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INVENTORY THEORY AND THE GODS OF OLYMPUS

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ABSTRACT. In inventory theory, the typical model assumes the existence of marginal cost data for ordering, holding, and shortages of stock. This paper questions the validity of inventory theory, since it appears to be impossible to measure any of these costs. We conclude that marginal costs would be irrelevant in a more empirical theory, which should concentrate on macrolevel policy analysis rather than microlevel cost minimization.

Management Scientists have traditionally been proponents of rationalism in the validation of theory. In the rationalist philosophy, theoretical validity often depends upon premises which are taken for granted as unquestionable truths. Immanuel Kant called these assumptions synthetic *a priori* premises:

> We do not need controlled experiments to establish their validity: they are so much the stuff of everyday experience that they have only to be stated to be recognized as obvious [Robbins, 1935].

The rationalist philosophy is particularly important in the field of inventory theory, where the typical model is designed to minimize the sum of marginal ordering, holding, and shortage costs for each item in the inventory, without specifying how these costs are to be measured. The premise that relevant cost information can somehow be obtained from the firm's accounting system appears to be almost universally accepted, judging from the classic texts in the field [Hadley and Whitin, 1963; Wagner, 1962; Whitin, 1953], the standard Operations Research texts [Hillier and Lieberman, 1974; Wagner, 1975], and the overwhelming number of papers on inventories published in recent years.

This essay urges reconsideration of the rationalist philosophy. The accounting evidence shows that the marginal cost parameters assumed in the theory are virtually impossible to measure. Thus we should question inventory theory on empirical, if not pragmatic, grounds. After a review of the accounting evidence on each category of inventory costs, we conclude that marginal costs would be irrelevant in a more empirical theory, which should be devoted to macrolevel policy analysis rather than microlevel cost minimization.

Ordering Costs

In placing a replenishment order for an inventory item, at least four distinct steps are involved, each of which may incur different cost elements:

1. Determining that an order is necessary
2. Placing the order with a supplier
3. Receiving, inspecting, and placing the item in storage
4. Paying the supplier.

INVENTORY/PRODUCTION—POLICIES

The theory usually assumes that there is some unique marginal cost associated with each replenishment order [Hadley and Whitin, 1963; Hillier and Lieberman, 1974; Wagner, 1962 and 1975]. This cost is assumed to incorporate all the steps above and to be the incremental addition to total costs, expressed as either an out-of-pocket expenditure or a lost opportunity for profit. If a given cost will occur regardless of the replenishment decision, it should not be considered in the inventory model.

The measurement of ordering costs which fit these assumptions presents grievous difficulties to the accounting community. The major obstacle is that ordering costs tend to be imbedded in common costs for several departments or activities of the firm, and may have little correlation with the number of inventory replenishment orders. An example is provided by the purchasing function. Few firms maintain purchasing departments devoted solely to inventory acquisition. More often these departments are also responsible for the procurement of office equipment and supplies, factory machinery and equipment, and numerous other materials. Segregating that portion of the cost of maintaining a purchasing department to the inventory acquisition function may be impossible, especially on a marginal basis. The same problem applies to the accounting and data processing departments, where the costs associated with inventory acquisition are usually merged with many other functions.

Even if we could isolate exactly the portion of total costs attributable to the inventory acquisition function, it is difficult to identify any costs which vary significantly with the ordering rate. Most of these costs are capacity related and tend to be fixed rather than variable [Gardner, 1978; Vollman, 1973; Wight, 1974; Ziegler, 1973]. Examples include depreciation and lease or rental charges on materials handling equipment, office and warehousing space, and computer systems. Personnel costs are at least semifixed in many situations, especially when the personnel involved in inventory acquisition work part-time on other functions. Thus the very concept of a marginal ordering cost may be illusory.

The result of these problems is that all the suggested approaches to ordering cost measurement in the accounting literature generate average, not marginal, costs [Ziegler, 1973]. Cost minimization models that employ average costs can certainly lead to decisions that are far from optimal. This weakness in ordering costs might still be acceptable, however, if the other costs could be measured with a reasonable degree of accuracy. Unfortunately, there are also significant problems in measuring inventory holding and shortage costs.

Holding Costs

Some components of inventory holding costs are fairly simple to measure on a marginal basis, such as service costs for insurance and taxes. But the major component of total holding costs is the cost of capital, a highly subjective measure, which depends on the risk environment of the firm and management goals for rates of return on investment. The appropriate cost of capital for any firm is an issue that is far from settled in the finance literature. Johnson [1971], for example, states that the cost of capital is never a refined statistical measure, but is encompassed by a broad range of possibilities in any situation. Lambert's survey [1975] of six companies illustrates the importance of the cost of capital in total inventory holding costs. Over 85% of the average holding costs for the companies in the survey were based on executive judgments on the cost of capital. Total holding costs ranged from 14 to 43% of the value of inventories.

Shortage Costs

Shortage costs present perhaps the most ambiguous measurement problems. First, some agreement must be reached on the appropriate definition of an inventory shortage. Some of the possibilities that have been proposed for shortage measures include: the number of times that a shortage condition occurs, regardless of value or duration; the dollar value of sales which are lost or back-ordered; the number of customer requisitions which cannot be filled immediately from stock and result in lost sales or back-orders; the duration of shortage conditions; and a variety of weighted measures such as the number of requisitions back-ordered weighted by the duration of each back-order.

