MANUFACTURERS' INVENTORIES, SALES EXPECTATIONS, AND THE ACCELERATION PRINCIPLE

BY MICHAEL LOVELL

The response of manufacturers' inventory holdings to changes in the volume of sales and the backlog of unfilled orders is examined on a quarterly basis for the period 1946–55 within a buffer-stock flexible accelerator framework. The hypothesis that manufacturers successfully hedge against increases in the price of purchased materials, enlarging their stocks in advance of actual price increases, is rejected. By introducing explicitly the impact of prediction errors it is possible to infer that manufacturers tend to underestimate actual changes in sales volume, but by a surprisingly small amount. An analysis of discrepancies between desired and actual inventory holdings reveals that manufacturers tolerated sizable deficiencies in stocks throughout the Korean conflict.

1. INTRODUCTION

IN HIS METICULOUS investigation of the behavior of manufacturers' inventories during the interwar period, Moses Abramovitz considered the most elementary of accelerator models, the hypothesis that maintains [1, p. 20]:

Manufacturers and merchants are both desirous and able to maintain inventories in constant ratio to their output or sales, . . . (that) inventories vary directly and proportionately with output.

Abramovitz found that this most simple concept of the accelerator was not consistent with observed behavior. Contrary to hypothesis, actual inventory investment does not lead peaks and troughs of output; inventory investment is not proportionate to the rate of change in output.

The greater variety and detail of data for the postwar period permit us to consider more complex versions of the acceleration principle. One modification involves the flexible accelerator concept originally presented by Richard Goodwin [6], a model that assumes that business firms attempt only a partial adjustment of stocks to their equilibrium level during each

1 This paper constitutes a revision of certain materials appearing in my doctoral dissertation [12, Ch. 3], a research project supervised by Wassily Leontief. I am indebted to the Earhart Foundation, the Social Science Research Council, and the Cowles Foundation for Research in Economics for financial support. Computations were performed at the Littauer Statistical Laboratory, Harvard University, and the Yale Computing Center. Albert Beaton, William Locke Anderson, Gerald Kraft, and Harold Watts, provided helpful advice in connection with data processing problems. I wish to express appreciation for the advice and criticism of Leo Bakony, George M. Cobren, James Henderson, Ruth Mack, Edwin S. Mills, Arthur M. Okun, Richard Porter, and Thomas M. Stanback, Jr.; but I must bear full responsibility for any remaining errors.
production period. A second complication of the basic accelerator involves
the hypothesis of Lundberg [13] and Metzler [16] that errors made by firms
in forecasting future sales generate discrepancies between the actual and the
desired level of inventories. In this paper both these complications are
considered in investigating the appropriateness of the accelerator as a
mechanism explaining inventory behavior. We also consider the possibility
that unfilled orders and expected price changes as well as the volume of
activity affect the desired level of stocks.

Both the flexible accelerator model of Goodwin and the buffer stock
type of inventory model advanced by Lundberg and Metzler explain the
generation of discrepancies between actual and "equilibrium" or "desired"
inventories. Estimates of the parameters of an accelerator model incorpo-
rating the complications introduced by these economists are utilized to
compute a series of surplus inventories, the deviation of actual stocks from
their equilibrium levels. These estimates of surpluses and deficiencies in
manufacturers' inventory holdings are presented in the concluding section
of this paper.

The task of investigating dynamic inventory phenomena is complicated
by the difficulties involved in obtaining appropriate data based on observa-
tions collected at more frequent than yearly intervals. Since the planning
horizon of the firm is surely shorter than a year for decisions involving output
adjustment and inventory, annual data will not do. I have not succeeded in
obtaining appropriate cross-section data on individual firms. This study is
based on quarterly time series data at a fairly high level of aggregation. For
total durable and total nondurable sectors of manufacturing, the Office of
Business Economics, Department of Commerce, publishes data broken down
by stage of fabrication into purchased materials, goods in process, and
finished goods categories. But when we turn to Commerce data for individual
industries we find that the more detailed breakdown as to industry must be
paid for by sacrificing the stage of fabrication classification. Nevertheless,
these are the data we must use. Thomas M. Stanback, Jr. of New York
University kindly provided deflated, deseasonalized sets of the Commerce
inventory data for the years 1948 to 1955. W. H. Locke Anderson of Harvard
University collaborated with me in deflating comparable sets of sales and
unfilled orders data from Office of Business Economics series published by
the Department of Commerce in the Survey of Current Business. Output is

2 Goodwin's flexible accelerator is related to Chenery's overcapacity principle [2].
3 Stanback has published a description of the deflation procedure in his excellent
study of postwar inventory behavior [19, p. 91]. For a general discussion of the diffi-
culties involved in deflating inventories see Cobden [3]. He describes the deflation
procedure utilized by the National Income Division, Department of Commerce, a
procedure similar to that employed by Stanback.
defined as sales plus any increase in finished goods inventory, rather than measured independently.

We shall first consider two separate accelerator models of inventory behavior. The first of these is appropriately applied to stocks of purchased materials and goods in process; the second to finished goods inventory. These models are tested against the durable and nondurable sector data in the next two sections of this paper. Then, in Section 4, we combine these two models into a single equation explaining the behavior of total inventory holdings in each of the five component durable goods industries.

2. STOCKS OF PURCHASED MATERIALS AND GOODS IN PROCESS

In applying the principle of acceleration to stocks of purchased materials and goods in process it seems reasonable to relate stocks at the beginning of the production period, $S_t$, to output forthcoming during the period, $Q_t$. If the relation is linear, the equilibrium level of stocks, $S'_t$, may be represented by the equation

$$S'_t = \alpha + \beta Q_t.$$  

The coefficient $\beta$ is the "marginal desired inventory coefficient."

