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ARE THERE EXOGENOUS VARIABLES IN SHORT-RUN PRODUCTION RELATIONS?*

BY CHRISTOPHER A. SIMS

Nearly all previous time series studies of demand for labor and investment have treated the assumption that right-hand side variables (usually output and a price variable) are exogenous as a maintained hypothesis. This paper tests that hypothesis. The hypothesis is accepted for output in an investment demand equation, but rejected for price variables in both investment and labor demand equations. In the labor equation, a formulation which treats labor as exogenous, determining output, appears more in accord with the data than the usual formulation.

1. INTRODUCTION

Econometricians understand very well that, in a regression equation, the "right-hand-side" variables should be exogenous if the regression estimates are to be treated as reflecting a causal relation. What seems to have been understood only quite recently is that, in time series, the assumption that the right-hand-side variables are exogenous can be tested directly.

Consider an equation in which y_t is dependent variable, X_t is the vector of independent variables, and u_t is the residual. Ordinary least squares can be given a justification if we assume only that X_t is predetermined—i.e., that u_t and X_t are uncorrelated. But almost any of the slightly more sophisticated techniques in common use (all those which reduce to or employ generalized least squares, for example) require the stronger assumption that X_t is exogenous—i.e., that X_t and u_s are uncorrelated for all t and s. When the correlation $r(t, s)$ between X_t and u_s can take any value, no particular set of values for the $r(t, s)$ vectors is testable on the basis of a sample of (y_t, X_t) values. But in time series it is often natural to assume that $r(t, s)$ depends only on $t - s$.[1] Within this class of alternatives, the null hypothesis that all values of $r(t, s)$ are zero can easily be tested by adding lagged or leading values of X_s to the right-hand side of the regression equation. If X_t is exogenous, the lagged or leading X_s values should have zero coefficients, and that null hypothesis we know how to test.[2]

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* Research for this paper was done entirely during the author's 1970–1971 tenure as a Research Fellow at the National Bureau of Economic Research. Special thanks are due to John Hause and M. I. Nadiri, who commented on an earlier version. Computational work was carried out by Josephine Su. H. I. Forman drew the charts. The author is Associate Professor of Economics, University of Minnesota.

[1] This follows, e.g., if X_t and y_t are jointly covariance-stationary.

[2] To be specific, one performs the test in a single-equation least-squares regression by estimating equations with and without leading values of the independent variable, then comparing the residual sums of squares using the usual F-test. The fact that this paper uses frequency-domain estimation methods should not be allowed to obscure the fact that the test it applies can easily be carried out with standard estimation techniques and packaged computer programs. One must, of course, eliminate serial correlation in residuals when applying the tests using ordinary least squares. My previous paper (1971) illustrates the use of the test with time-domain estimates.

In most practical applications the occurrence of significant coefficients on lagged X_s would tend to be read as evidence not of fundamental misspecification of what is exogenous, but rather as evidence that a more general pattern of distributed lag should be allowed in the model. That many dynamic causal mechanisms take time to act, implying distributed lags, is now a commonplace notion in econometrics; and it is usually easy to give theoretical explanations for a wide range of possible patterns for lag distributions in a particular model. The presence of significant coefficients on future X_s would in most models be harder to explain, however, without admitting new and troublesome elements into the model. Thus we might think that the occurrence of significant coefficients on future X_s indicated that economic agents had information about future values of the independent variable; then we would have to admit that the future values themselves must be error-ridden proxies for the forecasts on which decisions were actually based.

In an earlier paper (1971), I have shown the connection between exogeneity, Granger's (1969) definition of causal priority, and a certain form of the moving average representation of a vector stochastic process. In that same paper I applied the test for exogeneity to single-equation relations between money aggregates and GNP. At roughly the same time, Sargent (1971) recognized the importance of a test for "one-sidedness" in a distributed lag model, and applied such a test to data on inflation and interest rates. There is at least one example outside econometrics (Akaike (1967)) of the application of this kind of test. Not coincidentally, Sargent, Akaike, and I had all been working with estimates of lag distributions generated by Fourier techniques which automatically treat past and future symmetrically. Hannan (1963), when he originally suggested using such estimates, had pointed out that they lent themselves to a test for exogeneity.

In the remainder of the paper we will examine the exogeneity problem as it applies to aggregate short-run production relations. Tests on quarterly data for U.S. manufacturing show that: (1) shipments behaves as exogenous in a distributed lag investment relation; (2) manhours behaves as exogenous in a regression of current shipments on current manhours, but shipments is not exogenous in a distributed lag regression of manhours on shipments; and (3) factor price variables of the type commonly used in previous aggregate factor demand estimates are in most cases either insignificant or not exogenous in factor-demand equations.

An empirically relevant, explicitly stochastic theory of factor demand, capable of providing implications as to what should be taken as exogenous, is not developed in this paper. Such a theory would have to be fairly complicated, and it would have to take account of specific characteristics of the data, such as the degree of aggregation and the kinds of measurement error present. Developing such a theory—or rather the separate theories required for each kind of factor demand, each level of aggregation, each definition of "output" and "price"—is an important task. The purpose of this paper is to show how important the task is by testing the implicit assumptions about exogeneity made in most previous work. After the empirical results have been presented, possible economic explanations for them are explored, but this aspect of the paper is meant to be suggestive, not definitive.

2. METHODOLOGY OF THIS PAPER

There is a large existing literature on factor-demand functions estimated from time series.[3] With rare exceptions, previous time series econometric studies have treated output as exogenous and enter output with a distributed lag.[4] A good many studies in the literature also use as exogenous some sort of price variable. Most commonly, the price variable has been cost of capital deflated by output price or by wage rate. "Cost of capital" has been variously defined—it has been based on long term interest rates or on stock market rates of return and it has been modified with various degrees of sophistication to take account of tax law changes. Capacity and cash flow variables have also been used in some studies.

In this paper we look at gross investment, manhours, employment, and hours as factors, deflated sales as a measure of output, and various measures of price effects. The variables are all measured in natural logarithms, detrended and deseasonalized.[5] Much previous work has not been formulated with variables measured in logarithms, but this point of difference seems unlikely to be important.[6] In all other respects, the model estimated in this paper is more general than those used in previous work. The lag distributions on output and price are subject only to one maintained restriction: that they become negligibly small after about 12 quarters to either side of zero.[7] If in this general framework, future values of right-hand-side variables enter with significant coefficients, then *a fortiori* the right-hand-side variable is not exogenous in more narrowly specified models using, say, rational or Almon polynomial forms for the lag distribution.

Most of the statistical analysis which went into this paper started from frequency-domain estimates of the lag distributions. The technique used, the "Hannan inefficient" procedure, is described by Hannan (1963), (1967), and Wahba (1969), and in the appendix to this paper. This procedure is, for a single right-hand-side variable, equivalent asymptotically to generalized least squares, where the weighting matrix is based on the autocovariance function of the exo-

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[3] On investment, central figures have been Jorgenson (1963), (1969) and Eisner (1968). Bischoff has an important recent paper in this area (1969). On labor, the seminal econometric work was by Eckstein and Wilson (1964) and Kuh (1965), who acknowledge in turn the earlier, less formal, work of Hultgren (1965). Dhrymes (1969) has an important recent paper in this area. Nadiri and Rosen (1969) have taken the useful step of estimating labor and capital demand jointly. I attempt nothing like a complete bibliography here, since something close to that appears as part of Nerlove's Schultz lecture (1970), soon to be published.

