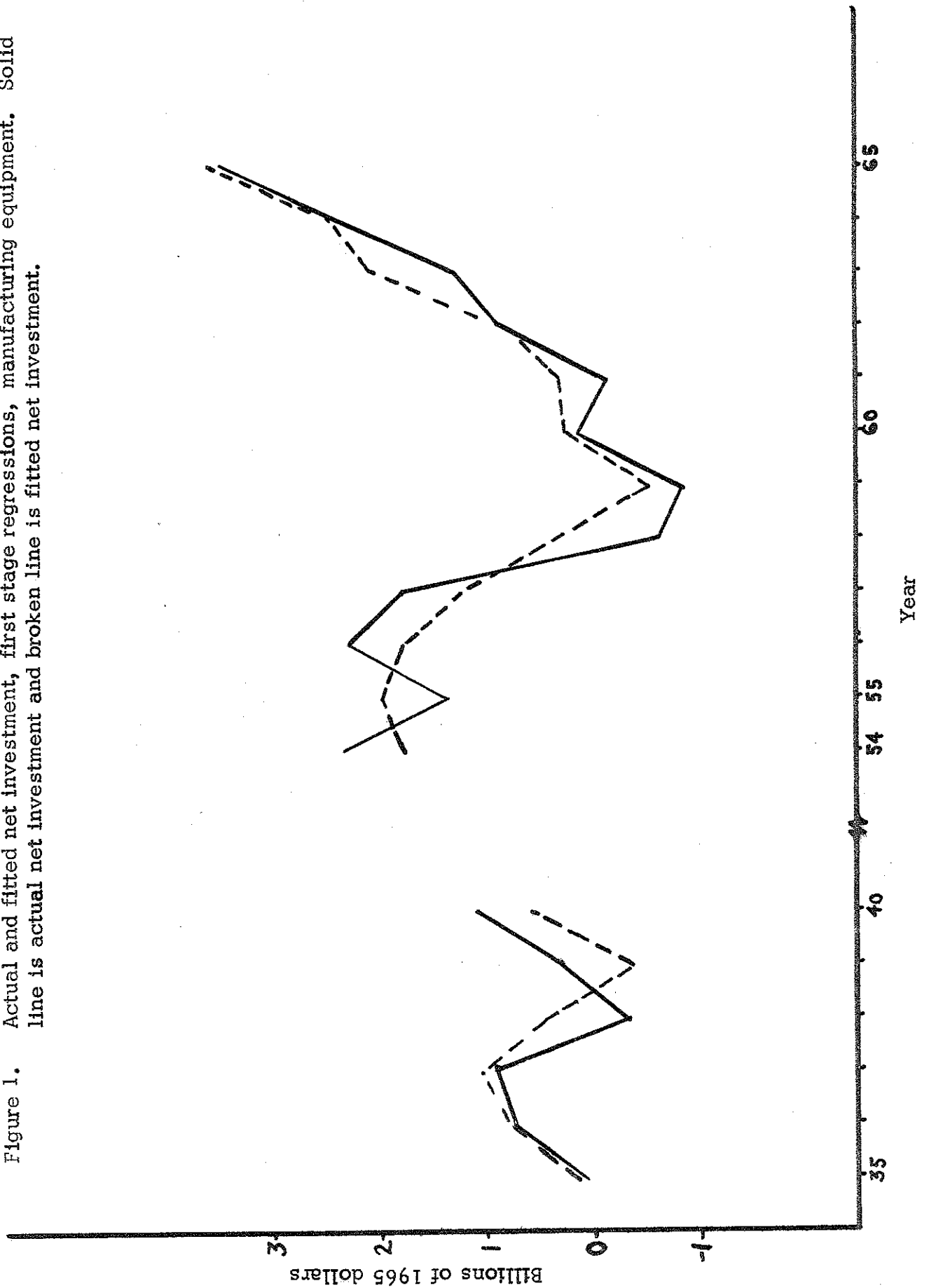


Figure 2. Actual and fitted net investment, first stage regressions, manufacturing structures. Solid line is actual net investment and broken line is fitted net investment.

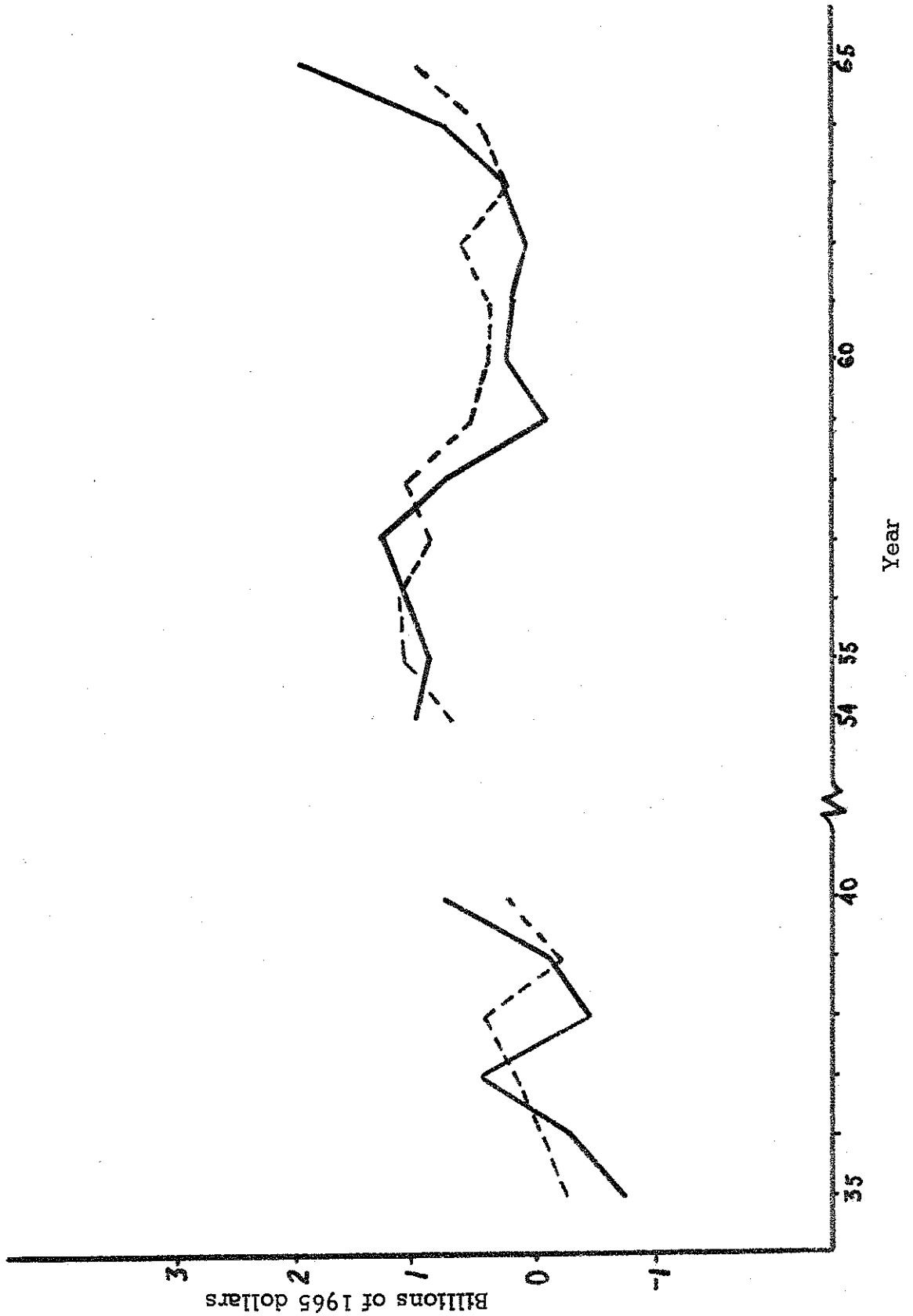


Figure 3. Actual and fitted net investment, first stage regressions, non-farm, non-manufacturing equipment.  
Solid line is actual net investment and broken line is fitted net investment.

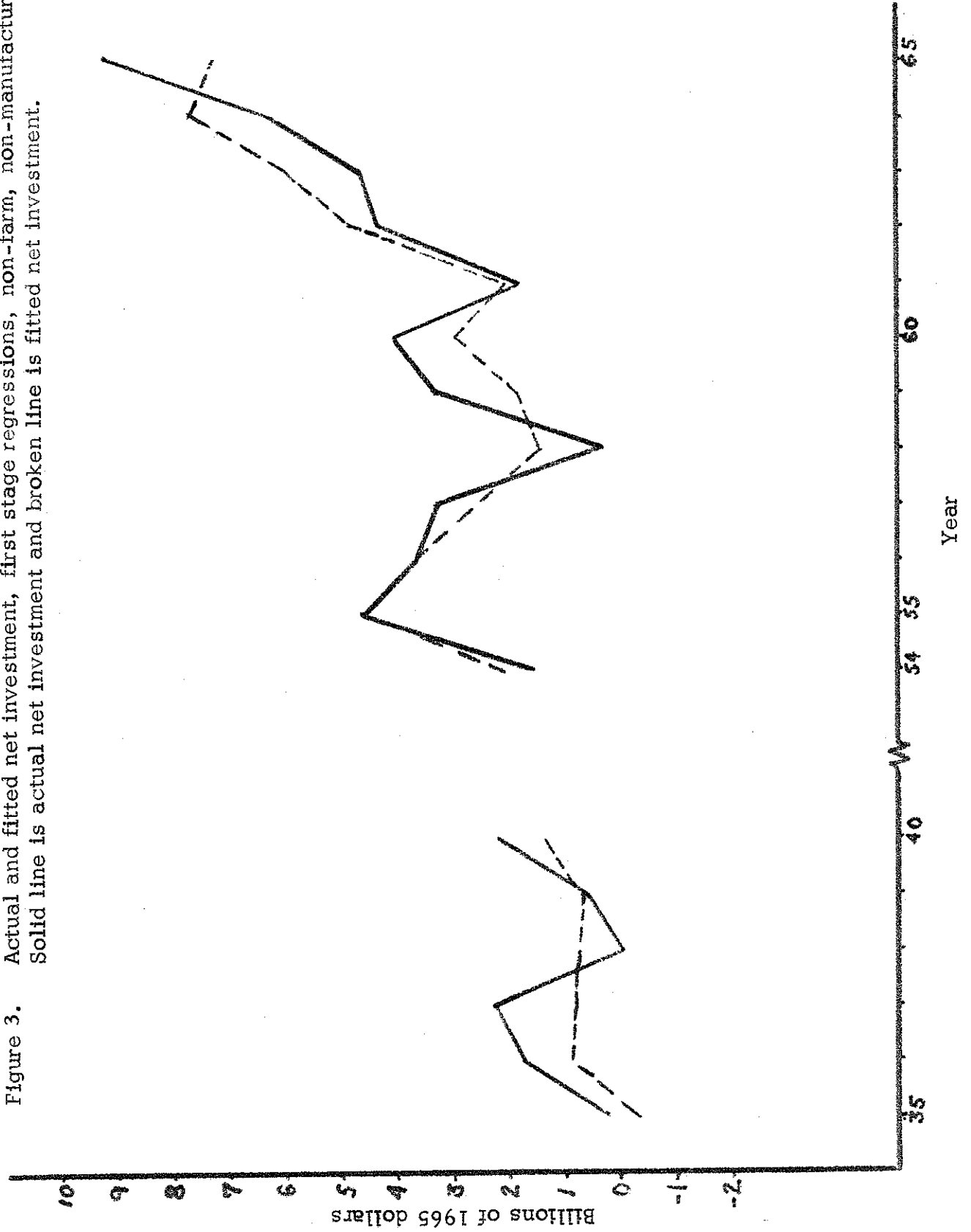




Figure 4. Actual and fitted net investment, first stage regressions, non-farm, non-manufacturing structures. Solid line is actual net investment and broken line is fitted net investment.

