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# ANTI-HOARDING LAWS: A STOCK CONDEMNATION RE-ASSAYED

Brian D. Wright

Yale University

and

Jeffrey C. Williams

Brandeis University

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Yale University and Brandeis University

ABSTRACT

Economists have regarded anti-hoarding laws as irrational reactions to non-existent monopoly in the storage of grain. In this paper, we show that anti-hoarding laws cannot be rationally directed against a monopolistic storer, for he will always store less, not more, than would be stored under competition. But seemingly perverse competitive storage, in the form of excessive stockholding, can arise when a price ceiling distorts the market. Additional public storage exacerbates this perverse private behavior, and may even induce behavior that appears to be active market manipulation. Under such circumstances, anti-hoarding laws can be a desirable second-best policy.

# ANTI-HOARDING LAWS: A STOCK CONDEMNATION RE-ASSAYED*

Brian D. Wright and Jeffrey C. Williams

Yale University and Brandeis University

One of the most ancient and persistent concerns of public policy has been regulation of traders involved in the purchase, storage, and resale of grain. In England up to the seventeenth century, for example, purchase of grain with the intention of resale in the same market at a later date was commonly forbidden, or allowed only when the price was below a specified level.[1] In modern times anti-hoarding laws have been enforced frequently in periods of scarcity. Over the last forty years in India and Pakistan, for example, public authorities have repeatedly taken measures against hoarding.[2]

Economists have inferred that anti-hoarding laws are directed against monopoly in the handling of grain, or more specifically, against price-manipulating behavior by private storers who, by withholding excessive amounts of grain, decrease supply below its socially optimal level. Adam Smith (1784), for one, accepts that these laws are concerned with monopoly. One argument he makes against them is that corn merchants are too numerous to collude, although this argument is disputed by Rashid (1980) who offers historical evidence to the contrary. Smith, however, further argues that, even if storage is monopolized, excessive hoarding will not occur. He reasons that "the corn merchant himself is likely to suffer the most by this excess of avarice ... from the quantity of corn which it necessarily leaves upon his hands in the end of the season, and which, if the next season happens to prove favourable, he must always sell for a much lower price than he might otherwise have had" (Vol. 2, p. 293).

Satisfied anti-hoarding laws are not justified as an attack against storage monopoly, he concludes that "The popular fear of engrossing and forestalling may be compared to the popular terrors and suspicions of witchcraft" (Vol. 2, p. 309).

In this paper we re-examine the case for anti-hoarding laws. We use a stochastic dynamic programming approach to confirm that a storage monopolist will not withhold grain excessively, though he will decrease consumption in times of scarcity. But anti-hoarding laws might have other justifications. In fact, we show that anti-hoardings laws may be socially desirable when price ceilings are imposed on the grain trade, as they frequently have been.[3] Price ceilings and related measures can induce competitive storers to withhold their grain during even the worst shortages, and to exhibit seemingly manipulative behavior.

## 1. Competitive Storage

In this analysis we assume a closed economy with a storable commodity subject to a random disturbance in production. Consider first the case where storers are risk-neutral atomistic price-takers with rational expectations. Profit-maximizing storage behavior is an inherently intertemporal problem because storage, like other forms of investment, connects one period with the next. In an undistorted economy with infinite horizon, the necessary conditions for competitive storage, which are also the necessary conditions for socially optimal storage, are:[4]

$$
(1) \qquad \begin{aligned}
P_t + K' &\geq (1 + r)^{-1} E_t[P_{t+1}] \quad , \qquad S_t^c = 0 \\
P_t + K' &= (1 + r)^{-1} E_t[P_{t+1}] \quad , \qquad S_t^c > 0
\end{aligned}
$$

where $E_t$ is the expectational operator conditional on the information available at time t, r is the interest rate, and K' is the net marginal cost of storage. Price $P_t$ is given by the inverse consumption demand function

$$(2) \qquad P_t = P_t(h_t + S^c_{t-1} - S^c_t) \qquad , \qquad P' < 0$$

where $h_t$ is the harvest and $S^c_t$ is the amount stored from period t to period t+1 .

Implicit in these conditions is a function relating competitive storage to the amount available:

$$(3) \qquad S^c_t = S^c(I_t) \qquad , \qquad S^c_t \geq 0$$

where the amount available, $I_t$ , is given by

$$(4) \qquad I_t = h_t + S^c_{t-1}$$

The implications of competitive storage have been examined by Wright and Williams (1982a), who use numerical methods to derive $E_t[P_{t+1}]$ as a function of $S^c_t$ , and thereby derive the storage behavior for zero and positive supply elasticities.[5]

## 2. Monopolistic Storage

In most agricultural markets the number of producers is large. In contrast, the market for the supply of storage services may be highly concentrated, in which case storers might try to extract some supernormal profits from their operations. When there is only one storer, or when cooperation is perfect, the limiting case of a storage monopoly occurs. If it existed, would such a monopoly justify an anti-hoarding law?