[4] Waud (1968) is one exception. He allows for cyclical variations in productivity through cyclical dummies, while suppressing any distributed lag in labor response to output. In unpublished work, Gould and Waud have taken output as endogenous in an investment model, assuming factor prices and GNP exogenous.

[5] For most variables, published deseasonalized data were used, though in one equation (noted below) it was necessary to go back to the raw data. Detrending was by a preliminary regression of the logged variables on a linear trend.

[6] Jorgenson (1967) seems to feel that the distinction between log-linear and linear investment models is important. This is a matter of personal judgement until the empirical evidence is in, of course. Thus it might be that the bad performance of price variables in the models of this paper reflects misspecification in the log-linear form. But it is equally possible that the apparent exogeneity of output in the log-linear model would not carry over to the slightly different models Jorgenson has worked with.

[7] In every estimated model coefficients on lags 9–12 were tested for significance as a group, and in every case the null hypothesis that all were zero was accepted. Thus the estimates themselves show no conflict with the maintained hypothesis that the lag distribution has become negligibly small by the 12th lag.

genous variable instead of on the autocovariance function of the residuals.[8] The procedure has substantial computational advantages over least squares regression, especially where several possible lengths of lag distribution are contemplated. It also makes seasonal adjustment easy and automatically takes account of complicated patterns of serial correlation in residuals in computing test statistics. Both these latter characteristics are important for this paper because: (a) as I pointed out earlier (1971), seasonal adjustment of dependent and independent variables by different methods can cause serious bias in distributed lag estimates; and (b) we will be making tests on groups of coefficients about whose sizes, signs, and interrelations we have little *a priori* notion, so that unbiased test statistics are a central concern.

The Hannan inefficient procedure has disadvantages too, however. Most obviously, it is less than fully efficient. Also, it requires relatively long series in order that it not be contaminated by "end effects," which arise because the method treats series as infinitely long, either periodic or filled out with zeroes. Lagged values of exogenous variables at the beginning of the sample are implicitly either taken as zero or taken as values from the end of the sample. The method also draws its computational advantages from the assumption of stationarity. Hence it will fail on data which show very different patterns of variation in different periods or which have many gaps. And, finally, the method does not allow exact test statistics, even if normal errors are assumed. All tests must be based on asymptotic distributions.

Because of these possible problems with the frequency-domain estimates, most of the main results of the paper were verified with least squares regression techniques.

3. RESULTS WITH FACTOR DEMAND RELATED TO SALES AND PRICES

With one marginal exception, every equation with both sales and price as independent variables showed either an insignificant price variable or significant coefficients on future values of price or sales. Experimentation with the form of the price variable, while considerable, did not cover every formulation which has appeared in the literature. It was decided not to proceed further with the search for a valid exogenous price variable, however, because: (a) an explicitly stochastic approach to the theory of factor demand leads to doubt that any single variable can summarize the influence of price and (b) the fact that positive results appear in equations without price variables suggests that such equations have valid interpretations as causal reduced forms even if price is excluded.

Two forms of the cost of capital variables, c, were tried. One was taken from previous work by Nadiri[9] and the other taken from an article by Coen (1968). Both are based on interest rates (rather than returns on equity) and both use the standard formula for user cost, as presented in, e.g., Hall and Jorgenson (1967). Coen, however, corrects for the effects of changes in depreciation guidelines, while

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[8] Hannan (1963) pointed out the equivalence of his efficient procedure with his inefficient procedure when the residuals and the exogenous variable have the same spectral densities. Amemiya and Fuller (1967) showed the equivalence of the efficient procedure to generalized least squares.

[9] Supplied to me by Professor Nadiri.

Nadiri's variable reflects no tax changes except the investment tax credit. Coen's data is annual and extends only through 1966.[10]

The wage variable is one recently added to the NBER data bank which has been corrected for interindustry shift and overtime hours effects.

In equations for labor inputs, the wage-to-c ratio was the price variable. For the gross investment equations, both the c-to-wage ratio and the c-to-output-price ratio were tried as price variables. Output price was taken as the wholesale price index for the appropriate industry.

The exception to the pattern of negative results described at the beginning of this section occurred in the equation explaining investment in non-durable manufacturing, using the Coen cost of capital deflated by the wholesale price index for non-durable manufactures. In this equation no coefficients on future values of sales or c were significant, current and past sales had significant effect and positive coefficients, and current and past c had the appropriate predominantly negative coefficients. The test statistic for the null hypothesis that current and eight past values of c all have zero coefficients is 13.45 with an asymptotic $\chi^2(9)$ distribution. This is not quite significant at the 10 percent level (the 0.10 level for $\chi^2(9)$ is 14.68). However, the first four lagged values of c are significant as a group.

Against this exceptional result we must balance the fact that in the durables equation for investment the corresponding c variable is quite insignificant and in the aggregate manufacturing equation it is highly significant—but equally so for past and future values. Furthermore, with the Nadiri c or with wage taking the place of wholesale prices in deflating c there is no example of an even marginally significant price effect except where future coefficients are significant. The conclusion can only be that empirical investigators should in general make tests for exogeneity before giving causal interpretations to single-equation estimates of price effects on factor demands.

The poor performance of price variables in the factor demand equations has a number of possible theoretical explanations, once we admit stochastic components into our theory instead of confining them to the "empirical" side of our research. What matters to an investment decision is not the cost of capital services this year, but the average cost over the investment's lifetime. This means in the first place that it is important to distinguish permanent from transistory variations in the c-to-output-price ratio. Thus if, e.g., output price regularly shows substantial quarter-to-quarter or year-to-year fluctuations, it is only reasonable that a change in the c-to-output-price ratio due to output price change should have a very different effect on investment in the short run from a similar change due to changes depreciation rules. A related point is that changes in c (as computed from the standard formula) of a given magnitude lasting a given time may have different implications for investment, depending on their source, even if the size and duration of the change is known exactly. Thus a reduction in c for one year due to a one-year investment tax credit is not at all the same thing as a one-year reduction due to a

