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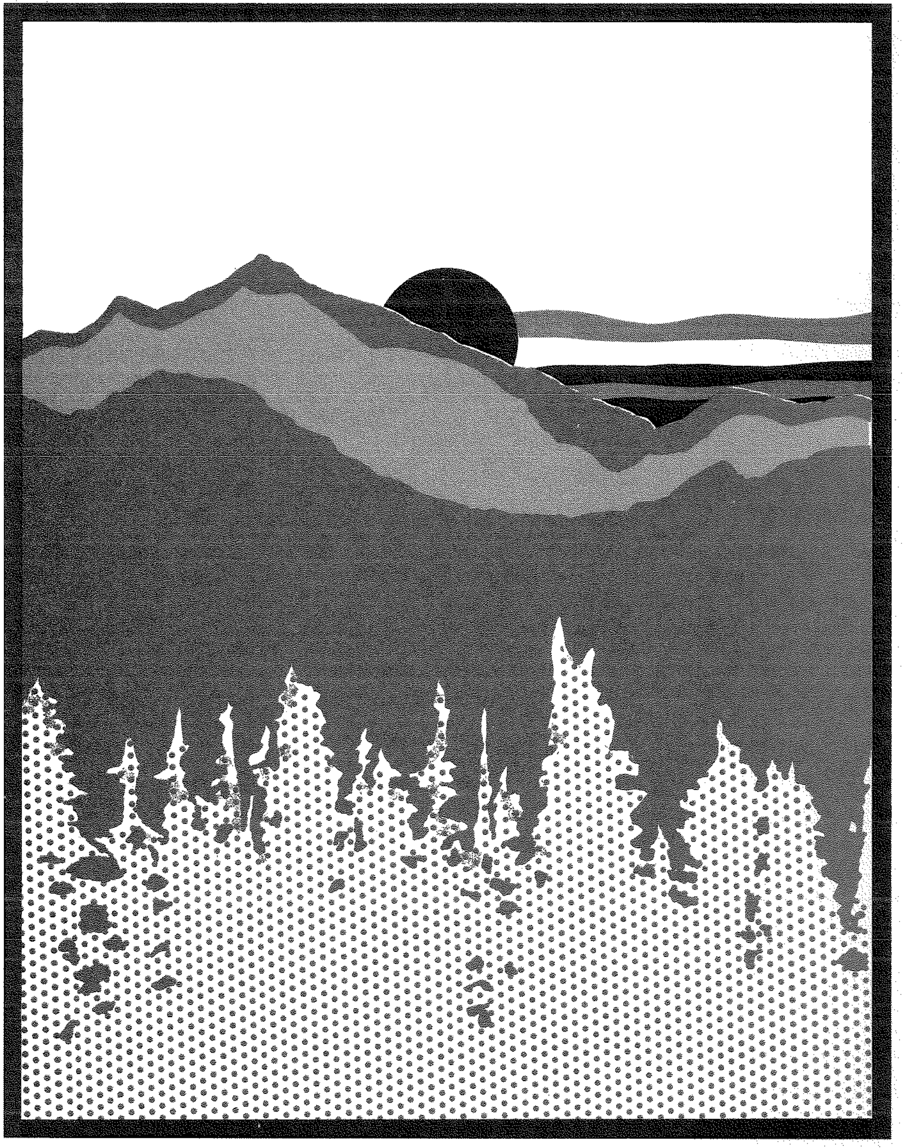

Problems of Resource Utilization

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Problems of Resource Utilization

A generation ago, in an era of depression, policymakers worried about the problem of stimulating aggregate demand in a world of presumably limitless excess resources. In today's inflationary atmosphere, however, the focus has shifted. The basic problem today is finding and developing new resources and more efficiently utilizing existing resources. Analysis of these issues is complicated by the tendency of the official mind to assume implicitly that supply is somehow unresponsive to price changes. Such views are not new; for example, the U.S. Geological Survey solemnly reported in the 1880's that little if any oil would be found in Texas or California.

To further complicate today's problems, the workings of the marketplace have frequently been hampered by forces of nationalism, environmentalism and consumerism. While each of these causes has a legitimate role and wide public support, at times their achievements are costly because they involve certain economic misallocations. The articles in this review apply the tools of economic analysis to examine the costs of single-mindedly striving for nationalistic, environmental or consumer goals. The first article considers the effect of nationalism on the mining of minerals in the deep sea. The second considers the effect of environmental and consumer legislation on the management and supply of timber. The third looks at the impact of environmental legislation on the stock of capital and the productive potential of the economy. The implication of these articles is that society must balance the costs and benefits of various programs so that they cause the least disruption of the economy consistent with the maximum achievement of other goals.

In the first article, Michael Gorham examines the Jules Verne-ish notion of exploiting the industrially important minerals at the bottom of the sea. He notes that this has been by far the most difficult issue raised at the Law of the Sea Conference, primarily because of the conflicts arising among three diverse politico-economic interests represented at the conference. These interests are: 1) the industrialized countries, which would probably receive the lion's share of the benefits under a free-access framework; 2) a small number of developing countries which would suffer some losses in export revenues from their present landbased mining resources; and 3) a very large group of countries which would be essentially unaffected by ocean mining but would still like to share in the benefits of what is considered international property.

The first group stands to gain the most from a free-access, unregulated, first-come first-served framework. The second group would gain the most from a total prohibition on ocean mining. The third group would gain the most from a situation in which full seabed production was assured but all economic rent was taxed away and redistributed in some fashion. Gorham claims that the conflict between the first and third groups would be resolved if the first group would satisfy itself with only the increased consumer surplus generated by this new source of minerals, and would be prepared to give up any economic rent captured by its ocean-mining firms. This compromise would not satisfy the second group, however, unless the appropriated rents could be used to compensate its land-based mining sector.

Gorham considers several factors which determine whether some people could be made better off without making others worse off through the advent of ocean mining. In the last analysis, however, he doubts that it would be either a socially or economically progressive precedent to prevent the introduction of a new technology, if compensation of the losers proved to be administratively difficult. "Accepting the principle that prohibited any technological innovation which did not allow full compensation of the losers would be putting a strong fetter on material progress. And if one decides that material progress is a desirable thing, then it may be better to have technological change without compensation than to have no technological change at all."

In a second article, Yvonne Levy analyzes the current debate over the proper criteria to be used in managing the nation's publicly-owned forest lands so that they can meet both timber demand and other public uses. She argues that, with current levels of forestry investment and timber-harvesting policies, the U.S. demand for softwood timber may be brought into balance with supply only at substantially higher relative prices for forest products. Conservation efforts may be insufficient to reduce demand enough to ease price pressures, so that most efforts will have to come from the supply side—which means increased harvests from the National Forests because of the modest increases projected for future harvests from private lands.

Most of the current controversy centers around the "even flow" harvest policy of the National Forest Service, which aims to supply a relatively constant quantity of timber each year. Many economists argue that this approach does not accomplish its stated objectives, but rather contributes to instability in forest-community employment during periods of declining private harvests, and also aggravates the inflation in timber and lumber prices during periods of sharply rising demand. They also claim that the current "even flow" policy results in inefficient management of public lands, because it treats timber harvested 70 years from now as providing the same value to society as timber harvested today, even though the latter is immediately available to provide society with housing and other services. In this view, the introduction of economic-efficiency criteria would not increase the economic returns on publicly-owned lands but also permit far greater yields of timber and nontimber outputs than are envisioned under current management strategies.