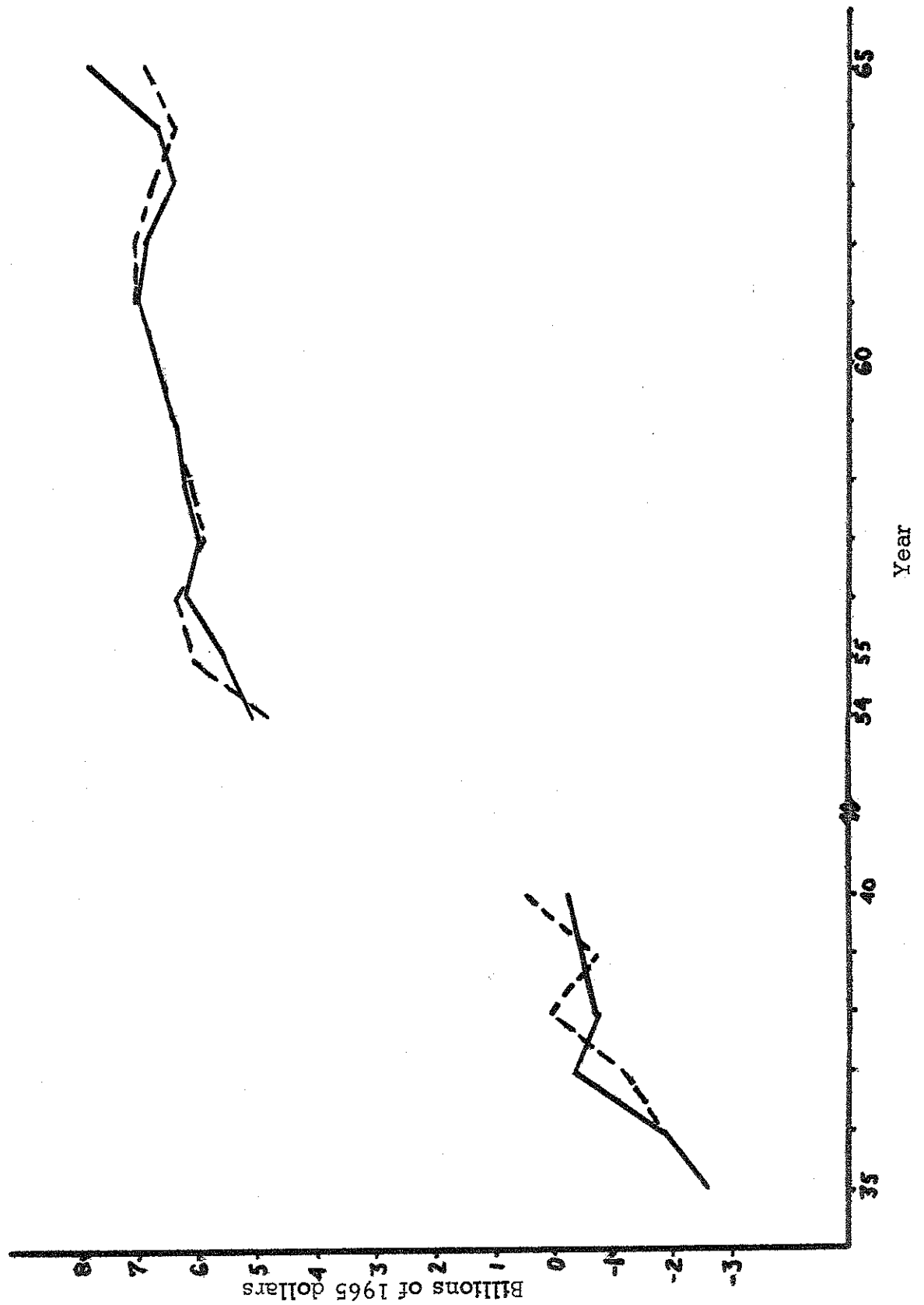


Table 2. Fitted Investment Functions, 1935-40 and 1954-65, Second Stage Results.

| Asset Class                         | $\hat{\alpha}\beta_0$ | $\hat{\alpha}\beta_1$ | $\hat{\alpha}\beta_2$ | $\hat{\alpha}\beta_3$ | $\hat{\alpha}\beta_4$ | $R^2$ | s     | d     |
|-------------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-------|-------|-------|
| Mfg.<br>Equipment                   | .0130<br>(.0047)      | .0200<br>(.0034)      | .0208<br>(.0040)      | .0153<br>(.0040)      | .0036<br>(.0053)      | .602  | .620  | 2.099 |
| Mfg.<br>Structures                  | .0041<br>(.0033)      | .0082<br>(.0030)      | .0093<br>(.0035)      | .0073<br>(.0032)      | .0024<br>(.0034)      | .186  | .513  | 1.304 |
| Non-farm,<br>Non-mfg.<br>Equipment  | .0374<br>(.0083)      | .0282<br>(.0038)      | .0211<br>(.0063)      | .0160<br>(.0047)      | .0129<br>(.0090)      | .800  | 1.190 | 1.724 |
| Non-farm,<br>Non-mfg.<br>Structures | .0059<br>(.0034)      | .0105<br>(.0032)      | .0118<br>(.0035)      | .0098<br>(.0031)      | .0046<br>(.0029)      | .169  | .506  | 1.825 |

are also given in Table 2. It should be noted that  $R^2$  for these regressions is a measure of the degree of explanation of the autoregressively transformed values of net investment. The only measure of goodness of fit comparable to those in Table 1 is the standard error of estimate  $s$ . This standard error is uniformly lower for all regressions, reflecting the fact that loss in explanatory power due to reduction in the number of parameters to be estimated is more than compensated by the reduction in the number of degrees of freedom required for estimation. Actual and fitted values of net investment from the second stage regressions are plotted in Figures 5 to 8. The actual values in these plots are net investment, not the transformed net investment series which served as the left-hand variable in the second stage. The fitted values were calculated by substituting the parameter estimates from the second stage into the first stage regression equation. It would not be meaningful to plot the actual and fitted values directly from the second stage because of the autoregressive transformation.

We have generated the distributed lag function for our econometric model of investment behavior by using two restrictions: (1) the distributed lag is finite (i. e., the error is autoregressive); and (2) the coefficients of the polynomial  $\beta(S)$  lie along a second-degree polynomial in the lag itself. To test the validity of these restrictions we employ the statistic derived above, based on sums of squared residuals with and without constraints. The resulting test statistic  $F$  is presented in the first column of Table 3. Comparing the very low values of

Table 3. Fitted Investment Functions, 1935-40 and 1954-65,  
Derived Results.

| Asset Class                               | $F_1$ | $F_2$   | Mean Lag<br>(years) | $\hat{\alpha}$ |
|---|-------|---------|---------------------|----------------|
| Manufacturing Equipment                   | .577  | 3.912   | 1.67                | .0727          |
| Manufacturing Structures                  | .138  | 4.764   | 1.86                | .0312          |
| Non-farm, Non-manufacturing<br>Equipment  | .623  | .004    | 1.47                | .1160          |
| Non-farm, Non-manufacturing<br>Structures | .655  | 156.681 | 1.92                | .0426          |

$F_1$ : F-statistic for the null hypothesis that the distributed lag is finite and has a parabolic shape. The critical value of F with 3 and 11 degrees of freedom is 3.59 at the .05 level.

$F_2$ : F-statistic for the null hypothesis that there is no autocorrelation. The critical value of F with 1 and 14 degrees of freedom is 4.60 at the .05 level.

$\hat{\alpha}$ : Estimate of the elasticity of output with respect to the capital input.

Figure 5. Actual and fitted net investment, second stage regressions, manufacturing equipment. Solid line is actual net investment and broken line is fitted net investment.

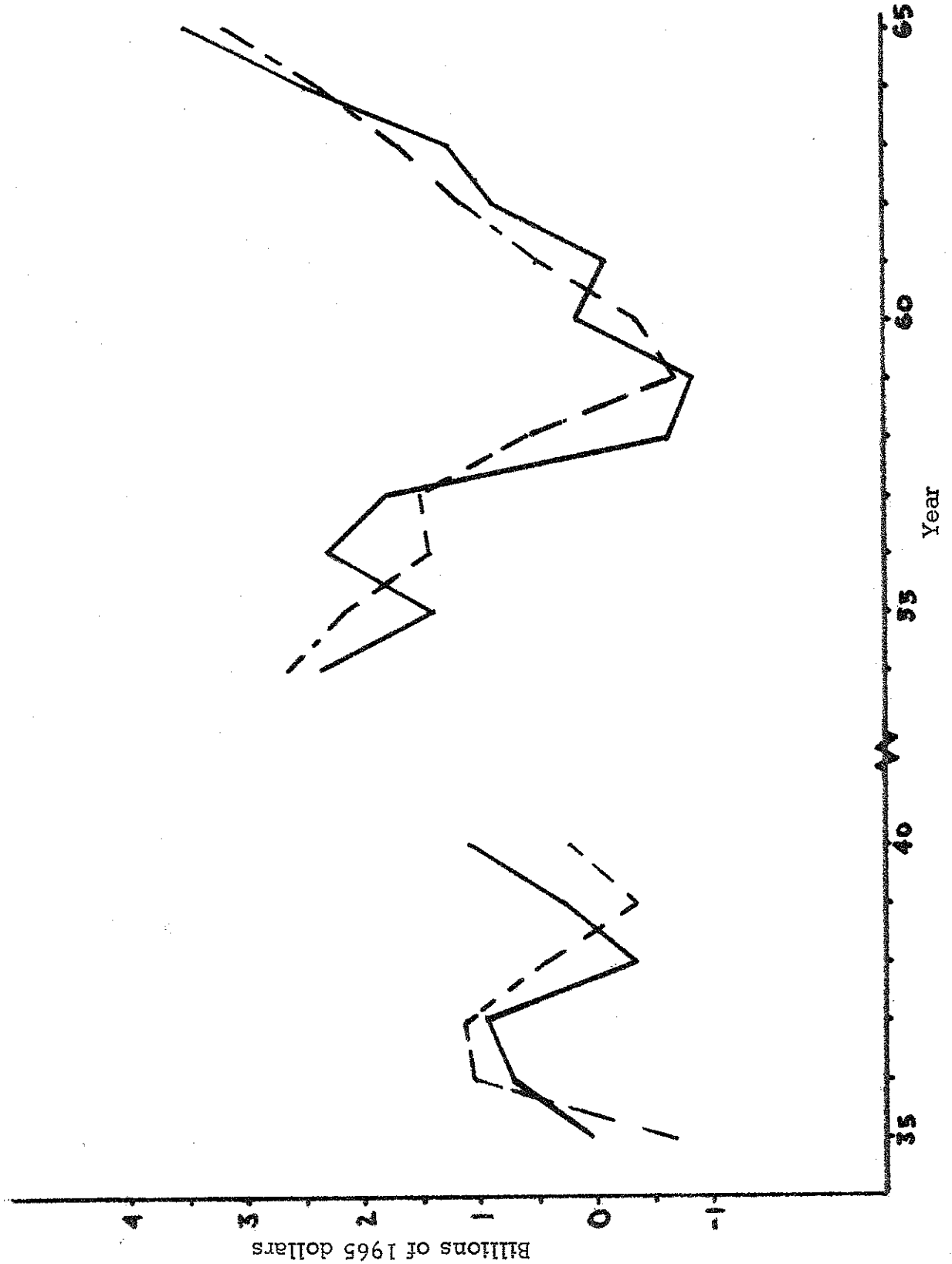


Figure 6. Actual and fitted net investment, second stage regressions, manufacturing structures.  
Solid line is actual net investment and broken line is fitted net investment.

