form:

\[ \ln M_t = \ln P_t = b_0 + b_1 \ln y_t \\
+ b_2 \ln x_{t-1} + b_3 (\ln M_{t-1} - \ln P_t) + \epsilon_t \]

(2)

The results of estimating this specification, shown in the fourth panel of Table I, support the argument that households’ demands for real balances have been significantly affected by deposit market deregulation though its impact on households’ opportunity cost of holding money. A likelihood ratio test fails to reject the hypothesis that the parameters of the households’ demand relationship have remained constant over the 1970s and 1980s \( (X(8) = 14.1 \text{ against a critical value of } X_{0.05}(8) = 15.5) \). So it seems that while deregulation has altered the aggregate money demand relationship, it has not significantly altered that of the household sector over the period of the 1980s.

In order to assess the pattern of recent errors in households’ money demand, the estimated equation from the 1970s was used to construct out-of-sample forecasts for the 1980s. The last column of Table II shows these errors. Only two statistically significant errors appear: one significant increase in 1981:3 when NOW accounts went nationwide, and one significant increase in 1983:1 when Super-NOWs were introduced. No significant errors occur in household money demand during 1980. Much more importantly, no significant unexpected increases occur in household money demand during 1985, when the aggregate money demand equation registered large unexpected increases. The 1985 experience seems to reflect the inability of the aggregate equation based on historical data to adequately capture the impact of recent changes in households’ opportunity cost of holding money on money demand, rather than any structural change in households’ demand for money.

VI. Conclusion

The recent pattern of errors from standard money demand equations makes it difficult to attribute their breakdown to deposit market deregulation. It is argued here that the role of deregulation may have been obscured by seasonal filtering of the data, failure to account for changes in households’ opportunity cost of holding money, and aggregation bias. Estimates of net seasonally adjusted household money demand suggest that deregulation has affected money demand by contributing to a more variable and recently lower opportunity cost of holding money for households. In addition, the introduction of nationwide NOWs and Super-NOWs each seems to have caused significant one-time increases in household money demand.

References

PRICE SMOOTHING, INVENTORY, AND RANDOM OUTPUT

EDWARD ZABEL

I. Introduction

This paper reconsiders the random demand, random output model introduced by Amihud and Mendelson [1] to examine market price flexibility. Implicit assumptions in that paper greatly limit the scope of the analysis. In fact, the results obtained by Amihud and Mendelson represent an extreme case of a model in which output is deterministic, rather than being random, and inventory is suitably limited. The inventory restriction arises naturally in that larger inventory levels are transitory. Though the issue is not discussed by Amihud and Mendelson, the restricted inventory is associated with states in which output is positive and constitutes an ergodic set of inventory levels. As shown here, the essence of output randomness is to amend the ergodic set of inventory levels and the corresponding set of ergodic prices. The amended set continues to include states in which (expected) output is positive and may or may not include states with zero expected output. With the Amihud and Mendelson assumption that output is additively random, which is itself a questionable assumption, states persist in which expected output is zero. However, using a modification of that assumption we show that, while the limits of the ergodic set change, states associated with zero expected output are again transitory.

The role of output randomness does not depend on the assumptions in the Amihud and Mendelson paper that output realization is lagged one period. Similar modifications of an ergodic set of inventory levels obtain in a model in which output determination occurs immediately after decisions are made. However, the assumption of lagged output is more reasonable than the common assumption of instantaneous output realization. Hence, it seems worthwhile to reconsider a model with an output lag as well as examining the impact of output randomness.

The next section examines the model in which output is deterministic and output is lagged one period. The following section introduces random output into the model. The concluding section reconsider the implications for price flexibility. An Appendix, which is

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1Lagged output has been considered in the standard inventory model where output price is fixed, rather than being a decision variable, by Raffel and Sraff [3] and Sraff [4]. The lesson there is that a model with an output lag of any number of periods is manageable if excess demand is backlogged but that analysis becomes intractable when the lag exceeds one period if excess demand is lost.
omitted, provides proofs of various statements. The Appendix is available from the author upon request.