Levy concludes that a more flexible harvest strategy, better tailored to meet the requirements of the market, is needed to alleviate the upward pressures on forest-product prices. "The use of economic criteria to determine appropriate harvest rates and investments on National Forests would seem to offer the best solution. It is certain that, through this approach, society would be able to obtain both a greater economic return on timber production and a greater set-aside of recreational land."

In a third article, David Condon analyzes the relationship between pollution-control legislation and business-investment spending. He notes that a vast body of Federal legislation has developed over the past decade to regulate industrial air, water, and solid-waste pollution. Consequently, according to the U.S. Council on Environmental Quality, the private sector's capital-investment requirements for pollution-control equipment will reach \$112 billion in the decade 1972–81. He attempts in his article to estimate the extent to which pollution-control standards have protracted the investment process for five industries which account for more than two-fifths of all pollution-control spending—petroleum, chemicals, paper, steel, and nonferrous metals. Investment delays could occur because of the permit process, or because of increased investment uncertainty engendered both by the unpredictability of future legislation and the case-by-case application of pollution controls.

Condon estimated parameters for a distributed-lag investment function incorporating capital appropriations and final expenditures for two separate periods, one prior to and one following the passage of pollution-control legislation. Also, to adjust for the influence of independent events on the time lag between appropriations and expenditures, he estimated parameters for a second group of industries (such as machinery and transportation-equipment) that are less affected by pollution-control legislation.

Condon's estimates indicate that for the five industries affected by pollution-control standards, 14.9 percent of appropriated expenditures were delayed over a period of four quarters due to uncertainty and the permit process. The paper industry experienced the most severe delays with 34.7 percent of expenditures postponed over a period of five quarters, while petroleum suffered the smallest delays with 12.3 percent of expenditures postponed over a period of two quarters. "In addition to the direct pecuniary costs involved in satisfying government-mandated regulations, the lengthening of the time process of investment spending as caused by pollution-control standards must therefore be included as an important secondary cost in terms of its impact on lowering the rate of capital formation."

Dividing Up the Minerals of the Deep Seabed

Michael Gorham*

Since 1973, the nations of the world have been meeting in what is known as the Law of the Sea Conference, in an attempt to reach an international consensus on the use of ocean resources. While they have made considerable progress on such subjects as shipping, fishing, and waste disposal, they have failed to agree about ways of allocating the industrially important minerals of the deep seabed.

The ocean offers three forms of minerals: those dissolved in seawater, those contained in the ocean floor, and those contained in the small potato-like forms resting on top of the sedimentary ooze of the ocean floor. These latter forms, known as manganese nodules, are concretions of nickel, copper, cobalt, manganese and a number of trace minerals. Of all the ocean forms, only these nodules are now considered capable of being developed economically. Perhaps for that reason, they represent the major obstacle to a Law of the Sea Treaty—and for that reason also, they provide the focus of this paper.

A number of countries would like to control the allocation of these resources: 1) those who want to exploit these resources directly; 2) those who want to prevent, or at least delay, such exploitation; and 3) those who simply want to share directly in the benefits of exploitation. This paper explores the rationale behind each of these three basic positions. It first examines the gradually increasing profitability of ocean mining—the basic factor underlying the position of the first group of countries. It then considers the likely short-term impact of ocean mining on Third World mineral producers, should ocean mining begin under the traditional framework of free access to ocean resources. This approach permits us to examine the second group's argument that it would suffer significant losses because of ocean mining. Finally, this paper examines the probable distribution of the benefits of ocean mining, in light of the international community's growing commitment to the notion that ocean minerals (in some sense) belong to all mankind—a notion binding together the third group of nations studied here.

The first group includes chiefly the developed industrialized countries. Their basic negotiating position—particularly the U.S. position—is that private enterprise should have as free access as possible to seabed minerals. These countries, with their important groups of potential ocean miners and processors, could derive several major benefits from ocean mining: decreased import dependence, an improved balance of payments, increased government revenues (through customary taxes) and eventual trickle-down benefits to secondary producers and consumers. But in addition, the industrialized countries support their position with the economic-efficiency argument that the world output of all goods and services would be greater with unfettered ocean mining than without.

The governments of the developed countries are trying, in the interest of national security, to ensure continued supplies of strategic raw materials. They are influenced by the extreme import dependence of some of them on a number of important minerals, and by the OPEC-induced fear of future cartelization of other commodities besides oil. The industrialized countries are also motivated by the desire to assist those among their nationals who are attempting to exploit seabed minerals. The latter, generally large natural-resource companies, see the seabed as a po-

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*Economist, Federal Reserve Bank of San Francisco. An earlier and longer version of this paper, "Ocean Mining in the Pacific Basin: Stimulus and Response," will appear in the *Proceedings of the Ninth Pacific Trade and Development Conference* to be published in the summer of 1978. The author gratefully acknowledges the comments of Kurt Dew, Joseph Bisignano and Rose McElhattan, and the research assistance of Gigi Hsu.

tentially cheaper source of minerals than the increasingly costly land-based sites. These companies also have the size and experience to command the large amounts of financial capital required to develop ocean mining and processing facilities.

The countries in the second group perceive themselves as being net losers should ocean mining become important, so for their own self-interest they could be expected to try to delay ocean mining or to demand compensation for damages suffered from such activities. Those affected would include countries like Gabon and Zambia, which employ more than 10 percent of their workforce in land-based mining, or others like Zambia, Chile, and Zaire, which derive more than half their export earnings from copper. Actually, as we shall argue later, only a small number are likely to be significant net losers from a situation of untaxed ocean mining with free access to all.

The third group neither intend to mine the seabed nor support domestic mining industries which would suffer losses from such activity. At the same time, they would like to benefit from the exploitation of what they generally believe to be international property. While legal scholars still debate the issue, the seabed has become transformed from being no one's property to being everyone's property, according to this very large portion of the international community.[1] Consequently, these nations believe that all countries should share directly in the benefits generated by the seabed's use, either through taxation and regulation of private firms or through direct exploitation by an agency representing the international community.

The next three sections consider, in turn, the economic conditions or forces underlying each of the three conflicting positions. The fourth section sketches a framework for a possible compromise solution to the ocean-mining problem.

I. First Group: Profitability of Ocean Mining

In the developed world, there is keen government interest in ocean mining as a means of decreasing dependence on imported strategic materials,[2] but there is also a growing belief in the economic viability of exploiting these ocean minerals. This is suggested by the large sums of private capital already expended on exploration and research-and-development on mining and processing technology. The prospects for profitable exploitation have improved because of a rise in potential revenues, due to the rise in the prices of minerals contained in the nodules, and also because of a fall in potential production costs, especially when compared to the costs of land-based production.

Value of nodules

There has never been a market for manganese nodules, and thus no observed price either. However, a time profile of the gross value of nodules can be constructed from historical price data for the four metals most likely to be extracted from them along with prospecting data on their average mineral composition. By gross value we mean the market value of the minerals contained in a given amount of nodules, without consideration of the cost of extracting the nodules from the seabed and of extracting the minerals from the nodules. (In our calculations, we assume that the quantity of minerals mined from the ocean will be so small as to leave mineral prices unaffected.) In both nominal and price-adjusted terms, the value of nodules rose during the early and mid-1950's, peaked in about 1957, slid back until the mid-1960's, and then began an almost uninterrupted ten-year ascent to reach a new record level in 1975 (Chart 1). Over the past ten years, the value of nodules more than doubled in nominal terms and increased about 50 percent more rapidly than either the U.S. wholesale-price index or the I.M.F. index of world-traded goods.[3]

However, relative to other goods, the value of nodules until recently lagged behind their mid-1950's value. In other words, the rise in metal prices was not sufficient in itself to stimulate the recent ocean-mining rush, since producers could obtain just as attractive a real price for nodules in 1957 as they could today. The full explanation requires a consideration of the cost side of the ocean mining picture.

