THE THEORY OF PRICE OF STORAGE

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The theory here considered is an attempt to solve a problem presented by conflict of accepted theory with observed price behavior. It seems to have important implications regarding consequences of futures trading, and to throw some light on the general subject of effects of economic expectations. The problem arises out of evidence on *inter-temporal price relations,* and we must first take time to get a clear view of the essential facts which must be comprised in a theoretical formulation.

I. *The Problem*

Inter-temporal price relations are here defined as relations *at a given time* between prices applicable to different times. For examples, one may take the relation at a given time between a spot price and a forward price for the same commodity; or one may take the relation between two forward prices, such as the relation between prices of the December and the May wheat futures, or the May and the September futures, at a given time.

We exclude from "inter-temporal price relations" the relation between price today and price at some previous date, or the relation between prices at two previous dates. Such relations are not relations between simultaneously quoted prices applicable to different times; they express price *changes* which occur through time, and may best be characterized simply as price changes. They are brought into relation only by the artifice of a statistical table or chart.

It has been customary to regard an inter-temporal price relation as commonly a relation between two substantially independent prices. For example, if the price of September wheat is quoted in April at 15 cents per bushel below the simultaneous quotation for the May future, the customary explanation has been that the relatively low price of the September future reflects expectation of a large wheat harvest, which will depress the price of wheat by September, but which (so the explanation runs) cannot affect the price of wheat in May.

Now empirical investigation has shown this explanation to be wholly

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mistaken. In the first place, the amount by which the price of the September future is discounted relative to the May future *does not* depend on the expected size of the crop to be harvested between May and September. In the second place, it is *not* true that expectations regarding the coming crop can have no effect on the price of the May future; on the contrary, expectations regarding the harvest which will occur after May affect the price of the May future in approximately the *same* degree as they affect the price of the September future. Sometimes, indeed, changes in expectations regarding the coming crop seem to affect the price of the May future *more,* in cents per bushel, than they do the price of the September future. There seems to be some tendency for the relation between the two futures to remain constant in *percentage* terms, if nothing happens except a change in expected size of the new crop. Suppose, for example, that in early April the price of September wheat is $1.50 per bushel, and the price of May wheat is 10 percent higher, at $1.65. Now suppose that serious crop damage is thought to be detected during April and the price of September wheat rises to $1.80; the price of May wheat may very well rise to about $1.98, maintaining the former percentage relation to the price for September delivery, but actually rising 33 cents, under the influence of supposed crop damage, where the rise in price of the September future was only 30 cents.

The foregoing statement of fact is based on empirical studies which have attacked the question from other angles besides the one suggested above.[1] The results from all lines of investigation concur in indicating that prices quoted at one time, in a futures market, for two different dates of delivery, stand in a relation which in general *does not* reflect expectations regarding events that may occur between the two delivery dates. This conclusion holds whether the dates lie in separate "crop years," as in the example considered above, or in the same crop year.

What, then, *are* the influences which determine inter-temporal price relations? In the example considered above, a true explanation would be that the price of May wheat (in April, let us say) is above the

[1] See the following publications, issued under *Wheat Studies of the Food Research Institute*: "The Post-Harvest Depression of Wheat Prices," November 1929, VI (1); "Price Relations between July and September Wheat Futures at Chicago since 1885," March 1933, IX (6); "Price Relations between May and New-Crop Wheat Futures at Chicago since 1885," X (5); "Price Relations of Liverpool Wheat Futures with Special Reference to the December-March Spread," XVII (3). All are by the present author, the last in collaboration with Sidney Hoos. Some theoretical implications of the findings other than those considered here are examined, and more detailed citation of evidence is given, in "Theory of the Inverse Carrying Charge in Futures Markets," *Jour. Farm Econ.*, Vol. XXX, No. 1 (Feb., 1948), pp. 1-28, and "Professor Vaile and the Theory of Inverse Carrying Charges," *Jour. Farm Econ.*, Vol. XXXI, No. 1 (Feb., 1949), pp. 168-72, also by the present author.

price of wheat for September delivery because the *last* crop was small (perhaps the carryover from still earlier crops was small also, contributing to the effect). So far as supplies are concerned, it is only supplies *already in existence* which have any significant bearing on a current inter-temporal price relation of this sort.[2]

This statement of fact poses the theoretical problem to which we now turn. How shall we account for the observation that it is existing supply rather than expected change in the supply which is involved in determining inter-temporal price relations? The answer is easy for one set of circumstances, which we may consider first.