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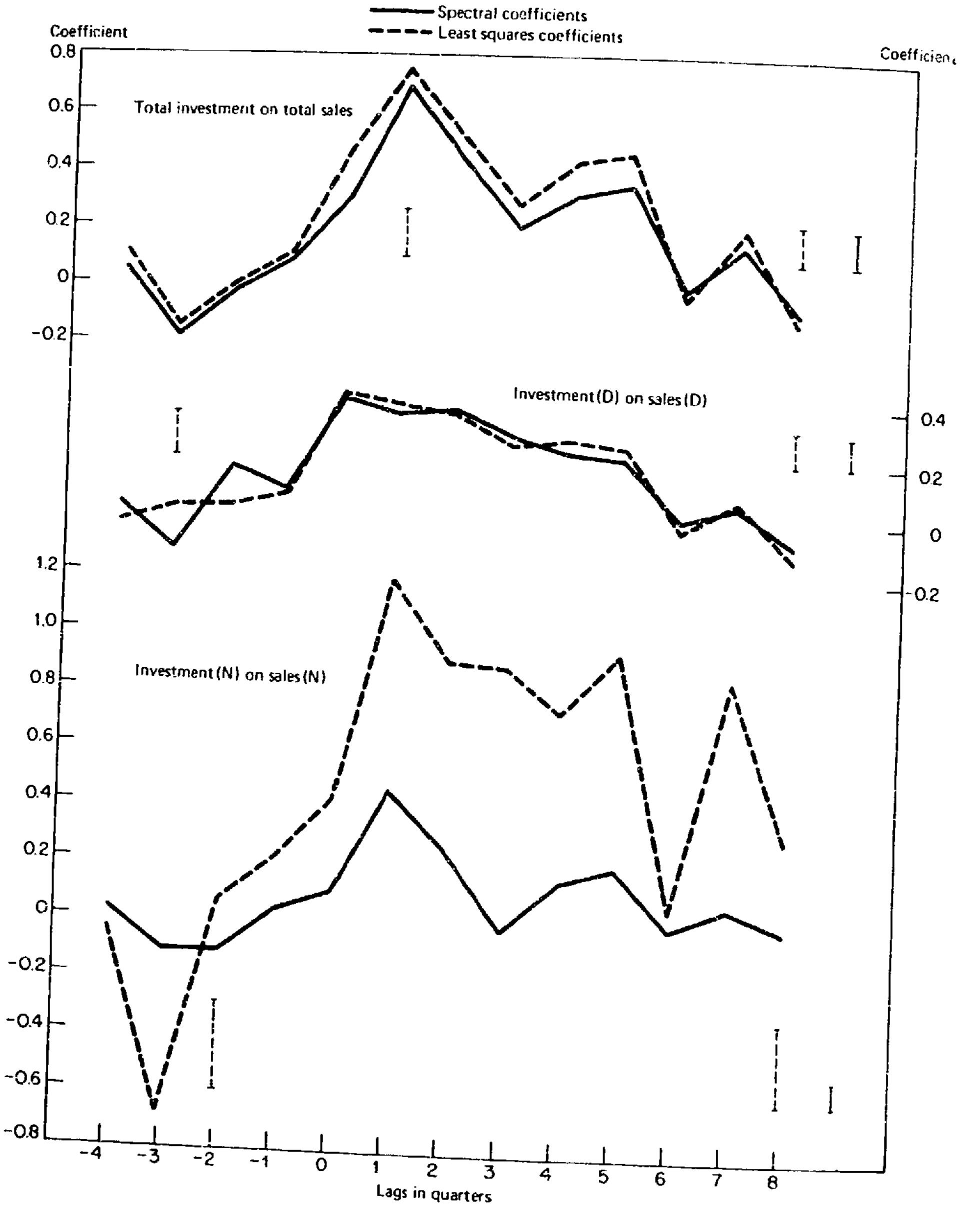
[10] Coen's annual data (actually semi-annual for one year when a major tax change occurred at mid-year) was converted to a quarterly basis by simply repeating each observation four times. This of course introduces a spurious seasonal in the data. However, by the argument in another paper of mine (1971), excess seasonal variance in an independent variable has the effect of "deseasonalizing" the estimated lag distribution, so unless the true lag distribution has a seasonal pattern, the resulting bias should not be large.

one-year drop in the corporate income tax rate. The reason is that the standard formula, which spreads tax changes and credits smoothly over an investment's lifetime, is not accurate as a measure of the true cost of capital when the formula's components are fluctuating over time. All of this suggests that we ought not to impose the same pattern of lagged response on all the components of factor-price ratios.

CHART I

LAG DISTRIBUTION FOR INVESTMENTS ON SALES

Note: Smallest and largest standard errors for least squares coefficients are displayed as vertical lines above or below corresponding coefficients, and standard error for spectral coefficients are at the right hand side of the chart.



The above argument does not apply to demand for labor, except insofar as labor behaves like a capital good. Both labor and capital equations, though, are subject to a variant of the classical sort of identification problem for a demand equation. In static competitive theory it is sometimes appropriate to take factor prices as determined outside any single industry. In empirical work, the same kind of reasoning may justify using prices as exogenous variables in cross-sectional or long run historical studies. But in quarterly time series analysis a considerable portion of variance in factor demands is likely to be cyclical, and hence will correspond to cyclical variation in factor prices. Unless industry-specific patterns of variation in factor demand dominate the dependent variable, the fact that analysis is at an industry level does not make it legitimate to ignore classical identification problems.[11]

4. Results with Factor Demand Related to Sales Alone

In comparison to the results for the price variables, results with sales alone as explanatory variable are clear cut. In the equations for gross investment, sales behaves like an exogenous variable. Chart I displays lag distributions for gross investment on sales for aggregate manufacturing and the two subaggregates. In all three lag distributions, coefficients on future sales (the coefficients with negative time index) are noticeably smaller than those on current and past sales, and the tests shown in Table 1 confirm that in each distribution, coefficients on the first four negative lags are insignificant as a group.[12]

TABLE 1

Tests for Significance of Groups of Coefficients, Investment on Sales Regressions

Coefficients which are Zero under Null Hypothesis	Manufacturing	Durables	Non-durables
Four future frequency-domain	$\chi^2(4) = 3.86$	$\chi^2(4) = 5.13$	$\chi^2(4) = 5.08$
Four future least squares	$F(4, 67) = 0.83$	$F(4, 67) = 0.08$	$F(4, 67) = 1.68$
Current and 8 past frequency domain	$\chi^2(9) = 43.9$*	$\chi^2(9) = 38.03$*	$\chi^2(9) = 43.56$*
Current and 8 past, least squares	$F(9, 71) = 4.97$*	$F(9, 71) = 2.71$*	$F(9, 71) = 4.91$*

Note: Frequency domain statistics have only asymptotic justification. Sample period for frequency domain, 1947 I–1970 IV, for least squares, 1949 III–1969 IV. See Appendix for data sources and definitions.

* Significant at 0.05 level.