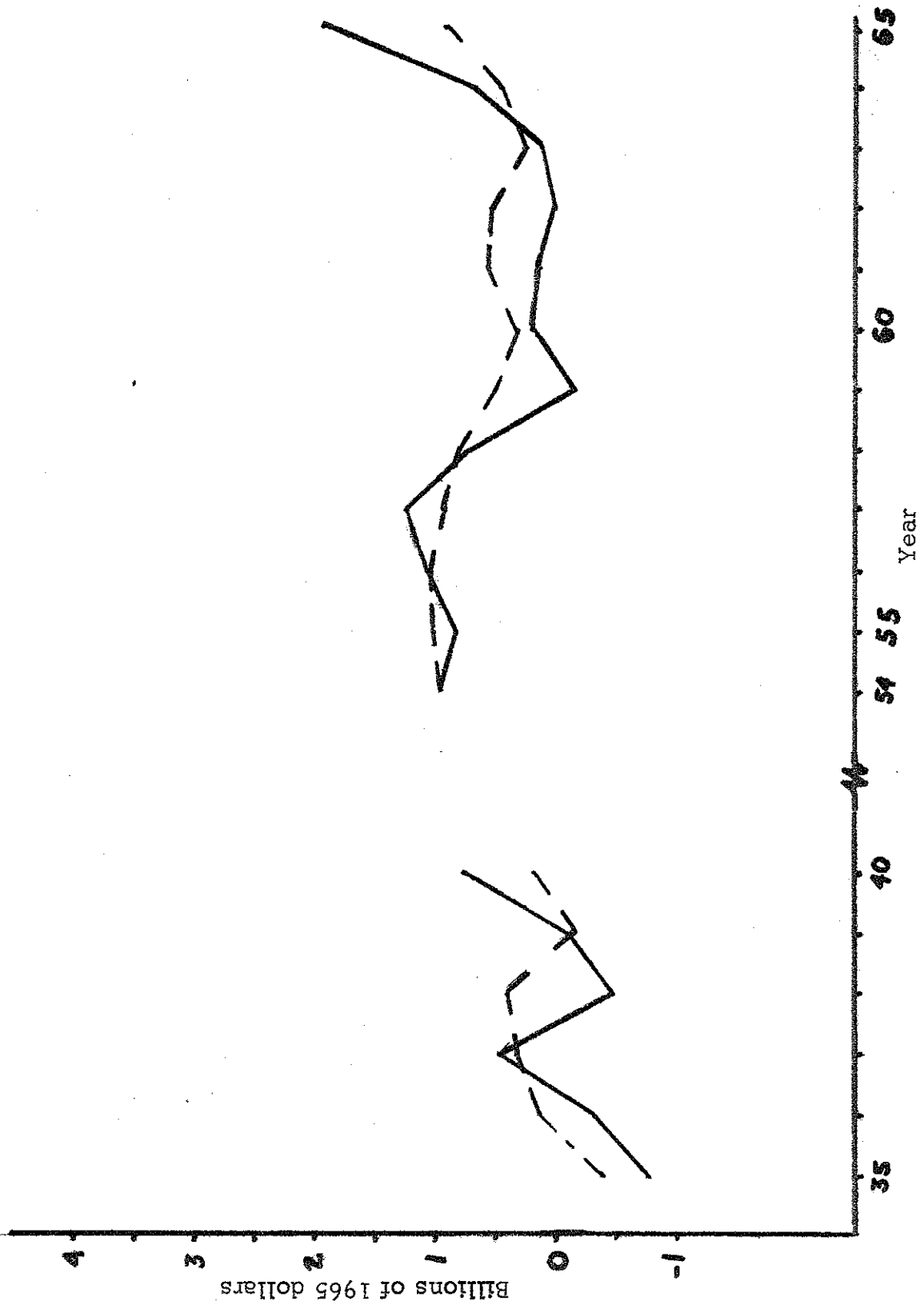


Figure 7. Actual and fitted net investment, second stage regressions, non-farm, non-manufacturing equipment. Solid line is actual net investment and broken line is fitted net investment.

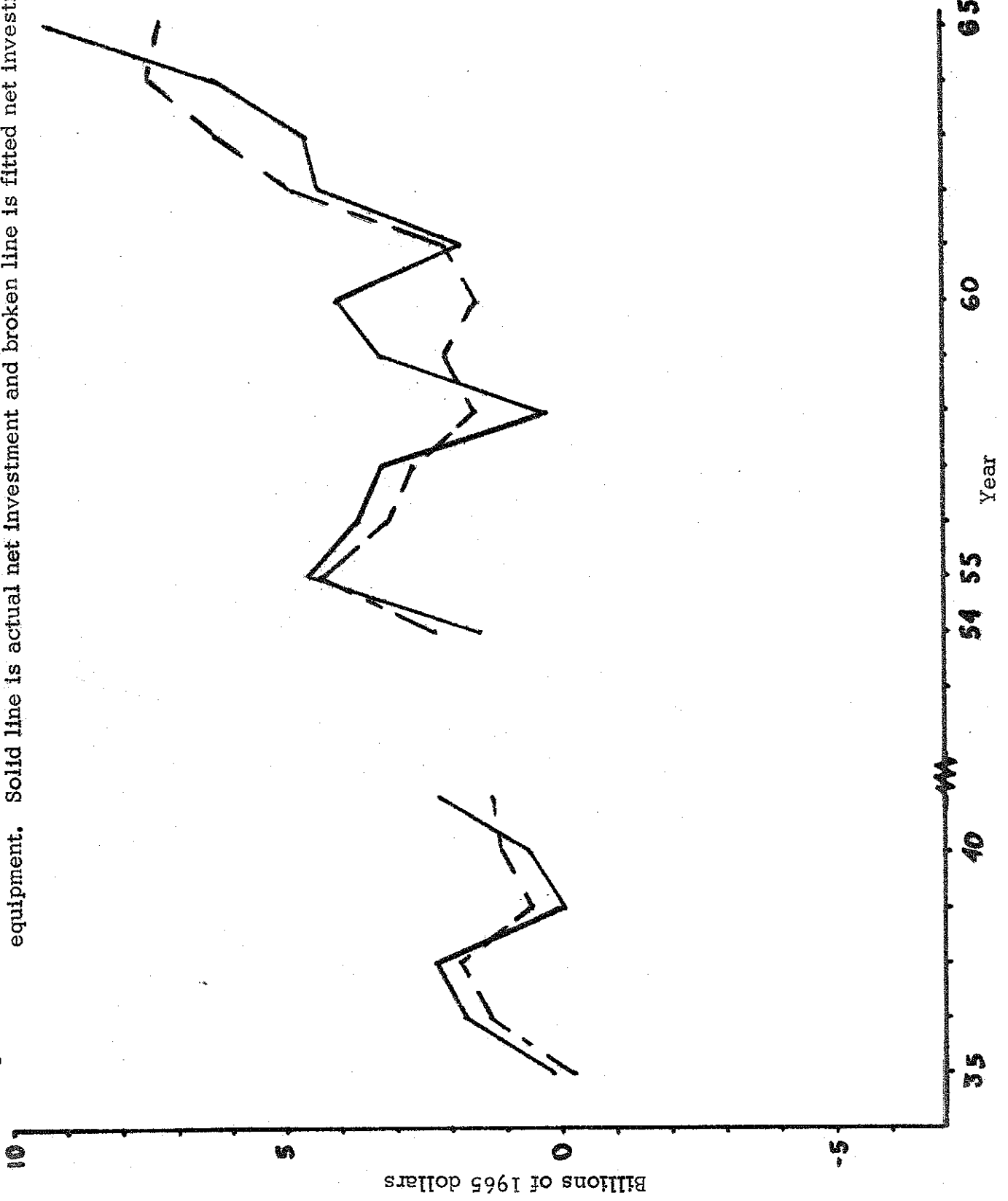
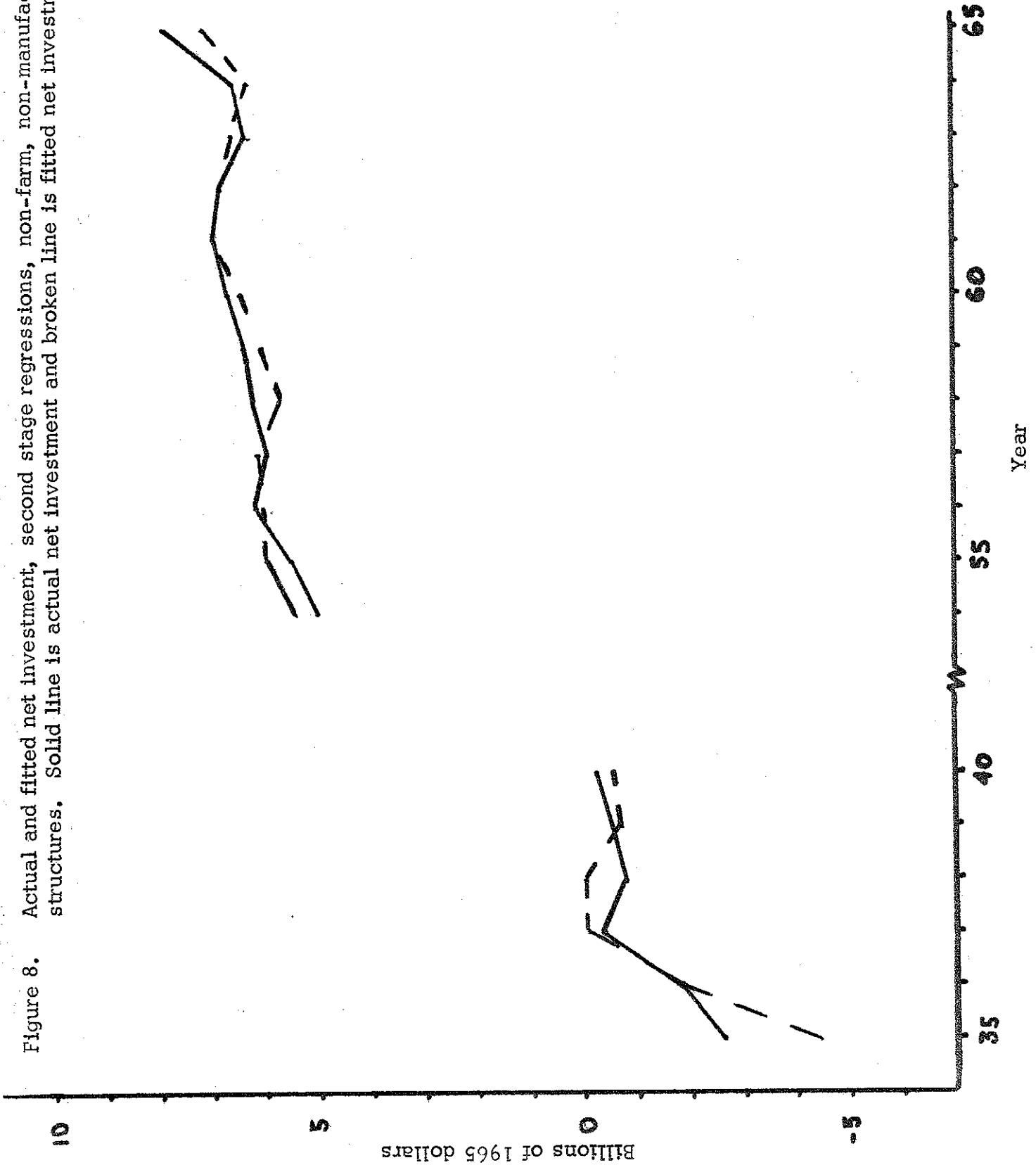