But first, one further point may be made about potential revenues. Nodules are almost ubiquitous in the world's oceans, yet all commercial ventures now under consideration have Pacific Ocean sites in mind. The reason is that the average Pacific nodule is roughly 20 percent more valuable than nodules from the Atlantic or Indian Oceans, since it contains a larger proportion of the more valuable minerals. Still, the variation within each ocean appears to be even greater than the variation among oceans. For example, the ocean-floor claim made by one mining consortium, Deepsea Ventures, is roughly 50-percent more valuable than the Pacific Ocean average.

Cost of ocean mining

The potential cost of nodule mining is difficult to assess, partly because commercial mining has not yet commenced, and partly because cost data is typically one of the most carefully guarded of company secrets, especially in a new industry. However, the technological environment has changed considerably since two decades ago, when the gross value of nodules first reached a peak. Details are provided elsewhere on the specific technical advances—many of them spinoffs from the offshore-oil industry—which have decreased the potential cost of ocean mining.[4]

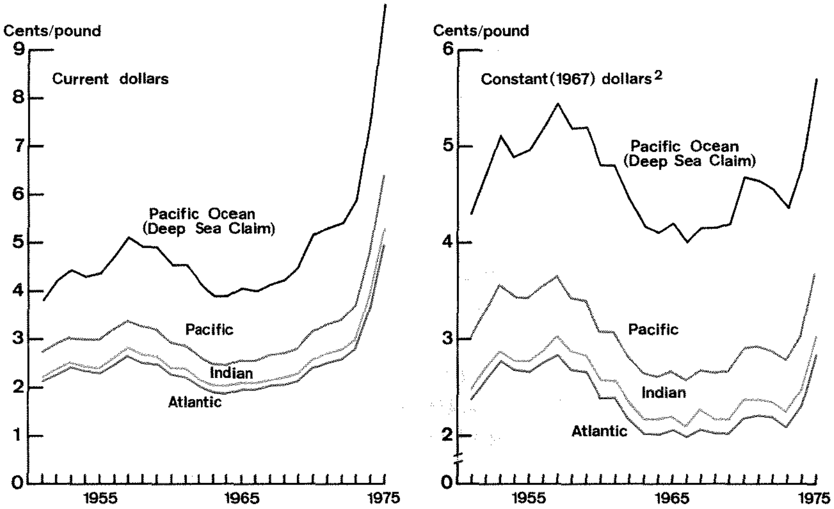
Some of these changes represent new technologies, while some represent improvements or adaptations of old technologies to new situations. Whatever the source, these changes in the technological environment have allowed all three components of ocean mining—exploration, exploitation and processing—to become relatively cheaper over the past two decades. Consequently, the ocean mining which did not take place in the mid-1950's may now do so in the early 1980's.

Ocean vs. land-based mining

But while ocean mining is now more attractive than heretofore, land-based mining may be becoming less so, which means that new mining projects may be developed on the seabed rather than on land. For a number of minerals, techno-

Chart 1

GROSS VALUE OF MANGANESE NODULES[1]



[1] Weighted sum of the annual average prices of copper, nickel, cobalt and manganese, where the weights reflect the mineral content of a typical nodule from each ocean.

[2] Deflated by the wholesale-price index.

Sources: Price data from 1) **Commodity Yearbook**, New York: Commodity Research Bureau, Inc., various years, and 2) **Yearbook of the American Bureau of Metal Statistics**, New York: American Bureau of Metal Statistics, various years. Nodule-composition data from 1) David R. Horn (ed) **Ferromanganese Deposits on the Ocean Floor**, Washington, D.C.: National Science Foundation, 1972, p. 20, p. 99, and p. 105; and Francis T. Christy Jr. (ed) **Law of the Sea: Caracas and Beyond**, Cambridge, Mass.: Bollinger, 1975.

logical improvements in land-based mining are no longer able to offset the costs of developing increasingly inferior ore bodies. Moreover, the development of increasingly remote land-based mines necessitates an increasingly expensive infrastructure—an expenditure kept to a bare minimum in ocean mining. Again, because of the inter-relationships of certain mineral prices, seabed mining may prove more attractive than one- or two-mineral land-based mining in terms of reduced revenue uncertainty.

Ore quality decline. A gradual decline in ore quality and accessibility should be expected, given the rational tendency to exploit the richest deposits first. The quality of nickel ore in New Caledonia (which produces about 18 percent of world nickel output) has declined from about 9-percent nickel in 1890 to roughly 3-percent nickel in 1950 and 2.3-percent nickel today.[5] Over the past decade, the average copper content of Kennecott's U.S. and Canadian ore has fallen from 0.82 to 0.71 percent—an ore quality decline of 13 percent.[6] Historically, technological improvements have tended to offset the effects of declining ore quality and accessibility, but this may no longer be true. According to one recent study, capital costs for a given amount of capacity rose at a 6-percent annual rate between 1965 and 1970, and 10 percent annually between 1970 and 1975—significant increases even after adjustment for inflation.[7]

In contrast to this decline in the quality of land-based ore, deep-sea nodules are virtually non-exhaustable. Nodules apparently are constantly being formed on the ocean floor, probably from dissolved minerals precipitated out of seawater around various nuclei. Scientists once believed that the formation of mineable nodules took centuries, but they no longer think so, in the light of laboratory successes as well as the recent discovery of nodules formed around soft-drink caps.

Relative infrastructure costs. Many new land mines, being located in inaccessible areas, typically require the development of shelter for workers and transport facilities for ore. For example, roughly two-thirds of $800 million invested in 11 major Australian mining projects in the 1960's went for infrastructure development.[8] In contrast, ocean mining minimizes such expenditures, since a) no railway or roads need be developed—the water can take one anywhere; b) existing port facilities can be used; and c) processing facilities can be constructed near established labor markets, eliminating the need for new worker housing.

Uncertainty. Two factors—uncertainty over cost and uncertainty over revenue—can influence choices between land-based and ocean mining. Because ocean-mining technology is new, it is clearly characterized by greater cost uncertainty than is the well-established land-based approach to mineral extraction. Yet ocean mining may be slightly less risky on the revenue side, since each ocean site typically encompasses a larger bundle of minerals than the typical land-based mine. To the extent that the prices of these joint-product minerals move against one another, revenue uncertainty would be less for the whole bundle than for only one or two minerals.

To measure that effect, we have calculated the coefficient of variation for the prices of individual metals and of nodules for the 1951–75 period. (The coefficient is a standardized variability measure which allows comparisons across commodities.) As seen in Table 1, both the six- and the four-mineral nodule extraction process would have yielded revenues at least as stable as those

Table 1
Relative Revenue Uncertainty of Nodules and Component Minerals of Nodules*

.46	Nickel
.43	Zinc
.38	Copper**
.31	Nodules (Ni, Cu, Co)
.28	Molybdenum, Vanadium
.27	Cobalt, Manganese, Nodules (Ni, Cu, Co, Mn)
.26	Nodules (Ni, Cu, Co, Mn, Mo, V)

*As measured by the coefficient of variation of per-pound revenues of nodules and component metals, 1951–75. Coefficient of variation is the standard deviation of a variable, divided by its mean to eliminate scale effects.

