

RESEARCHING INVENTORIES: WHY HAVEN'T WE LEARNED MORE¹

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I. INTRODUCTION:

Empirical research on inventories has been underway for more than four decades. It is fair to date the start of this line of empirical research with Abramovitz's 1950 study, based on the Burns-Mitchell NBER business cycle methodology. It can also be said that empirical inventory research has been successful: graduate students have had their doctoral dissertations accepted, articles and books have been published, scholars have earned tenure. But how much have we actually learned about the behavior of inventories from almost a half century of empirical research?

In this paper I am not going to review the literature. This would be superfluous, for Blinder and MacCini[1991] present a careful summary of the current state of our knowledge about inventories in "Resurgence of Inventory Research --- What Have we Learned?" Rather than developing still another model, or running even one more regression, it may be best to step back and ask about what we have not learned: What questions remain unanswered? It may be even more useful to ask: Why have we not learned more?

In the next section of this paper I shall enumerate the issues that I think have been, ever since Abramovitz's time, on the research agenda for macro-economists interested in the empirical study of inventories. Then we shall focus our attention on a variety of methodological factors that may help to explain why we have not been more successful at resolving these issues.

II. THE RESEARCH AGENDA:

What do we want to know about inventories? The strategic role that inventories and forecast errors play in

the generation of cyclical fluctuations in economic activity had been recognized long before the advent of quantitative research on inventories. R.G.D. Hawtrey[1928] had argued that monetary policy has its primary impact through its effect on inventory investment. Pigou[1922] highlighted the importance of waves of expectational errors in explaining cyclical movements, arguing that they were of equal importance to the monetary factor. Lundberg[1937] and Metzler[1941] stressed the role of expectational errors in clearly articulated models of the inventory cycle based on a straightforward accelerator model complicated by errors in forecasting sales volume.

While Abramovitz's study clearly established the importance of inventory investment to the explanation of cyclical developments, it left for subsequent research a variety of open issues. Thus the research agenda for anyone contemplating the empirical study of inventory investment after Abramovitz naturally included the following questions:

- #1. Abramovitz had objected that the simplest version of the accelerator, the assumption that firms always adjust stocks so as to maintain a fixed stock/sales ratio, was inconsistent with the observed timing of inventory investment over the course of the business cycle. Can the accelerator model be modified in a way that will enable it to explain the timing of inventory investment over the course of the business cycle?
- #2. Are errors in anticipating sales volume (the basic ingredient of the Lundberg-Metzler inventory cycle model) of fundamental importance in explaining the path of inventory investment?

¹ Forthcoming, *International Journal of Production Economics*. This paper has benefited from the many constructive suggestions I received when I presented an earlier version at the June 1992 Conference at the University of Siena on Business Cycles, Inventory Fluctuations, and Monetary Policy and at the Seventh International Symposium on Inventory Research, August 24-28, 1992, Budapest.

- #3. To what extent do firms adapt to unexpected shifts in demand by adjusting price or advertising expenditure or by backlogging orders or rescheduling production rather than by making finished goods inventory buffer the shock?
- #4. Do changes in short term interest rates have a major impact on inventory investment? Do financial variables and liquidity considerations influence inventory investment?
- #5. Are inventories influenced by the desire of firms to schedule production efficiently? Do firms attempt to "smooth production," and if so how does this influence inventory movements and overall economic stability?
- #6. Is speculation --- euphemistically called "price hedging" --- a major factor?
- #7. Are the problems of aggregation over time, over firms and over industries critical? Do firms revise their production plans within the period of observation? Is it necessary to use data at the level of the individual firm or is it reasonable to work with industry and GDP aggregates?

These are not new issues --- they have been with us for at least forty years (eight recessions). It seems to me that the agenda of open questions about inventories has been remarkably stable for a number of decades. The list is essentially unchanged from the list of questions I had hoped to resolve in my own dissertation, accepted in 1959. While the list of topics deserving our attention has not changed, there have been major shifts of style and fundamental improvements in research technology; and successive generations of graduate students have shifted the focus from topic to topic and back again in a way which a historian of thought might find difficult to rationalize. But who would claim that even one of the seven issues has been satisfactorily resolved with evidence sufficient to generate a consensus view among informed members of our profession?