In discussing the behavior of the storage monopolist, it is convenient to proceed as if he sells all his stock and then rebuys the amount he wants to store till the next period. (Handling costs and shrinkage are ignored.) Expected monopoly profits in the infinite horizon case are given by

$$E_t\Pi(S_t) = -P_tS_t - K'S_t + [S_tE_t(P_{t+1}) + E_t\Pi(S_{t+1})](1 + r)^{-1} \tag{5}$$

An expected-profit maximizing monopolist must consider that each additional unit stored depresses his return on preceding units and that the opportunity cost of each additional unit put into store is the marginal expenditure, which of course will be higher than the price. A monopolist, with rational expectations, will also recognize the effects of his current actions on his stream of future profits. The more he stores this period, the greater will be the availability and the larger will be his profits next period. The prospect for greater storage next period will in turn lead to higher expected profits in even more distant in even more distant periods. Thus a monopolistic storer follows the arbitrage conditions:

$$\begin{aligned} &MX_t + K' \geq (1 + r)^{-1} E_t[MR_{t+1}] \quad , \qquad S_t^m = 0 \\ &MX_t + K' = (1 + r)^{-1} E_t[MR_{t+1}] \quad , \qquad S_t^m > 0 \end{aligned} \tag{6}$$

where $E_t[MR_{t+1}]$ denotes marginal revenue which equals $\frac{\partial S_tE_t[P_{t+1}]}{\partial S_t}$, plus the effect on expected future profits, $\frac{\partial E_t[\Pi(S_{t+1})]}{\partial S_t}$, and $MX_t$ is marginal expenditure, $\frac{\partial P_tS_t}{\partial S_t}$. Using a numerical approach analogous to that used to derive $E_t[P_{t+1}]$ as a function of $S_t^c$ in the competitive case, we can derive $E_t[P_{t+1}]$ and $E_t\Pi[S_{t+1}]$ as functions of $S_t^m$. From these, the amount stored by the monopolist, $S_t^m$, is derived as a function of the amount available:

$$S_t^m = S^m(I_t) \quad , \quad S_t^m \geq 0 \tag{7}$$

At first glance, it might not be clear why a monopolist is concerned with marginal expenditure in period $t$ rather than marginal revenue. If his problem were the allocation of total supply among periods, he would in fact be concerned with marginal revenue in the current period. But if one party controlled all distribution such that consumers could buy only from him, it is by no means obvious that he would store anything at all. When the demand curve is inelastic over the relevant range of supply, a monopolist over distribution will want to restrict supply to an infinitesimal amount or to an amount where demand becomes elastic.[6] He would not incur additional charges to store the crop but would destroy it. A monopolist over distribution would store only when he was somehow constrained from destroying supplies, although a more plausible reaction would be for him to maneuver to restrict production. If the disturbance in production is small, the monopolist will rationally store only if consumption demand is locally elastic, which is surely not the case for staple foodstuffs. (In any case, the more elastic the demand, the less role there is for storage, even under competition.)

Because a monopolist over distribution is most likely to be destroying crops or restricting plantings, the likely legal response would be anti-destruction laws and laws against limiting production. If anti-hoarding laws are directed against some form of monopoly, the monopoly power must be over only storage, not over the entire system of distribution. A storage monopolist competes in the market for current consumption. Hence he pays attention to the marginal expenditure on what he puts into store, as seen in equation (6).

3. Comparison of Competitive and Monopolistic Storage Behavior

The storage rules for both competition and monopoly depend in practice on the particular demand curve, the supply elasticity, the variability of the harvest, the interest rate, and storage costs. An important fact about real-world grain storage is that the net marginal cost of storage is not linear, and more important, becomes negative as storage falls below medium levels. Working (1953) identified such a nonlinear relation for the cost of storage in a study relating the spread between the spot price and the new-crop futures price to the level of wheat stocks at the end of the crop year. Subsequent studies have confirmed Working's findings for many other commodities.

One reason for the negative marginal cost of storage at low levels of availability is that stocks have "convenience yield" or accessibility value to processors and other intermediate users, because either inflows or outflows are not predictable and the expected cost of running out is sufficiently high. For much the same reason people hold currency at the cost of foregone interest.[7] A related reason is that the cost of transport or transformation of stocks may rise as stocks fall, so that the net marginal cost of storage becomes negative at low levels of stocks. This is observed, for example, in grain stocks held in barges. Because of the positive relation between barge speed and cost of transport, and the negative relation between speed and total floating inventory, at sufficiently low levels of the latter a negative net marginal storage cost occurs. Thus some grain is found on barges even when prices are failling.

To compare competitive and monopolistic storage, we use the following example. Suppose consumption demand has a constant elasticity of -0.2 in every period, and the real interest rate, $r$ , is constant at 5%. The harvest, supplied by atomistic competitive farmers, is $\hat{h}(1 + v_t)$ where $v_t$ is a serially uncorrelated disturbance, and $\hat{h}$ is the same every period. Let $v_t$ have a five-point distribution of -20%, -10%, 0% , +10%, and +20% with probabilities .05, .20, .50, .20, and .05 respectively, a harvest sufficiently variable to provide considerable contrast between competitive and monopolistic storage. Define the market equilibrium with no uncertainty in the harvest as $\hat{h} = 100$ tons, $P = \$100$. Following the recent empirical study of Gray and Peck (1981) of the Chicago wheat market, we chose a piecewise linear functional form for marginal storage cost, as shown in Figure 1.