II. The Model With Deterministic Output

Before restricting output to be deterministic we review the random output model introduced by Anandh and Mendelson. Omitting all the details, the problem is represented by the equation

\[ G(x) = \max_{Q \in S} \{ R(x, Q) - e \cdot E[Q - x - u^d]^+ - h \cdot E[Q - x - u^d]^+ - k \cdot y + \beta \cdot E[G(x + y + u)] \}. \]  

(1)

Briefly, \( G \) is the infinite horizon value function; \( x \) is an inventory level which can be positive or negative (the backlog when \( x \) is negative); \( Q \) is the expected demand depending on the price \( p \) where \( Q \) is a random variable with mean \( \mu \) and \( \sigma \), \( \phi(\cdot) \) is the distribution function of \( Q \); \( E[\cdot] \) is expected value; \( e \) and \( h \) are unit backlog penalty cost and unit production cost; \( 0 < \beta < 1 \) is a discount factor and \( u = \min(u^d, u^c) \). The symbol \( E \) signifies the expectation operator with \( E[\cdot]^+ \) as the expectation when the argument is positive and \( E[\cdot]^+ \) as the expectation when the argument is negative.

It is assumed that \( R(Q) \) is a continuously differentiable concave function with \( R''(Q) > 0 \). While no assumptions are made explicitly in Anandh and Mendelson about restrictions on \( Q \) and \( y \), it seems to be understood that \( Q \geq 0 \) and it is clearly consistent with problem (1) to require expected output \( y \geq 0 \). If \( y = 0 \) were allowed to be negative, then not only is the production process costs irreversibly so that we may recover \( -k \cdot y \) when \( y \) is negative, but, since there is no bound on \( y \), we may recover costs even for output which we have not produced. When expected demand has a price intercept, either \( R'(0) > h + e > 0 \) or \( R'(0) < k \cdot h \). The former condition is analogous to the profitability condition in the deterministic theory of monopoly that at zero output marginal revenue exceeds marginal cost. Here, if price \( b \) satisfies \( \hat{b}(b) > 0 \), it excludes the possibility that \( p = \beta \). Anandh and Mendelson use this condition in their example and elsewhere. When \( R'(0) \leq k \cdot h \) there will exist an inventory interval \((-\infty, x_1)\) with \( p = \beta \). Henceforth, for purposes of comparison, we assume \( R'(0) > k \cdot h \). To assure the possibility of positive output one other assumption needs to be made explicit. Clearly, a necessary condition for expected output to be positive for some \( x \) is that the discounted value of the unit penalty cost exceed the unit production cost, i.e., \( \beta h/\beta(1 - \beta) > k \). Standard arguments now guarantee that the various assumptions imply the concavity of the value function \( G(x) \).

Now, if \( x = x - q \cdot y \) represents the expected inventory next period, \( x \) may replace \( y \) as a decision variable and (1) becomes

\[ G(x) = \max_{Q \in S} \{ R(x, Q) - e \cdot E[Q - x - u^d]^+ - h \cdot E[Q - x - u^d]^+ - k \cdot q + \beta \cdot E[G(x + u)] \}. \]  

(2)

Anandh and Mendelson claim that (2) is separable and that \( y \) and \( x \) may be chosen independently in the problem

\[ G(x) = \max_{Q \in S} \{ R(x, Q) - e \cdot E[Q - x - u^d]^+ - h \cdot E[Q - x - u^d]^+ - k \cdot q \} + \max_{Q \in S} \beta \cdot E[G(x + u)] \cdot k \cdot x \]. \]  

(3)

However, the claim of separation is correct only if expected output is unrestricted. If we require output to be nonnegative, the variable \( y \) is constrained to satisfy the inequality \( y = x - q \cdot y \), so that the choice of \( y \) depends on \( x \) and \( q \) and, in general, the separation in (3) is not valid. The separation would be acceptable if expected output were always positive so that the constraint \( y = x - q \cdot y \) would be ineffective or if expected output were allowed to be negative. Hence, if expected output is constrained to be nonnegative, the conclusion by Anandh and Mendelson that the optimal \( k \) is a constant which is the unique solution of the first order equality condition, \( \beta \cdot E[G(x + u)] = k \), is incorrect unless expected output is always positive. To test whether expected output is always positive requires consideration of problems (1) or (2) where decisions are made jointly. However, intuition suggests the contrary since if inventory is very large, positive expected output will not only impose production cost but also increase expected holding cost without a corresponding addition to expected revenue. To verify this conclusion we first consider problem (1) in the event output is deterministic and then consider random output in the next section.