Figure 8. Actual and fitted net investment, second stage regressions, non-farm, non-manufacturing structures. Solid line is actual net investment and broken line is fitted net investment.





this statistic with the critical value of the F-ratio at the .05 level, 3.59, we find that the null hypothesis is easily accepted for all regressions.

We conclude that the distributed lag is finite and that the coefficients of  $\beta(S)$  lie along a second-degree polynomial. Accordingly, we employ the second stage regressions for further analysis of the distributed lag function.

We also present in column 2 of Table 3 the results of testing the null hypothesis of no autocorrelation in the finite parabolic distributed lag model. The F-statistic for this test is

$$F = 14 \frac{e_0' e_0 - e_1' e_1}{e_1' e_1},$$

where 14 is the number of degrees of freedom in the unconstrained regression,  $e_1' e_1$  is the sum of squared residuals in that regression, and  $e_0' e_0$  is the sum of squared residuals in the constrained regression. The unconstrained regressions are those reported in Table 2. The constrained regressions are of precisely the same form as those in Table 2 except that the variables have not been subjected to the autoregressive transformation. As can be seen, there is evidence of autocorrelation in all sectors except non-manufacturing equipment. The null hypothesis is rejected in both structures equations. These results are exactly in accord with the regression results for the first stage regressions reported in Table 1. The very high autocorrelation in the non-manufacturing structures equation suggests the possibility of specification error.

The parameters of the distributed lag function  $\{\mu_{\tau}\}$  may be estimated by employing the constraint that the sum of the coefficients of this function must be unity to estimate the parameter  $\alpha$ .<sup>28</sup> The resulting estimates are given in Table 3. The derived estimates of the parameters of the distributed lag function are plotted in Figures 9-12. The mean lag for each function is also given in Table 3. Comparing these mean lags with estimates from our earlier studies we find that the new estimates are very similar for investment in equipment. The mean lag is now estimated to be slightly lower for manufacturing equipment and slightly higher for non-farm, non-manufacturing equipment. For structures the new estimates differ substantially from the old. The old estimate of the mean lag for manufacturing structures was 3.84 years whereas the new estimate is 1.86; the old estimate of the mean lag for non-farm, non-manufacturing structures was 7.49 years whereas the new estimate is 1.92. For both sets of results the lags for structures are estimated to be longer than for equipment.

A disturbing feature of our earlier results is that the lag pattern fails to agree with the substantial body of evidence from studies at the level of two-digit industries by Jorgenson and Stephenson [27] and studies at the level of the individual firm by Jorgenson and Siebert [26]. For manufacturing Jorgenson and Stephenson estimate the average lag at about two years while results from individual industries range from six to eleven quarters with results clustering in the neighborhood of the overall average. The results for individual firms are characterized by more variability than the results for industries, as would be expected. The average lags

Figure 9. Estimated lag function,  $\beta_T$ , for manufacturing equipment.

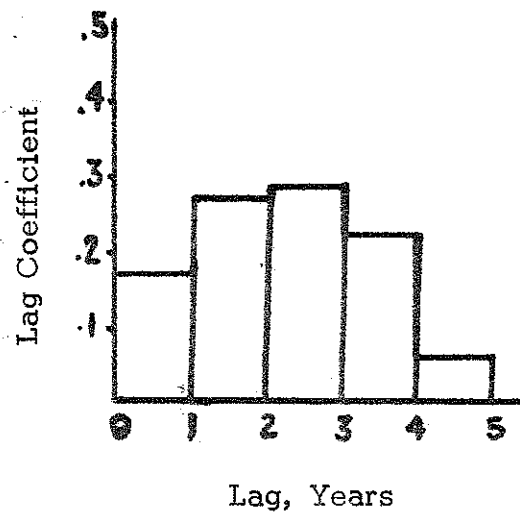


Figure 10. Estimated lag function,  $\beta_T$ , for manufacturing structures.

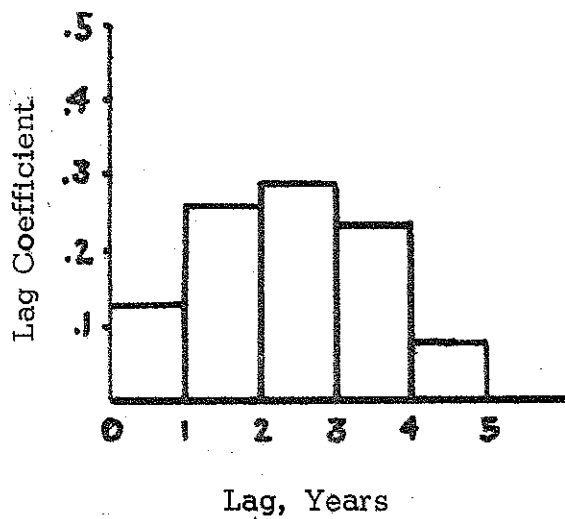


Figure 11. Estimated lag function,  $\beta_T$ , for non-farm, non-manufacturing equipment.

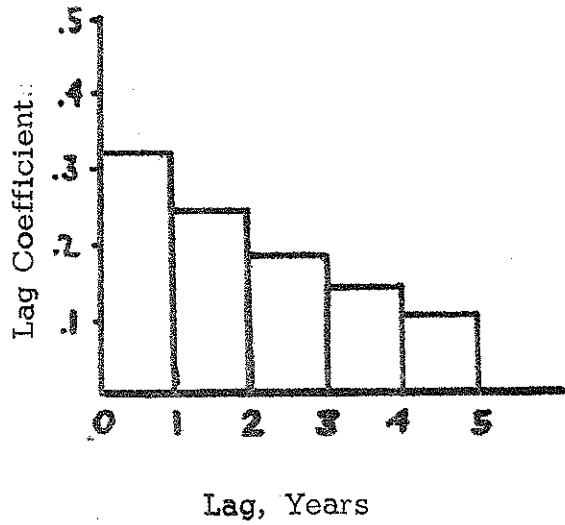
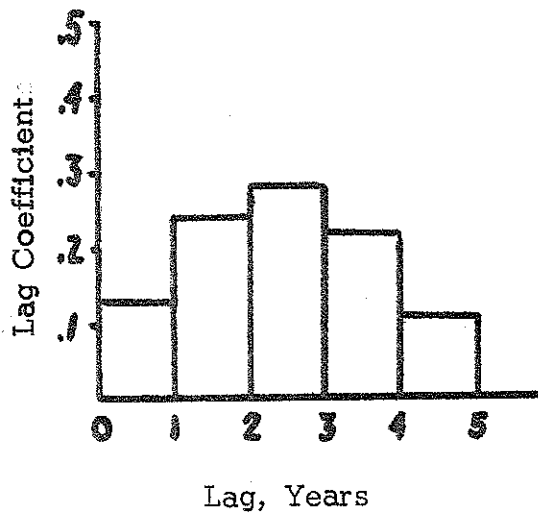


Figure 12. Estimated lag function,  $\beta_T$ , for non-farm, non-manufacturing structures.



estimated by Jorgenson and Siebert range from less than a year to over three years with values between one and two years predominating. Mayer's estimate of average lags from the decision to undertake investment to the completion of the project for manufacturing and electric power combined on the basis of surveys is seven quarters.<sup>29</sup> We conclude that our new estimates agree closely with Mayer's survey results and with estimates derived from investment functions for industry groups and for individual firms. Our previous estimates of the average lags for structures are evidently biased by specification errors in the underlying distributed lag functions and should be replaced by our new estimates.

5. The impact of tax policy on investment behavior.

The tax policies which we analyze affect investment behavior through the rental price of capital services. A change in tax policy produces a change in the rental price, resulting in a change in the desired level of capital stock. If desired capital stock is increased by the change in tax policy, additional net investment is generated; if the determinants of investment then remain at stationary levels, this net investment eventually brings actual capital stock up to the new desired level. The initial burst of net investment increases gross investment at first, but this effect gradually declines to zero as the gap between desired and actual capital stock is eliminated. However, gross investment is permanently increased by the higher levels of replacement associated with higher levels of capital stock. If desired capital stock is decreased by tax policy, all of these effects work in precisely the opposite direction.

The qualitative features of the response of investment to a change in tax policy are essentially the same for all changes. To evaluate the effects of particular tax measures it is useful to assess the response of investment quantitatively. Accordingly, we calculate the effects of changes in tax policy that have taken place in the United States in the post-war period. Our calculations are based on a partial equilibrium analysis of investment behavior. We hold all determinants of investment expenditures except for tax policy equal to their actual values. We then measure the impact of tax policy by substituting into our investment functions parameters of the tax structure--tax rate, depreciation formulas,

tax credit, and depreciation lifetimes--appropriate to alternative tax policies. The difference between investment resulting from actual tax policy and investment that would have resulted from alternative tax policies is our measure of the impact of tax policy.