The storage rules for both competition and monopoly derived numerically for this example are shown in Figure 2. Obviously monopoly has a dramatic effect on carryover behavior. The marginal propensity to store is greatly reduced, to less than one-half that of competitive storage, and storage begins at a higher level of availability.[8]

Since this result is derived numerically, a simplified analytical example may help the reader to appreciate the underlying economic rationale. Consider a two-period case with a small perfectly anticipated production disturbance $+Z$ in the first period, $-Z$ in the second. If planned production is fixed at $\hat{h}$ , a linear inverse demand function yields a first period price of

$$(8) \qquad P_1 = P(\hat{h}) + Z\,\hat{h}(1 - s)\,P'(\hat{h})$$

where $s$ is the fraction of excess production stored in the first period, and released from storage in the second period. Price in the second period is

$$(9) \qquad P_2 = P(\hat{h}) - Z\,\hat{h}(1 - s)P'(\hat{h})$$

The profit from storage, assuming no carrying charges or interest expenses is $\Pi = -(-ZsP_1) + ZsP_2$ . Profit-maximizing monopolistic storage occurs at

$$(10) \qquad \frac{\partial \Pi}{\partial s} = Z^2\,hP'[2(2s - 1)] = 0$$

Thus $s = 0.5$ . On the other hand under atomistic competition

$$(11) \qquad \frac{\partial \Pi}{\partial s} = -(-ZP_1) + Zp_2 = 0$$

Substituting from (8) and (9), the solution is $s = 1.0$ in this case. So the marginal propensity to store under monopoly is half that under competition. The difference in storage propensities in this simple exercise is similar to that seen in the results derived from our numerical model, which is more realistic in that it has an infinite horizon, and the sequence of disturbances is not conveniently known in advance.

Obviously at all levels of availability the monopolist holds less than competitive storers. The common contrary presumption that a storage monopoly restricts the supply of grain during scarcities by excessive withholding follows plausibly from consideration of the static textbook case of the profit-maximizing behavior of a single firm with a finite and negative elasticity of demand for its product. The confusion arises over what the storage monopolist supplies. He does not extract his extra profits by keeping grain off the market to keep the price high but by restricting his output, his output being the provision of storage. A storer must, ignoring shrinkage, expect to sell at some point any grain he buys. The rule "buy low, hold high" is no more conducive to success for a storage nomopolist than for a price-taker. Hence the true offense of a monopolistic storer is the exact reverse of the standard charge of over-withholding. The monopolist is not innocent because he withholds no more than competitive storers, as Adam Smith suggests, but guilty because he withholds too little at all levels of availability!

This comparison of storage rules actually understates the case that a monopolist stores too little because it considers storage behavior at equal availabilities. But the amount available in one period depends in part on the storage in the previous period, and this means the monopolist's low storage will feed on itself. As an illustration of this cumulative effect, consider what a monopolist and an industry of competitive storers would be storing after a string of normal harvests (i.e., harvests when the disturbance $v$ is 0). Both will reach a period when they store the same amount as in the previous period. For competitors this amount would be 9.1 tons, but for the monopolist only 2.2 tons. While this accumulation proceeds, consumption is actually higher under monopolistic storage than competitive storage. The advantage of competitive storage becomes clear only when a disastrous harvest interrupts the string of normal ones. Because of the extra stock available under competition, consumption is higher than under monopoly in these bad periods. The cumulative effect of monopoly on stocks can also be seen with the help of a simulation using a series of 7500 random draws for the disturbance in production. Under competition mean storage is 11.3 tons while under monopoly it is only 4.5 tons. Not surprisingly the variability of price and consumption is considerably higher with monopoly. Under competition, standard deviations of consumption and price are 4.6 and 29.2 respectively; the equivalent figures under monopoly are 7.9 and 48.0.

## 4. An Alternative Cause for Excessive Withholding

A monopolist's storage behavior is the opposite of that at which the ancient and modern prosecution of hoarders appears to be directed. But does this imply that such measures are misguided, or are there other reasons for such interventions in the private storage market? Although excessive withholding in times of scarcity is not consistent with monopoly, it can occur under another distortion commonly found in grain markets ancient and modern, namely an implicit or explicit price ceiling.

A price ceiling constrains the return storers can obtain for their holdings. If, as is usually the case, storers are "middle men" such as millers and shippers, then the price ceiling also puts a ceiling on the cost of their input into storage, or their shadow price of what they retain in inventory. Consequently they adjust their arbitrage conditions to reflect these distorted prices, and so change their storage behavior.

To illustrate these responses, we considered the case where a ceiling of $112.50 is imposed.[9] As Figure 2 shows, this price ceiling induces a significant change in competitive storage behavior - a positive amount is stored no matter how great the scarcity.

At last here is the kind of over-withholding during scarcity consistent with historical complaints and penalties. Why competitive storers retain some stocks during scarcities can be explained using Figure 3. The marginal return to a unit stored is the spread between the price expected in the next period, appropriately discounted, and the current market price. At any level of availability below 100.5 tons, the equilibrium market spread, -$14.48, is equal to the marginal storage cost of 3.2 tons, this cost being negative because of the high convenience yield of that amount of storage. Because of this negative storage cost, private storers might as well hold grain as sell it in the current period at the price ceiling. Consequently, competitive storage is socially excessive below an availability of 96.8 tons, as can be seen in comparison with the "shadow spread" curve, calculated from the marginal social value of storage instead of the distorted market price. Above 96.8 tons availability, the shadow spread is above the market spread, and this implies private storage is deficient over that range. At very high levels of availability the possibility that the price ceiling might be hit in the next period becomes remote, so the social and private spreads converge.[10]

## 5. Private Storage with Public Storage

One way to prevent this sub-optimal private storage behavior would be simply to remove the price ceiling, which, besides distorting storage, also discourages production when it is responsive to price. Removing a price ceiling may be infeasible in practice, because of political pressure or because the ceiling conforms with the government's distributional objectives. Moreover, it may be impossible for the government to convince storers that it would never impose a price ceiling, since the government is subject to no higher authority forcing it to keep its promises. A possible remedy for the distortions of price ceilings is direct participation in the storage activity. The types of public storage schemes frequently observed may prompt unusual behavior on the part of private storers because of the government's frequently arbitrary or inefficient formulation and operation of its rules. But even an efficient decentralized public storage authority whose managers use the shadow price of consumption $\hat{P}$ (the price of a tradeable ration coupon plus the market price) rather than the market price as their guide can induce competitive private storage that would likely be characterized as manipulative or monopolistic.