II. *Clear Aspects of the Theory*

The theory of inter-temporal price relations is simple and has long been fairly well understood so far as concerns the condition of large supplies, involving stocks which must be carried from one date to another in such volume that direct economic reward must be offered for the service of stock-carrying. In those circumstances, relations between prices for delivery at the two different dates are commonly regarded as depending on the "cost" of carrying the stocks. This is a condition which has often existed for wheat in the United States as regards the relation between prices for December and for May delivery. It is commonly said, with approximate accuracy, that in the presence of abundant supplies the price for May delivery tends to be the price for December delivery plus the cost of storing wheat from December to May. At various times in the past supplies have been so large that even the relation between the price for May delivery near the end of one crop-year, and the price for delivery in the subsequent September following a new harvest, seemed clearly determined by the cost of storing wheat over the interval.

This theory of inter-temporal price relations under the condition of abundant or super-abundant supplies has the defects common to all cost theories of return for an economic service. If the return for a service is determined freely and competitively, it will vary according to demand and supply conditions. Such is the case with returns for storage of wheat. If stocks to be stored are exceptionally large, the return for carrying wheat may exceed the "cost" of storage, as conventionally calculated. If stocks are quite moderate, competition among firms with storage facilities tends to result in the storage being provided for a rather small return per bushel.

[2] In some special cases this statement is subject to minor qualification, but the cases are such as have not been found in the United States wheat market. The basic theory of inter-temporal price relations must be founded on conditions such as are described in the text and then elaborated, if necessary, to cover conditions of more complex character.

This amendment of the theory first described above leads to explaining inter-temporal price relations under the pertinent conditions as determined by a competitive "necessary return for storage." We may now say that the price of wheat for May delivery exceeds the price for December delivery by the amount of the *necessary return for storage* from December to May. Given a futures market, active informed competition occurs in determination of the necessary return, because any elevator operator who hedges the stocks he carries knows within rather narrow limits what return he will receive for the storage service rendered.

Near the end of November, for example, the hedger may make a choice whether to sell wheat which he has in store or to carry it until May. For purposes of the reasoning, it makes little difference whether the wheat at the time of decision is hedged in the December or in the May future; if the hedge is in the December future, decision to hold beyond December will require transfer of the hedge to the May future, at a cost, at most, of only 0.3 cent per bushel, and at a cost of only 0.15 cent per bushel if the hedger holds membership in the exchange, as large hedgers do for the sake of such savings. Suppose the hedge already in the May future. In making his decision, the hedger assumes as a first approximation that at the end of April the price of the wheat he owns will stand in the same position relative to the price of the May future as it holds at the end of November relative to the December future. If events should conform to that assumption, his return for storage would be exactly the amount by which the price of the May future exceeded the price of the December at the time the decision was made. If he thinks that the price of the wheat he owns will either appreciate or depreciate relative to the price of the specific quality of wheat represented by the futures contract, any such expected change must be applied as an adjustment to the known price difference between the two futures in order to arrive at his expected return for storage. Yet even in cases where there is opportunity for substantial change in relation between the price of the wheat owned and the price of "contract wheat"—opportunity which may exist either because of a large difference in quality or because of a large difference in location—it is common to make no adjustment for this possibility because the most reasonable assumption at the time is that no change in relation will occur. In any case, the known relation between prices of the two futures gives the hedger a basis for anticipating his return for storage which is far superior to any estimate which could be made in the absence of a good hedge in a futures market or of an outright forward sale of the actual wheat.

Thus existence of a futures market, coupled with the practice of

hedging, gives potential holders of wheat a precise or at least a good approximate index of the return to be expected from storing wheat. This is an important fact which has been too much neglected in discussion of the economics of futures trading. It is through supplying a direct measure of the return to be expected from storage, and a means, through hedging, of *assuring* receipt of that return, or of approximately that return, that a futures market makes its most direct and powerful contribution to the economical distribution of supplies of a commodity over time.

A known return for storage is, in essentials, a price of storage. The fact that the price of storage is not quoted directly, but must be derived by taking the difference between quoted prices of wheat for two different dates of delivery is immaterial for the economic reasoning. The price difference, at least when it is positive, is in all essential respects itself a price of storage, determined in a free market through the competition of those who seek to supply storage service. The general form of the storage supply curve is known from statistical studies and may be represented as in Figure 1.