We present estimates of the impact of the adoption of accelerated depreciation in 1954, the adoption of new lifetimes for depreciation of equipment and the investment tax credit in 1962, the tax cut of 1964, and the effects of suspension of the tax credit for equipment and accelerated depreciation for structures in 1966-7. The tax cut of 1964 involved a reduction in the corporate tax rate from 52 percent to 48 percent and a change in the treatment of the investment tax credit. Before 1964 the tax credit was deducted from the depreciation base for tax purposes; after 1964 no deduction was made. In our earlier studies we presented calculations of the effects of all these changes in tax policy. In view of the substantial revisions in the underlying investment data and the alterations in our specification of the investment functions, we provide a complete set of estimates based on our new results.

In our new calculations both investment and capital stock are measured in prices of 1965. We estimate the impact of all changes in tax policy through 1970. In order to make these estimates, we employed a rough set of projections of the determinants of investment. No great precision was required in these projections, since the estimates of the differential impacts of alternative policies are not at all sensitive to the assumed level of investment. The projected levels of gross value added

and the price deflators for investment goods were the following:<sup>30</sup>

|  | 1966  | 1967  | 1968  | 1969  | 1970  |
|--|-------|-------|-------|-------|-------|
| Gross value<br>added,<br>manufacturing                                 | 198.4 | 209.1 | 221.6 | 234.9 | 249.0 |
| Gross value<br>added, non-farm,<br>non-manufacturing                   | 363.6 | 383.2 | 406.2 | 430.6 | 456.4 |
| Equipment deflator,<br>manufacturing,<br>1965 = 1.000                  | 1.031 | 1.068 | 1.103 | 1.142 | 1.183 |
| Equipment deflator,<br>non-farm,<br>non-manufacturing,<br>1965 = 1.000 | 1.031 | 1.068 | 1.095 | 1.121 | 1.150 |
| Structures<br>deflator, both<br>sectors, 1965 = 1.000                  | 1.043 | 1.079 | 1.100 | 1.121 | 1.144 |

Although these are current dollar figures and are likely to be serious underestimates because of the relatively rapid rate of inflation which has developed recently, this will not affect our results, since only the ratio of gross value added and the investment deflator enters our calculations. Finally, all tax variables were assumed to stay at their 1965 values, except for the brief suspension of the investment tax credit and accelerated depreciation in 1966-1967; the treatment of this suspension is described in detail below.

As a basis for comparison with alternative tax policies we present in Table 4 data on the actual levels of net investment, gross investment, and capital stock, for 1950 to 1965. Also included are extrapolated values calculated from the fitted investment functions for 1966 to 1970 for plant and



Table 4. Data on Gross Investment (I), Net Investment (N), and Capital Stock (K), Actual Levels of 1950-1965 and Calculated Levels for 1966-1970 (Billions of 1965 Dollars)

| Year | Manufacturing |            |               | Non-Farm, Non-Manufacturing |            |               |        |       |         |        |       |         |
|------|---------------|------------|---------------|-----------------------------|------------|---------------|--------|-------|---------|--------|-------|---------|
|      | Equipment     | Structures | Capital Stock | Equipment                   | Structures | Capital Stock |        |       |         |        |       |         |
|      | I             | N          | K             | I                           | N          | K             |        |       |         |        |       |         |
| 1954 | 8.544         | 2.351      | 42.100        | 3.276                       | .960       | 37.051        | 14.327 | 1.472 | 66.849  | 11.345 | 5.001 | 91.407  |
| 1955 | 7.927         | 1.388      | 44.451        | 3.222                       | .846       | 38.011        | 17.699 | 4.561 | 68.321  | 12.195 | 5.504 | 96.408  |
| 1956 | 9.034         | 2.291      | 45.840        | 3.526                       | 1.097      | 38.858        | 17.714 | 3.699 | 72.882  | 13.264 | 6.191 | 101.912 |
| 1957 | 8.875         | 1.795      | 48.131        | 3.751                       | 1.254      | 39.955        | 17.973 | 3.246 | 76.581  | 13.445 | 5.943 | 108.104 |
| 1958 | 6.726         | .618       | 49.926        | 3.321                       | .745       | 41.209        | 15.595 | .244  | 79.827  | 14.125 | 6.210 | 114.046 |
| 1959 | 6.423         | .830       | 49.308        | 2.490                       | -.132      | 41.954        | 18.671 | 3.273 | 80.072  | 14.740 | 6.394 | 120.256 |
| 1960 | 7.299         | .168       | 48.477        | 2.821                       | .207       | 41.822        | 20.090 | 4.063 | 83.345  | 15.459 | 6.669 | 126.651 |
| 1961 | 7.067         | -.089      | 48.645        | 2.786                       | .159       | 42.029        | 18.617 | 1.809 | 87.408  | 16.190 | 6.936 | 133.320 |
| 1962 | 8.040         | .897       | 48.557        | 2.681                       | .044       | 42.188        | 21.475 | 4.319 | 89.216  | 16.563 | 6.829 | 140.258 |
| 1963 | 8.550         | 1.275      | 49.454        | 2.836                       | .196       | 42.233        | 22.641 | 4.654 | 93.535  | 16.582 | 6.374 | 147.087 |
| 1964 | 9.941         | 2.479      | 50.729        | 3.353                       | .701       | 42.429        | 25.175 | 6.293 | 98.189  | 17.251 | 6.601 | 153.461 |
| 1965 | 11.333        | 3.506      | 53.208        | 4.659                       | 1.963      | 43.130        | 29.323 | 9.231 | 104.482 | 18.977 | 7.869 | 160.061 |
| 1966 | 11.434        | 3.092      | 56.714        | 4.462                       | 1.644      | 45.093        | 28.337 | 6.470 | 113.713 | 19.557 | 7.903 | 167.930 |
| 1967 | 11.259        | 2.462      | 59.806        | 4.306                       | 1.385      | 46.737        | 28.149 | 5.038 | 120.183 | 20.127 | 7.924 | 175.833 |
| 1968 | 11.138        | 1.978      | 62.268        | 4.216                       | 1.208      | 48.122        | 29.198 | 5.118 | 125.221 | 20.841 | 8.088 | 183.757 |
| 1969 | 11.044        | 1.593      | 64.246        | 4.165                       | 1.082      | 49.330        | 29.598 | 4.534 | 130.339 | 21.610 | 8.296 | 191.845 |
| 1970 | 11.104        | 1.419      | 65.839        | 4.222                       | 1.071      | 50.412        | 30.243 | 4.307 | 134.873 | 22.446 | 8.556 | 200.141 |

equipment and for manufacturing and non-farm, non-manufacturing sectors.

The first change in tax policy we attempt to evaluate is the adoption of accelerated methods of depreciation for tax purposes in 1954. As an alternative policy we suppose that only the straight-line formula was permitted from 1954-70 with all other determinants of investment unchanged. The reductions in the rental price of capital services brought about in 1955 (the first full year) through the adoption of accelerated methods of depreciation were:

|   | Without<br>accelerated<br>depreciation | With<br>accelerated<br>depreciation |
|---|--|-------------------------------------|
| Manufacturing Equipment                   | .293                                   | .267                                |
| Manufacturing Structures                  | .229                                   | .208                                |
| Non-Farm, Non-Manufacturing<br>Equipment  | .375                                   | .341                                |
| Non-Farm, Non-Manufacturing<br>Structures | .239                                   | .217                                |

Estimates of the increase in net investment, gross investment, and capital stock resulting from the adoption of accelerated depreciation in 1954 are given in Table 5.

The effects of the adoption of accelerated depreciation are very substantial. Although the same pattern prevails in all four classes of assets, it is useful to trace out the quantitative impact of tax policy on net investment, gross investment and capital stock, for each class. The peak effect on net investment for manufacturing equipment is attained in

Table 5. Change in Gross Investment (I), Net Investment (N), and Capital Stock (K), Resulting from Accelerated Depreciation, 1954-1970 (Billions of 1965 Dollars)

| Year | Manufacturing |       |            |      |           |       | Non-Farm, Non-Manufacturing |       |            |        |            |       |       |
|------|---------------|-------|------------|------|-----------|-------|-----------------------------|-------|------------|--------|------------|-------|-------|
|      | Equipment     |       | Structures |      | Equipment |       | Equipment                   |       | Structures |        | Structures |       |       |
|      | I             | N     | K          | I    | N         | K     | I                           | N     | K          | I      | N          | K     |       |
| 1954 | .209          | .209  | 0          | .079 | .079      | 0     | .847                        | .847  | .847       | 0      | .204       | .204  | 0     |
| 1955 | .627          | .596  | .209       | .280 | .275      | .079  | 1.871                       | 1.708 | 1.708      | .847   | .649       | .635  | .204  |
| 1956 | .862          | .744  | .805       | .432 | .410      | .354  | 1.756                       | 1.265 | 1.265      | 2.555  | .944       | .886  | .839  |
| 1957 | .878          | .650  | 1.549      | .450 | .402      | .764  | 1.723                       | .988  | .988       | 3.820  | 1.023      | .903  | 1.725 |
| 1958 | .621          | .298  | 2.199      | .323 | .250      | 1.166 | 1.662                       | .737  | .737       | 4.808  | .867       | .684  | 2.628 |
| 1959 | .395          | .027  | 2.497      | .181 | .092      | 1.416 | 1.519                       | .453  | .453       | 5.545  | .584       | .354  | 3.312 |
| 1960 | .369          | -.002 | 2.524      | .153 | .059      | 1.508 | 1.294                       | .141  | .141       | 5.998  | .448       | .194  | 3.666 |
| 1961 | .406          | .035  | 2.522      | .169 | .071      | 1.567 | 1.386                       | .205  | .205       | 6.139  | .478       | .214  | 3.810 |
| 1962 | .487          | .111  | 2.557      | .180 | .078      | 1.638 | 1.573                       | .353  | .353       | 6.344  | .430       | .201  | 4.024 |
| 1963 | .545          | .152  | 2.668      | .172 | .065      | 1.706 | 1.779                       | .491  | .491       | 6.697  | .473       | .178  | 4.225 |
| 1964 | .660          | .245  | 2.820      | .165 | .053      | 1.771 | 2.090                       | .708  | .708       | 7.188  | .440       | .134  | 4.403 |
| 1965 | .733          | .282  | 3.065      | .159 | .045      | 1.824 | 2.049                       | .531  | .531       | 7.896  | .384       | .070  | 4.537 |
| 1966 | .727          | .235  | 3.347      | .093 | -.024     | 1.869 | 2.067                       | .446  | .446       | 8.427  | .206       | -.114 | 4.607 |
| 1967 | .696          | .170  | 3.582      | .041 | -.074     | 1.845 | 2.068                       | .362  | .362       | 8.873  | .113       | -.205 | 4.593 |
| 1968 | .682          | .131  | 3.752      | .097 | -.014     | 1.771 | 2.213                       | .437  | .437       | 9.235  | .258       | -.046 | 4.388 |
| 1969 | .702          | .131  | 3.883      | .193 | .083      | 1.757 | 2.214                       | .354  | .354       | 9.672  | .471       | .169  | 4.342 |
| 1970 | .728          | .138  | 4.014      | .287 | .172      | 1.840 | 2.309                       | .377  | .377       | 10.049 | .675       | .362  | 4.511 |

1956 with a level of \$.744 billion (constant dollars of 1965) or 32 percent of net investment in that year. By 1959 the effect is essentially nil; however, the adoption of new equipment lifetimes for tax purposes and the investment tax credit in 1962 provide an additional stimulus from the use of accelerated methods of depreciation. We estimate that over the period from 1954-70 17.5 percent of the net investment in manufacturing equipment may be attributed to the change in methods for calculating depreciation. Similarly, the peak effect for non-farm, non-manufacturing equipment is \$1.708 billion in 1955 or 37.4 percent of the net investment that took place in that year. Over the period from 1954 to 1970 15.4 percent of the net investment in non-farm, non-manufacturing equipment may be attributed to the change in depreciation rules in 1954.