The absence of reasonably precise answers to these questions makes it difficult for us to offer much in the way of serious policy recommendations. From time to time economists have made recommendations: Abramovitz concluded that a tax levied upon the average level of inventories, by inducing firms to operate with leaner stocks, would contribute to economic stability[1950, pp. 293-4]. But Albert G. Hart[1954, pp.

Hart[1954, pp. 293-4] argued that a tax levied each quarter on the changes in inventory holdings from the corresponding period of the preceding year would better contribute to inventory stability. And Henry Wallich advocated, back in 1961, that firms that held their inventories stable should be rewarded with a 1% or 2% tax credit; he asserted that the Treasury would recoup the revenue cost of the credit because of the improved pace of business activity.² I would hope that no one would advocate an inventory policy panacea today, but I cannot imagine a policy proposal that would receive support from a majority of the experts.

We are still not in a position to advise the Chairman of the Federal Reserve Board about the magnitude of the effect of shifts in the Federal Funds Rate on inventory investment. Strangely, this important topic has been largely neglected.³ For example, at a conference on inventory investment held at Wesleyan University in 1987 none of the 21 papers presented by economists addressed the question of how central bank policy would affect inventory investment.

III. WHY HAVEN'T WE LEARNED MORE?

Over the years the study of inventory investment itself has been the subject of periodical cycles of attention simulated in part by substantial theoretical advance and the development of more sophisticated econometric procedures. But why, after all this effort, do the basic questions on the agenda remain unanswered? Here are a few factors that may help to explain why we have not made more progress:

1. The Output, Price, Order Backlog Decision:

Much of the empirical research on inventories, perhaps inspired by the work of Lundberg and Metzler, has been based on one or another variant of the accelerator model: the sales quantity has been regarded as exogenously determined. At the macro level this approach is open to question because of the likelihood of simultaneous feedback of inventory investment on effective demand. But at least as serious are the problems created by the options that a firm has of respond-

² Interview in McGraw-Hill's Purchasing Week, as reported in the New Haven Journal-Courier, November 4, 1961, p 23.

³ An important exception is provided by the studies of Owen Irvine [1981a,b].

ing to a shift in demand by revising the production schedule, by manipulating price, by changing advertising expenditure, or by adjusting delivery lags rather than by buffering with finished goods inventories.

One dimension differentiating researchers is the extent to which they give primacy to one or another of these adjustment mechanisms, neglecting some of the alternatives entirely and arguing that others involve a longer time-lag.⁴ I do not think there is one right way to proceed. The emphasis on price adjustments in Michael Brennan's [1959] early work and the recent contributions by such writers as Deaton and Laroque [1992] obviously dominate in commodity markets.⁵ Does the accelerator model make more sense in many manufacturing industries?

When the accelerator model is used to explain manufacturers' inventories, shipments are customarily used as the measure of sales or demand, which are assumed to be exogenous. This may be expedient, but it would be much better to capture the fact that the shipments data represent a decision by the manufacturing firm about the prioritizing of the order backlog and ease of production scheduling rather than an appropriate measure of exogenously determined product demand. The data published for the United States by the Department of Commerce reveal that unfilled orders are particularly important in the durable manufacturing sector. While inventories are typically about twice monthly sales, unfilled orders swing from 2 1/2 to as high as 4 times monthly sales. That is to say, while firms on average may have two months inventory on hand the average delivery lag may be on the order of four months. Finished goods constitute about 25% of inventory stocks, and they may co-exist with a backlog

⁴ One cannot help but admire Gerald Childs's [1957, p 8] frank admission: "Although they may be important, price changes are beyond the scope of this book."