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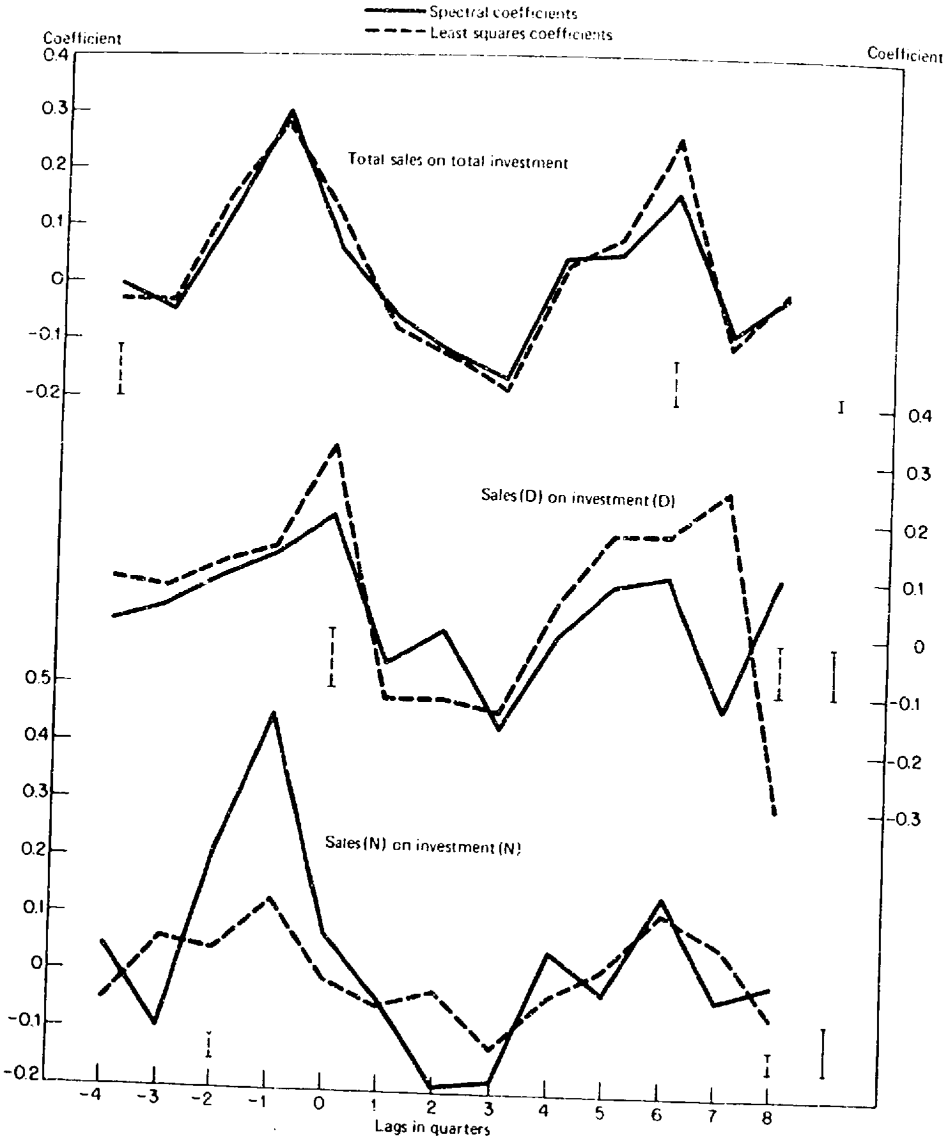
[11] It is interesting to speculate on why the identification problem has so seldom received even passing mention in aggregative investment and labor demand studies. One possibility is that the Brookings Model, which provided the context for much of the early work on both these two problems, encouraged researchers to pass the buck on identification to a hypothetical future "system estimate" of the model. Of course the model in the end has become so large that the usual methods of equation system estimation, which assume that the number of observations is large relative to the number of variables, have no rationale.

[12] Though the test statistics cited here and in what follows are for the first four negative lags and for the zero'th through eighth non-negative lags, tests were actually computed in each instance for coefficients on lags −1 to −6, −1 to −8, 1 to 8, 1 to 12, 1 to 4, and 9 to 12 as well. In no case would conclusions have been altered by explicit consideration of these other statistics.

CHART II

LAG DISTRIBUTION FOR SALES ON INVESTMENT

Note: Smallest and largest standard errors for least squares coefficients are displayed as vertical lines above or below corresponding coefficients, and standard error for spectral coefficients are at the right hand side of the chart.



It is worthwhile to note from Chart II and Table 2 that future coefficients are indeed significant as a group in the reversed relationship with sales regressed on investment. This latter result is not a necessary consequence of the first result. It is possible to have a system in which distributed lag regressions in both directions yield zero coefficients on negative lags. Had our results been consistent with

TABLE 2

TESTS FOR SIGNIFICANCE OF GROUPS OF COEFFICIENTS SALES ON INVESTMENT

Coefficients which are Zero under Null Hypothesis	Manufacturing	Durables	Non-durables
Four future, frequency-domain	$\chi^2(4) = 35.75$†	$\chi^2(4) = 6.22$	$\chi^2(4) = 44.01$†
Four future least squares	$F(4, 67) = 3.51$†	$F(4, 67) = 1.23$	$F(4, 67) = 3.58$†
Current and 8 past frequency domain	$\chi^2(9) = 27.54$†	$\chi^2(9) = 16.04$*	$\chi^2(9) = 16.35$*
Current and 8 past. least squares	$F(9, 71) = 2.50$†	$F(9, 71) = 4.86$†	$F(9, 71) = 1.69$

Note: See note to Table 1.
* Significant at 0.10 level.
† Significant at 0.05 level.

investment and sales being such a system, it would not have been appropriate to conclude that the results support a causal interpretation of the investment on sales relation.[13]

In Charts I and II and Tables 1 and 2, results for both the frequency-domain and time-domain (least-squares) estimates are displayed. In all the remaining results, only frequency-domain estimates are displayed because they all followed the pattern of close agreement between the two types of estimate shown by the durables and total manufacturing data in Charts I and II. The sharp divergence between the two types of estimate which appears in the non-durable investment equation was unique. The divergence apparently stems from strong non-stationarity in the investment series, so in this case the least-squares results are probably more reliable than the frequency-domain estimates.

For the least-squares estimates, the sample was split and tested for significant changes in coefficients between earlier and later halves. These test statistics are shown in Table 3, where it can be seen that no significant shifts appear. However, a

TABLE 3

TESTS FOR DIFFERENCES IN COEFFICIENTS, 1949 III–1959 III vs. 1959 IV–1969 IV, FOR INVESTMENT AND SALES REGRESSIONS

	Manufacturing	Durables	Nondurables
Investment on sales	$F(11, 60) = 0.59$	$F(11, 60) = 0.64$	$F(11, 60) = 0.77$
Sales on investment	$F(15, 52) = 0.70$	$F(15, 52) = 1.70$*	$F(15, 52) = 0.31$

Note: See note to Table 1. For the investment on sales tests, the tested equation includes only the current and eight past lags. For sales on investment, four future lags were included as well. Test applies to all coefficients in regression, including constant and trend term. Null hypothesis is that all coefficients are the same in the two subperiods.

* Significant at 0.10 level.

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[13] For a more extensive discussion of the various special cases in which a regression might pass the test for exogeneity on the independent variable applied in this paper even though the regression did not in fact represent a causal relation, see my earlier paper (1971).

TABLE 4

ESTIMATED LAG DISTRIBUTIONS FOR INVESTMENT ON SALES

Lag	Coefficients: Manufacturing	Coefficients: Durables	Coefficients: Nondurables	Nondurables, Least Squares
8	−0.0714	−0.0795	−0.0154	0.2957
7	0.1492	0.0493	0.0664	0.8467
6	−0.0037	−0.0062	−0.0147	0.0520
5	0.3599	0.2145	0.2000	0.9308
4	0.3236	0.2283	0.1516	0.7312
3	0.2130	0.2767	−0.0312	0.8883
2	0.4407	0.3726	0.2466	0.9025
1	0.6978	0.3560	0.4577	1.1818
0	0.3098	0.4067	0.1042	0.4253
−1	0.0851	0.0860	0.0321	0.2172
−2	−0.0209	0.1606	−0.1161	0.0712
−3	−0.1939	−0.1178	−0.1198	−0.6848
−4	0.0522	0.0282	0.0649	−0.0390
Standard error of coeff.'s	0.124	0.102	0.085	0.279 to 0.311
Sum of coeff.'s 0–8	2.42	1.818	1.165	6.254
Standard error of sum	0.089	0.122	0.169	

Note: See note to Table 1. Except for right-hand-most column, all these lag distributions are from frequency-domain estimates.

qualification to all the results reported in this section is that the standard error of the residuals declines by a factor of approximately two between the earlier and later portions of the sample. The effects of this heteroskedasticity on the test statistics are hard to judge. Probably there is no general bias, but probably null hypotheses are too easily rejected (degrees of freedom in the regressions are exaggerated).