Although the average lag in response is longer for investment in structures than for investment in equipment the effects of accelerated depreciation are broadly similar. For manufacturing structures the peak effect on net investment occurs in 1956 with \$.410 billion or 37.3 percent of the net investment that took place in that year. For the 1954-70 period the increase in net investment in manufacturing structures due to accelerated depreciation is estimated at 15.0 percent of net investment. For non-farm, non-manufacturing structures the peak effect on investment occurs in 1957 with \$.903 billion or 15.2 percent of the net investment that took place in that year. Over the whole period we estimate that 4.5 percent of the net investment in non-farm, non-manufacturing structures may be attributed to the adoption of accelerated methods for depreciation in 1954.

Capital stock is a cumulation of net investment so that its behavior is implied by that for net investment. For both manufacturing and non-farm, non-manufacturing equipment two phases in the response of capital stock can be distinguished. First, the immediate impact of adoption of accelerated depreciation was to raise desired capital substantially above its actual level. By 1959 the gap resulting from accelerated depreciation was eliminated. More than half the increase over the period 1954-9 had occurred by 1957. Second, adoption of accelerated depreciation in 1954 resulted in additional stimulus from subsequent changes in lifetimes for tax purposes and from adoption of the investment tax credit. Half the total rise in the stock of manufacturing equipment from 1954 to 1970 took place by 1958 while half the rise in non-farm, non-manufacturing equipment took place by 1959. The patterns of development for structures in both manufacturing and non-farm, non-manufacturing sectors is qualitatively similar but without a clear demarcation between successive phases. Half the total rise in the stock of manufacturing structures over the period as a whole took place by 1958 while half the rise in non-farm, non-manufacturing structures took place by 1959.

Gross investment is the sum of net investment and replacement; further, replacement rises in proportion to capital stock. By 1958 replacement had become the dominant component in the response of gross investment in equipment to the adoption of accelerated depreciation for both manufacturing and non-farm, non-manufacturing sectors. For manufacturing the peak response of gross investment occurs in 1957 with a change of

\$.878 billion. By 1970 added replacement requirements will have maintained gross investment at near peak levels at \$.728 billion. Similarly, in 1970 gross investment in non-farm, non-manufacturing equipment reached a peak of \$1.871 billion, declined for several years, and now will rise to a new peak of \$2.309 billion by 1970, propelled by rising replacement requirements. For manufacturing structures the peak level of \$.450 billion was attained in 1957; by 1970 the level is estimated to be \$.287 billion. The general pattern of response for investment in non-farm, non-manufacturing structures is similar in time pattern but different in magnitude. The peak level of response of gross investment was \$1.023 billion in 1957; the level in 1970 is estimated to be \$.675 billion.

The total effect of the adoption of accelerated depreciation in 1954 on gross investment during the whole period from 1954 to 1970 may be assessed by comparing investment resulting from the new methods of depreciation with investment that would have to take place under the old methods. For equipment 6.7 percent of gross investment in manufacturing and 8.0 percent of the gross investment in non-farm, non-manufacturing may be attributed to accelerated depreciation over the period from 1954 to 1970. For structures the percentages are 5.7 for manufacturing and 3.0 for non-farm, non-manufacturing. By 1970 we estimate that 7.3 percent of gross investment in manufacturing equipment will be due to the adoption of accelerated depreciation in 1954; similarly, 7.7 percent of gross investment in non-farm, non-manufacturing equipment in 1970 will result from accelerated depreciation. The corresponding percentages for structures

are 6.8 for manufacturing and 3.0 for non-farm, non-manufacturing.

The adoption of new guidelines for the determination of lifetimes allowable for tax purposes in 1962 [48] affected only lifetimes allowable for investment in equipment. The reductions in the rental price of capital services brought about through the adoption of the 1962 depreciation guidelines were:

|  | Without<br>Guidelines | With<br>Guidelines |
|--|-----------------------|--------------------|
| Manufacturing Equipment                  | .315                  | .307               |
| Non-Farm, Non-Manufacturing<br>Equipment | .384                  | .374               |

Estimates of the increase in net investment, gross investment, and capital stock in equipment resulting from adoption of the new guidelines are given in Table 6.

A second change in tax policy during 1962 was the adoption of an investment tax credit of 7 percent for equipment in the Revenue Act of 1962. As we have already indicated, various limitations on the applicability of the tax credit reduce the effective rate to 6 percent for manufacturing and 5.8 percent for non-farm, non-manufacturing sectors. Under the Long Amendment the depreciation base was reduced by the amount of the investment tax credit for 1962 and 1963. This Amendment was repealed in 1964 so that the depreciation base is unaffected by the tax credit for 1964 and subsequent years. Reductions in the rental price of

Table 6. Change in Gross Investment, Net Investment, and Capital Stock Resulting From 1962 Guidelines and From the Investment Tax Credit, 1962-1970 (Billions of 1965 Dollars)

| Year | Depreciation Guidelines |      |       |                                       |      |       | Investment Tax Credit   |      |       |                                       |       |       |
|------|-------------------------|------|-------|---------------------------------------|------|-------|-------------------------|------|-------|---------------------------------------|-------|-------|
|      | Manufacturing Equipment |      |       | Non-Farm, Non-Manufacturing Equipment |      |       | Manufacturing Equipment |      |       | Non-Farm, Non-Manufacturing Equipment |       |       |
|      | I                       | N    | K     | I                                     | N    | K     | I                       | N    | K     | I                                     | N     | K     |
| 1962 | .165                    | .165 | 0     | 0.743                                 | .743 | 0     | .185                    | .185 | 0     | .804                                  | .804  | 0     |
| 1963 | .292                    | .268 | .165  | 0.770                                 | .627 | .743  | .527                    | .500 | .185  | 1.711                                 | 1.556 | .804  |
| 1964 | .375                    | .311 | .433  | 0.845                                 | .582 | 1.370 | .992                    | .891 | .685  | 2.773                                 | 2.319 | 2.360 |
| 1965 | .369                    | .260 | .744  | 0.816                                 | .441 | 1.952 | 1.229                   | .997 | 1.576 | 2.726                                 | 1.826 | 4.679 |
| 1966 | .260                    | .112 | 1.004 | 0.828                                 | .368 | 2.393 | 1.015                   | .637 | 2.573 | 2.069                                 | .818  | 6.505 |
| 1967 | .215                    | .051 | 1.116 | 0.641                                 | .110 | 2.761 | .724                    | .252 | 3.210 | 2.017                                 | .609  | 7.323 |
| 1968 | .211                    | .039 | 1.167 | 0.687                                 | .135 | 2.871 | .635                    | .126 | 3.462 | 2.516                                 | .991  | 7.932 |
| 1969 | .218                    | .041 | 1.206 | 0.687                                 | .109 | 3.006 | .723                    | .195 | 3.588 | 2.283                                 | .567  | 8.923 |
| 1970 | .226                    | .043 | 1.247 | 0.716                                 | .117 | 3.115 | .884                    | .328 | 3.783 | 2.330                                 | .505  | 9.490 |



capital services for 1963 brought about by adoption of the tax credit were:

|  | Without<br>Credit | With<br>Credit |
|--|-------------------|----------------|
| Manufacturing Equipment                  | .316              | .297           |
| Non-Farm, Non-Manufacturing<br>Equipment | .383              | .361           |

Estimates of the increase in net investment, gross investment, and capital stock in equipment resulting from the investment tax credit are given in Table 6. The impact of both of these policies is substantial, although the effect of the investment credit is several times larger than that of the depreciation guidelines. For the guidelines the peak response in manufacturing industries of net investment in equipment took place in 1964, when it accounted for 12.5 percent of total net investment. The peak response to the investment credit took place a year later in 1965; in that year the credit accounted for 28.4 percent of net investment in equipment in the manufacturing sector. In non-manufacturing industries, both peak responses took place earlier, reflecting the shorter lag in equipment investment in that sector. The respective percentages of net investment were 17.2 percent for the guidelines in 1962 and 36.8 percent for the investment credit in 1964.

The responses to the investment credit in both industries show a dip resulting from the suspension of the credit in 1966-1967; our calculations

are based on the assumption that if there had been no tax credit, it would not have been suspended during this period. Interestingly, a smaller dip appears in the estimated effect of the depreciation guidelines during the same period, especially in the non-manufacturing sector. This is explained by the fact that after the repeal of the Long Amendment, investment credit and depreciation policies acted to enhance each other's effect. Thus the depreciation guidelines had a smaller impact during the period of the suspension of the investment credit for equipment.

In 1964 two changes in tax policy affecting the level of investment expenditures took place. First, the corporate tax rate was cut from 52 percent to 48 percent. In analyzing the effect of the tax cut we assume that the before-tax rate of return was left unchanged. Under this condition the effect of a change in the tax rate on the rental price of capital services is neutral provided that depreciation for tax purposes is equal to economic depreciation.<sup>31</sup> Under the conditions actually prevailing in 1964 depreciation for tax purposes was in excess of economic depreciation for both plant and equipment in manufacturing and non-farm, non-manufacturing sectors. Accordingly, the rental price of capital services resulting from the tax cut was actually greater than the rental price before the cut. Following are the rental prices for 1965, the first full year of the tax cut:

|   | Without<br>Tax Cut | With<br>Tax Cut |
|---|--------------------|-----------------|
| Manufacturing Equipment                   | .296               | .299            |
| Manufacturing Structures                  | .237               | .240            |
| Non-Farm, Non-Manufacturing<br>Equipment  | .352               | .355            |
| Non-Farm, Non-Manufacturing<br>Structures | .247               | .250            |

Our estimates of the decrease in net investment, gross investment, and capital stock resulting from this change are given in Table 7. In general, the effects of the rate reduction are small and negative. It should be emphasized that these estimates are conditional on the level of output actually resulting from the tax cut; quite clearly the over-all effect of the tax cut was to stimulate investment by increasing output. A second, little-noticed change in tax policy in 1964 was the repeal of the Long Amendment; after repeal the tax credit was no longer deducted from the depreciation base for tax purposes. This change raises the effective rate of the tax credit to almost 10 percent as compared with approximately 6 percent under the Long Amendment. Reductions in the rental price of capital services for equipment in 1964 resulting from repeal of the Long Amendment are:

Table 7. Changes in Gross Investment (I), Net Investment (N), and Capital Stock (K) Resulting from the Tax Cut of 1964 (Billions of 1965 Dollars)

| Year | Manufacturing    |                   |                    | Non-Farm,<br>Non-Manufacturing |                   |                    |
|------|------------------|-------------------|--------------------|--------------------------------|-------------------|--------------------|
|      | Equipment<br>I N | Structures<br>I N | Capital Stock<br>K | Equipment<br>I N               | Structures<br>I N | Capital Stock<br>K |
| 1964 | -.049            | -.020             | 0                  | -.135                          | -.044             | 0                  |
| 1965 | -.136            | -.062             | -.049              | -.241                          | -.125             | -.135              |
| 1966 | -.181            | -.088             | -.178              | -.145                          | -.167             | -.376              |
| 1967 | -.186            | -.087             | -.333              | -.123                          | -.168             | -.521              |
| 1968 | -.155            | -.066             | -.470              | -.150                          | -.142             | -.644              |
| 1969 | -.120            | -.038             | -.556              | -.092                          | -.099             | -.794              |
| 1970 | -.119            | -.032             | -.594              | -.043                          | -.088             | -.886              |

|  | With<br>Long<br>Amendment | Without<br>Long<br>Amendment |
|--|---------------------------|------------------------------|
| Manufacturing Equipment                  | .302                      | .293                         |
| Non-Farm, Non-Manufacturing<br>Equipment | .363                      | .352                         |

Estimates of the increase in net investment, gross investment, and capital stock resulting from this change are given in Table 8.