When output is deterministic \( n = -u^d \) so that problem (1) becomes

\[ G(x) = \max_{Q \in S} \{ R(x, Q) - e \cdot E[Q - x - u^d]^+ - h \cdot E[Q - x - u^d]^+ - k \cdot y + \beta \cdot E[G(x + y + u)] \}. \]  

(4)

We now modify an assumption. Anandh and Mendelson assume \( Q \geq 0 \) but that requirement does not guarantee nonnegative demand. Hence, we assume \( Q = u^d \geq 0 \). If \( \hat{b}(L) < \beta \) for any \( L > \hat{b}(L) \), then we need \( Q \geq \hat{b}(L) \). Consistent with this change we also modify the expected marginal revenue condition to require \( R'(L) > k \cdot h + e \) and if \( \hat{b}(L) = \beta \), this condition excludes \( p = \beta \).

To analyze (4) requires properties of \( G(x) \) other than its concavity. In particular, the Appendix shows that \( k \cdot h \cdot G'(x) = -e - (1 - \beta) \cdot G'(x) = -e - (1 - \beta) \cdot G'(x) \) at \( x = \infty \). These inequalities are intuitive. If inventory \( x \) is sufficiently small an additional unit of inventory saves the unit production cost \( k \) plus the unit backlog cost \( x \). As \( x \) becomes very large an additional unit may incur the unit backlog cost \( c \) indefinitely into the future.

For convenience of analysis only, we introduce one more assumption. Its absence complicates analysis but does not change the character of outcomes. In the case where \( x = \infty \) does not have an upper bound it is possible to show that optimal expected demand \( p^*(x) \) is bounded above or, equivalently, that optimal price \( p^*(x) \) goes to zero. When expected demand has a quantity intercept, say \( c \), where \( f(0) = e > 0 \) for nonnegative price, the condition \( e > -c(1 - \beta) \) guarantees that \( p(x) \cdot x > 0 \). If \( x = \infty \) is not bounded above an analogous condition obviously holds since \( R'(L) \) goes to zero as \( x \to \infty \). Henceforth, for brevity in stating and proving a proposition, we suppose that expected demand has both price \( b \) and quantity \( c \) intercepts.

The proposition below now presents the major outcomes of the analysis. Proof is given in the Appendix.

**PROPOSITION (2).** Given that \( G(x) \) is a concave function which satisfies \( k \cdot h \cdot G'(x) = -e - (1 - \beta) \cdot G'(x) = -e - (1 - \beta) \cdot G'(x) = -e - \hat{b}(L) \) at \( x = \infty \) and assuming \( R'(L) > k \cdot h \cdot \hat{b}(L) \) and \( R'(c) < -c(1 - \beta) \), the unique critical inventory levels \( x_1 < x_\infty \) have the following properties. For \( x \leq x_1 \), \( p(x) \) attains a lower bound above above an analogous condition obviously holds since \( R'(L) \) goes to zero as \( x \to \infty \). Henceforth, for brevity in stating and proving a proposition, we suppose that expected demand has both price \( b \) and quantity \( c \) intercepts.
bound \( p_a(x) \) a lower bound \( q_1 \) and optimal output \( p_1(x) \) an upper bound \( q_1 \). For all \( x \), \( q_1(x) \) has an upper bound \( q_1(x) < a \) and \( p_1(x) \) has a lower bound \( p_1(x) > 0 \). Hence, the next period’s optimal expected inventory \( I'(x) \) is a constant for \( x \leq \bar{x} \). More detailed properties are the following.

(a) \( R'(q_1) = k + h \), \( q_1 = \bar{q} \), \( q_1 = \tilde{J}(p_0) \)

(b) \( R'(q_2) = b q_2 - C(q_2) \), \( q_2 = f(p) \)

(c) \( p = q'(x) + U \) and when \( x = q'(x) + U \), \( R'(q'(x)) = k - c \)

(d) \( q'(x) = \bar{q} - q'(x) \), \( x \leq \bar{x} \)

(e) \( 0 < q'(x) < 1 \), \( -1 < q'(x) < 0 \), \( 0 < q'(x) < 0 \), \( x_1 < x \leq q'(x) \)

(f) \( 0 < q'(x) < 1 \), \( 0, q'(x) > \bar{x} \), \( x \leq \bar{x} \).