The second problem with shortage costs is that, given a subjective choice for the most appropriate shortage measure in an inventory, there is still no justifiable way to attach a dollar cost to a shortage. The accounting literature contains little guidance on this point [Ziegler, 1973]. Hansmann [1962] sums up this problem well: "It appears that there is nothing sensible to be said about possible losses due to customer aggravation."

Conclusions

Bertrand Russell's perspective on theoretical validity is useful in evaluating inventory theory:

> As time went on, my universe became less luxuriant. Gradually, Occam's razor gave me a more clean-shaven picture of reality. I do not mean that it could prove the non-reality of entities which it showed to be unnecessary; I mean only that it abolished arguments in favor of their reality. I still think it impossible to disprove the existence of integers or points or instants or the Gods of Olympus. For ought I know these may all be real, but there is not the faintest reason to think so [Russell, 1959].

Russell's early years were devoted to populating the universe with great numbers of metaphysical entities; he spent the remainder of his career systematically decimating the metaphysical population by Occam's razor, which rejects theories built upon premises which cannot be established by an examination of the evidence. In the case of inventory theory, the evidence cannot be stretched to justify the metaphysical entities of marginal ordering, holding and shortage costs. Like the Gods of Olympus, these entities may exist, but there is not the faintest reason to think so.

One answer to this dilemma is to redefine the inventory decision problem in the theory. Although most theory deals with microlevel analysis [Hadley and Whitin, 1963; Hillier and Lieberman, 1974; Wagner, 1962 and 1975; Whitin, 1953], or the study of individual items in the inventory, the strategic problem in practice is really one of macrolevel analysis [Brown, 1975; Gardner, 1978; Gardner and Dannenbring, 1979; Wight, 1974], where marginal costs are largely irrelevant. Top management's task is to find some acceptable trade-off among at least three aggregate inventory variables. These include the lump sum investment in inventories on the balance sheet, the overall level of customer service (the number of inventory shortages however defined), and the total reordering work load as it affects changes in capacity. Because of the ambiguous nature of the cost of capital and any costs or benefits attributable to different levels of customer service, selection of the most appropriate trade-off is a complex policy decision, not a cost minimization problem. Costs certainly influence this decision, but the only objective cost data available are service costs on inventory investment and the fixed costs associated with different levels of capacity. These costs are best considered at the aggregate level.

We conclude that the focus of inventory theory should shift from microlevel cost minimization models to macrolevel policy analysis. For example, models which could make systematic, optimal trade-offs among aggregate inventory variables would likely be of considerable benefit in practice. Such models should also convert top management objectives for aggregate variables into operating level decision rules for individual order quantities and safety stocks. One modest step in this direction is found in Gardner and Dannenbring [1979], which includes a simple, cost-free aggregate inventory model that returns optimal values of inventory shortages for inputs of various combinations of constraints on investment and reordering work load.

The rich variety of practical inventory decision problems provides a vast opportunity for more empirical research at the macrolevel. Journal editors could contribute to the development of empirical theory by stipulating that inventory papers which assume the existence of some cost structure should specify how those costs are to be measured.

References

Brown, R.G., 1977, *Materials Management Systems — A Modular Library*, John Wiley and Sons, Inc., New York.

Churchman, C.W., 1961, *Prediction and Optimal Decision: Philosophical Issues of a Science of Values*, Prentice Hall, Inc., Englewood Cliffs, N.J.

Gardner, E.S., 1978, Aggregate Inventory Models: Theory and Application, unpublished Ph.D. dissertation, University of North Carolina.

Gardner, E.S. and Dannenbring, D.G., 1979, "Using Optimal Policy Surfaces to Analyze Aggregate Inventory Trade-offs," *Management Science* Vol. 25, No. 8 (August).

Hadley, G. and Whitin, T.M., 1963, *Analysis of Inventory Systems*, Prentice Hall, Inc., Englewood Cliffs, N.J.

Hansmann, F., 1962, *Operations Research in Production and Inventory Control*, John Wiley and Sons, Inc., New York.

Hillier, F.S. and Lieberman, G.J., 1974, *Operations Research* (2nd ed), Holden-Day, Inc., San Francisco.

Johnson, R.W., 1971, *Financial Management*, Allyn and Bacon, Inc., Boston, Mass.

Lambert, D.M., 1975, *The Development of an Inventory Costing Methodology*, National Council of Physical Distribution Management, Chicago, Ill.

Popper, K.R., 1959, *Logic of Scientific Discovery*, Basic Books, New York.

Robbins, L., 1935, *An Essay on the Nature and Significance of Economic Science*, Macmillan and Company, Ltd., London.

Russell, B., 1959, *My Philosophical Development*, Simon and Schuster, New York.

Shannon, R.E., 1975, *Systems Simulation: the Art and Science*, Prentice Hall, Inc., Englewood Cliffs, N.J.

Vollman, T.E., 1973, *Operations Management, A Systems Model Building Approach*, Addison-Wesley Publishing Co., Inc., Reading, Mass.

Wagner, H.M., 1962, *Statistical Management of Inventory Systems*, John Wiley & Sons, New York.

———, 1975, *Principles of Operations Research* (2nd ed), Prentice-Hall, Inc., Englewood Cliffs, N.J.

Whitin, T.M., 1953, *The Theory of Inventory Management*, Princeton University Press, N.J.

Wight, O.W., 1974, *Production and Inventory Management in the Computer Age,* Cahners Publishing Co., Inc., Boston, Mass.

Ziegler, R.E., 1973, Criteria for Measurement of the Cost Parameters of an Economic Order Quantity Inventory Model, unpublished Ph.D. dissertation, University of North Carolina.