These increases are quite substantial. The peak effect for manufacturing equipment took place in 1965 at which time the net investment in equipment attributable to the repeal was 10.4 percent of total net investment. In the non-farm, non-manufacturing sector, the peak effect in 1964 was over a billion dollars and accounted for 16.3 percent of net investment in equipment in that sector. Once again, a dip in the effect of this policy change can be seen in 1966-1967 and one or two years after, resulting from the suspension of the investment credit. The lag structure in the non-manufacturing sector makes the dip much more noticeable there than in the manufacturing sector.

In 1966 an important objective of economic policy was to restrain investment. After a number of alternative changes in tax policy were considered and rejected,<sup>32</sup> the investment tax credit for equipment was suspended beginning October 10, 1966; at the same time accelerated depreciation for structures was replaced by 150 percent declining balance depreciation. In the original legislation implementing these changes in tax policy the suspension was to remain in effect until the end of 1967, a

Table 8. Changes in Gross Investment (I), Net Investment (N), and Capital Stock (K) Resulting from the Repeal of the Long Amendment (Billions of 1965 Dollars)

| Year | Manufacturing Equipment |      |       | Non-Farm, Non-Manufacturing Equipment |       |       |
|------|-------------------------|------|-------|---------------------------------------|-------|-------|
|      | I                       | N    | K     | I                                     | N     | K     |
| 1964 | .238                    | .238 | 0     | 1.042                                 | 1.042 | 0     |
| 1965 | .400                    | .365 | .238  | .958                                  | .758  | 1.042 |
| 1966 | .412                    | .329 | .567  | .706                                  | .360  | 1.800 |
| 1967 | .349                    | .217 | .896  | .750                                  | .335  | 2.160 |
| 1968 | .229                    | .067 | 1.113 | 1.021                                 | .541  | 2.495 |
| 1969 | .236                    | .064 | 1.180 | 0.761                                 | .177  | 3.036 |
| 1970 | .297                    | .115 | 1.244 | 0.792                                 | .174  | 3.213 |

total period of almost fifteen months. The suspension was lifted on March 9, 1967, so that the total period of suspension was a little less than five months. The effect of the suspension on the annual rental price of capital in 1967 was the following:

|   | Without<br>Suspension | With<br>Suspension |
|---|-----------------------|--------------------|
| Manufacturing Equipment                   | .320                  | .351               |
| Manufacturing Structures                  | .259                  | .276               |
| Non-Farm, Non-Manufacturing<br>Equipment  | .379                  | .414               |
| Non-Farm, Non-Manufacturing<br>Structures | .270                  | .287               |

Our estimates of the effects of the suspension on net investment, gross investment, and capital stock are given in Table 9.

For all categories of assets the suspension had a restraining effect on the level of investment in 1967. We estimate that this effect continued into 1968 for all assets except non-farm, non-manufacturing equipment. For all classes of assets the restoration of the original tax credit for equipment and accelerated depreciation for structures will result in a stimulus to investment in 1969 and 1970. For no class of assets is the level of capital stock as high at the end of 1970 as it would have been in the absence of the suspension. The total gross investment for the five year period 1966-70 is considerably lower than it would have been in the absence of the five month suspension.





If the suspension of the investment tax credit for equipment and accelerated depreciation for structures had continued for fifteen months, the impact on the level of investment would have been much more substantial. Our estimates are given in Table 10. For investment in structures the restraining effect of the suspension would have continued into 1969, although the impact would have been very slight in that year. For investment in equipment as well as for structures the magnitude of the impact would have been much greater. As a result the stimulus from restoration of the tax credit and accelerated depreciation would have been correspondingly increased.

## 6. Conclusion.

The objective of this paper is to assess the effects of tax policy on investment behavior. For this purpose we have presented an econometric model of investment behavior based on the neoclassical theory of optimal capital accumulation. This model differs from an earlier version used in two previous studies [18, 19] mainly in the use of further restrictions on the parameters of the underlying distributed lag function. These restrictions enable us to improve our specification of the lag structure and to economize on the number of parameters to be estimated. The resulting numerical estimates of the unknown parameters of our econometric model reflect the alterations in our statistical technique and incorporate data that have become available since our earlier studies. The lag structure derived from our new estimates suggests that the average lag between changes in the

Table 10. Change in Gross Investment (I), Net Investment (N), and Capital Stock (K) Resulting from Hypothetical Suspension of the Investment Tax Credit for Equipment and Accelerated Depreciation for Structures from October 10, 1966 to December 31, 1967 (Billions of 1965 Dollars)

| Year | Manufacturing |        |            |       | Non-Farm,<br>Non-Manufacturing |        |            |        |
|------|---------------|--------|------------|-------|--------------------------------|--------|------------|--------|
|      | Equipment     |        | Structures |       | Equipment                      |        | Structures |        |
|      | I             | K      | I          | N     | I                              | N      | I          | K      |
| 1966 | -.177         | 0      | -.046      | -.046 | 0                              | -.762  | -.119      | 0      |
| 1967 | -.872         | -.177  | -.250      | -.247 | -.046                          | -3.190 | -.614      | -.119  |
| 1968 | -.567         | -1.023 | -.234      | -.216 | -.293                          | .208   | -.475      | -.725  |
| 1969 | -.181         | -1.439 | -.063      | -.032 | -.509                          | .171   | -.154      | -1.150 |
| 1970 | .270          | -1.408 | .117       | .152  | -.541                          | .093   | .193       | -1.224 |

determinants of investment and actual expenditures for structures is shorter than that derived from our previous estimates. The new results are in much better agreement with evidence on the lag structure from sample surveys and from econometric models of investment fitted to data for industry groups for individual firms.

Tax policy affects investment behavior through the rental price of capital services. To assess the response of investment to changes in tax policy we have calculated the change in investment resulting from a given change in tax policy, holding all other determinants of investment, including other aspects of tax policy, at their actual levels. We have presented estimates of the effects of the adoption of accelerated depreciation in 1954, the adoption of new lifetimes for depreciation and an investment tax credit for equipment in 1962, the reduction of the tax rate from 52 to 48 percent and the repeal of the Long Amendment to the investment tax credit in 1964, and the effects of the suspension of the investment tax credit for equipment and accelerated depreciation for structures in late 1966 and early 1967. The evolution of tax policy during the post-war period provides a broad range of experience for a quantitative assessment of the impact of tax policy on investment behavior.

Our over all conclusion is the same as in our previous studies: Tax policy can be highly effective in changing the level and timing of investment expenditures. Qualitatively speaking, a change in tax policy that reduces the rental price of capital services will increase the desired level of capital stock. This increase will generate net investment that

eventually brings actual capital up to the new desired level. Gross investment follows the course of net investment at first but gradually replacement requirements resulting from the higher level of capital stock come to predominate. Even if all the determinants of desired capital remain stationary at their new levels, gross investment is permanently increased by the higher levels of replacement associated with higher levels of capital.

From a quantitative point of view the tax measures we consider have substantially different impacts. The investment tax credit, essentially a subsidy to the purchase of equipment, has had a greater impact than any of the other changes in tax policy during the post-war period. The repeal of the Long Amendment, making this credit even more effective, has also had a substantial impact. Of course, the effects of the tax credit are limited to investment in equipment. The shortening of lifetimes used in calculating depreciation for tax purposes and the use of accelerated methods for depreciation are very important determinants of levels of investment expenditure since 1954. Suspension of the investment tax credit and accelerated depreciation during 1966-7 have had an important restraining effect on the level of investment; if this suspension had been allowed to remain in force for fifteen months rather than for five, the impact would have been proportionately greater. Of all the tax measures we consider only the reduction of the corporate tax rate in 1964 has had little impact on the level of investment expenditures. The reason for this is that tax depreciation and economic depreciation had

achieved virtual equality by 1964 so that any change in the tax rate would have been neutral in its effects on the price of capital services. The much-acclaimed tax cut of 1964 affected investment, but its main direct impact was through the enhanced effectiveness of the investment tax credit; reduction in the tax rate had a small but clearly negative impact on the level of investment.

<sup>6</sup>Comparisons of these alternative econometric models of investment behavior are given by Jorgenson and Nadiri [24].

<sup>7</sup>The predictive performance of these alternative econometric models is compared by Jorgenson and Nadiri [25].

<sup>8</sup>A recent survey of the econometric literature on cost and production functions by Walters [49] lists 345 references, almost all presenting the results of econometric tests of the neoclassical theory of the firm.

<sup>9</sup>Here we assume that investment is fully reversible. Arrow [3] has discussed the relationship between the price of capital goods and the present value of future rentals where investment is irreversible.

<sup>10</sup>A detailed derivation is given by Jorgenson [22].

<sup>11</sup>A direct subsidy at the rate  $k$  results in a cost of acquisition of investment goods  $q(1-k)$ . With tax rate  $u$  and present value of depreciation  $z$ , we obtain the same formula for the rental price of capital as for the investment tax credit,

$$c = q(1-k)[(1-u) + \delta] \frac{1 - uz}{1-u}.$$

<sup>12</sup>Similar results are given by Brown [5] and Samuelson [39].

<sup>13</sup>Similar results are given by Brown [5], Musgrave [35], and Smith [40].

<sup>14</sup>For recent contributions to this controversy, see footnote 2 above. The results of Gordon [12] support our assumption that the before-tax rate of return is unaffected by changes in the tax rate or "no shifting." Alternative assumptions are suggested by the results of Cragg, Harberger and Mieszcowski [9] and by Musgrave and Krzyzaniak [35]. None of these empirical results is based on a complete econometric model appropriate to a general equilibrium analysis of the incidence of the corporate income tax.