Only the simplest version of the accelerator hypothesis asserts that entrepreneurs always succeed in maintaining stocks at the equilibrium level. Goodwin's flexible accelerator concept provides one explanation of departures of stocks from their equilibrium level.\(^4\) Now suppose output is initially at $Q_1$ with stocks at $S_1$, not necessarily the equilibrium level. If output then increases to $Q_2$, the simple accelerator hypothesis implies that stocks would be adjusted immediately to the new equilibrium level $S'_2 = \alpha + \beta Q_2$, that supplies acquired would exceed immediate production requirements by $S'_2 - S_1$. But Goodwin supposes that an immediate adjustment of stocks is not attempted. Entrepreneurs are assumed to make only a partial adjustment of stocks to the equilibrium level each period. This may be due to costs involved in changing the level of stocks. It may also stem from problems concerned with the heterogeneous nature of stocks, the infrequent intervals at which certain items are ordered, and so forth. Certain categories of purchased materials may be held by the firm in relatively large stocks as a result of recent deliveries of carload orders; they will be liquidated only gradually as production demands require their utilization. On the other hand,

\(^4\) We shall regard production plans as reasonably firm at the beginning of periods so that the buffer stock motive can be neglected in the study of purchased materials and goods in process stocks; but this alternative explanation of departures of stocks from their equilibrium level will be considered in the examination of finished goods inventory behavior.
a rapid increase in the holdings of certain items warranted by a higher level of activity would be costly if a premium has to be paid for fast delivery. Such factors as these may explain why only a partial attempt to adjust inventories to the level dictated by equation (2.1) may be attempted in any one period. The assumption that actual inventory investment, $\Delta S_t$, is only a fraction of that required to adjust stocks to the equilibrium level is reflected in the equation

$$\Delta S_t = S_t - S_{t-1} = \delta(S^e_t - S_{t-1}) = \delta x + \delta p_Q t - \delta S_{t-1}. \quad (2.2)$$

Adding $S_{t-1}$ to both sides of this equation yields

$$S_t = \delta x + \delta p_Q t + (1 - \delta) S_{t-1}. \quad (2.3)$$

This generalization reduces to the simple accelerator hypothesis for the special case in which $\delta$, the reaction coefficient, is unity.

The flexible version of the acceleration principle is related to Ruth Mack's notion of "passive inventory investment." She asserts [14, p. 480]:

Passive inventory investment or disinvestment takes place in part because plans about the proper size of stocks are hardly precise figures; instead they are ranges, and variation within the range or band is a matter of indifference.

But our equation implies that while there may be a precise notion as to the appropriate size of stocks, business firms' investment in stocks is "passive" in the sense that they are not overly concerned with obtaining a rapid adjustment to that level when changes in business conditions cause stocks to depart from it.\(^5\)

Within the framework of the flexible accelerator model three additional factors that may complicate the determination of the size of stocks of purchased materials and goods in process deserve consideration.

(a) Price speculation. Manufacturers may attempt to hedge against anticipated increases in the price of inputs by adjusting their inventory position, purchasing additional stocks when price rises are expected and reducing the level of stocks when price reductions are anticipated. An adequate test of the prevalence of inventory speculation would require knowledge of expected price changes. Unfortunately, data on price anticipations are not available. While a possible approach would be to attempt to incorporate within the model assumptions concerning the actual structure by which anticipations of future price changes are generated, there are a

\(^5\) Franco Modigliani has commented upon the relation between the flexible accelerator and Ruth Mack's concept of passive inventory investment. He quite rightly suggested that the speed of adjustment may depend upon the size of the discrepancy between desired and actual inventories [18]. One might well conjecture that it would be difficult to distinguish passive from delayed adjustment inventory behavior empirically.
vast number of alternative equations based on a naive projection of past
price changes, distributive lag relations and so forth, admissible as candidates
for this purpose. Rather than attempt on the basis of experimentation with
a sample of inadequate size to determine the actual structure by which
anticipations are generated, an alternative approach may be followed to
the issue of whether a speculation motive partially determines the size
of stocks of purchased materials and goods in process. Profitable speculation
would involve expanding inventories above the level dictated by other
considerations in advance of actual price increases and in reducing them
below customary levels prior to actual reductions in price. Including the
percentage increase of actual prices in the next period in the regression
amounts to testing the hypothesis that entrepreneurs in fact speculate
successfully, accumulating stocks that are larger than would be suggested
by purely nonmonetary considerations in advance of actual price increases,
and conversely. It assumes that actual changes are correctly anticipated,
as is required for profitable speculation. Conversely, if entrepreneurs are
the opposite of clairvoyant, speculating on the basis of perverse price
anticipations that are negatively correlated with actual developments,
the regression coefficient for the actual future price change would be
negative.

(b) Changes in output. Departures of stocks from the level suggested
by the simple accelerator principle may also occur when output is sharply
changing. When output is increasing, orders may be placed with suppliers
in an attempt to build up stocks, but considerable delays may be involved in
obtaining delivery. Consequently, there may be a tendency for stocks of
purchased materials to fall below the desired level when output is rising,
when ΔQt > 0, and conversely. This tendency, which is quite apart from
flexible accelerator complications, may be accentuated by the need to
measure output only at the final stage of the production process; output
is defined as sales plus any increase in finished goods inventories.