To solve simultaneously for competitive private and public storage, it is necessary to obtain an equilibrium where both the public and private arbitrage conditions hold. For public storage:

$$\hat{P}(I_t - S_t^g - S_t^c) + K_g'(S_t^g) \geq E_t(\hat{P}_{t+1})[1 + r]^{-1} \quad , \quad S_t^g = 0$$

(12)

$$\hat{P}(I_t - S_t^g - S_t^c) + K_g'(S_t^g) = E_t(\hat{P}_{t+1})[1 + r]^{-1} \quad , \quad S_t^g > 0$$

where $K_g'$ represents the marginal cost of public storage. The private storers take the government's actions as given and follow:

$$P(I_t - S_t^g - S_t^c) + K_c'(S_t^c) \geq E_t(P_{t+1})(1 + r)^{-1} \quad , \quad S_t^c = 0$$

(13)

$$P(I_t - S_t^g - S_t^c) + K_c'(S_t^c) = E_t(P_{t+1})(1 + r)^{-1} \quad , \quad S_t^c > 0$$

where $P$ denotes the distorted market price faced by private storers, and $K_c'$ their net marginal storage costs.

Because a public stockpile is not owned by processors, it may offer little or no convenience yield. Consequently the net marginal storage costs of private stocks may be below those of the public stockpile, and it is possible that private storers will hold some stocks even though the price ceiling depresses their return P relative to the "shadow incentive" $\hat{P}$ for government storage activity. Of course if there were no price ceiling, there would be only private storage under these circumstances.

Because of the price ceiling and the interaction of public and private storage, withholding and even accumulation in a tight market might be rational for competitive storers. This can be illustrated with the numerical example used above, assuming that $K_g'(S^g)$ is constant at \$2.50 per period, and $K_c'(S_t^c)$ is the nonlinear function presented in Figure 1. The private and public storage rules, given a price ceiling of \$112.50 and these storage costs, are shown in Figure 4. The interaction of public and private storage is complex indeed.

Government intervention increases total storage. Mean storage, public and private together, is 12.2 tons, while when private storage alone is allowed mean storage is 9.9 tons. (If there is no price ceiling, mean private storage is 11.3 tons.) But part of public storage simply replaces private storage. Mean public storage is 4.9 tons and this implies that on average 53 percent of public storage substitutes for private storage, the mean of which falls to 7.3 from 9.9 tons. This happens because over the higher availabilities, public storage depresses private storage.

In times of scarcity, because of the anticipated public demand for grain to store in future periods, private storers can expect a higher average market price for what they themselves store. When their alternative is selling at the price ceiling in the current period, this higher expected price induces them to hold even more off the market (at negative net storage cost) than if there were no public intervention in the storage activity. In Figure 2, private storage is 3.2 tons under the price ceiling, while in Figure 4 it is 4.1 tons. In short, government intervention exacerbates the excessive withholding of private storers when price is at the ceiling.

But the presence of public storage introduces a new, dynamic dimension to appenrently perverse private storage behavior. Note that over a certain range of availabilities, private storage will actually be less than at extremely low amounts available. Figure 4 shows that if a poor harvest follows a normal one, and price rises, private storers may actually accumulate stocks even as a public authority is reducing its holdings. For example, if the availability was approximately 102.5 the previous period and is 95.1 this period, observed private storage would be higher now, although less of the commodity is available. Moreover, because price would also be higher, it might will be construed that private storers had manipulated the price.

Of course, such seemingly perverse private market activity is partly an artifact of the particular storage costs and price ceiling. But this example is by no means unique. If the cost of storage at small amounts of storage were slightly less negative, private storage might even fall to nothing over a middle range of availabilities. Furthermore, if, as is generally the case, the government tried to defend a price band, rather than adjust its storage continuously as market prices change, the private reactions to such a crude policy could well seem even more perverse.[11] On the other hand if the government attempted to take into account the private reaction to its own actions, that is, to act as a Stackelberg leader, a policy whose sophistication is beyond any observed public storage scheme, it can still induce seemingly perverse private behavior.[12]

A casual observer of this market could well be forgiven for inferring that private storage is collusive and manipulative. Although the diagnosis would be wrong, the natural prescription - action against hoarding in times of scarcity - may well be socially desirable, despite the general disapproval of economists, as we now show.