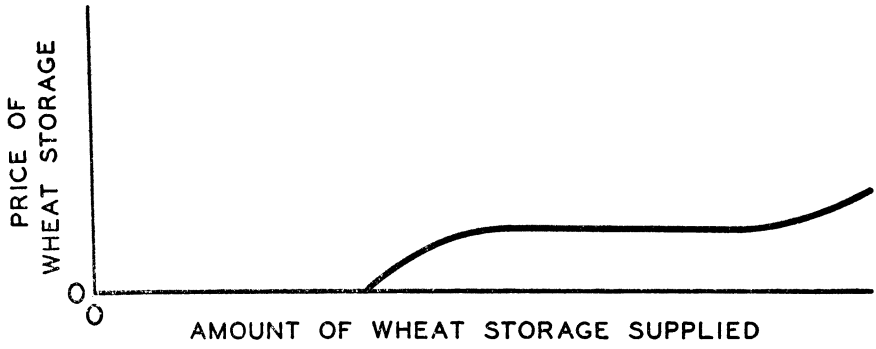

FIGURE 1. STORAGE SUPPLY CURVE

Because Figure 1 is a generalized representation, scale values are not shown except at the origins, which are taken as zero for both price and amount of storage. The price scale depends, among other things, on the length of time-interval involved; for example, the price figures will be larger for storage from September to May than for storage from December to May. The quantity scale depends, for one thing, on the time of year, for reasons that are somewhat complicated, but relate partly to opportunities to use the storage facilities for storing other grains. This observation suggests that the position and form of the curve itself may change somewhat from year to year with variation in those alternatives. The scale depends also on the measure used

for amount of storage; the indices of amounts which are available for statistical analysis are not quite the measures which would be chosen for theoretical discussion.

III. *The Theoretical Problem*

The foregoing theoretical treatment does not meet the problem posed at the outset because this theory considers only the case in which the price for later delivery is *above* the price for earlier delivery, affording a positive return for storage, or price of storage, whereas the problem tends to emerge clearly only when the price for deferred delivery is *below* the "nearer" price.

One approach to treatment of the latter class of circumstances is afforded by extending the theory to admit consideration of negative prices of storage. We may then draw the supply curve for storage as in Figure 2, which differs from Figure 1 only in that the curve of the

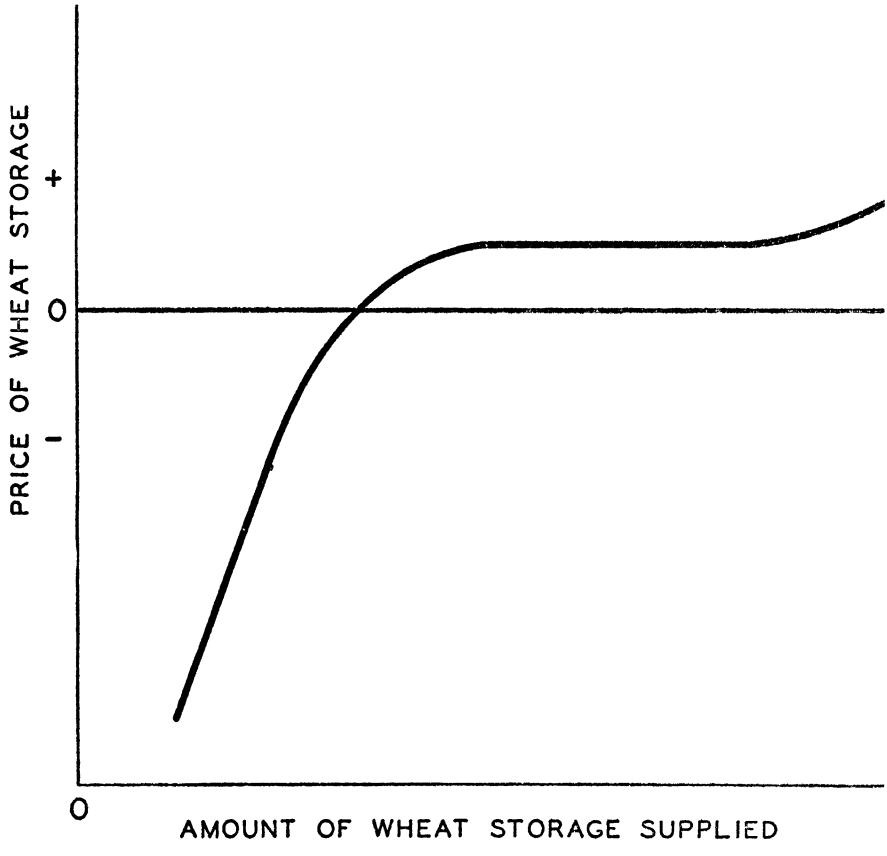

FIGURE 2. COMPLETE STORAGE SUPPLY CURVE

earlier diagram is extended downward and to the left, into an area of negative prices.