**U.S. producer-price coefficient, which compares with a coefficient of .48 for London Metal Exchange price.

of any single mineral producer, and considerably more stable than those of nickel and copper producers. Even the three-mineral nodule miner would have recorded considerably more stable revenues than mines producing only nickel or copper. So if the past 25 years is any guide to the future, nodule mining should create much less revenue instability than land-based mining.

Profitability

The discussion to date only says that costs and revenues are moving in a direction which could make ocean mining eventually profitable. Is profitability a decade down the road or is it upon us today? Authorities differ widely on this point, with estimates of pre-tax rates of return to nodule mining ranging from 9 to 112 percent.[9] This should not be surprising, since such estimates require long-term forecasts of metal prices, assumptions about how many metals will be extracted from nodules, and assessments of the cost of a technology which has yet to be commercially tested.

According to one summary of these studies, the average pre-tax rate of return to nodule mining might be roughly twice the average 27-percent rate of return to U.S. mining firms (1974-75).[10] Whatever the true figure might be, the potential has already attracted at least a half-billion dollars in private sector R & D. Nonetheless, private investment in full-scale mining will probably have to wait until after the issue of property rights in the deep seabed is resolved, either by an international treaty or by unilateral U.S. action.

II. Second Group: Ocean Mining's Impact on Land-Based Producers[11]

Some countries would like to prevent the development (or slow the growth) of ocean mining in order to protect their own land-based mining industries. How significant is the threat to their interests? No conclusive answer can be made because of a lack of adequate information. Ocean mining may drive some marginal producers from the market via a world price decline for specific minerals, but one can determine which producers are the marginal ones only from information on costs of production—information which is not available. However, an indirect approach can be tried, first by examining the quantitative importance of ocean mining in four relevant metal markets, and then by examining the export-earnings vulnerability of the current mineral-producing countries.

We assume, first, that interested producers will have an unregulated, untaxed, free access to deep-sea minerals. While this situation is unlikely, it should be considered because it is the worst-case situation from the point of view of the current land-based producers. We assume, next, that 4 to 12 million metric tons of nodules will be produced annually during the first decade of ocean mining. Naturally, it is impossible to generate an econometrically-estimated supply schedule for an industry which has yet to begin operations. But according to the consensus view, four mining groups are likely to become part of the first generation of ocean miners, and each of these groups will be producing from one to three million metric tons (dry weight) of nodules per year.[12] The assumption may be somewhat unrealistic, since supply will probably not be perfectly price-inelastic even in the short run. But supply schedules for minerals tend to exhibit less than unitary price elasticity, so that the 4- to 12-million ton production assumption is probably broad enough to include any short-run adjustments in supply.

A third assumption, widely accepted in most discussion, is that most of the first-generation nodule processing will take place in the United States—and mainly on the West Coast.[13] This assumption seems safe, considering that mining will occur in the North Pacific about halfway between Hawaii and Mexico, that the U.S. already provides the largest single market for these minerals, that the U.S. (and Canada) are perceived to have the most stable investment climates in the area, and that all of the four ocean-mining groups are now based in this country.

Effect on four mineral markets

It is difficult to discuss the broader impact of ocean-mineral exploitation without first developing a sense of the relative importance of each ocean mineral in its own market. Despite the existence of a number of trace minerals in nodules (such as vanadium, molybdenum and zinc), it is generally believed that only nickel, copper, cobalt and perhaps manganese can be commercially extracted. The total value of all four metals would be roughly $15 billion, if their 1974 mine production were valued at U.S. refined prices. Copper would account for four-fifths of total value, and nickel for most of the rest. Cobalt and manganese are relatively unimportant in terms of volume, but they are both important industrial materials—manganese, for example, currently has no substitute in steel production.

The impact of ocean mining on each of these metal markets can be ascertained by examining the ratio of the potential seabed production of each mineral to its current land-based production (Table 2). The various ratios suggest that seabed copper will scarcely make a dent in the world copper market, while seabed cobalt will play a very significant role in the world cobalt market. Seabed production of the other two metals should fall somewhere between those two extremes. (Only one of the four ocean-mining groups currently plans to extract manganese, so the manganese column probably should be scaled down by a factor of four.)[14] It should be noted that the table compares hypothetical seabed production in the early 1980's with actual land-based production in 1975. Since land-based production should increase over the next several years, the ratios of sea to land production should be smaller than what the table indicates for the early 1980's.

A more refined analysis of the impact of ocean mining has been attempted by F. Gerald Adams.[15] In his study, Adams built, borrowed, modified and integrated economic models for the four metal markets, then simulated the production of from one to 20 million tons of nodules, in order to determine new equilibrium levels of prices and quantities. For example, with an intermediate output assumption (7 million metric tons), world mineral prices in the sixth year of operations would tend to be lower than they would be without ocean mining by the following amounts: copper, 1.6 percent; manganese, 2.9 percent; cobalt, 9.7 percent; and nickel, 11.6 percent. Adams' models leads to different conclusions than those suggested by our own Table 2. Specifically, he finds manganese and cobalt price reductions to be much smaller than would be indicated by Table 2 because he treats these two markets as oligopolistic. For example, he has Zaire reducing its cobalt output by almost the full new supply from the ocean, thus considerably dampening any price decline.

Trade patterns and export earnings

In theory, the creation of a new ocean-mining industry could affect three categories of internationally-traded goods: 1) the minerals to be mined from the ocean floor (since both the level and distribution of production of these minerals will be altered), 2) the factors of production to be used in the new industry (since both the level and international distribution of demand for these factors will change), and 3) the various intermediate and final products produced with these minerals (since the increased supply and lowered cost of these minerals should increase the supply

Table 2
Seabed Production of Minerals as a Proportion of 1975 Land-Based World Production*

Nodule Mining Capacity (Millions of metric tons)	Manganese	Nickel	Copper	Cobalt
1	3.0	1.8	0.1	8.9
5	14.9	8.6	0.7	44.6
10	29.9	17.2	1.5	89.2
15	44.8	25.8	2.3	133.7
20	59.6	34.4	3.1	178.4

*Average nodule mineral content from Deepsea Venture estimates, i.e., 29.00% manganese, 1.28% nickel, 1.07% copper and 0.25% cobalt. World production figures taken from *Commodity Yearbook, 1976*.

and lower the cost of the goods produced with them). In practice, any shifts in the trade patterns of the latter two categories of goods are likely to be negligible. In the one case, the demand from the ocean-mining industry for any factor of production is likely to constitute an imperceptibly small portion of the total demand for that factor. In the other case, the value of raw materials generally represents only a small portion of the value of the final (or even intermediate) product, so that declines in mineral prices should have little effect on the prices or supply of intermediate or final goods. We may thus confine ourselves to a discussion of the changes affecting the minerals themselves.

The shift in trade patterns will reflect the fact that most first-generation nodule processing will take place in the United States. Thus, the immediate effect of nodule mining will be to displace U.S. imports of nickel, copper, cobalt, and manganese.[16] Exporting countries will then attempt to sell this displaced metal in other markets. Prices will fall, but given the price-inelastic nature of mineral demand, the increase in the quantity sold will not be sufficient to prevent aggregate mineral revenues from falling. The countries hurt the worst will be those with mines that were just marginal at the old price, since these mines (if not subsidized) will be forced to close down.