The proposition indicates that all choice variables are contained within control bounds and have intuitive properties. From \( F(e) \) and \( F(f) \), price varies inversely and expected demand directly with inventory in an effort to offset inventory changes. However, expected demand increases by an amount less than the increase in inventory so adjustment is dampened. Output is positive when inventory is small and falls to zero when inventory is large in order to reduce subsequent holding cost. As a consequence of constant marginal production cost, \( P(e) \) indicates that next period’s expected inventory is a constant when output is positive. Otherwise, \( P(f) \) implies that \( p(x) \) increases with inventory reflecting the partial adjustment in price and expected demand.

Now consider the inequality \( x \leq \bar{q} + U \) in \( P(e) \). First, using an example, we verify that the inequality may become an equality only in an extreme case and, then, examine the dependence of \( x \) on various parameters. If we let \( H(q, q, x) \) represent the maximum of \( (4) \) and \( D_2 H \) and \( D_2 H \) its partial derivatives with respect to \( q \) and \( x_1 \), then, from the proof in the Appendix, \( x \) satisfies the equation

\[
D_2 H(q'(x), x, x) = -k + \beta \cdot E[q'(x) - q'(x) - u] = 0
\]

where for \( x \leq \bar{x} \), \( q'(x) \) satisfies

\[
D_2 H(q'(x), x, x) = R'(q'(x)) = (k + h) + (e + h)q'(x) = 0
\]

Following Amihud and Mendelson suppose \( q_0 = F_0 = F_1 = p_a \) and \( u \) has a distribution function which is uniform over the interval \(-a, a\). Now, if \( q_1 = q'(x) \) and \( q_2 = u \) where \( U = a \), \( \beta \) implies \( R'(q'(x)) = k - e \) and \( x \) and \( p_2'(x) \) are given by

\[
x = (F_0 - (k - e)F_1)/2 + a, \\
p_2'(x) = R_0/2F_1 + (k - e)/2
\]

Here, \( x \) and \( p_2'(x) \) are identical to \( x_2 \) and \( p_1 \) computed by Amihud and Mendelson. However, it is clear that \( \beta \) cannot provide a general solution to the problem since if \( e \) is sufficiently large \( p_2'(x) > 0 \) violating the requirement \( p_2'(x) > 0 \). Moreover, since \( q'(x) = \bar{x} - x \), it also follows that \( q'(x) < 0 \) if \( k \) is sufficiently large. Thus, it would seem that \( \beta \) provides a correct solution only if \( e \) and \( k \) are suitably restricted.

In fact, omitting the computations, it can be shown that, in general, \( x \) and \( (k - e)q'(x) \) increase with \( h \) and a positive shift in the expected demand function (an increase in \( F_0 \) in \( \beta \)) and decrease as \( e \) and \( k \) increase. Consequently, \( \beta \) provides an extreme solution where \( e \) and/or \( k \) are sufficiently small relative to other parameters. In particular, the response of next period’s expected inventory \( (k - e)q'(x) \) to parameter changes is insensitive. When \( h \) is large, the firm chooses next period’s expected inventory to be large to economize on expected backlog cost with the reverse true when \( e \) or \( k \) is large in order to economize on holding cost or production cost.

To complete the description of outcomes we need to consider the adjustment process further and to distinguish ergodic and transient states of the system. First, we show that states \( x \in (x, \infty) \) are transient in that it is repeated trials of the system such states cannot persist. For any \( x \geq \bar{x} \), output is zero but demand is positive since \( q'(x) > 0 \). Hence, the new period’s inventory will diminish and in subsequent periods will continue to diminish until \( x \leq \bar{x} \). More detailed properties of next period’s inventory cannot exceed \( x \leq \bar{q} + U \) which is less than \( \bar{x} \). Finally, when \( x \leq \bar{x} \) next period’s inventory cannot be less than \( x \leq \bar{q} + U \). Hence, in a finite number of periods \( x \) will enter and remain in the ergodic set \( \{x \leq \bar{q} + U \} \).