This diagram also is founded on statistical observation. When the difference between prices for near and for later delivery, which we have seen may profitably be regarded as a price of storage if it is positive, takes negative values, wheat is nevertheless stored in substantial quantities over the time-interval considered. The amount which is stored, however, tends to be less when the "price of storage" is negative and large, than when it is negative and small. There is strong evidence that the continuity of the curve is uninterrupted where it crosses the zero line.

Let us now consider a question which might have been raised with regard to Figure 1. Both Figure 1 and Figure 2 show, as is demonstrably the case, that a large amount of storage is supplied even when the price of storage is exactly zero. One condition which makes that possible is the fact that storage of grain is an enterprise in which most of the costs are fixed costs, from a short-run standpoint. Another important condition is that for most of the potential suppliers of storage, the costs are joint; the owners of large storage facilities are mostly engaged either in merchandising or in processing, and maintain storage facilities largely as a necessary adjunct to their merchandising or processing business. And not only are the facilities an adjunct; the exercise of the storing function itself is a necessary adjunct to the merchandising or processing business. Consequently, the direct costs of storing over some specified period as well as the indirect costs may be charged against the associated business which remains profitable, and so also may what appear as direct losses on the storage operation itself. For any such potential supplier of storage, stocks of a commodity below some fairly well recognized level carry what Kaldor has aptly called a *convenience yield*.[3] This convenience yield may offset what appears as a fairly large loss from exercise of the storage function itself.

Thus we have an explanation not only of why large quantities of wheat are stored in the absence of any direct return for storage, but also of why wheat is stored when the figure which we have chosen to call "price of storage" is negative. There remains, however, the question whether it is good theory to treat these negative values as negative prices. Should we, rather, say that the difference between prices of a commodity for two different dates of delivery may be considered a price of storage only when the indicated price is positive, and that some other theoretical treatment of the relation should be provided to cover the

[3] Nicholas Kaldor, "Speculation and Economic Stability," *Rev. Econ. Stud.* (1939-40), Vol. VII, p. 6.

area of negative values? Other possible treatments come to mind, but none which seems to me to have merits which warrant advancing it as preferable to recognition of the existence of negative prices of storage.

IV. *Supplementary Considerations*

If we leave open the question which has just been raised, there may be occasion to reconsider how well, in fact, the price-of-storage theory serves in the area of positive "prices of storage." Two limitations of the theory may be noted: (1) much storage is supplied by people who do not hedge and who decide to store, or not to store, without regard to what we have called the price of storage; and (2) much storage by those who do hedge earns a return which is not exactly equal to the market price of storage. Neither of these limitations has any importance from the standpoint of principle, however; each has its counterpart in familiar price theory. If people store without regard to the current market price of storage, so do people produce vegetables without regard to the current market price of vegetables. And if some people store because they expect to receive a higher return than the quoted market price of storage, so also do people produce goods in expectation of a higher return, owing to quality or to place of sale, than the price recorded in available quotations.

A particular merit of the price-of-storage theory is that it exposes clearly the fact that in the presence of hedging much storage does occur in response to a recorded, and competitively determined, assurance of return specifically for the storage itself. This creates a situation very different from that where storage is undertaken simply in the hope of price appreciation. As has been remarked, this establishment and recording of an exactly or approximately known return for storage is a principal means by which futures markets facilitate the economical distribution of supplies through time.

This merit of the price-of-storage theory is one which argues for extending the theory to cover negative prices. The negative prices occur when supplies are relatively scarce. They then impose pressure on hedging merchandisers and processors to avoid holding unnecessarily large quantities out of consumption in the form of stocks which they can do without.[4] Thus a negative price of storage makes available for consumption in a year of shortage, supplies which would otherwise remain tied up in "convenience stocks." In the case of wheat in the United States, the quantity which may be drawn out of pure con-

[4] A correspondent whose remarks have been much appreciated has advanced the objection that recognition of a negative price of storage implies that people are paid for *not storing*. To my mind, it implies that people are paid *in reverse* (that is, have to pay) for such storing as they choose to do.

venience stocks and made available for current consumption by a negative price of storage is of the order of 75 million bushels.

The main reason, of course, for adopting the cost-of-storage theory, or some alternative which provides *direct* explanation of inter-temporal price relations, is that some such explanation is necessary to account for observed price behavior. Only some direct explanation of the price relation in terms of an existing condition can account for the fact that expectations regarding future events, which are directly pertinent to a distant forward price, have approximately the same effect on spot and near forward prices as on a distant forward price.