(c) Unfilled orders. The equilibrium level of stocks may depend on other
factors besides output. In particular, we argue that unfilled orders as well
as output should be included in equation (2.1). Entrepreneurs may have
reasonably precise plans for production in the next period. They may also
consider a longer planning horizon in deciding upon the change in stocks to be
made in the current period. After all, delivery lags and costs of adjustment
will prevent in any case the attainment of the level of stocks that is sug-
gested by current output and speculation considerations. If unfilled orders
represent an established demand, indeed a possible committal to deliver at
some future date, entrepreneurs may well consider it advisable to carry addi-
tional stocks when unfilled orders are large as a hedge against possible shortage
and price commitments. In addition, a rise in the backlog of unfilled orders

may be expected to lead to an acceleration of production that is felt first
in terms of an increase of goods in process rather than a rise in the
output of completed commodities. These considerations suggest that
stocks of purchased materials and goods in process should be positively
related to the backlog of unfilled orders.\footnote{Stanback observed a close correspondence between turning points for unfilled
orders and stocks of purchased materials [19, p. 90]. P. Darling suggests that the change
in unfilled orders should be considered in explaining the behavior of total inventory
holdings [4].} Conversely, if unfilled orders were only a surrogate measure of the tightness of the markets on which
firms purchase their inputs, a negative relationship between orders and
stocks would be revealed when unfilled orders at the beginning of the
period, \( U_t \), are considered in the regression. These considerations suggest
that a more complicated equation than (2.1) describes the equilibrium
level of manufacturers’ stocks of purchased materials and goods in process:

\[
S_t^* = \alpha + \beta_1 Q_t + \beta_2 \Delta Q_t + \beta_3 \left( \frac{p_t - p_{t-1}}{p_t} \right) + \beta_4 U_t ,
\]

where \( p_t \) is the level of the price index at the end of period \( t \).

If, following Goodwin, actual stocks are assumed to result from only a par-
tial adjustment of last period’s stocks towards the current equilibrium level,
we have

\[
S_t = \delta(\alpha + \beta_1 Q_t + \beta_2 \Delta Q_t + \beta_3 \left( \frac{p_t - p_{t-1}}{p_t} \right) + \beta_4 U_t) + (1 - \delta)S_{t-1} + \epsilon_t .
\]

The residual, \( \epsilon_t \), may be regarded as representing variables omitted from
the analysis. It may be observed that an expression for investment in stocks is
obtained by subtracting \( S_{t-1} \) from both sides of the equation, yielding

\[
\Delta S_t = \delta \alpha + \delta \beta_1 Q_t + \delta \beta_2 \Delta Q_t + \delta \beta_3 \left( \frac{p_t - p_{t-1}}{p_t} \right) + \delta \beta_4 U_t - \delta S_{t-1} + \epsilon_t .
\]

Since the magnitude of the residual is unaffected, it is immaterial which of
these two equations we fit by the method of least squares.\footnote{The magnitude of the regression coefficients and their estimated standard errors
will be precisely the same; of course, the multiple correlation coefficient will probably
be smaller for (2.4), as the variance of inventory investment is usually larger than the
variance of the stock itself.} The regression coefficients obtained by least squares may obviously be unscrambled
in order to obtain implied estimates of the model’s parameters.

Do entrepreneurs speculate in stocks? Are unfilled orders a major factor
influencing the inventory position of firms? Does a flexible accelerator model
provide a reasonable description of observed inventory behavior during the
post World War II period? These are interesting questions, but it must be
emphasized that the estimates presented in this paper have been obtained by applying crude least squares procedures to embarrassingly short time series. True, Mann and Wald [15] have demonstrated that if the residuals of a model of the form (2.4) are normally and independently distributed, the least squares procedure will yield maximum likelihood estimates of the equation's parameters. But this is of little consolation, at least for hypothesis testing, as it has been demonstrated by Leonid Hurwicz [8] that the inclusion of the predetermined variable $S_{t-1}$ means that the estimates are biased. Quite apart from this, if the error terms $e_t$ are autocorrelated, the $t$ distribution may not be appropriately applied in tests of hypotheses about the magnitude of the regression coefficients without adjustment\footnote{For the case in which predetermined variables are not present Wold [21, pp. 209-213] has derived the appropriate correction procedure; the corrected value of $t$ may be either larger or smaller than that obtained by dividing the regression coefficient by the "standard error" obtained by simple, least squares procedures. An alternative approach is suggested by Klein [10, pp. 85-92].} and, in addition, the estimating procedure is not efficient. Perhaps the most crucial limitation is that consideration of a single equation neglects the underlying, possibly simultaneous, interdependent nature of the economy. These difficulties must be kept firmly in mind in examining estimates of the parameters of equations obtained by applying the least squares procedure, particularly in interpreting estimates of the standard errors of the regression coefficients. While the figures reported in the following tables are carried out to four places, this represents a spurious accuracy and is not indicative of precision estimates.

Table I presents the estimates.\footnote{Least squares estimates of the standard error of the regression coefficients appear below each estimate in parentheses. The coefficient of determination, $R^2$, applies to the case in which total stocks are taken as the dependent variable. $d$ is a statistic utilized in the Durbin-Watson test for serial correlation of residuals. Let $h = 5$ be the number of explanatory variables, $n = 29$ the number of observations, and $d = \Sigma (e_t - e_{t-1})^2 / \Sigma e_t^2$, where $e_t$ is the observed residual. Then the hypothesis of no serial correlation is to be rejected at the 5 per cent level if $d < 1.05$ or accepted if $d > 1.84$; otherwise the situation is indeterminate. This test is based on a distribution derived only for equations which do not involve predetermined variables; consequently, it is not strictly valid for our problem. Cf. Durbin and Watson [5].} It is to be observed that all the reaction coefficients, $\delta$, are of the right sign and less than unity. This is encouraging, for one would be at a loss to explain a value of $\delta$ outside this range. Indeed, a reaction coefficient of acceptable magnitude is a prerequisite that must be satisfied if any meaning is to be attached to the other coefficients obtained in the regression. It must be admitted that the reaction coefficient for nondurable manufacturing is exceedingly small, indeed almost unreasonably so; this implies that entrepreneurs are little concerned with adjusting inventories to the appropriate level for this sector of the economy. For all sectors
\[ S_t = \delta \alpha + \delta \beta_1 Q_t + \delta \beta_2 \Delta Q_t + \delta \beta_3 (p_t - p_{t-1})/p_t + \delta \beta_4 U_t + (1 - \delta)S_{t-1} + \varepsilon_t. \]