⁵ Deaton and Laroque analyze the behavior of commodity markets in the presence of rational expectation competitive storage, where the speculators are assumed to know the current harvest and the carryover from the previous year. In fact, such quantity information is often not available --- indeed Deaton and Laroque do not use quantity information in their estimation efforts. This raises two questions: How should rational economic agents behave if all they know is current price? Is it socially useful for the government or some other agency to collect and distribute information about harvest prospects?

of customer orders because the items on order are not the same as what happens to be in the warehouse --- much is hidden here because as macro economists we are inclined to be satisfied with looking at gross aggregates; but even firm balance sheet data would hide the complexities created for firm management by heterogeneous product lines

Unfortunately, not all that much is known about orders. In particular we do not have reliable information on the proportion of orders that represent solid commitments to deliver specific quantities of merchandise at a specific price by a specific date and the extent to which orders are evaluated at current market price or projected future delivery price.⁶ Something of the complexity of this process is suggested by Foss, Fromm and Rottenberg [1980, page 152]:

"In some industries firms may delay filing orders, when demand rises, as an alternative to charging higher prices. Sellers may prefer to maintain good customer relations and not to clear the market by charging higher prices but instead require that buyers wait... Under some circumstances producers refuse to accept new orders or to permit backlogs to rise because of capacity limitations, and they may resort to shipment allocations. Under this arrangement sellers ration their capacity output among buyers on the basis of some historical contribution of purchases..."

Of course, what happens varies at least from industry to industry, and probably also from firm to firm and even product line to product line. Order backlogs in the United States are of particular significance in transportation equipment and military hardware sectors. In the nondurable manufacturing sector they are not nearly as significant as inventories.

Twenty five years ago Gerald Childs [1967] carefully studied the link between unfilled orders and inventories. It is unfortunate that the order-sales-inventory nexus has been largely neglected since that pioneering investigation. Instead, we may have been devoting a disproportionate share of our energies to the following two issues.

⁶ Foss, Fromm and Rottenberg [1980, p 55] report that about one quarter of the BLS wholesale price quotations in material manufacturing industries are orders rather than shipment prices.

2. Speed of Adjustment:

Perhaps the most frequently raised objection against the flexible accelerator model is that it yields unreasonably slow estimates of the speed of adjustment. This may be a problem, but my own view is that this is of only secondary importance relative to some of the other difficulties already mentioned in this paper.

In the first place, the adjustment speeds for inventories do not seem all that slow relative to those obtained in many econometric studies of the demand for money.

In an early study based on annual data, Bronfenbrenner and Mayer[1960, p 558] found an inertia term of 0.344 on the lagged dependent variable in regressions of money balances on the commercial paper rate, wealth and income. And in "The Case of the Missing Money" Goldfeld[1976, p 687] reports that in "conventional demand for money regressions based on quarterly data he has a lagged endogenous variable coefficient of 0.676 for M_1 , 0.661 for demand deposits and 0.863 for currency.

In the second place, slow adjustment may arise for several reasons: Seasonal merchandise (e.g., beach umbrellas and lawn mowers) may be carried over to next year rather than liquidated at distressed prices in an effort to encourage the consumer to store the item. Also, expansion of inventories may have to await the construction of additional storage capacity, which can be particular protracted process in some sectors, such as at retail gasoline stations. And to the extent that inventory holdings are used to hide mistakes --- wrong item ordered, defective intermediate items that are tossed back in the barrel rather than fixed --- every effort may be made to keep what is involved out of sight rather than uncovering error by liquidating stocks. These considerations, plus a reluctance to revise decision rules that may be based on tedious calculations --- whether they be based on optimal lot size considerations or the solution of quadratic cost function optimizing problems, or rules of thumb --- may go a long way toward explaining the slow adjustment speeds encountered in applications of the flexible accelerator model to inventory behavior.⁷

⁷ It is easy to recalculate optimal-lot-size (S,s) trigger points when carrying costs change, but most of the literature, based on the assumption that sales are stationary, neglects the question of how frequently the optimal trigger points should be adjusted. While it is extremely difficult to determine the