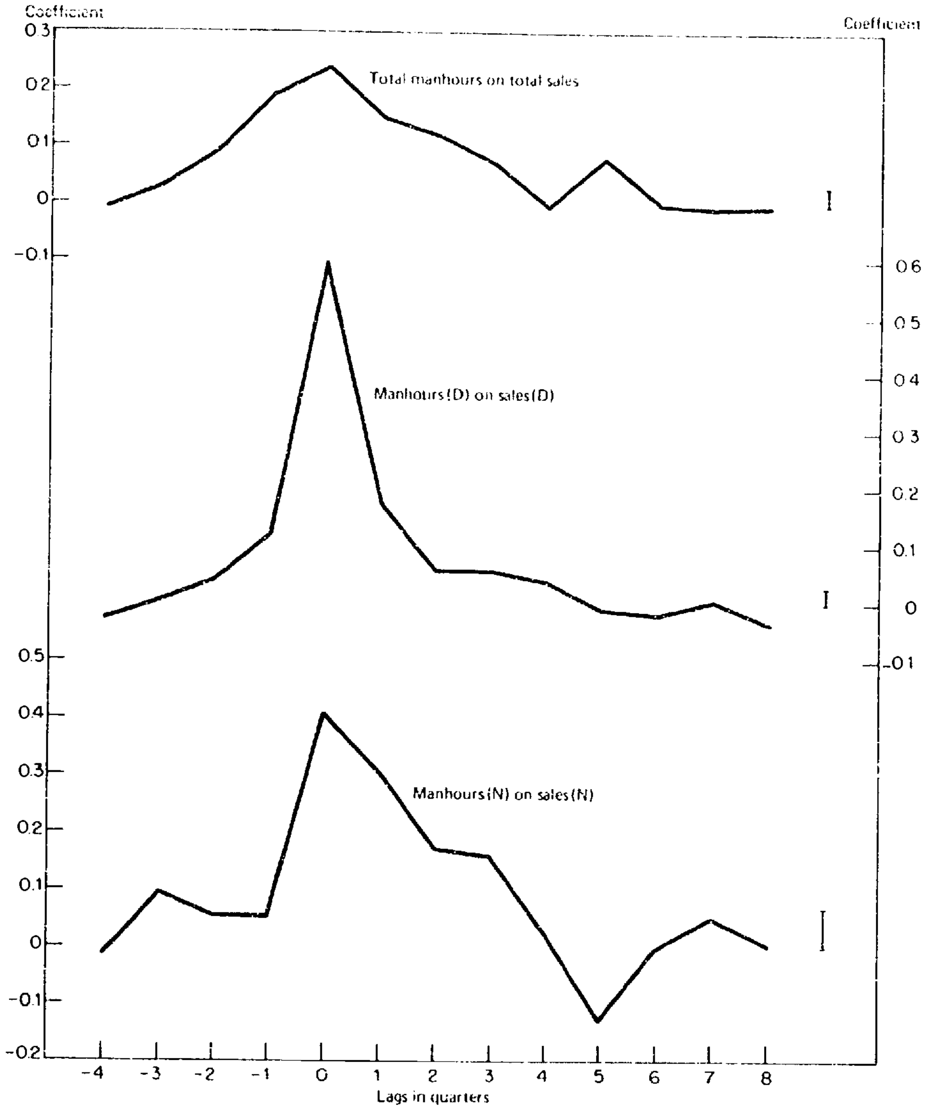
The estimated lag distributions for investment on sales (see Table 4) accord with the theory of a distributed lag accelerator. Coefficients are positive, and of the right order of magnitude. The fact that for the two well-determined distributions, total manufacturing and durables, the sum of coefficients over lags 0 through 8 is close to two and significantly greater than one might seem surprising. However, the really long run effect of output growth on gross investment works entirely through depreciation. It seems reasonable that for the first two years output increases induce more than proportionate increases in gross investment; and that the negative coefficients which bring the total effect back to unity are so spread out over a long tail to the lag distribution that they do not show up as significant in these estimates. These results differ from those of some previous investigators in finding that the largest individual coefficients are on the zero'th or first order lags, and that the entire positive effect of sales appears spent within five quarters.

Labor demand functions also give relatively clear-cut results, but here the pattern is less comforting in its implications about previous research. Chart III displays lag distributions for manhours of production workers regressed on

CHART III

LAG DISTRIBUTION FOR MANHOURS ON SALES

Note: Standard errors are displayed as vertical lines at the right hand side of the chart.

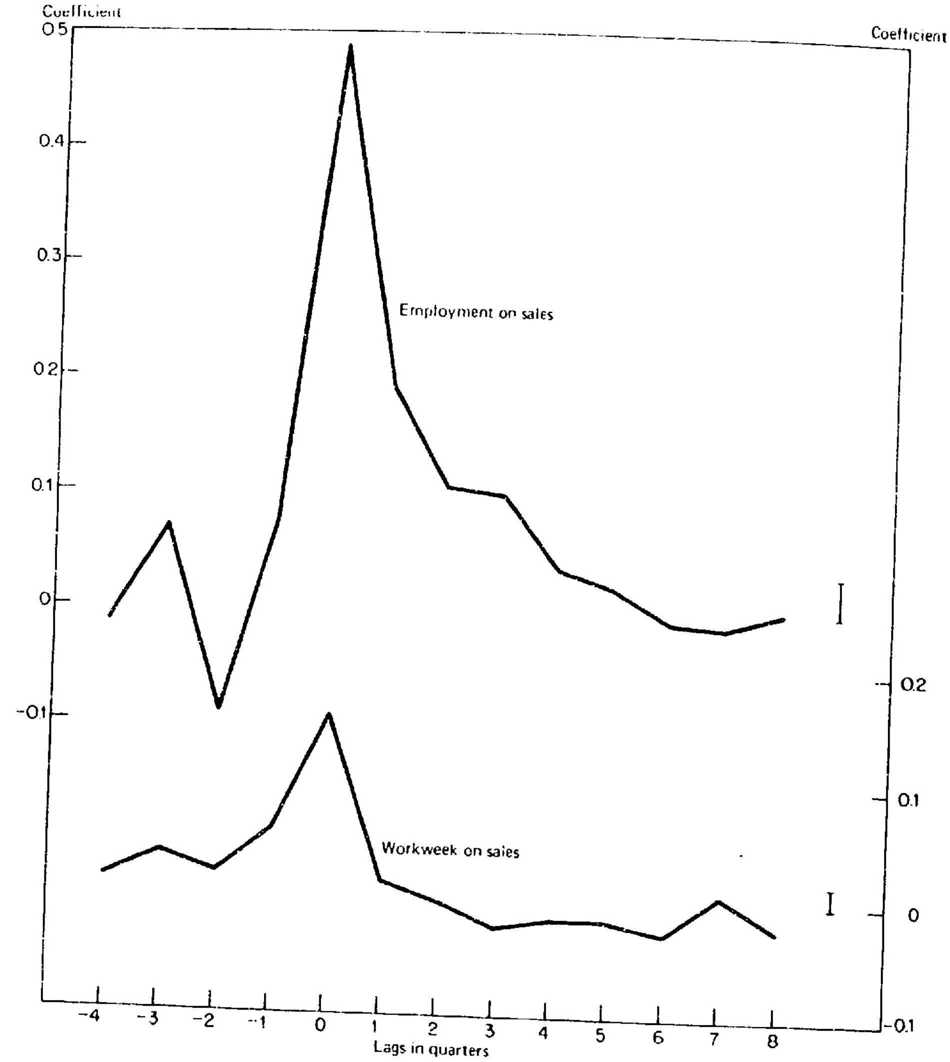


deflated sales. For all three industries, the largest coefficient is at zero and some tendency for coefficients on the past to be larger does appear. However, the tests reported in Table 5 show that the first four future coefficients are significant as a group in the total manufacturing and durable goods regressions. Turning to Chart IV, we see that breaking manhours into its work-week and employment components does not improve the shape of the lag distributions much, and the tests in Table 5 verify that these separate equations also show significant coefficients on negative lags. Furthermore, the employment on sales regression is unique

CHART IV

LAG DISTRIBUTION FOR EMPLOYMENT ON SALES AND WORKWEEK ON SALES

Note: Standard errors are displayed as vertical lines at the right hand side of the chart.



among the relations presented in this paper with any *a priori* or *expost* claim to being causal, in that it showed a highly significant change in coefficients between the earlier and later halves of the sample. (This test was made using time-domain estimates, but for the full sample time-domain and frequency-domain estimates were, as already noted, in very close agreement.)