## 6. The Desirability of an Anti-Hoarding Policy

Suppose an anti-hoarding law can be enacted that effectively liquidates private stocks whenever the price ceiling is reached.[13] Such a law could make a considerable improvement in social welfare.[14] In this example, the present value of the dead-weight burden of the price ceiling amounts to 4.5% of the expenditure on the commodity in a typical period.[15] Prohibiting private storage at low levels of availability would reduce this dead-weight loss by 65% of the loss. Decentralized public storage, of the type considered above, without anti-hoarding laws, actually increases the welfare loss by 28% because of its perverse effect on private storage.[16] Given the price ceiling, the best of the policies considered is to combine public storage with anti-hoarding laws aimed at private storers. With that combination, 71% of the dead-weight loss can be recovered.

The rational use of anti-hoarding laws, of course, illustrates the general theory of the second best. It is reasonable to believe some other distortion, bad in its own right, might partly cancel out an initial distortion. Once price is controlled, public storage is a natural supplement for deficient private stockholding. But public storage further distorts private storage; the addition of anti-hoarding laws moves the system closer to the first-best world of no distortions.

## 7. Conclusion

A storage monopoly in the grain market does not lead to excessive withholding in times of scarcity; rather it results in far too little carryover in both good and bad seasons. Thus, anti-hoarding laws do not address the problems caused by monopolistic practices. On the other hand, because carryover stocks can have negative net storage costs, competitive private storage behavior in the presence of a price ceiling may lead to excessive withholding in times of scarcity. Such private behavior, although competitive, may well appear collusive. This problem is exacerbated when the government operates a public stockpile to mitigate the effects of the price ceiling. In this case the private storers may appear even more socially undesirable, engaging in seemingly manipulative trading behavior, even though they actually remain price-takers. If an anti-hoarding law prevents privately rational but socially excessive private holdings during scarcities, it can improve social welfare. Thus, anti-hoarding laws may not be so akin to laws against witchcraft after all, even if their proponents are in error in believing that their social value comes from preventing monopolistic abuses.

FOOTNOTES

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[1]This offense was denoted "regrating," or could be included under wider charge "engrossing". An excellent description of the English laws regulating the corn trade is Gras (1915), especially Chapters V and VI.

[2]For a descripton of these laws see Chaudhary (1974), Hamid (1974), Patel (1965), or Vyas and Bafna (1965).

[3]Numerous recent examples of price controls are found in the literature on India and Pakistan referred to above. References to past British measures are found in Smith (1784), Vol. 2, pp. 298-310, Rashid (1980), Gras (1915), and Barker (1920). In England prices were often indirectly controlled by allowing imports only above a certain price, or, when an export surplus developed, by prohibiting or taxing exports above a certain price. In the United States, the Nixon administration imposed a brief embargo on soybean exports in 1973 to reduce domestic inflation of food prices.

[4]The following transversality conditions (Samuelson (1971)) rule out infinite explosion of storage or expected price:

$$\lim_{T \to \infty} (1 + r)^{-T} S_t = \lim_{T \to \infty} (1 + r)^{-T} EP_t = 0$$

[5]A description of the numerical approach is available from the authors.

[6]See Stiglitz (1976), footnote 2.

[7]For a discussion of accessibility in the context of inventory theory, see Williams (1980).

[8]Further numerical results not reported here confirm that these conclusions about monopoly would be the same if production were elastic, or the demand curve had a different shape (e.g. linear), or marginal storage costs were constant, although the exact storage rules would be slightly different.

[9]In the undistorted case considered above, price exceeded \$112.50 approximately 25% of the time, and mean price was \$103.75.

[10]In this example the price ceiling is deterministic. Even if the price ceiling is higher, or expected at a given price with some probability less than unity, qualitatively similar distortions of storage incentives will occur.

[11]Examples of apparently perverse private responses to arbitrary price band or price peg government stockpiling rules are found in Gardner (1979) and Salant (forthcoming).

[12]We examined a similar numerical example (available from the authors) in which we modelled the government as a Stackelberg price leader constrained to choose a time-consistent storage rule. In that case we observed, as in Figure 4, excessive storage at the price ceiling, and private accumulation as prices rise to the ceiling, but in addition we observed a private marginal propensity to store in excess of unity, and negative public marginal propensity to store,

over a higher range of availabilities. For a discussion of Stackelberg public storage behavior and of the problems of deriving fully optimal public storage behavior in a distorted market see Wright and Williams (forthcoming 1982b).

[13]In this particular example, a prohibition on hoarding during scarcities can be modelled by replacing the market price, $P$, with the shadow price $\hat{P}$ on the left hand side of the arbitrage conditions for competitive storage, when a price ceiling is in force.

[14]Social welfare is defined as the present value of expected surplus arising from current storage and all future harvests and storage. Assuming a low income elasticity of demand or a low budget share, this can be approximated (see Willig 1976) by the area under the consumption demand curve minus production costs, if any, and storage costs. Some of the benefits accrue because of additional storage subsequently. The expected social value of current and future consumption, SV, is a function of current storage.

$$SV(S_t) = E_t\left[\int_o^{h_{t+1}+S_t-S_{t+1}} P(C_t)\ dC_t - \int_o^{S_{t+1}} K_c'(S_{t+1}(h_{t+1}+S_t))\ dS_{t+1} - C(\hat{h}_{t+1}) + SV(S_{t+1})(1+r)^{-1}\right]$$

where $C(\hat{h}_t)$ is the cost of production, which is in this case zero because supply is perfectly inelastic. This function is derived, as is $E_t[P_{t+1}]$, by a process of successive numerical approximation. When there are no distortions, the marginal social value curve is the storage demand curve.