(7).

<sup>16</sup>See [19], p. 394, formula (8).

<sup>17</sup>This result corrects an error in our earlier paper [19], p. 394, formula (9); fortunately, this error did not affect any of the empirical results presented in that paper or in our subsequent paper [18].

<sup>18</sup>Griliches [16], p. 290.

<sup>19</sup>For further discussion of this point, see Jorgenson [21], pp. 137-9.

<sup>20</sup>Further details on properties of the least squares estimator are discussed by Jorgenson [21], pp. 142-3.

<sup>21</sup>See Durbin [10], pp. 150-3.

<sup>22</sup>Unpublished data from the 1966 Capital Goods Study [43] were kindly made available to us by Mr. Robert Wasson of the Office of Business Economics.

<sup>23</sup>Our original estimate of the rate of growth of this bias was .00651 per year or about one-third the bias for structures. See [19], p. 399.

<sup>24</sup>See Gottsegen [14].

<sup>25</sup>Depreciation under the sum of the years' digits formula has a higher present value for the range of lifetimes and rates of return of interest for this study. See [19], Table 1, p. 395.

<sup>26</sup>These estimates of the effective rate of the tax credit are based on data from tax returns for 1963 [47].

<sup>27</sup>See Griliches [17] and Malinvaud [31].

<sup>28</sup>For detailed discussion of this restriction and its use in estimation of the parameter  $\alpha$ , see Jorgenson [21], pp. 135, 147-8.

<sup>29</sup>See Mayer [32].

<sup>30</sup>These are crude extrapolations of previous trends, modified by fragmentary data available at the time of the computations (October 1967).

<sup>31</sup>For further discussion of tax neutral depreciation, see Section 2 and the references given in footnotes 12 and 13 above.

<sup>32</sup>Policies under consideration during early 1966 and their potential impact on investment expenditures are discussed in our earlier study [18].



## REFERENCES

- [1] Almon, Shirley, "The Distributed Lag between Capital Appropriations and Expenditures," Econometrica, Vol. 33, No. 1 (January 1965), pp. 178-196.
- [2] Anderson, W. H. L., Corporate Finance and Fixed Investment (Boston: Division of Research, Graduate School of Business Administration, 1964).
- [3] Arrow, Kenneth J., "Optimal Capital Policy with Irreversible Investment," Technical Report No. 146, Institute for Mathematical Studies in the Social Sciences, Stanford University, December 1966.
- [4] \_\_\_\_\_, H. B. Chenery, B. S. Minhas, and R. M. Solow, "Capital-Labor Substitution and Economic Efficiency," Review of Economics and Statistics, August 1961, pp. 225-250.
- [5] Brown, E. C., "Business-income Taxation and Investment Incentives," in Income, Employment and Public Policy: Essays in Honor of Alvin H. Hansen (New York: Norton, 1948).
- [6] \_\_\_\_\_, "The New Depreciation Policy Under the Income Tax: An Economic Analysis," National Tax Journal, Vol. 8 (March 1955), pp. 81-98.

- [7] \_\_\_\_\_, "Tax Incentives for Investment," American Economic Review, Vol. 52, No. 2 (May 1962), pp. 335-345.
- [8] Chase, S. B., Jr., "Tax Credits for Investment Spending," National Tax Journal, Vol. 15 (March 1962), pp. 32-52.
- [9] Cragg, John G., Arnold E. Harberger, and Peter Mieszkowski, "Empirical Evidence on the Incidence of the Corporation Income Tax," Journal of Political Economy, Vol. 75, No. 6 (December 1967), pp. 811-821.
- [10] Durbin, J., "Estimation of Parameters in Time-Series Regression Models," Journal of the Royal Statistical Society (series B), Vol. 22 (1960), pp. 139-153.
- [11] Eisner, R., "Realization of Investment Anticipations," in J. S. Duesenberry, G. Fromm, L. R. Klein, and E. Kuh (eds.), The Brookings Quarterly Econometric Model of the United States (Chicago: Rand McNally, 1965), pp. 95-128.
- [12] Gordon, R. J., "The Incidence of the Corporation Income Tax in U. S. Manufacturing, 1925-1962," American Economic Review, Vol. 57, No. 4 (September 1967), pp. 731-758.
- [13] \_\_\_\_\_, Problems in the Measurement of Real Investment in the U. S. Private Economy, Ph.D. Dissertation, Massachusetts Institute of Technology, June 1967.
- [14] Gottsegen, Jack J., "Revised Estimates of GNP by Major Industries," Survey of Current Business, Vol. 47, No. 4 (April 1967), pp. 18-24.

- [15] Griliches, Zvi; "Distributed Lags: A Survey," Econometrica, Vol. 35, No. 1 (January 1967), pp. 16-49.
- [16] \_\_\_\_\_, "Production Functions in Manufacturing: Some Preliminary Results," in M. Brown (ed.), The Theory and Empirical Analysis of Production (New York: National Bureau of Economic Research, 1967), pp. 275-322.
- [17] \_\_\_\_\_, "A Note on Serial Correlation Bias in Estimates of Distributed Lags," Econometrica, Vol. 29, No. 1 (January 1961), pp. 65-73.
- [18] Hall, Robert E., and D. W. Jorgenson, "The Role of Taxation in Stabilizing Private Investment," in V. P. Rock (ed.), Policy Makers and Model Builders (Amsterdam: North-Holland), forthcoming.
- [19] \_\_\_\_\_, and \_\_\_\_\_, "Tax Policy and Investment Behavior," American Economic Review, Vol. 57, No. 3 (June 1967), pp. 391-414.
- [20] Harberger, A. C., "Tax Stimuli and Investment Behavior," this volume, pp. - .
- [21] Jorgenson, Dale W., "Rational Distributed Lag Functions," Econometrica, Vol. 34, No. 1 (January 1966), pp. 135-149.
- [22] \_\_\_\_\_, "The Theory of Investment Behavior," in R. Ferber (ed.), Determinants of Investment Behavior (New York: National Bureau of Economic Research, 1967), pp. 129-156.

- [23] Jorgenson, Dale W., and Zvi Griliches, "The Explanation of Productivity Change," Review of Economic Studies, Vol. 34, No. 99 (July 1967), pp. 249-281.
- [24] Jorgenson, Dale W., and M. I. Nadiri, "A Comparison of Alternative Econometric Models of Quarterly Investment Behavior," Working Paper No. 55 (Revised), Institute of Business and Economic Research, University of California, Berkeley, submitted for publication.
- [25] \_\_\_\_\_, and \_\_\_\_\_, "The Predictive Performance of Econometric Models of Quarterly Investment Behavior," Working Paper No. 111, Institute of Business and Economic Research, University of California, Berkeley, submitted for publication.
- [26] Jorgenson, Dale W., and Calvin D. Siebert, "Optimal Capital Accumulation and Corporate Investment Behavior," Journal of Political Economy, forthcoming.
- [27] Jorgenson, Dale W., and J. A. Stephenson, "The Time Structure of Investment Behavior in United States Manufacturing, 1947-1960," Review of Economics and Statistics, Vol. 49, No. 1 (February 1967), pp. 16-27.
- [28] L. R. Klein, Economic Fluctuations in the United States, 1921-1941 (New York: Wiley, 1950).
- [29] \_\_\_\_\_, "Studies in Investment Behavior," in Universities-National Bureau Committee for Economic Research, Conference on Business Cycles (New York: National Bureau of Economic Research, 1951), pp. 233-303.

- [30] Krzyzaniak, M., and R. A. Musgrave, The Shifting of the Corporate Income Tax, An Empirical Study of its Short-term Effect on the Rate of Return (Baltimore: Johns Hopkins Press, 1963).
- [31] Malinvaud, E., "Estimation et Prévision dans les Modèles Economiques Autorégressifs," Revue de l'Institut International de Statistique, Vol. 29, No. 2 (1961), pp. 1-32.
- [32] Mayer, Thomas, "Plant and Equipment Lead Times," Journal of Business, Vol. 33, No. 2 (April 1960), pp. 127-132.
- [33] Meyer, J. R., and R. R. Glauber, Investment Decision, Economic Forecasting and Public Policy (Boston: Division of Research., Graduate School of Business Administration, Harvard University, 1964).
- [34] Musgrave, R. A., "Effects of Tax Policy on Private Capital Formation," in Commission on Money and Credit, Fiscal and Debt Management Policies (Englewood Cliffs: Prentice-Hall, 1963), pp. 45-142.
- [35] \_\_\_\_\_, The Theory of Public Finance (New York: McGraw-Hill, 1958).
- [36] Nerlove, M., "Recent Empirical Studies of the CES and Related Production Functions," in M. Brown (ed.), The Theory and Empirical Analysis of Production (New York: National Bureau of Economic Research, 1967), pp. 55-122.
- [37] Roos, C. F., "The Demand for Investment Goods," American Economic Review, Vol. 38, No. 2 (May 1948), pp. 311-320.

- [38] Roos, C. F., and V. S. Von Szeliski, "The Demand for Durable Goods," Econometrica, Vol. 11, No. 2 (April 1943), pp. 97-122.
- [39] Samuelson, Paul A., "Tax Deductibility of Economic Depreciation to Insure Invariant Valuation," Journal of Political Economy, Vol. 72, No. 6 (December 1964), pp. 604-606.
- [40] Smith, V. L., "Tax Depreciation Policy and Investment Theory," International Economic Review, Vol. 4, No. 1 (January 1963), pp. 80-91.
- [41] Tinbergen, J., Statistical Testing of Business Cycle Theories, Vol. I, "A Method and Its Application to Investment Activity," (Geneva: League of Nations, 1939).
- [42] Ture, N. B., "Tax Reform: Depreciation Problems," American Economic Review, Proc. Vol. 53, No. 2 (May 1963), pp. 334-353.
- [43] U. S. Department of Commerce, Office of Business Economics, 1966 Capital Goods Study, 1967.
- [44] \_\_\_\_\_, U. S. National Income and Product Accounts, 1929-1965, 1966.
- [45] U. S. Department of Treasury, Bureau of Internal Revenue, "Income Tax Depreciation and Obsolescence Estimated Useful Lives and Depreciation Rates," Bull. F (Revised January 1942).
- [46] \_\_\_\_\_, "Supplementary Depreciation Data from Corporate Returns," Statistics of Income, 1959.

- [47] \_\_\_\_\_, "Supplementary Depreciation Data from Corporate Returns," Statistics of Income, 1963.
- [48] \_\_\_\_\_, "Supplementary Depreciation Guidelines and Rules," Pub. 456 (7-62), July 1962.
- [49] Walters, A. A., "Production and Cost Functions: An Econometric Survey," Econometrica, Vol. 31, No. 2 (April 1963), pp. 1-66.
- [50] White, W. H., "Interest Inelasticity of Investment Demand--The Case from Business Attitude Surveys Re-examined," American Economic Review, Vol. 46, No. 4 (September 1956), pp. 565-587.