It is now clear that the solution proposed by Amihud and Mendelson is correct when output is deterministic, \( x \leq \bar{x} \) and the extreme case \( x \leq \bar{q} + U \) prevails. As shown in the next section, with their assumption that output is additively random, states will persist in which \( q'(x) \) is greater and \( p_2'(x) \) is lower than the bounds given in the Amihud and Mendelson solution.

III. The Model With Random Output

For notational convenience let \( q_0 \) represent output. Then with the Amihud and Mendelson assumption that \( q_0 = y + u \) the relevant problem is given by \( I \). In this problem it is not difficult to show that the outcomes are again specified by the proposition in the previous section with the proviso that \( p_2'(x) \) now represents optimal expected output. The interpretations are also unchanged and the value functions, represented by \( G(x) \), differ only in that random output amends a constant to include terms involving moments of the \( u \) distribution function. Nevertheless, randomness of output does introduce a major change in the specification of transient and ergodic states of the system. Specifically, the ergodic set of the previous section, \( \{x \leq \bar{q} + U, x \leq \bar{q} + U \} \), is extended on the right to include states in which \( q'(x) \leq 0 \), \( q'(x) \geq \bar{q} \) and \( p_2'(x) \leq \bar{q} \). That result is most easily seen by considering states \( x \leq \bar{x} \). Let \( M > 0 \) be the upper bound on \( u \). Then, since \( u = u - u \), next period’s inventory may be as large as \( x \leq \bar{q} + U + M \) which clearly exceeds \( x \leq \bar{q} + U \).

Output peculiarity makes exact determination of the upper bound of the ergodic set difficult. Since \( u \) has a negative lower bound, output may be negative and the left hand bound of the ergodic set is reduced by the amount of the lower bound of \( u \). However, since output may be nonzero even if expected output is zero, a right hand bound may not exist. Hence, the firm loses control of the system. For example, when \( x_1 > x \) and \( q'(x) = 0 \), the firm wishes to reduce the inventory level but that desire may be thwarted by a large positive realization of \( u \). Since similar experience may be encountered in subsequent periods, very large values of inventory may persist.

In the remainder of the section we consider a multiplicative output assumption which corrects deficiencies of additivity and restores control to the firm. Let \( Q = \lambda y \) where \( E(x) = 1 \) and \( 0 \leq \lambda \leq M \). Here output is nonnegative and equals zero when \( y = 0 \). The problem now becomes

\[
G(x) = \max \{R(q_1) - c \cdot E(x - q_1 - u + k) \cdot E(x - q_1 - u - h) \}
\]

\[
- k \cdot y \cdot \beta \cdot E[(x - q_1 - \lambda y - u)]
\]

To keep the length of the paper within reasonable bounds we only sketch out details with help provided in the Appendix. As in the proposition of the previous section, there exist critical inventory levels \( x_1 < x \) with analogous properties except that \( q'(x) \) is not a constant for \( x \leq \bar{x} \). Properties \( P(e) \), \( P(f) \), \( P(e) \) and \( P(f) \) also describe outcomes
for multiplicative output uncertainty. The major differences are the following. The critical inventory levels \(x_i\) and \(k_i\) and decisions \(q(x)\) and \(y(x)\) now depend on properties of the output distribution function. While \(P(d)\) is replaced by \(g(x)\), no general conclusion is available regarding the sign of \(a(x)\) for \(x < A\). A similiar indeterminacy arises in comparing outcomes here with those of the previous section. For example, \(x_i\) and \(X\) may rise or fall as a consequence of multiplicative output uncertainty relative to deterministic output. Despite indeterminacy in comparing outcomes, there does exist an analogous ergodic set of inventory levels such that for each point \(x\) in the set \(g(x) > 0\). Since \(Q_\infty = 0\) when \(g(x) = 0\), justification follows the argument of the preceding section.

To provide some insight into the derivation of these results we briefly outline a few steps of the analysis in the Appendix. Using the previous notlation first order conditions analogous to (5) and (6) determine \(q(x)\) and \(y(x)\) for \(x \leq \infty\). Here

\[
\begin{align*}
D_x H^*(x) &= -k + \beta \mathbb{E}(x - q(x)) + \lambda p(x) - u = 0 \\
D_y H^*(x) &= -k + \beta \mathbb{E}(x - q(x)) + \lambda p(x) - u = 0
\end{align*}
\]

(9)

The essential difference between multiplicative and deterministic output cases is highlighted in (9) where \(G^*\) is weighted by \(\lambda\). In the absence of this weight \(g(0)\) could be solved for \(G^*(0)\) and substituted into (10) to yield (6). Even though this substitution is now not legitimate, analysis of (9) and (10) will, nevertheless, verify that \(q(x)\) and \(y(x)\) satisfy \(P(x)\) and \(P(y)\). To verify \(P(x)\) and \(P(y)\) requires a continuation of the argument for the interval \(x \geq A\).