[15]The present value of the dead-weight loss of monopoly in the same example is approximately that of the price ceiling. The dead-weight loss of a price ceiling if supply were responsive and affected by the ceiling would be considerably larger.

[16]If the government acted as a Stackelberg price leader with time consistent behavior, welfare would be increased somewhat by public storage even without an anti-hoarding law. Nash public behavior would also improve welfare if supply were sufficiently elastic.

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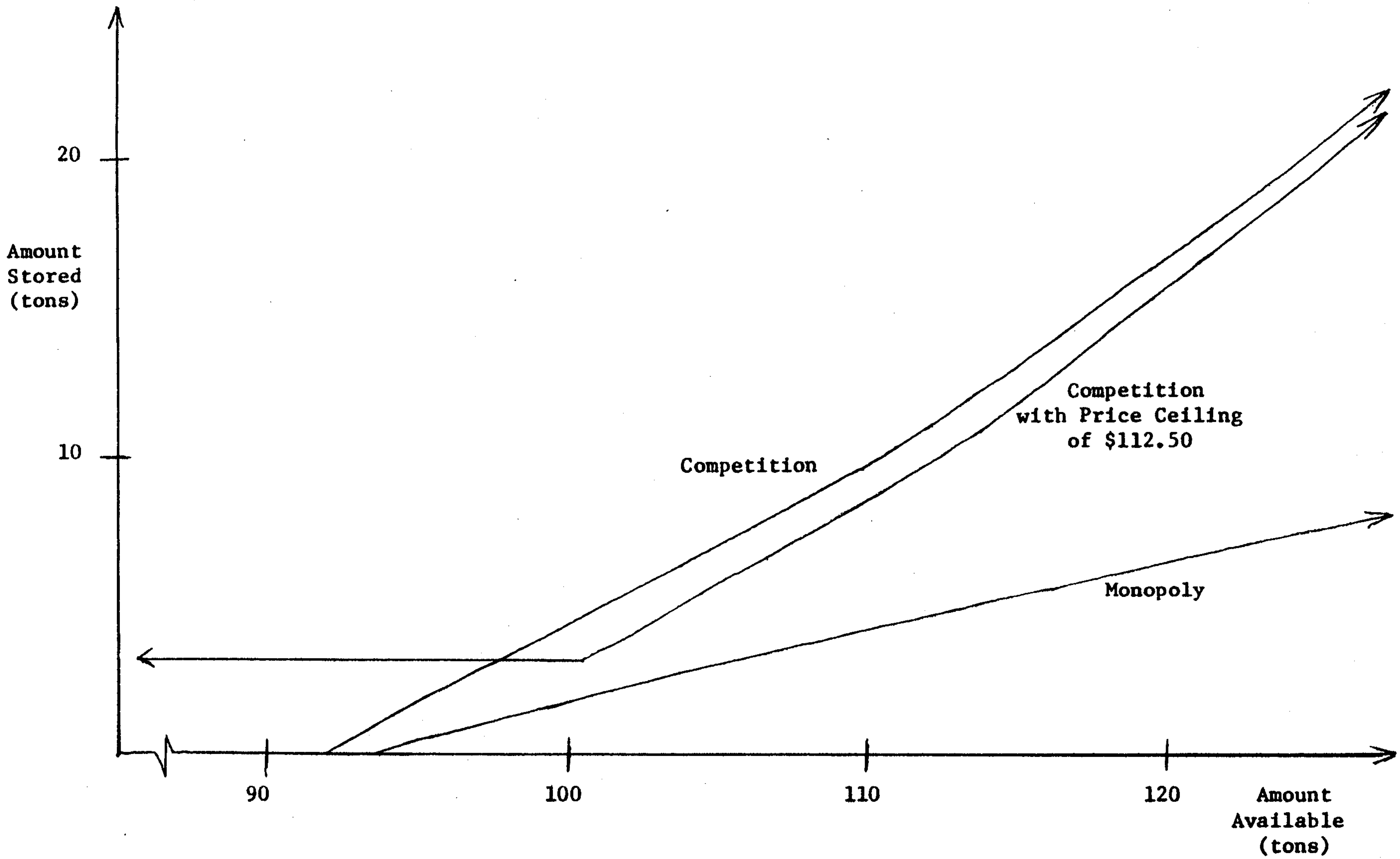