<table>
<thead>
<tr>
<th>Number of Observations</th>
<th>Total Manufacturing</th>
<th>Total Durables</th>
<th>Total Nondurables</th>
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The values of the reaction coefficients are sufficiently small to be inconsistent with the simple accelerator hypothesis which maintains that entrepreneurs attempt an immediate adjustment of inventories to the desired level; these estimates of the reaction coefficients lend support to the flexible accelerator concept of Richard Goodwin.\(^{10}\)

Perhaps the evidence is clearest with regard to speculation. Certainly, there is no support for the hypothesis that manufacturers successfully speculate in stocks of purchased materials and goods in process. The sign for total manufacturing is negative, contrary to hypothesis; while the coeffi-

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\(^{10}\) These estimates of the reaction coefficients for inventories may be compared with idle money balance adjustment figures implied by a recent study by M. Bronfenbrenner and T. Mayer. They report in "Liquidity Functions in the American Economy," *Econometrica*, Vol. 28 (1960), p. 817, three annual adjustment coefficients for the money market ranging in magnitude from 0.28 to 0.46. If the quarterly inventory reaction coefficients of Table I are converted by the equation \( 1 - (1 - \delta)^4 \) we obtain annual reaction coefficients of 0.34, 0.84, and 0.91 for nondurable, durable, and total manufacturing stocks respectively. Relative to the adjustments of the money market, manufacturers adapt their stocks of purchased materials and goods in process rather rapidly. This touches upon the issue of the speed with which the full impact of fiscal as opposed to monetary policy is felt by the economy.
TABLE II

Finished Goods Inventory

\[ I_t = \delta x + \beta X_t - (\delta \beta + 1) q \Delta X_t + (1 - \delta) I_{t-1} + \epsilon_t \]

<table>
<thead>
<tr>
<th>Number of Observations</th>
<th>Total Manufacturing</th>
<th>Total Durables</th>
<th>Total Nondurables</th>
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<tr>
<td>30</td>
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| \( \delta x \)          | -258.2             | -325.8         | 418.7            |
| \( \delta \beta \)      | .0419              | .0550          | .0058            |
| (.0203)                 | (.0143)            | (.0292)        |
| \( (\delta \beta + 1) q \) | .1315             | .0970          | .1695            |
| (.0417)                 | (.0283)            | (.0685)        |
| \( (1 - \delta) \)      | .8479              | .8171          | .9331            |
| (.0649)                 | (.0523)            | (.0850)        |
| \( \delta \)           | .1521              | .1829          | .0649            |
| \( \varrho \)          | .1262              | .0919          | .1685            |
| \( \beta \)           | .2755              | .3007          | .0894            |
| \( \delta \)           | 1.39               | 1.33           | 1.57             |
| \( \varphi \)          | .958               | .966           | .947             |

cients are of the right sign for the durable and nondurable sectors, they are exceedingly small relative to their standard errors. While there is no reason for questioning Abramovitz’s tentative conclusion that price hedging is not an important phenomenon [1, pp. 127-31], two qualifications to our argument must be mentioned. In the first place, successful speculation on the part of individual firms may involve adjustments in the composition of inventories rather than any change in their aggregate volume; firms may expand their holdings of those commodities whose prices are expected to increase most rapidly and make proportionate reductions in their holdings of other commodities whose prices are expected to fall or at least rise less rapidly. A second qualification also arises from a problem of aggregation. It is possible that while firms within each industry successfully anticipate price changes and adjust the size of their inventory holdings accordingly, the effects of speculation may cancel out when we aggregate over several industries in examining data for total durables and nondurables. Evidence for individual industries presented in Table III below suggests that the negative conclusion concerning speculation is not simply the consequence of aggregating to the durable and nondurable level. While there is no basis for rejecting the conjecture that firms change only the composition rather than the magnitude of their inventory holdings in response to price changes, it may well be that such a restricted form of speculation would be of little import as far as explaining cyclical disturbances in the general level of economic activity is concerned.
TABLE III

Total Inventories

\[ H_t = \delta x + \delta \beta_1 X_t + (1-\delta) H_{t-1} - (\delta \beta_2 + 1) \varrho \Delta X_t + \delta \beta_3 U_t + \delta \beta_4 (\Delta P_{t+1}/P_t) + \epsilon_t \]

<table>
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<tr>
<th>Number of Observations</th>
<th>Total Manufacturing</th>
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</table>

* Lack of data precluded the inclusion of unfilled orders in the stone, clay, and glass regression and of both the percentage price change and unfilled orders for other durables.
The estimates obtained for $\beta_4$ suggest that unfilled orders are an important determinant of the level of stocks. To the extent that the backlog of unfilled orders represents an established demand, entrepreneurs increase their stocks of purchased materials as output expands at earlier stages of production. The rather small estimates obtained for the marginal desired inventory coefficient, $\beta_1$, reflects the role of the backlog of unfilled orders as well as the scale of output in determining the desired level of purchased materials and goods in process. Nevertheless, it is surprising that in every case $\beta_1$ plus $\beta_2$ add to a negative figure as this implies that stocks are lower, other things being equal, in advance of increases in output.\textsuperscript{11} But with the exception of this peculiarity, which may best be attributed to sampling error,\textsuperscript{12} all parameter estimates are in conformity with the flexible accelerator inventory model, modified by the inclusion of unfilled orders.