It is also true that too slow adjustment coefficients may arise from biased estimation procedures. They may, as Owen Irvine[1988] suggests, be symptomatic of omitted variables. And I have been led to believe on the basis of my experiments with recovering parameters from artificial data generated by simulation that one artifact of aggregation may be a systematic tendency to underestimate speeds of adjustment (Lovell[1992]).

aggregative implications of (S,s) behavior, progress has recently been reported by Caballero and Engel[1991]

The linear decision rules relied upon by Childs[1967] and Belsley[1969], which are derived from quadratic cost functions, may explicitly incorporate inventory carrying costs. The decision rules are convenient for the firm to apply precisely because they are linear in sales; furthermore, certainty equivalence holds. But the decision rules are not linear with respect to factors influencing the parameters of the cost function, such as interest rate changes. Therefore, the speed of response to changes in cost factors may be much slower than the response to changes in sales volume.

3. Production Smoothing:

The question of whether firms attempt to smooth production, while long on the agenda of economists interested in studying inventory movements, has received a disproportional share of our attention in the last decade, which is somewhat surprising in that this is far from being a burning policy issue. It seems to me that the effort of firms to schedule production efficiently will often impact on inventories. But for several reasons the attempt to schedule production efficiently will not necessarily lead to the variance of production (sales plus inventory) being smaller than the variance of sales. First of all, efficient production scheduling may not require that output fluctuate less than shipments: some processes run intermittently, the machine operating either at rated speed or turned off; further, set-up costs may mean that processes are most efficiently run in batch mode until an optimal lot size is produced, with the machine then waiting on standby ready to be set up for some other production assignment. Second, the "fallacy of composition" may operate: the implications of a host of interacting firms all attempting to smooth production may be counter-intuitive, and the attempts of individual firms to smooth production relative to sales might conceivably influence the sales of supplying firms in a way that contributes to instability. The multiplier-accelerator models of Lundberg and Metzler did not imply that production would have a smaller variance than sales at cyclical frequencies. And in a multisector generalization of their model I found (Lovell[1992]) that the ratio of the variance of sales to the variance of production is not a reliable indicator of how vigorously firms are trying to smooth production; I also found that increased efforts by firms to smooth production could conceivably lead to a more violent inventory cycle.

4. Market Structure:

The diverse types of inventory behavior in different sectors of the economy in part reflect differences in market structure as well as technology. In studying inventories we have not taken market structure appropriately into account. For example, Valerie Ramey[1991] has invoked falling marginal cost to explain production smoothing. Blinder and Maccini[1990, p 14] are leery about such an explanation, cautioning that "with falling marginal costs the main foundation of the law of supply would crumble." But they are inconsistent in not raising similar concerns later in their paper when they are concentrating atten-

tion on the (S,s) type decision rule without worrying about the fact that optimal lot sizing implies increasing returns to scale, which is incompatible with the basic tenet of competition.

It is interesting to note that while macro-economists have for the most part neglected issues of market structure in studying inventory behavior, the longest textbook discussion of inventories is not to be found in a macroeconomics textbook but in a text in industrial organization. Scherer and Ross[1990, pp. 268-73] explain how market structure may influence the inventory decision. Rather than allowing price to fluctuate when demand shifts, firms operating in oligopolistic markets may find it advisable to absorb the shock in inventories in order to minimize the threat to industry pricing discipline. More than this, an oligopolist may carry exceptionally large stocks in order to make more creditable the threat of a bitter price war if potential price chiselers risk destabilizing the orderly price structure.

And marketing strategy can have a strong impact on inventory holdings. The New York Times recently reported that over the past ten years grocers have spent millions of dollars to build warehouses solely to stockpile excess inventories of goods bought during manufacturers promotional specials, sometimes stockpiling to the point where they will not have to reorder for six months.⁸ Proctor and Gamble has recently discontinued the promotional specials while at the same time cutting its standard price schedules dramatically. It was explained that "smoothing out production runs" was one reason for the change. Prior to the change, factories sometimes had to work around the clock for four weeks to meet demand for a product on special and then operate at less than capacity for several months, until supermarkets had depleted their inventories and were ready to reorder.