We could stop here, noting that employment demand functions which treat sales as exogenous appear to be unjustifiable, were it not that the reversed regressions of sales on labor inputs show an unexpected pattern. In no case could significant groups of future coefficients be found in the sales on labor regressions. And

TABLE 5

TESTS FOR SIGNIFICANCE OF GROUPS OF COEFFICIENTS, LABOR VARIABLES ON SALES REGRESSIONS

Coefficients which are Zero under Null Hypothesis	Manufacturing	Durables	Nondurables
Four future:			
Manhours on sales	51.23*	24.61*	3.22
Employment on sales	8.41†	—	—
Workweek on sales	26.97*	—	
Current and eight past:			
Manhours on sales	88.28*	550.23*	60.77*
Employment on sales	297.44*	—	—
Workweek on sales	127.21*	—	—

Note: See note to Table 1. Statistics shown have asymptotic chi-squared distribution with degrees of freedom equal to number of coefficients in group being tested.

* Significant at 0.05 level.

† Significant at 0.10 level.

the reversed regression of sales on employment does not show a significant time-shift. Lag distributions for the relevant regressions appear in Charts V and VI and test results are in Table 6.

If inventory holding costs are high, there is no difficulty in explaining how sales could be determined by labor input. With high inventory costs, producers will use price and promotion to insure that sales and production remain in close correspondence. Deviations of sales from production might then be dominated by overshoots in marketing effort rather than by demand shifts. Hence the deviations between sales and production would not feed back into production decisions. If labor inputs and production are in very close correspondence in the short run, labor would be exogenous to sales.[14] The essential parts of this argument are (a) that deviations of sales from production might not carry any information about demand shifts and (b) that labor inputs and production might correspond with very small error in the short run. Thus measurement error in sales, large relative to that in labor input, could also explain the results.

But, if sales contains a substantial component of noise variance, unrelated to demand shifts, why does sales appear as exogenous in the investment demand equation? One plausible answer is that, because the standard errors on the labor equations are smaller, the effect of the errors in the sales variable simply fails to show up significantly in the investment equations. Sales, though an imperfect measure of demand shifts, is good enough to behave very well in an investment equation. If the proposed explanation for the exogeneity of labor with respect to sales is correct, manhours should also be exogenous to investment. Some pre-

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[14] By "close correspondence" is meant a relationship which leaves small residual error, though it may involve a lag distribution.

CHART V

LAG DISTRIBUTION FOR SALES ON MANHOURS

Note: Standard errors are displayed as vertical lines at the right hand side of the chart.

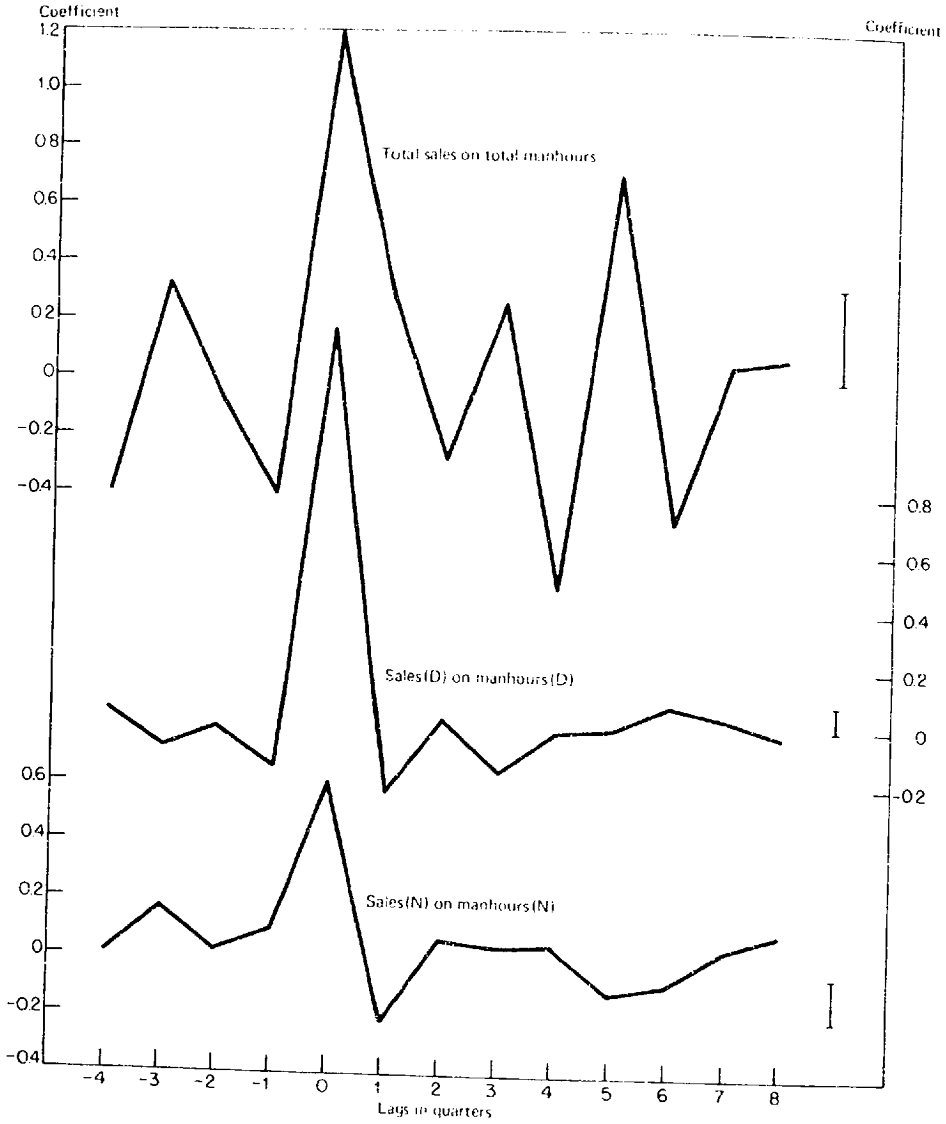


CHART VI

Lag Distribution for Sales on Employment and Workweek

Note: Standard errors are displayed as vertical lines at the right hand side of the chart.