3. INVENTORIES OF FINISHED GOODS: THE BUFFER STOCK MOTIVE

Planned output is one of the variables considered by the firm in determining the appropriate adjustment of purchased materials and goods in process. The decision concerning the appropriate level of output is in turn based upon anticipated sales and the current inventory of finished goods. The buffer stock inventory model recognizes that the production process is time consuming. It is a modification of the basic accelerator designed to take into account errors made by firms in anticipating future sales. In the form in which the model was originally considered by Lundberg and Metzler, desired end of period inventories, $I_t^d$, were assumed to be linearly related to sales volume

\begin{equation}
I_t^d = \alpha + \beta X_t.
\end{equation}

But actual sales are not known by the firm in advance of output when the production decision must be made. A planned level of inventories, $I_t^p$, may be defined by substituting anticipated sales, $X_t$, into (3.1). Actual end of period inventories will differ from this planned level if sales turn out to exceed the expected volume, and conversely. Consequently, actual end of period inventories, $I_t$, are given by the equation

\begin{equation}
I_t = I_t^p + (X_t - X_t) = \alpha + (1 + \beta) X_t - X_t.
\end{equation}

\textsuperscript{11} Because $\beta_1 Q_t + \beta_2 (Q_t - Q_{t-1}) = \beta_1 Q_{t-1} + (\beta_1 + \beta_2) [Q_t - Q_{t-1}]$.

\textsuperscript{12} An alternative explanation, in the spirit of the analysis of finished goods inventory that follows, is to assume that observed output, $Q_t$, is the result of a flexible adjustment, based on subsequent sales experience during the quarter, of the production plan that was utilized in determining the initial stock of purchased material and goods in process.
Lundberg and Metzler explained deviations of actual inventories from the equilibrium level in terms of errors in anticipating future sales.\(^{13}\)

The buffer stock inventory model is readily married with Goodwin's flexible accelerator. If it is again supposed that the firm attempts only a partial adjustment of its inventory to the new equilibrium level, we have as the equation for the planned level of inventory

\[
I_t^p = \delta I_t^p + (1 - \delta) I_{t-1}, \quad 0 < \delta \leq 1,
\]

where \(\delta\) is the reaction coefficient. Output is set at anticipated sales plus the excess of planned inventory over actual beginning period inventory. Since this production decision is assumed irrevocable, any subsequent deviation of actual sales from the anticipated volume leads to a corresponding departure of actual inventory from the planned level.\(^{14}\) As with the simple buffer stock inventory model, actual inventories will deviate from the planned level by any excess of anticipated over actual sales:

\[
I_t = I_t^p + \dot{X}_t - X_t = \delta I_t^p + (1 - \delta) I_{t-1} + \dot{X}_t - X_t = \\
\delta (\alpha + \beta \dot{X}_t) + (1 - \delta) I_{t-1} + \dot{X}_t - X_t.
\]

This is the flexible accelerator version of the buffer stock inventory model. For the special case in which \(\delta = 1\) it reduces to the more elementary equation considered by Lundberg and Metzler, (3.2) above.

Investigation of the buffer stock motive of inventory behavior necessarily involves complications concerning the nature of sales expectations. Since sales expectations are not an item in the accounting records of firms they may be measured directly only by \textit{ex ante} questionnaires; consequently, it is most difficult to obtain quantitative measures of manufacturers' sales expectations.\(^{15}\) We adopt a strategy which enables us to analyze the buffer

\(^{13}\) It may be objected that the buffer stock model is not appropriate in those cases in which the scale of production is determined on the basis of specific orders for finished commodities; but Stanback may well have been justified in concluding that finished goods made to specific order are shipped almost upon completion so that variations in the size of this inventory category make a negligible contribution to fluctuations in total finished goods inventory [19, p. 89]. Abramovitz has emphasized that a test of the buffer stock model is "plagued by lack of an objective standard by which to judge a surplus or deficit of stocks." He rejects the special case of the theory in which it is assumed that \(\alpha = 0\), that manufacturers attempt to keep a constant ratio of inventories to sales [1, p. 152].

\(^{14}\) Observe that an upper bound to actual sales is provided by the restraint that inventories cannot be negative.

\(^{15}\) When data relating to expectations are accumulated, their validity may still be open to question. Albert G. Hart has made a gallant attempt to "reconstitute" Railroad Shippers Forecast data for the interwar period into a revised series more in conformity with preconceived concepts as to how expectations should behave [7].
stock inventory model without relying upon any attempt at measuring actual sales expectations. We look for the impact of errors in forecasting upon measured inventory and sales data. We shall find that the need to consider sales expectations does not only present difficulties in the analysis of inventories; it is also rewarding in that something may be inferred concerning the nature of sales expectations as well as desired inventories from observing actual sales and inventory behavior.

One possible strategy would be to adopt the assumption of static expectations, to let \( X_t = X_{t-1} \). But we will consider a more general hypothesis concerning the nature of expectations. After all, the assumption of naive expectations is an insult to the entrepreneur; surely he can do better than this. On the other hand, to assume perfect expectations is to attribute to him the power of the soothsayer.\(^{16}\) John Maynard Keynes makes a provocative suggestion that may help us. He states [9, p. 51]:

\[ \ldots \text{it is sensible for producers to base their expectations on the assumption that the most recently realized results will continue except in so far as there are definite reasons for expecting a change.} \]

If the firm's adjustment of the simple, naive projection based on definite information is in the right direction, the level of sales actually expected would fall between the two extremes of static and perfect forecasting. More precisely, we may hypothesize

\[
(3.5) \quad \dot{X}_t = \varrho X_{t-1} + (1 - \varrho) X_t, \quad 0 \leq \varrho \leq 1.
\]

If \( \varrho = 1 \) we have the extreme of static expectation; \( \varrho = 0 \) corresponds to the opposite case in which there is no systematic tendency either to over or to underestimate the actual change in sales.\(^{17}\) Contrariwise, \( \varrho < 0 \) would imply that the actual change in sales is generally overestimated.

But how can one check the validity of such a reconstitution? One check is a pragmatic one: is the devised series useful in prediction? In connection with sales expectations, one appropriate test concerns the usefulness of the series in describing inventory behavior. The application of this test to a "sales expectations" series I devised from the same data utilized by Hart, but for the postwar period, gave a negative answer; the procedure described in this paper for obtaining a surrogate measure of expectations provides a closer prediction of actual inventory behavior.