⁸ New York Times, April 267, 1992, page 5, Section 3.

5. Powers of observation:

Part of our problem arises, I suspect, because macro-economists do not have well developed powers of observation. The accepted research paradigm is to derive models based on the assumed maximization behavior of economic agents and test them on aggregate data. I do not think that this strategy suffices to provide a "sound micro foundation" for our research. We should also interview economic agents to find out what they say they do and how they do it. Perhaps we should also attend trade-association meetings in order to find out what firms perceive their problems to be. While the data collected by the National Association of Purchasing Managers has proved useful in forecasting, the possibility that it would help our understanding of inventory movements has not been extensively explored.⁹ Perhaps we should try to learn more from our colleagues in Operations Research, although they may also have a tendency to focus their efforts on devising more elegant solutions to stylized problems rather than learning about new problems from field contacts. It seems to me that we have been inclined to underestimate the potential contribution of research conducted in the spirit of Ruth Mack's study [1956] of the hide, leather, shoe sequence, which provided the institutional framework that was subsequently modeled and tested by Kalman J. Cohen[1960]. And again, the behavioral theory of the firm of Cyert and March[1963] provides useful insight into how department store behavior should be modeled.

6. Data Limitations:

I think that data limitations are a major impediment to progress in learning about the determinants of inventory behavior. For the most part we rely on aggregate series, often restricting our attention to series that are conveniently available on an electronic data base, such as Citibase. With the passage of time more observations have accumulated. And there have been a substantial number of methodological improvements, prompted in part by the recommendations of Murray Foss, Fromm and Rottenberg[1980]. But in certain other respects the situation has deteriorated.

The Quarterly Survey of Manufacturers' Inventory and Sales Expectations, designed by Murray Foss,

⁹ Forecasting uses of dispersion measures based on the NAPM survey are discussed by Dasgupta and Lahiri[1992].

provided an unparalleled source of information about sales expectations and inventory condition. Albert Hirsch and I were privileged to be able to analyze these data at the firm level, testing a variety of models of expectations formation and the rational expectations hypothesis as well as the flexible accelerator model.¹⁰ There were limitations to this data source; in particular, information about other variables of interest, including new and unfilled orders, was not collected. Nevertheless, it is most unfortunate that this survey was discontinued in 1976, and I know of no other data source of comparable value.

The Federal Reserve System's monthly survey of department store sales and inventories has also been discontinued. As a measure of current economic conditions, this survey may have become outmoded. But it did contain useful information on orders that is not provided by any other source --- it reported outstanding orders placed by the retailer for new merchandise, which meant that it was possible to measure Ruth Mack's[1961] intriguing concept of "ownership position," the sum of stocks on hand and on order. I was able to analyze the data at the firm level for seven department store chains, finding that the flexible accelerator worked at the firm level not only at explaining retail inventories but also the placement of orders[Lovell, 1969].¹¹ It is unfortunate that data on orders placed with suppliers, and hence ownership position, is no longer available from any source, at least in the United States.

Part of the frustration encountered by anyone interested in the empirical study of inventories arises from the fact that much data that is collected is not made available in the form that would be most convenient for statistical analysis. A particular case in point is the categorical business-test data, pioneered by the Ifo-Institut, Munich, which has conducted monthly surveys since 1949. When direction of change survey data are aggregated over firms, the result is essentially a diffu-

¹⁰ Hirsch and Lovell [1969] analyzed data for 83 firms in five industries through 1964.