Since no information is available on the relative cost structures of current land-based producers, it would be difficult to forecast which countries would suffer mine closures and layoffs, along with the consequent declines in national income and export earnings. But by constructing a worst-case scenario, we can determine which countries might face serious problems should they find themselves with a string of closed mines after the establishment of a post-ocean mining equilibrium. The analysis is confined to the potential decline in export earnings, because data constraints make it difficult to estimate the purely domestic effects of mining operations.

The initial adjustment to ocean mining involves the potential displacement of metals currently imported into the U.S. Land-based producers incur certain adjustment costs in this stage, but many of them will be able to find buyers in other markets within a relatively short time. The second, and more serious, stage is the movement to a final structure of trade, in which ocean mining has become established and marginal producers have been closed out of the market.

By comparing total imports to potential seabed production, we can roughly determine the extent to which total U.S. imports may be displaced by the advent of ocean mining. Again, by noting the share of each country's mineral production exported to the United States, we can determine how seriously that country would be affected by such displacement (Table 3).

The data suggest that seabed production could completely displace any one country's exports of any of the four minerals in the U.S. market, with the possible exception of Canadian copper and nickel. This means that high-cost producers presently exporting to the U.S. should begin searching for alternative outlets for their minerals. Second, while roughly a quarter of U.S. imports of copper and two-thirds of U.S. imports of nickel and manganese may be displaced by seabed minerals, the cobalt impact could be even more dramatic. The U.S. could actually become a net exporter of cobalt, producing more than twice as much from the sea as she currently imports. Thus, present cobalt exporters would not only be displaced in the U.S. market, but could also find themselves competing with seabed cobalt in other markets.

Some countries send very large shares of their mineral output to the U.S.—roughly a third in the case of Mexican and Japanese manganese, Zairean and Finnish cobalt, Peruvian copper and Rhodesian and South African nickel; and roughly a half in the case of Canadian and Dominican nickel. The closer their average variable costs are to the current price, the more difficulty they will have in shifting from the U.S. market to other markets, especially while new ocean supplies are creating downward pressure on mineral prices.

Many of the countries displaced from the U.S. market could compete with other producers in other markets, with the ultimate losers being countries who do not even appear on the present list of U.S. suppliers. In order to determine which countries are at risk and stand to lose the most, it is necessary to consider all metal exporters, noting the share of each country's export earnings

Table 3

U.S. Imports in 1973 of Metals to be Extracted from Seabed Nodules

Manganese

Supplier	Imports 1,000 Short Tons	Share of Production Exported to U.S.
Brazil	303	27%
Gabon	196	19
South Africa	167	9
France	107	a
Australia	61	8
Mexico	44	31
Norway	39	a
Zaire	36	20
India	35	6
Japan	21	36
Ghana	19	14
Morocco	14	17
Other	16	17
Total imports–1973	1,058	
Total imports–1981	1,411[d]	
Seabed output, low[e]	320	
Seabed output, high[e]	959	
High seabed/1981 imports	70.0%	

Cobalt

Supplier	Imports 1,000 lbs.	Share of Production Exported to U.S.
Zaire	11,196	34%
Belgium	4,819	b
Norway	972	b
Finland	909	33
Canada	666	17
France	204	b
U.K.	192	b
Taiwan	109	b
West Germany	40	b
Australia	5	0
Other	89	b
Total imports–1973	19,201	
Total imports–1981	25,601[d]	
Seabed output, low[e]	22,000	
Seabed output, high[e]	66,000	
High seabed/1981 imports	257.8%	

Copper

Supplier	Imports 1,000 Short Tons	Share of Production Exported to U.S.
Canada	142	16%
Peru	86	36
Chile	54	7
South Africa	23	12
Philippines	15	6
Mexico	11	12
Zambia	5	1
Other	36	5
Total imports–1973	372	
Total imports–1981	496[e]	
Seabed output, low[e]	47	
Seabed output, high[e]	142	
High seabed/1981 imports	28.6%	

Nickel

Supplier	Imports 1,000 Short Tons	Share of Production Exported to U.S.
Canada	121	45%
Norway	15	c
Dominican Republic	14	53
U.K.	11	c
New Caledonia	10	9
Australia	5	10
Rhodesia	4	30
USSR	4	2
South Africa	3	30
France	2	c
Greece	2	12
Other	1	12
Total imports—1973	192	
Total imports—1981	256[d]	
Seabed output, low[e]	56	
Seabed output, high[e]	169	
High seabed/1981 imports	66.0%	

[a] *France* obtains all its manganese from Gabon, Morocco and Brazil. *Norway* obtains its manganese from Brazil.

[b] *Belgium* obtains its cobalt from Zaire, *Norway* from Canada, U.K. from Zambia, *West Germany* from Finland. *Taiwan's* source is unknown. *Other* obtains cobalt from Zambia and Australia.

[c] *Norway* obtains its nickel from Canada, *U.K.* from Canada and South Africa, and *France* from its possession, New Caledonia.

[d] Import assumption: By 1981, imports will grow 3.5 percent annually, in line with the long-term real rate of growth of the U.S. economy. Ocean mining is expected to begin in 1981 at the earliest.

[e] Production assumption (with four firms): One million metric tons of nodules each at low output, and three metric tons each at high output. (Only one firm will extract manganese from nodules.) Nodule-composition assumption (Deepsea Venture average): 29.0 percent for manganese, 1.28 percent for nickel, 1.07 percent for copper, and 0.25 percent for cobalt.

Source: *Mineral Facts and Problems, 1975.*

derived from these metals and the level of each country's exports compared to potential seabed output. Two categories should be differentiated: 1) copper exporters, whose price will be largely unaffected by the arrival of seabed copper, and 2) other nodule mineral exporters, whose price will be strongly affected by the production of seabed minerals.

Copper. Five countries are quite heavily dependent upon their export earnings from copper, and another six countries derive from 2 to 6 percent of their export earnings from that metal (Table 4). The former in particular would tend to be wary of any change in the international economy which might threaten to reduce those earnings. Nonetheless, the first generation of ocean mining may have only a very small effect on these exporters. A 2-percent reduction in copper prices (as forecast by Adams) would go largely unnoticed given the 5- to 10-percent annual price swings typically observed in this market. Even the high estimate of 1980 seabed production would exceed 1974 copper-export earnings for only a single country, Uganda—a relatively minor producer. Over the longer term, however, rapid technological advances in ocean mining could create a more substantial threat to land-based copper producers.

Table 4
Countries Deriving At Least Two Percent of 1974 Export Earnings from Copper[1] (Exports in millions of dollars)

	Copper Exports	Share of Total Exports
Zambia (1973)	$1,072.4	94.4%
Chile	1,898.0	76.5
Zaire	953.8	69.0
Peru	347.9	23.2
Philippines	396.7	14.7
South Africa	283.6	5.8
Yugoslavia	216.3	5.7
Uganda	16.9	5.4
Belgium–Luxemburg	1,042.6	3.7
Australia	303.8	2.8
Canada	661.6	2.0
Potential seabed output		
Low estimate	60.7	
High estimate	182.0	

[1] Includes both unrefined and refined copper (SIC Codes 682 and 283.11).