\(^{16}\) A perfect forecasting record may be achieved by a firm willing to push goods by advertising, salesmanship, or price cutting when sales lag behind the predicted quantity and, conversely, to refuse to sell additional goods once the forecast of sales has been fulfilled; obviously, such behavior is at the expense of profits. A basic assumption underlying the buffer stock type of model is that firms respond passively to changes in demand in the sense that they do not adjust either price or sales policy to short run changes in demand.

\(^{17}\) Edwin S. Mills based an econometric investigation of inventory behavior on the assumption that sales anticipations deviate from actual developments by a random variable with zero mean [17].
The hypothesis expressed in equation (3.5) may be investigated by studying data on actual anticipations.¹⁸ But this is by no means the only approach. Let us substitute the expression for expectations, (3.5), into equation (3.4), the flexible accelerator buffer stock inventory model. This yields

\[(3.6) \quad I_t = \delta x + (\delta \beta + 1) \rho X_{t-1} + (\delta \beta + 1)(1 - \rho)X_t - X_t + (1 - \delta)I_{t-1}\]

The estimates of the parameters of this model were obtained by applying least squares after it had been reformulated in the form

\[(3.7) \quad I_t = \delta x + \delta \beta X_t + (\delta \beta + 1) \rho (X_{t-1} - X_t) + (1 - \delta)I_{t-1} + \varepsilon_t\]

It is clear that unambiguous estimates of all parameters of the model may be obtained by unscrambling the coefficients obtained from the regression.

Estimates of the parameters of equation (3.7) are presented in Table II. It is to be observed that all point estimates of the reaction coefficients, the \(\delta\)'s, fall within the correct range; they are slightly smaller than the estimates obtained for stocks of purchased materials and goods in process. The estimated marginal desired inventory coefficients, all of correct sign, are larger for finished goods than for stocks in every case.

The estimates of the \(\rho\)'s, the anticipation coefficients, all lie between zero and unity, implying that firms in manufacturing typically anticipate a sizable share of the actual change in sales volume.¹⁹ Even for nondurables, the estimate of 0.1685 suggests that on the average more than four-fifths of the actual change in sales is generally anticipated. But an alternative interpretation of the evidence is possible, an interpretation suggested to me by James Henderson and by Arthur Okun. Sales anticipations held at the beginning of the quarter may not be so unbiased; rather, a degree of flexibility in production scheduling may permit a partial modification of

¹⁸ In a recently published study Theil reports on an extensive study of the prediction record of a number of forecasts made in several different countries. His investigation suggests a general tendency for anticipations to understate actual changes [20, Ch. V]. Hypothesis (3.5) was formulated and investigated independently of Theil's study.

¹⁹ Since the calculations are based on aggregative data rather than figures for individual firms, the resulting estimates might result from a mixture of companies that make naive projections and other firms that typically overestimate the actual change in sales. Even if data on individual firms were available, a value of \(\rho\) close to unity would have to be interpreted as implying that there is no systematic tendency generally to over or underestimate actual changes in sales, a lack of bias in forecasting that is not necessarily indicative of precision. Nevertheless, the results are of considerable interest; for one thing, there is no hint of any tendency for expectations to be "regressive" in the sense of having a general tendency to swing back in the opposite direction from recent changes, a characteristic of the questionable, unprocessed Railroad Shippers Forecast expectations data. Cf. Hart [7] for a discussion of an attempt to correct the raw railroad forecast data for its systematic, regressive tendency.
the original production plan when the actual change in sales is underesti-
mated. Okun suggests that flexibility implies that actual stocks are related
to the planned level by a coefficient of inflexibility in terms of the following
modification of equation (3.4):

\[(3.4')\]

\[I_t = I_t^p + \lambda(X_t - X_t)\]

If production plans are partially flexible, \(1 > \lambda > 0\), an excess of actual
sales over the anticipated level will lead to only a partial discrepancy be-
tween actual and planned end-period inventories. If production plans are com-
pletely inflexible, \(\lambda = 1\), we have the special case already investigated. If,
on the other hand, \(\lambda = 0\), we would have the opposite extreme of complete
flexibility that would be possible only if production were instantaneous
rather than involving time. If one proceeds in the same way as before, one
eventually derives from (3.4') a revision of equation (3.7):

\[(3.7')\]

\[I_t = \delta \alpha + \delta \beta X_t - (\delta \beta + \lambda) \delta(X_t - X_{t-1}) + (1 - \delta) I_{t-1}\]

Now this equation is "underidentified" in the sense that we cannot un-
scramble the least squares coefficients in order to estimate \(\delta\) and \(\lambda\), although
we still obtain precisely the same estimates of \(\beta\), \(\delta\), and \(\alpha\) as before. While
this means that the effects of errors of anticipations cannot be segregated
from production inflexibility empirically, Arthur Okun suggests that
reasonable assumptions concerning the value of the coefficient of inflexi-
iblity still imply a quite high value of \(\delta\). Suppose, for example, that \(\lambda = \frac{1}{2}\),
presumably a low value for a three month planning period. Then for total
manufacturing the value of \(\delta\) computed under this assumption is only 0.2427
rather than the figure of 0.1521 obtained under the assumption of complete
inflexibility. A similar insensitivity holds for the other regressions. Although
the assumption of complete inflexibility may imply an erroneously low value
of \(\delta\), manufacturers still appear to anticipate on the average a large portion
of changes in sales volume even when a considerable degree of production
flexibility is assumed.

4. TOTAL INVENTORY BEHAVIOR: A BREAKDOWN BY INDUSTRY

Evidence concerning the behavior of stocks of purchased materials and
goods in process was presented in Section 2; finished goods inventories
were examined in Section 3. But both studies were based on a high level of
aggregation. Ideally, of course, one would like to utilize a cross-section ap-
proach relying on data for individual firms. Failing this, a disaggregation of
the totals, at least to an industry level, is most useful. Such a breakdown is
possible with existing data currently released by the Office of Business
Economics, but only at a cost. In return for the greater detail of data as to
industry, it is necessary to sacrifice the classification of inventory by stage of fabrication.