FIGURE 2

STORAGE RULES

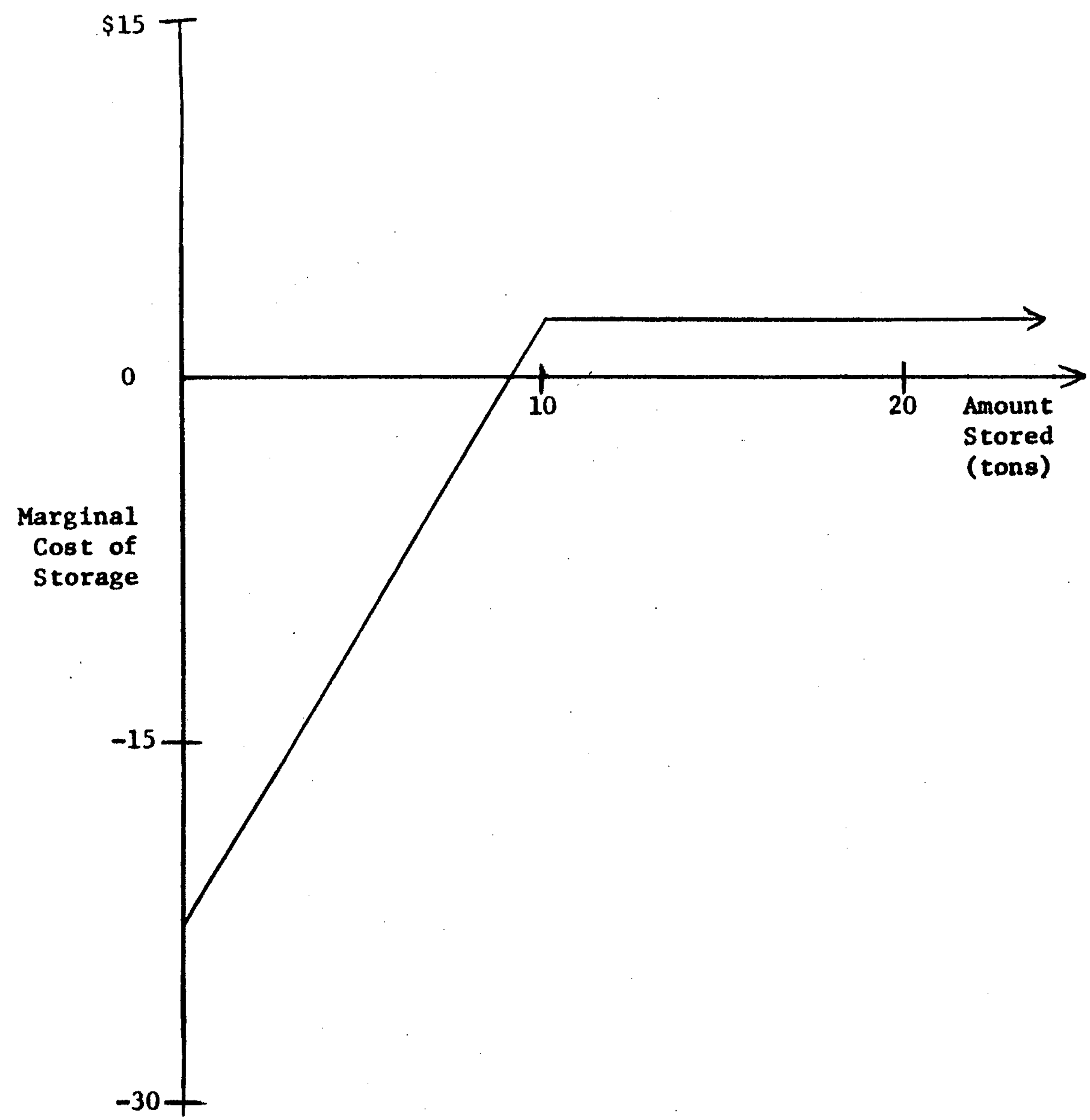


FIGURE 1

MARGINAL COST OF STORAGE

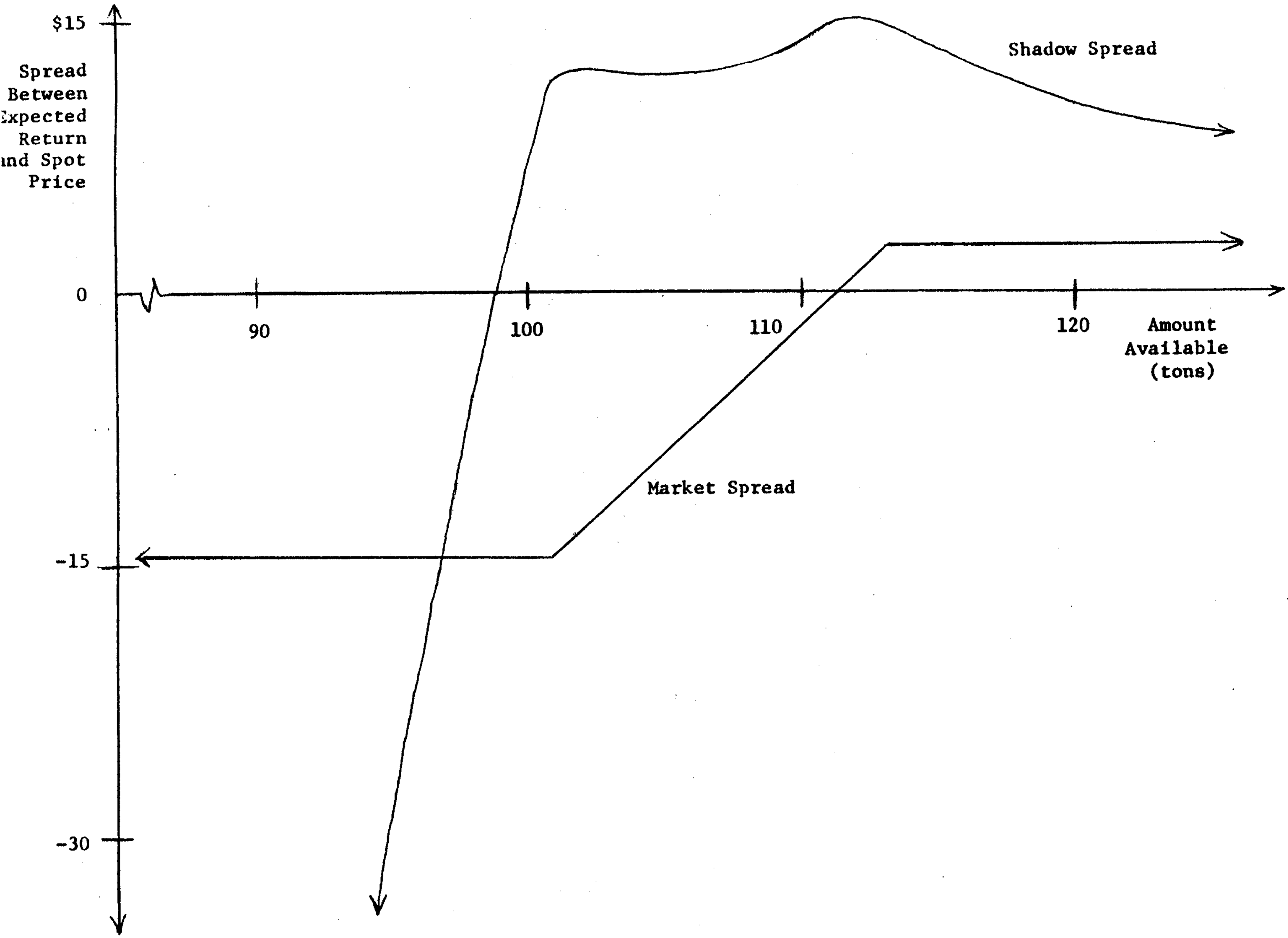