¹¹ I also showed how the two variable vector-autoregression could be decomposed into two separate equations, one involving only inventories and the other only orders; the separated equations are of a higher order and suggest a slower adjustment process than inspection of the inventory vector autoregression equation.

sion index. Thus we may have a tally of the proportion of firms that regard their inventories as "high," "low" or "about right" rather than an actual measure of inventory imbalance, which confronts the econometrician with the challenge of trying to infer the movements of the underlying magnitudes; Nerlove[1983] reported on some of these efforts. It would obviously be more useful to ask about the magnitudes to begin with. Perhaps firms would be reluctant to provide such detail; perhaps asking for magnitudes would lower the response rate or yield very crude estimates. Maybe so, but it would be constructive to conduct a special survey to check out these conjecture and perhaps also to find out whether the concept of inventory imbalance which underlies the Lundberg-Metzler inventory cycle models has an actual quantitative counterpart in the minds of economic agents.

There is another area for potential improvement. In testing inventory models economists are inclined to look at the published aggregates. In other areas, particularly consumption and finance, much has been learned by looking underneath the macro data at the original questionnaire data. Confidentiality restrictions are a factor that must be overcome, but this is a difficult hurdle to negotiate, particularly for under-funded graduate student researchers confronting a thesis deadline. But obviously much could be learned by unlocking the raw data. This may be too large a project for any one researcher to attempt, but a team or consortium of researchers might formulate an appropriate project. The data would not have to be fresh, which weakens concern about preserving confidentiality. And while American researchers may be ethnocentric, it is clear that micro data from any country might well provide a fruitful basis for research.

7. Econometric Ambiguities:

I think that another difficulty confounding our attempts to learn through empirical investigation arises from ambiguities about appropriate econometric practice. Dewald et al. [1986] have cautioned that a majority of applied econometric papers may not be replicable, sometimes because of ambiguities in the reporting of research procedures and sometimes as a result of actual computational or data processing error, and there is reason to believe that inventory research is by no means exempt from this problem. But even if there are no data acquisition or processing errors, considerable ambiguity remains. The results may be sensitive to the choice of whether to use seasonally

adjusted data or seasonal dummy variables, they may be influenced by the decision to drop variables of inappropriate sign or that fail to achieve a specified level of "significance," and the outcome may depend on the particular diagnostic criteria that may have guided attempts at statistical model selection. The choice of estimation strategy may be influenced by the econometric package one happens to employ, or even which version of a particular program. When I compared several popular econometric packages (RATS, TSP and MICROFIT) I found that subtle differences in econometric practice built into the programs, such as the procedure for handling autocorrelated error terms, could lead to substantial differences in the parameter estimates. I suspect that reported empirical results may be quite sensitive to how the researcher happened to cope with the ambiguities in our research paradigm.

IV. CONCLUSION:

I think the primary reason why we have not learned more in four or more decades of empirical research on inventory behavior is that we have been trying to do research on the cheap¹² --- we try to answer fundamentally difficult questions with an inexpensive research paradigm, using a lot of calculus, a little data, and a fast computer.

Our evidence is, of course, not generated by controlled experiments. But worse than this, the data that we do have is not collected with the needs of the economic researcher primarily in mind; rather, the surveys are designed to gather information about the current condition of the economy that is thought to be most useful for business analysts and economic forecasters. Much data, such as the Munich Business Survey data, are not collected in the form that would be most useful for economists. Opportunities to look at the raw survey responses rather than the published survey aggregates have been few and far between. But these problems have been compounded by the mind-set of economists. We are not inclined to look at what business firms do, why they do it, and how well it works. Instead we communicate primarily with fellow practitioners, focusing our efforts on generating more refined solutions to stylized problems. The situation would be less serious if American economists were not

¹² The NSF spends more money on earthquake research than on economics research.

so ethnocentric, but we have a proclivity for focusing our attention on data for the United States. If we are to look more intently at these different types of evidence, we will inevitably find the behavioral relationships more diverse than is customarily assumed in the construction of macro economic models. Rather than limit our attention to simplified models that are analytically tractable, we must be prepared to resort to simulation of complex models in order to work out the macroeconomic implications of diverse types of behavior.¹³

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¹³ The appropriate strategy may follow the "socioeconomic systems approach" advocated by Guy Orcutt et.al.[1961], which was ahead of its time.

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