In this section we report on an investigation based on an industry breakdown for five component durable goods industries. Let the variable $H_t$ represent total inventory stocks held at the end of the period. Since $S_{t+1}$ represents stocks of purchased material and goods in process in the hands of producers at the beginning of period $t+1$ while $I_t$ stands for inventories of finished goods held at the end of period $t$, we have the identity

$$H_t = S_{t+1} + I_t.$$  \hfill (4.1)

In view of this correspondence, it seems appropriate to add together the explanatory terms of equations (2.3) and (3.7), the expressions for stocks and for inventories, respectively. Since our measure of quantity, $Q_t$, cannot be derived without knowledge as to the change in finished goods inventory, this term in equation (2.4) must be approximated by sales. In this way we obtain as the equation explaining total inventories held by each industry

$$H_t = \delta x + \delta \beta_2 X_t + (1 - \delta)H_{t-1} - (\delta \beta_1 + 1)\rho \Delta X_t + \delta \beta_3 U_{t+1}$$

$$+ \delta \beta_3 \left( \frac{\Delta p_{t+1}}{p_{t+1}} \right) + \epsilon_t.$$  \hfill (4.2)

It was possible to reprocess the data for total durable, total nondurable, and the total manufacturing sectors in addition to analyzing the new data for component industries. The statistics appear in Table III. A check on the effects of aggregating over stages of fabrication is provided by the total inventory estimates obtained for these sectors. Before turning to the individual industry estimates, let us test the consistency of these estimates for the aggregates with those obtained earlier. The comparison will lend support to the conjecture P. Darling advances “that aggregation may be pushed much further in inventory analysis than has heretofore been generally felt justified” [4, p. 958]. It will provide justification for the interpretation of the estimates obtained for individual industries where data broken down by stage of fabrication are, unfortunately, unavailable.

First of all, one would surmise that the total inventory reaction coefficient obtained for each sector would be a rough average of the sector’s stock and inventory reaction coefficients obtained under the separate regressions utilizing the stage of fabrication breakdown. This indeed proves to be the case, as may be seen by comparing the data in Tables I and II with the figures presented here. Again, remembering that sales are now being utilized as a proxy for output, we should find the total marginal desired inventory coefficient to be roughly the sum of the coefficient for purchased materials and goods in process stocks and that for finished goods inventory; this
indeed holds, the approximation being particularly good for total manufacturing and total durables. Also, for total manufacturing and total durables, if not for the nondurables, the unfilled orders coefficient is remarkably stable. The estimates of the coefficient of anticipations obtained when the stage-of-fabrication breakdown is neglected quite closely approximate those obtained with the finished goods regression; even the largest discrepancy, that for total manufacturing, is only a contrast of 0.13 versus 0.15 in estimating the anticipations coefficient. Only the coefficient of the rate of change in prices of purchased materials and goods in process shows a marked sensitivity to the level of aggregation; we find them larger in absolute value and all negative, implying that total inventories are smaller when prices of purchased materials are on the increase.

With the exception of a possible distortion of the role of prices, the estimates obtained when the data on finished goods inventory are combined with the figures for stocks of purchased materials and goods in process are remarkably consistent with the earlier estimates utilizing the breakdown. It seems quite reasonable to conjecture, then, that the estimates we present for the five component durable goods industries do not differ greatly from those that would have been obtained with separate regressions if stage of fabrication data could be utilized.

Let us turn to the data for the five component durable goods industries. It is to be observed that all reaction coefficients are of the correct sign and of reasonable magnitude. The point estimate of the reaction coefficient for the transportation equipment industry is largest, implying that firms in this industry attempt the most rapid adjustment of stocks to the desired level; firms in primary metals appear to be the slowest. Observe that the total durable reaction coefficient is larger than that for any component industry rather than a rough average of the estimates for different industries; this suggests that at least some distortion may be involved when data limitations require aggregating over component industries in order to work with data for a major sector of the economy.

All marginal desired inventory coefficients appear to be of correct sign. The considerable range in the value of these coefficients may be partially due to sampling errors as well as to interindustry differences in the extent to which the optimal level of inventories is actually related to the volume of sales. The point estimate is lowest for machinery; the largest coefficient, that for primary metal, is almost ten times the figure for machinery. The figure obtained from the aggregate regression for total durables was about three times the smaller figure.

The coefficients of anticipations are all positive and less than unity. This suggests that firms are successful in attempting to adjust the simple naive projection of sales in the direction of actual developments. They do not
overshoot, but rather tend to underestimate the actual change in sales by a surprisingly small amount. In the transportation equipment industry a particularly low bias in forecasting changes in sales is suggested by the point estimate. But even in stone, clay, and glass—the least accurate industry considered—almost four-fifths of the actual change is anticipated on the average. The regressions for individual industries confirm the conclusion, based on the data for durable and nondurable totals, that manufacturers tend to anticipate both the direction and magnitude of changes in sales volume.

In sum, the parameter estimates obtained utilizing the industry data are reasonably consistent with the values one would expect on the basis of the data that are aggregated over industries but broken down by stage of fabrication. While the estimates are clearly inconsistent with the simple, naive accelerator hypothesis already rejected by Abramovitz, they are in conformity with more complicated versions of the accelerator which incorporate the flexible principle of Goodwin and the buffer stock concept of Lundberg and Metzler.