FIGURE 3

PRICE SPREADS UNDER A PRICE CEILING

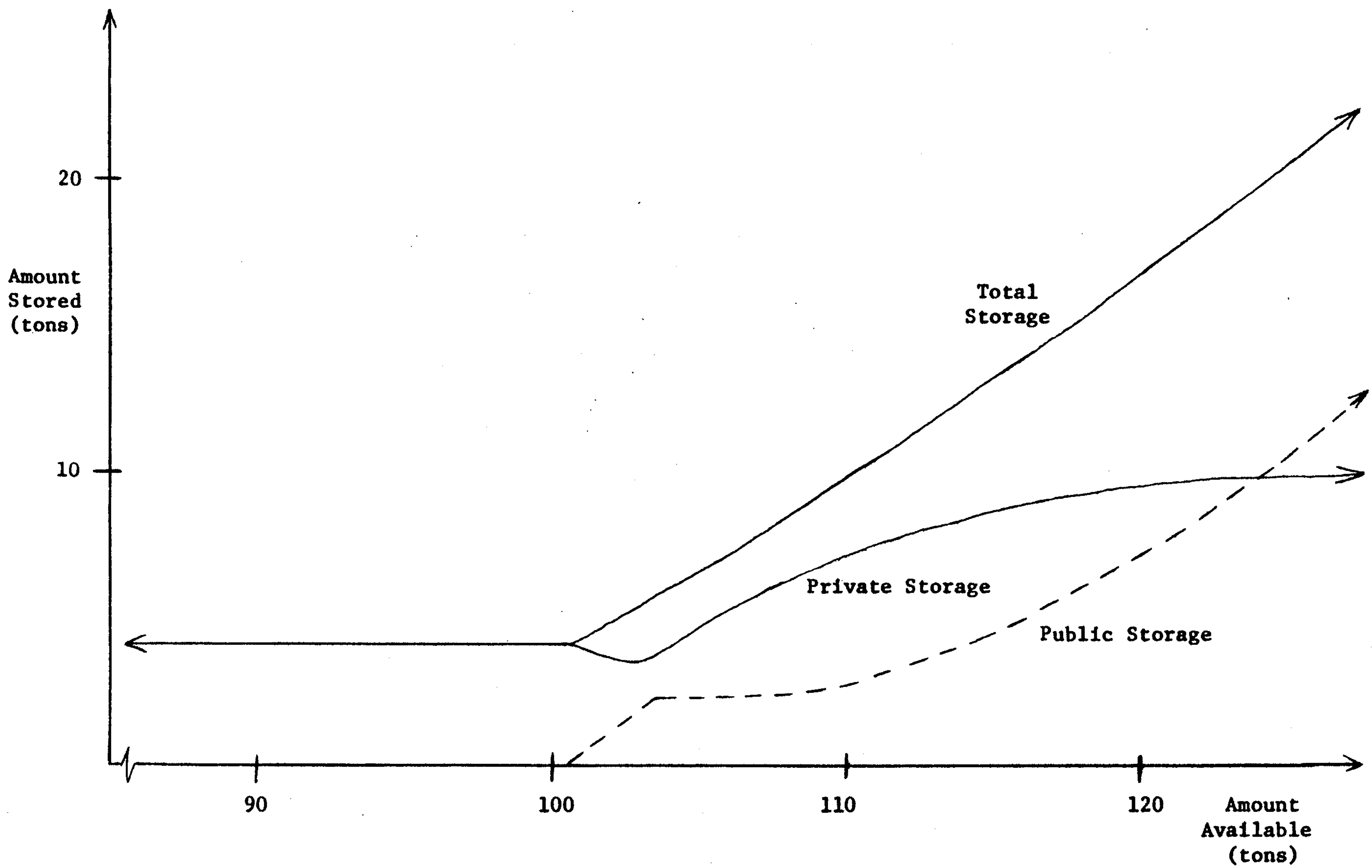


FIGURE 4

PUBLIC AND PRIVATE STORAGE RULES

UNDER A PRICE CEILING