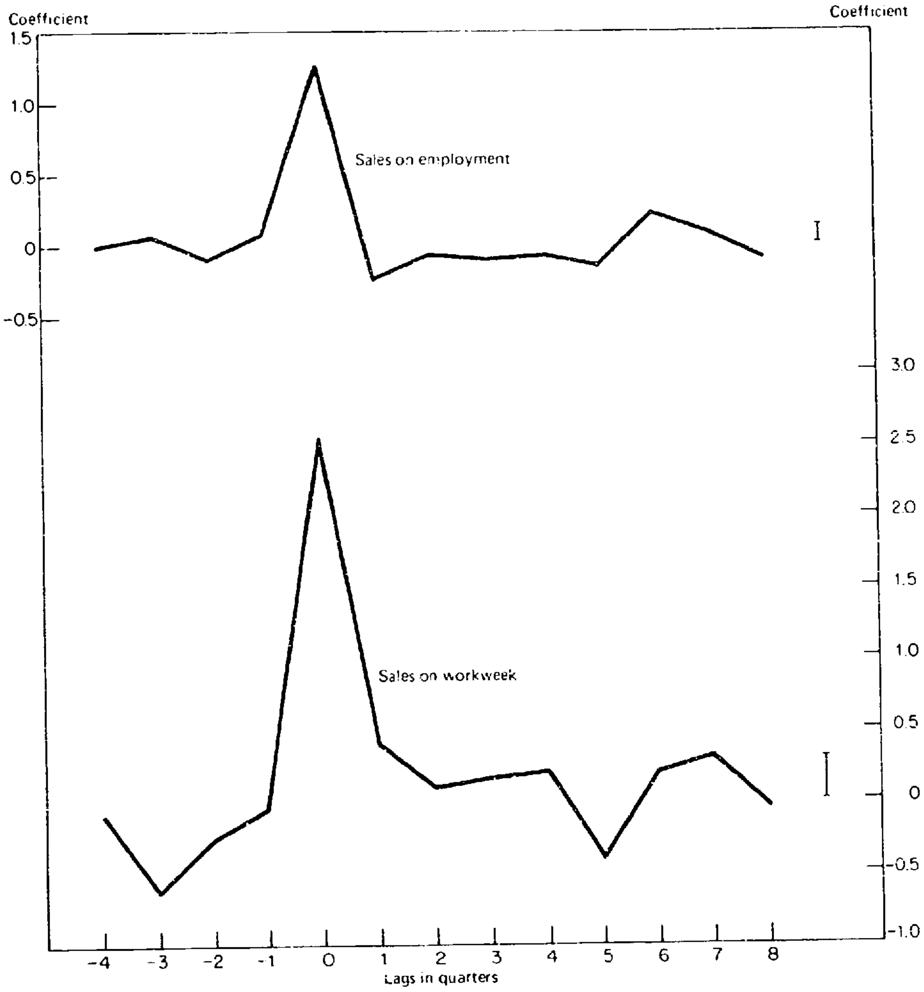


TABLE 6

TESTS FOR SIGNIFICANCE OF GROUPS OF COEFFICIENTS, SALES ON LABOR REGRESSIONS

Coefficients which are Zero under Null Hypothesis	Manufacturing	Durables	Nondurables
Four future:			
Sales on manhours	4.15	7.51	5.43
Sales on employment	0.93	-	
Sales on workweek	6.50	-	-
Current and eight past:			
Sales on manhours	38.36*	344.28*	24.93*
Sales on employment	148.04*	-	
Sales on workweek	121.08*	-	

Note: See note to Table 5.

* Significant at 0.05 level. Statistics not so marked are not significant even at 0.10 level.

liminary experiments with manhours and investment for total manufacturing suggest that this is indeed the case.

5. A REMARK ON SEASONALITY

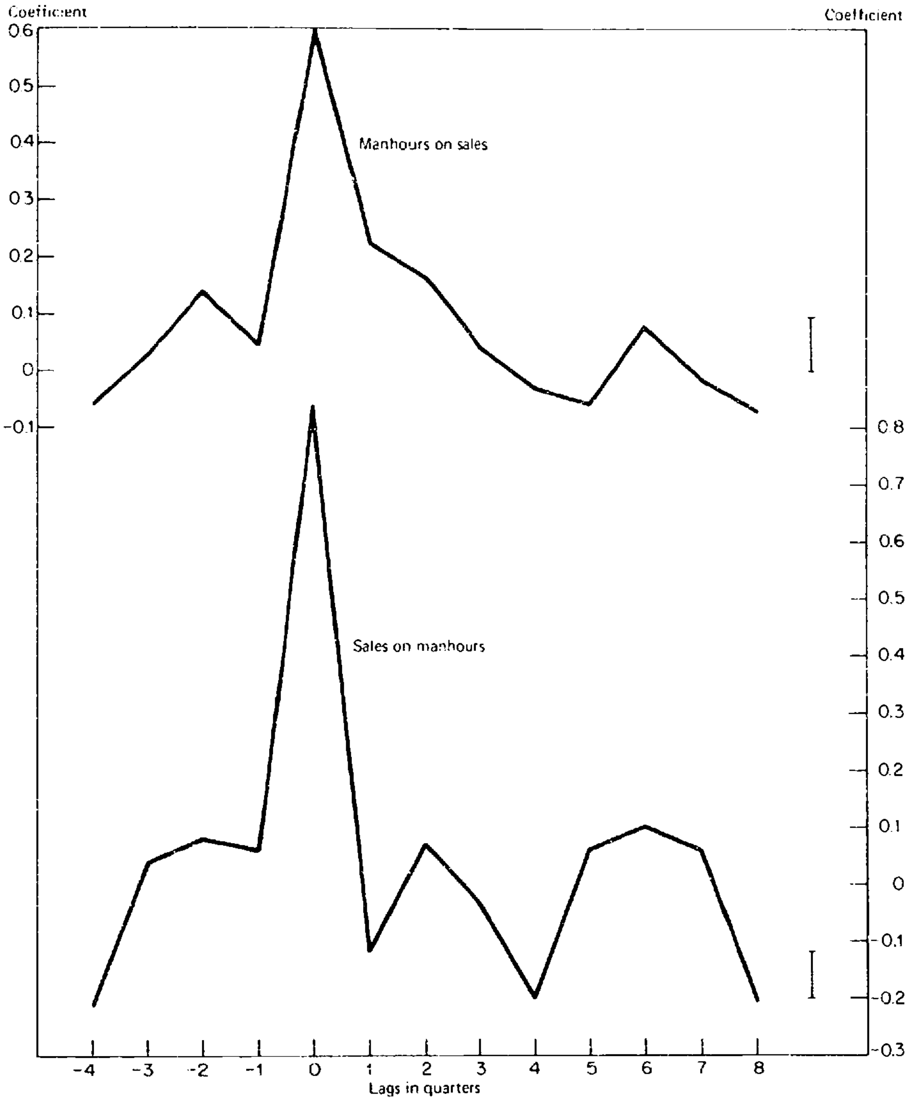
As I argued at some length in the earlier paper (1971), work with seasonally adjusted data in distributed lag estimation has some pitfalls. Most seasonal adjustment procedures used for published data allow the season pattern to shift in time, with the rate of shift flexible, depending on the particular series being adjusted. In the frequency domain, seasonal adjustment can be thought of as multiplication by a function which has the value one except near seasonal frequencies. If the seasonal pattern is not allowed to change in time, then the frequency-domain adjustment function will have a very narrow dip in absolute value near the seasonal frequencies. The more rapidly the adjustment procedure allows the seasonal pattern to change, the broader will be the dips near seasonal frequencies. It is not hard to show that this means that when the dependent variable has had a slowly-changing seasonal component extracted from it and the independent variable has had rapidly-changing seasonal component extracted from it, the estimated lag distribution will have a spurious pattern of seasonal variation.