To illustrate various indeterminacies we consider (10) and (12) when \(x \rightarrow \infty\) as \(x\) becomes small. When \(x = x_s\) and \(y(x) = 0\), \(G^*\) is independent of \(\lambda\) and (9) becomes

\[
D_y H^*(x_s, 0) = -k + \beta \mathbb{E}(x_s - q(x_s) - u) = 0.
\]

(11)

Now as \(x_s\) becomes small in (10) no particular relationship exists between the expectations in (10) and (11) so that in (10) the expectation \(E[x - q(x)] + \lambda p(x) - u\) may exceed or fall short of \(k\), depending on the output distribution. Hence, there is no particular relationship between the previous condition \(R(L) > k + h\) and whether \(q_s\) or equals or exceeds \(L\). Thus, a comparison of \(q_s\) and \(q(x)\) in the multiplicative and deterministic output cases depends on characteristics of the output distribution function and \(P(x)\) is not correct in the multiplicative case. A similar indeterminacy arises in comparing \(x\) in the two cases. When \(x = x_s\), it is now legitimate to solve (11) for \(G^*(0)\) and substitute into (10) to yield

\[
D_x H^*(x_s, 0) = -k + \beta \mathbb{E}(x_s - q(x_s)) = 0.
\]

(12)

While (5) and (6) and (11) and (12) appear to be identical when \(x = x_s\), the outcomes for \(x\) (and \(q(x)\) and \(x - q(x)\)) need not be identical since in the multiplicative output case \(G^*\) depends on the output uncertainty with the direction of dependence being indeterminate in general. Similar indeterminacies arise in comparing \(q(x)\) and \(y(x)\).

Consequently, while qualitative behavior is similar in the multiplicative and deterministic output cases, a comparison of the numerical values of output, expected demand and other variables hinges on the particular distribution function of the random output.

References


*Backlog models with increasing marginal production cost are considered by Blinder [2] and Zabel [5]. As shown by Zabel increasing marginal production cost also induces ergodic and transitive sets for price and inventory."
CHOICE OF TECHNIQUE IN A PUTTY-CLAY MODEL OF PRODUCTION

LAWRENCE J. LAU and BARRY K. MA*

I. Introduction

Under the putty-clay hypothesis, it is of interest to identify and estimate the ex ante production possibilities available to the firm from observed ex post data. Fuss [1], and Fuss and McFadden [2] have shown that the ex ante production technology can be identified through the choice of technique (or design) of the firm. In Fuss [1], it is assumed that there is no uncertainty in prices. In Fuss and McFadden [2], the choice of technique is considered under uncertainty in prices. However, their framework assumes that the expected profit function of each technique is linear in the technique-specific parameters.

In this paper, we re-examine the choice of technique for a risk-neutral firm under uncertainty in prices. Under the assumption of expected cost minimization, the optimal technique can be derived by certainty equivalence at the mean of the prices. However, under the assumption of expected profit maximization and gamma distributed prices, the optimal technique is the same as that of certainty equivalence at the means if and only if the ex ante production function is of a specific Cobb-Douglas form. It is also shown that the expected profit function of each technique is not linear in the technique-specific parameters.

II. The Model

We assume that, other than capital, there are n variable inputs denoted by x1, ..., xn. Capital is heterogeneous. The production technology embodied in each type of capital equipment is characterized by a fixed maximum output capacity and fixed input coefficients which are the quantities of variable inputs required per unit output. A given vector of input coefficients, denoted by a = (a1, ..., an), is referred to as a technique. We assume constant

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[1] For a discussion of the putty-clay hypothesis, the reader is referred to Fuss [1], or Fuss and McFadden [2].


[3] We assume that it is feasible to produce any quantity of output up to the maximum output capacity.