Source: *United Nations Yearbook of International Trade Statistics, 1975.*

Table 5
Countries Deriving At Least Two Percent of 1974 Total Export Earnings from Three Minerals Potentially Available for Ocean Mining (Export earnings in millions of dollars)

	Export Earnings				Share of Total Export Earnings			
	Nickel	Cobalt	Manganese	All Exports	Nickel	Cobalt[2]	Manganese	Combined Share
Gabon	—	—	$33.7[1]	$177.8	—	—	19.0%[1]	19.0%
Dominican Republic	$93.1	—	—	636.8	14.6%	—	—	14.6
Zaire	—	$132.5[1]	2.0	1,381.5	—	9.6%[1]	0.3	9.9
Australia	115.8	—	16.0	10,787.3	1.1	—	3.1[1]	4.2
Norway	167.2	—	—	6,274.4	2.7	—	—	2.7
South Africa	40.7	—	84.5	4,906.1	0.8	—	1.7	2.5
New Hebrides	—	—	0.3	17.6	—	—	2.2	2.2
Seabed output:								
Low estimate	194.3	75.3	82.9					
High estimate	583.0	226.1	248.6					

[1] 1971 figures for Gabon and Zaire, and 1973 figure for Australia.

[2] Value of mine production of cobalt; export figure not available.

Source: *United Nations Yearbook of International Trade Statistics, 1975.*

Other minerals. Seven countries derive at least 2 percent of their export earnings from the other three nodule minerals, but only three of them obtain more than 5 percent of their foreign sales from these minerals (Table 5). They are Zaire (cobalt), Dominican Republic (nickel) and Gabon (manganese), which receive roughly 10, 15 and 20 percent, respectively, of their export earnings from such sources. Nonetheless, all of these countries are endangered by ocean mining, because even the low seabed estimates exceed most of their recent levels of production.

One government-owned firm in Zaire produces about 60 percent of the total world output of cobalt. Since the ocean could probably supply from one-third to all of the cobalt consumed in 1975 (Table 2), Zaire can plan on a noticeable loss in export earnings—perhaps approaching the full 10 percent of earnings the country now derives from cobalt. With Zaire's foreign-debt repayment problems, such a loss would not be easy to absorb.

The price of nickel could fall by roughly 12 percent, given an intermediate estimate of seabed production, so that all nickel exporters could experience some decline in export earnings. However, only the Dominican Republic obtains more than 3 percent of its foreign earnings from nickel (Table 5). Dominican export earnings are typically volatile because the country derives roughly half of its export earnings from sugar—a very mercurial commodity. The ocean-mining impact could be cushioned if the nickel price decline should occur during a sugar price boom—but of course the reverse would be true in the event of a slump in the sugar market.

The country most dependent upon the export of nodule minerals is Gabon, which earns about a fifth of its foreign exchange from mangenese. Like other nations, its potential losses would depend upon the efficiency of its mine operations. Should these mines be marginal, it could suffer an export-earnings decline of up to 20 percent (i.e., the share accounted for by manganese). Of course, any hardship should be cushioned somewhat by Gabon's oil holdings, which caused its export earnings to more than double between 1973 and 1974 alone.

Over the long run, the displacement of the land-based mining industry could be greater than indicated here, if the ocean-mining sector should lower its production costs substantially through economies of scale and rapid technological improvements. If that occurs, practically all the world's nickel could come from the ocean in four or five decades—and the same might be true elsewhere. On the other hand, ocean miners a century from now may be expressing serious concern over the threat of minerals from space.[17] But whatever happens over the long term, few countries are likely to suffer losses over the short term.

III. Third Group: Equitable Distribution of Benefits

We turn now to the third group of countries—those who neither intend to mine nor possess vulnerable land-based mining sectors, but simply want their share of the benefits of the "common heritage of mankind." Their position is easy to understand. The increasing acceptance of the "common heritage" notion makes them feel that they should benefit in some way from the exploitation of these minerals. However, an unregulated, untaxed ocean-mining industry would most likely permit the industrialized countries to capture the lion's share of the benefits. For that reason, this third group of countries desires some new institutional framework which will promote a more equitable distribution of benefits.

There is little doubt that the benefits of ocean mining will more than offset the losses. Any time society develops a more efficient method of production, it ends up with either more of that good or more of other goods, since resources now saved in the production of the first good can now be allocated to the production of others. Most technological changes probably involve a combination of these two effects.

In the case of ocean mining, extensive and lower-cost sources of industrially important minerals should ultimately lower the price to consumers of goods containing (or produced with) these minerals. This could happen because new mineral technology—that is, ocean mining—would tend to lower the cost of producing minerals, stimulate a rise in mineral output, and thereby lead to a fall in mineral prices. Cheaper minerals should stimulate mineral-using firms to expand their own output, thus causing a decline in the price of those goods. If all markets in this linkage are competitive, all cost savings would be passed on to consumers in the form of lower prices. Where markets are not competitive, monopolists and oligopolists would tend to transform some of the cost savings into higher profits.

The total benefits of ocean mining could be measured by the increase in consumer surplus plus the increase in factor rents attributable to ocean mining. However, the distribution of benefits would be heavily skewed toward the industrialized countries. Since only the large multinational corporations would have the size and expertise to undertake such activity, any rents generated would be captured by those firms and their factor suppliers. Developing countries could expect only a negligible (if any) share in the rents, since very few suppliers to (or stockholders in) the large ocean-mining firms would be likely to be residents of (non-oil-exporting) developing countries.

To the extent that people in developing countries consume goods containing or produced with ocean-based minerals, they will share in the increased consumer surplus generated by ocean mining. But since this share is proportional to consumption, and since consumption of most goods is positively related to the level of development, the developing countries would probably capture only a relatively small share of increased consumer surplus. For example, per capita consumption of copper in the United States and West Germany is more than 100 times per capita consumption in India (Table 6). Actually, the gap between the industrialized and developing countries is not quite so great as this would indicate, but a correction of the bias (if this were possible) would probably only reduce but not erase the gap (Table 6, footnote).

Table 6
Per Capita Copper and Nickel Consumption (1974)*
(Pounds)

	Copper	Nickel
West Germany	25.98	2.18
United States	20.76	2.02
Japan	17.71	2.39
Yugoslavia	11.34	0.15
Brazil	3.44	0.13
Albania	3.38	—
Mexico	2.51	—
India	0.18	—

*Consumption = production + imports − exports + declines in stocks. Thus consumption refers to use in production, regardless of whether the final products are used domestically or exported. To the extent that industrial countries are net exporters of manufacturers, their domestic consumption would be less than shown here, and to the extent that developing countries are net importers of manufactures, their domestic consumption would be greater than shown here. Thus the table would tend to overstate the gap between industrial and developing countries in terms of domestic mineral consumption in final products.

Sources: Population from *World Bank Atlas,* World Bank, 1976. Total Consumption from *Metal Statistics 1964–1974,* Frankfurt Am Main, 1975.

IV. A Solution?

In this paper, we have analyzed the positions of three groups of countries: 1) the industrialized countries—the potential ocean miners—which would receive the lion's share of the benefits under a free-access framework, 2) a small number of developing countries which stand to suffer temporary losses in export revenues, and 3) a very large number of countries which, although essentially unaffected by ocean mining, would still like to share in the benefits of what has come to be considered international property. It is not difficult to see that the interests of these groups are not in harmony. The first group stands to gain the most from a free-access, unregulated, first-come first-served framework. The second group would gain most from a total prohibition on ocean mining. The third group would gain most from a situation which allowed a competitive level of output, but which also taxed away all economic rent for redistribution according to some agreed-upon criterion.