In the initial round of estimates, there was one exception to the pattern of exogenous labor in the labor equations. Chart VII shows the estimated distributions for total manufacturing manhours on sales and sales on manhours with the published seasonally adjusted data. For these estimates, future coefficients were significant in the manhours on sales regression but also marginally significant for the sales on manhours regression. However, note that in the sales on manhours regression a sharp seasonal pattern appears: except for the large positive coefficient at zero, the distribution would be three rounded humps, with sharp dips at lags

CHART VII

LAG DISTRIBUTION FOR MANHOURS (SEASONALLY ADJUSTED DATA) AND SALES (SEASONALLY ADJUSTED DATA)

Note: Standard errors are displayed as vertical lines at the right hand side of the chart.



−4, 4, 8, and (presumably) zero. This makes it almost certain that aggregate manhours has been more rigidly deseasonalized than aggregate sales, and this regression was therefore re-estimated using data adjusted by a known procedure, no more rigid for dependent than for independent variable. The procedure actually used is described in the appendix. In extensive use of this procedure with other data, I have found that, except where a spurious seasonal appears in the lag distribution estimated from the published deseasonalized data, the method usually yields results almost identical to those obtained with published seasonally adjusted data.

As can be seen by comparing Chart VII with Charts III and V, use of consistently adjusted data has the expected effect of removing the seasonal pattern from the sales on manhours regression estimates. The flatter lag distribution obtained with the consistently adjusted data for manhours on sales would be expected if manhours not only were more flexibly deseasonalized than sales, but retained relatively more residual power at the seasonal than sales. In terms of the frequency domain, the latter result suggests that the official procedures multiply manhours by a function which has a broad dip near seasonal frequencies but with the dip not approaching zero as nearly as the corresponding dip for sales adjustment. Since the manhours series is obtained from separately adjusted employment and hours series, such "imperfect" seasonal adjustment seems not at all unlikely.

6. CONCLUSION

We can recapitulate this paper's results in order of increasing degree of conflict with the assumptions of past research. First, the practice of treating sales or output as exogenous in time series estimates of distributed lag accelerator models of investment has been confirmed as reasonable. Second, doubts have been raised about the practice of treating factor-price variables as exogenous in factor-demand equations, at least at this level of aggregation. At the very least, estimates of price effects should be accompanied by tests of the exogeneity assumption. Third, the practice of treating sales as exogenous in labor demand functions has been strongly rejected. There is evidence that a better approach to finding the short-run relation between labor inputs and output is to estimate short-run single-factor "production functions," in which labor input variables are treated as exogenous.

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APPENDIX

1. *Estimation Methods*

The frequency domain estimation method applied in this study is Hannan's inefficient procedure, as described in, e.g., Wahba (1969). This method takes the estimated lag distribution for y regressed on x as the inverse Fourier transform of $S_x^{-1}S_{yx}$, where S_{yx} is a consistent estimate of the cross-spectral density of y and x and S_x is a consistent estimate of the spectral density matrix of x. These estimates have (under certain conditions on the lag distribution, the autocovariance function for x and y, and the choice of estimator for S_{yx} and S_x) an asymptotically normal distribution with autocovariance function given by the inverse Fourier transform of $(1/T)S_x^{-1}S_u$, where S_u is the spectral density of the regression residual and T is sample size.

The Hannan inefficient estimator has the great advantage that the estimate for an individual coefficient is independent of how many other lagged values are included in the regression. Thus there is no need for repeating the estimation procedure several times when the length of the lag distribution is not well-determined *a priori*. The method also can save absolutely on computation time, even for a single regression estimate, because it exploits the fact that the sample variance-covariance matrix of lagged values of a single variable in stationary time series data will be roughly constant along diagonals.

In work for this paper, the frequency-domain manipulations were accomplished with the program SPECTRE (available from NBER, written in IBM 360/65 Fortran IV) which is a Fast Fourier transform subroutine surrounded by provisions for input-output and complex arithmetic. Data series were initially Fourier transformed, with the transforms calculated at $2^n > T$ points. Spectral density and cross-spectral densities were estimated directly by smoothing the periodograms with a square, or Daniell, window. Seasonal adjustment, when necessary, was accomplished by setting to zero the components of the periodogram and cross-periodogram within some band about the seasonal frequencies. This of course leads to some bias toward zero in the smoothed spectral and cross-spectral estimates, but since the bias occurs in a similar way for both the spectrum and the cross-spectrum, the bias tends to cancel out in the estimates of the lag distribution.

Tests on groups of coefficients from the frequency-domain estimates were accomplished by using the fact that for a normal vector x with mean zero and variance-covariance matrix W, $x'W^{-1}x$ is chi-squared with degrees of freedom equal to the order of W. Since the frequency-domain estimates are asymptotically normal and we can estimate their autocovariance properties, asymptotically chi-squared test statistics can be directly computed. An auxiliary program was used to do this on an IBM 1130.

As noted in the test, most of the frequency-domain estimates involving a single independent variable were verified using time domain least squares estimates. In these estimates the logged data were filtered so that each variable y was replaced by $Y(t) = y(t) - ay(t-1) + by(t-2)$. In all cases but one, the initial choice of $a = 1.5$, $b = 0.5625$ sufficed to remove gross evidence of serial correlation in the residuals. In the case of the non-durable investment equation, a choice of $a = 1.2$, $b = 0.36$ proved necessary in order to avoid negative serial correlation. All regressions included trend term and a constant.

2. *Definitions of Variables and Data Sources*

All data except those for c came directly from the NBER data bank. Original sources are given below. Investment: New plant and equipment expenditures, quarterly, seasonally adjusted (from the *Survey of Current Business*) deflated by the implicit price deflator for nonresidential fixed investment in the GNP accounts.

Employment: Employment of production workers, seasonally adjusted monthly data aggregated to quarterly (from *Business Statistics* and *Employment and Earnings*).

Workweek: Average weekly hours of production workers, seasonally adjusted monthly data aggregated to quarterly (from *Business Statistics* and *Employment and Earnings*).

Manhours: Product of preceding two variables.

Sales: Manufacturing shipments (from *Business Statistics* and *Current Industrial Reports, Series M3-1, Manufacturers Shipments, Inventories, and Orders*) deflated by wholesale price index for manufacturing (from unpublished source, but available on NBER data bank).

c: The Nadiri *c* was obtained directly from him and has been used by him in recent work on factor demands. The Coen *c* came from his paper (1968), p. 205. Nadiri uses a long-term government bond rate as the base for user cost. Coen the AAA bond yield. Nadiri adjusts for the investment tax credit in 1962 and 1963, but makes no adjustments for the 1954 and mid-1962 changes in depreciation guidelines. Coen does adjust for changes in depreciation guidelines. As noted in the text, the Coen series is shorter than the sample used in the regressions in this paper not using the Coen series, and was crudely converted to a quarterly basis for the purposes of this paper.

Wage: Seasonally adjusted wage for manufacturing production workers, adjusted for overtime hours and interindustry shifts (available on NBER data bank. Original source in part BLS publications, though back data for seasonally adjusted series is as yet unpublished).

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