5. SURPLUS INVENTORIES

Discrepancies between the desired or equilibrium level of inventories and the actual size of stocks are explained by the complicated version of the acceleration principle developed in this paper, a model incorporating the flexible accelerator principle of Goodwin and the buffer stock concept of Lundberg and Metzler. Estimates of the parameters of the model were provided in Table III. In this section these estimates of the model's parameters are utilized to construct a series for the surplus inventory holdings of five durable goods industries for the years 1948 to 1955.20

The equilibrium level of inventories is defined as that level which entrepreneurs would work to obtain on the basis of the current level of sales and the backlog of unfilled orders if they were not disturbed by dynamic factors.21

20 An alternative and equally feasible approach would be to discuss discrepancies between the observed and the desired inventory to sales ratio. If both sides of equation (4.2) are divided by \( X_o \), an expression for the observed inventory-output ratio is obtained. If equation (5.1) below is also divided by \( X_o \), one obtains an equation explaining the desired inventory to sales ratio in terms of both sales volume and the backlog of unfilled orders.

21 A periodic survey currently conducted by the Office of Business Economics, Department of Commerce, inquires as to whether the firms' current inventory position is above, below, or approximately equal to the volume of stocks that the firm would like to hold on the basis of current sales and the backlog of unfilled orders, but a figure as to the size of the surplus or deficit is not requested. Lawrence Klein utilized residuals from an equation predicting actual inventories as a measure of undesired stocks in one of his econometric investigations (11, p. 102).
The equation for estimating the desired level of inventories is obtained from (4.2) by eliminating the dynamic disturbances of price changes and errors in anticipating future sales, by setting $\Delta p_{t+1}/p_t = \Delta X_t = 0$. Then,

$$H_t = \alpha + \beta_1 X_t + \beta_2 U_t.$$

Here are the estimates of the parameters of the equilibrium level of inventory equation for each of the five durable goods industries:

<table>
<thead>
<tr>
<th></th>
<th>$\alpha$</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone, Clay, and Glass</td>
<td>102.7</td>
<td>.4668</td>
<td>—</td>
</tr>
<tr>
<td>Primary Metal</td>
<td>3119.1</td>
<td>1.1390</td>
<td>.3231</td>
</tr>
<tr>
<td>Transportation Equipment</td>
<td>841.7</td>
<td>.2617</td>
<td>.1009</td>
</tr>
<tr>
<td>Machinery</td>
<td>2514.9</td>
<td>.1161</td>
<td>.1983</td>
</tr>
<tr>
<td>Other Durable</td>
<td>168.5</td>
<td>.6278</td>
<td>—</td>
</tr>
</tbody>
</table>

If equation (5.1) is subtracted from (4.2) one obtains an equation for estimating surplus inventories:

$$(5.2) \quad H_t - H^d = (\delta - 1)\alpha + (\delta - 1)\beta_1 X_t + (1 - \delta)H_{t-1} - (\delta \beta_1 + 1)q \Delta X_t + (\delta - 1)\beta_2 U_{t+1} + \delta \beta_3 \frac{\Delta p_{t+1}}{P_{t+1}}.$$

The estimates of the parameters of this equation for the five durable goods industries appear in Table IV.

**Table IV**

<table>
<thead>
<tr>
<th>Coefficients of Surplus Inventory Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone, Clay, and Glass</td>
</tr>
<tr>
<td>$(\delta - 1)\alpha$</td>
</tr>
<tr>
<td>$(\delta - 1)\beta_1$</td>
</tr>
<tr>
<td>$(\delta - 1)\beta_2$</td>
</tr>
<tr>
<td>$\delta \beta_3$</td>
</tr>
<tr>
<td>$-(\delta \beta_1 + 1)q$</td>
</tr>
<tr>
<td>$(1 - \delta)$</td>
</tr>
</tbody>
</table>

These last coefficients were applied to the same data utilized in the original regression in order to obtain time series representing surplus inventory holdings for each of the durable goods industries. For each quarter the surplus holdings of the five industries were summed so as to provide an estimate of total surplus inventory holdings for the durable manufacturing
sector of the economy. The data appear in Table V together with a constant dollar series of actual durable manufacturing inventories. The provisional character of the derived series of surplus inventories must be emphasized; their validity depends upon the accuracy of our specification of the equation explaining actual inventory behavior. They are obviously subject to sampling error. While the evidence presented should be considered as most tentative, it nevertheless provides an interesting interpretation of the behavior of
durable goods inventories during a period of military mobilization.

At the end of 1949 durable manufacturing firms held considerable excess stocks; almost one-sixth of their total inventory holdings were surplus. Three months later stocks were deficient. They remained below the equilibrium level until the end of 1953. From midyear 1950 to midyear 1951 durable goods manufacturing firms accumulated some two and one-half billion dollars of inventories, measured in 1947 prices. But this dramatic rate of inventory investment was not sufficient to prevent the deficiency of stocks from enlarging considerably. Indeed, actual inventory accumulation during the first year of the Korean emergency was only slightly more than one-half the change in the desired level of stocks. Although the deficiency in inventory holdings reached its peak at the end of June, 1951, the additional stocks necessary to eliminate the gap between desired and actual stocks were not accumulated until two more years had elapsed.

It may well be that inventory investment would have been much larger during the period of military mobilization except for two basic factors. First of all, firms in manufacturing follow a flexible inventory policy, attempting only a partial adjustment of actual inventories to the desired level during each production period. Second, our estimates of the coefficients of anticipations all imply a tendency for manufacturers to underestimate actual increases in sales. It is tempting to hypothesize that during the Korean crisis these two factors, by reducing actual inventory investment, served to limit effective demand during a period of inflation. This would imply that inaccurate expectations and a flexible inventory policy may at times serve to stabilize the economy. This is a conjecture concerning the behavior of the economy for alternative, hypothetical values of the parameters of the equation determining inventory behavior. But it must be observed that if the parameters of the equations explaining inventory investment in certain sectors of the economy had been different, the level of sales and possibly the backlog of unfilled orders might well have been affected; consequently, inventory behavior would have been different from that implied by considering the actual level of sales. The interdependent nature of the economy means that considerable difficulty is involved in appraising the effects of alternative inventory practices. A paper on theoretical problems related to the present article will appear in a future issue of this journal.

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REFERENCES