The conflict between the first (industrialized) group and the third (uninvolved) group would be resolved if the first group satisfied itself with the consumer surplus and the third group captured the economic rent generated by the ocean-mining companies. Implementing such a solution could be difficult because of the problem of identifying economic rent for purposes of taxation. We need not get into a detailed discussion of this problem, but suffice it to say that the Single Revised Negotiating Text of the Law of the Sea Conference appears to provide a reasonable approach to a solution.

The conflict between both of these groups and the land-based mining group would not be reduced by this compromise, unless the latter were compensated in some way by the appropriated rents. This leads to a basic question: Can the advent of ocean mining make some people better off without making others worse off? To make that possible, the third group of countries would have to allow the general fund of appropriated rents to be reduced by an amount sufficient to compensate the land-based mining group, thus leaving less for themselves. Again, the fund of appropriated rents would have to be large enough to allow ample compensation for losses to the land-based mining group. While the total benefits of ocean mining (increased rents plus increased consumer surplus) would surely exceed the losses (the reduction in factor incomes in land-based mining), there is no assurance that the increase in rent alone would exceed the losses. Thus, even if the third group were willing, it might not be able to compensate the other group sufficiently out of the appropriated-rent fund.

Nonetheless, the total benefits would outweigh the total costs of ocean mining, since new and more efficient technologies could allow greater production with the same use of resources. Thus, it may not be either socially or economically useful to prevent the introduction of a new technology, simply because compensation of the losers is not administratively possible. In the distant past, the application of such a principle would have prevented the transition from the stone age to the age of metals, and thus would have prevented the development of those very land-based producers who are attempting to impede the progress of ocean mining today. In other words, prohibiting any technological innovation which does not allow full compensation of the losers would be a strong fetter on material progress. And if we believe that material progress is a desirable thing, then it may be better to have technological change without compensation than to have no technological change at all.

FOOTNOTES

1. This thought was first expressed in the Maltese Ambassador's 1967 speech to the United Nations, in which he declared that seabed resources were the "common heritage of mankind." In December, 1969, the UN passed Resolution 2574-D, better known as the "Moratorium Resolution," which declared that no claims to seabed ore deposits should be recognized and no seabed mining should take place until an international regime was established. A year later, the General Assembly passed a "Declaration of Principles," which stated that no party should acquire or exercise rights to the seabed that were incompatible with the yet-to-be decided international regime.

2. For the four major minerals contained in seabed nodules, the U.S. supplied the following proportions of its 1974 consumption requirements from domestic sources: copper, 81.8 percent; nickel, 7.3 percent; manganese, 2.3 percent; and cobalt, zero. **Mineral Facts and Problems,** 1975 (Washington, D.C.: U.S. Bureau of Mines, 1976).

3. Nodule value deflated by the IMF Index (not shown in Chart 1) exhibits a pattern almost identical to the one derived from the U.S. wholesale-price index.

4. Michael Gorham, "Ocean Mining in the Pacific Basin: Stimulus and Response," to be published in the **Proceedings of the Ninth Pacific Trade and Development Conference** in the summer of 1978.

5. Conrad Welling, "Ocean Mining System," **Mining Congress Journal,** (September 1976), p. 3.

6. Kennecott Copper Corporation, **Annual Report 1975,** p. 11. Kennecott's Nevada Mines experienced a 22-percent ore quality decline in a single year, from 0.78-percent copper in 1973 to 0.60-percent copper in 1974. **Op. cit.,** p. 10.

7. **Mineral Developments in the Eighties: Prospects and Problems,** Washington, D.C.: British-North American Committee and the National Planning Council, 1977; cited in testimony of Conrad G. Welling before the Mining Subcommittee of the House Committee on Interior and Insular Affairs (April 4, 1975), summary p. 2.

8. Welling, **op. cit.,** p. 2.

9. See Nina Cornell, "Manganese Nodule Mining and Economic Rent," **Natural Resources Journal** (Oct. 1974), p. 528 for the 9-percent estimate; and Danny M. Leipziger and James L. Mudge, **Seabed Mineral Resources and the Economic Interest of Developing Countries** (Cambridge, Mass.: Ballinger 1976), p. 159 for the 112-percent estimate.

10. Leipziger & Mudge, **op. cit.,** p. 161.

11. Leipziger and Mudge's work, which became known to this author after the present paper was in draft form, is a comprehensive treatment of the potential effect of ocean mining on the de-

veloping countries. There are no major differences between their results and those contained in this section.

12. The four groups include: Deepsea Ventures (U.S. Steel, Union Miniere of Belgium, and Tenneco holding the service contract), International Nickel Group (INCO of Canada, the German AMR group, and a Sumitomo-led Japanese group), Kennecott Copper Group (Kennecott, Rio Tinto Zinc of U.K., Consolidated Gold Fields, Noranda Mines and Mitsubishi), and Lockheed Group (Lockheed, Royal Dutch Shell and Standard Oil of Indiana).

13. One firm, Deepsea Ventures, apparently plans to process a portion of its nodules on the U.S. Gulf Coast and another portion in Belgium.

14. U.S. Steel, one of the major partners in Deepsea Ventures, may be trying to assure itself of a secure source of manganese, which is an essential ingredient of steel production.

15. F. Gerald Adams, "Applied Econometric Modeling of Non-Ferrous Metal Markets: The Case of Ocean Floor Nodules," in William A. Vogely (ed.), **Mineral Materials Modeling** (Washington, D.C.: Resources for the Future, 1975).

16. But since international consortia are involved, agreements could be made within each consortium to ship some of the processed metal to Japan or Europe, which would mean displacing Japanese or European as well as U.S. imports.

17. A recent article quite seriously discussed the technical feasibility of extracting nickel and other minerals from asteroids. T.B. McCord and M.J. Gaffey, "Mining Outer Space," **Technology Review** (June 1977), pp. 50-59.

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An Economic Alternative to Current Public Forest Policy

Yvonne Levy*

A debate is currently raging among foresters as to the appropriate criteria to be used in managing the nation's publicly-owned forest lands, so as to meet the nation's growing demand for timber while also increasing their nontimber outputs. The latter outputs include outdoor recreation, wildlife protection and water storage—uses which sometimes appear to conflict with timber production. The controversy has been sparked by the recent sharp rise in timber prices, and by the expectation that prices will continue to rise in excess of the overall inflation rate if timber supplies continue to be limited by public-forest management policies and environmental pressures. Actions which reduce the supply of timber in the face of rising demand, and thereby raise the price of forest products, can strongly affect the implementation of the nation's housing goals, since nearly one-half of the nation's total output of softwood sawtimber is used for residential construction.

Specifically, the controversy centers around the "non-declining even-flow" harvest policy presently followed by the Forest Service and other governmental agencies in determining the allowable cut on public forest lands. The controversy has important implications with regard to timber supplies, forestry investments, and the allocation of forest land among competing uses. Critics of the even-flow policy argue that it does not accomplish its stated objectives of promoting local forest-community stability and curbing the inflation in lumber prices. Because this policy generates a relatively constant supply of public timber, it can contribute to instability in forest-community employment during periods of declining private harvests and can also aggravate the inflation in timber and lumber prices during periods of sharply rising demand. Again, in the critics' view, the current policy results in an inefficient management of forest lands. They believe that the introduction of economic-efficiency criteria in the harvest and investment decision-making process, as a replacement for the "biological maximization" principles currently followed, might not only increase the financial returns on publicly-owned lands but also permit far greater yields of timber and nontimber outputs than are envisioned under current management strategies.

This article examines the rationale, mechanics and implications of the non-declining even-flow policy presently used in scheduling public timber harvests. Further, it contrasts this policy with an economic approach to harvest and investment determination which seeks to earn the highest net financial return on public holdings consistent with other social objectives. Section I discusses the characteristics of the nation's publicly-owned forest land base and softwood-timber inventory. It contrasts the harvest and growth rates realized on National Forest lands with those realized on private forest-industry lands, which are managed by large integrated forest-product firms operating with a profit-maximization goal. Section II shows that the differences in performance are attributable in part to the biological approach to timber management followed by government agencies on public-forest lands. In this section, the current process of harvest and investment determination on public lands is discussed in detail. Section III outlines an alternative economic approach which seeks to maximize net financial return on public timber holdings. This section demonstrates how it might be possible—through an improved allocation of available land and other resources—to raise timber output yet still accommodate the demands of environmentalists for increased withdrawal of land from timber harvest. The entire analysis—and the entire debate—is confined to softwood timber—the species generally used for construction and paper manufacturing.

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I. Public Forest Characteristics

According to the latest (1970) inventory of U.S. timber resources, the United States contains about 500 million acres of "commercial" forest land, defined by the Forest Service as land which is producing or capable of producing more than 20 cubic feet of industrial wood per acre per year in stands that are not withdrawn from timber harvest.[1] Industrial wood includes wood suitable for lumber, plywood, pulp, paper and all other uses except fuelwood. The phrase "withdrawn from timber harvest" means the exclusion of areas reserved from cutting by law, such as national parks or wilderness areas. Commercial forest land constitutes about one-third of the total land area of the United States, making it a major form of land use.

Only about one-quarter of this land is publicly-owned, but on that land stands 58 percent of the nation's total inventory of softwood growing stock—wood measured in cubic feet, inherent in trees at least five inches in diameter at breast height.[2] The preponderance of this public timber is located on National Forest land owned by the Federal government and managed by the Forest Service (Table 1). The remainder of the publicly-owned timber is located on lands under the jurisdiction of the Bureau of Land Management and other Federal, state and county agencies. The 42 percent of the total softwood inventory under private ownership is about equally divided between the forest-products industry and "other private" owners (such as farmers).

Most of the National Forests and other publicly-owned lands are located in the Pacific Coast and Rocky Mountain states. This Western region contains three-fourths of the nation's total (public and private) softwood growing stock—compared with only 18 percent held by the South, the next most important region. Because of the West's importance both as the leading timber-producing region and as the location of most of the nation's publicly-owned timber, it has provided the focal point for the controversy over forest-management policies. Pressures to increase harvest rates are doubly strong in this region because most of the Western timber is slow-growing old-growth timber, and because harvest rates under present policy are dependent upon growth.

Public vs. private

In the West, National Forests contain nearly two-thirds of the region's total softwood-timber inventory, compared with only 13 percent for forest-industry lands (Table 2). Yet in 1970, National Forests supplied no more timber than forest-industry lands—around 38 percent of the total. Over the entire 1952–70 period, the volume of softwood growing stock in Western National Forests declined by less than 1 percent, com-

Table 1
U.S. Commercial Forest Land and Softwood Growing Stock, by Ownership Class, 1970*

	Commercial Forest Land		Softwood Growing Stock	
Ownership Class	**Area (Million acres)**	**Percent of Total**	**Volume (Billion cubic ft.)**	**Percent of Total**
National Forest	91.9	18.4	199.8	46.3
Other Public	44.2	8.8	48.4	11.2
Forest Industry	67.3	13.5	73.2	16.9
Other Private	296.3	59.3	110.5	25.6
All Ownerships	499.7	100.0	431.9	100.0

*Note: Western national forests account for 76.9 percent of all national-forest acreage and for 94.5 percent of all national-forest softwood growing stock.

Source: U.S. Department of Agriculture, Forest Service, *Forest Statistics For the United States, by State and Region, 1970.*

pared with a 22-percent decline for forest-industry lands. The annual removals per acre on National Forest lands were only one-fifth those on forest-industry lands, and inventory turnover rates showed similar results.

The productive potential of Western National Forest lands—measured as the amount of timber the land would be capable of producing per acre per year if fully stocked with natural stands—is considerably below the average for forest-industry lands. This reflects the fact that National Forests were established after private industry had acquired some of the more productive lands. But their annual growth is low even in relation to their own potential growth. In 1970, the actual growth realized on National Forests represented only 31 percent of productive capacity, compared with 52 percent for forest-industry lands. Thus, while neither ownership class is growing wood at anywhere near full potential, the growth rate realized on National Forest lands is particularly low.

This relatively low growth rate partly reflects a conservative harvest policy, which has led to a heavy preponderance of virgin timber on public lands. The old-growth stands on these lands typically show little net growth, partly because of advanced age but also because of high mortality and decay losses. But the difference in growth rates also reflects the fact that National Forests are less intensively managed than industrial lands; that is, less labor and new investment are applied per acre to bring actual growth closer to productive potential. That condition in turn may be due to the fact that the Forest Service not only has less money per acre to spend on timber management, but also allocates those funds in a way that does not maximize productivity gains. For example, National Forests show very little correlation between their management expenditures and their cash receipts from the sale of timber.[3]

Public forest managers argue that their conservative harvest policies are necessary to meet the multiple-use objectives of the public forests, to conserve forest resources for future generations, and to ensure a sustained yield of timber products over the long-run. They argue further that increased timber harvests might conflict with the restrictive goals of environmental protection. Finally, they contend that management of public forest lands for maximum economic return would adversely affect the income of private forest owners.[4]

Critics agree that public forest lands should not be managed solely for profit—that social as well as economic objectives must be satisfied in their management. But they maintain that these objectives are not inconsistent with the applica-

Table 2
Production Indicators For National Forests and Forest-Industry Forests, Western Region*

Wood Production Indicator (1970)	National Forests	Forest-Industry Forests
Inventory (billion cu. ft.)	189.8	41.3
Inventory as percent of regional total	60.4	13.1
Annual removals (billion cu. ft.)	1.9	1.9
Annual removals as percent of regional total	38.0	37.8
Annual harvest as percent of inventory	1.0	4.6
Annual removals per acre (cu. ft.)	27.3	136.2
Estimated productive capacity (cu. ft./acre)	80.0	120.1
Growth achieved in 1970 (cu. ft./acre)	24.6	61.9
Actual growth as percent of productive capacity	30.8	51.5
Change 1952–70		
Annual growth per acre (cu. ft.)	3.6	9.7
Annual removals per acre (cu. ft.)	15.6	−3.1
Inventory (percent)	−0.5	−21.6

*Data refer to softwood growing stock in national forests (containing 71 million acres of commercial forest land) and in forest-industry forests (containing 14 million acres of commercial forest land).

Source: U.S. Department of Agriculture, Forest Service, *Forest Statistics for the United States by State and Region, 1970.*

tion of economic-efficiency criteria to timber management—that, in fact, these criteria should be applied to all management decisions involving alternative outputs and land uses. The use of economic-efficiency criteria would not only increase returns to the public treasury from timber growing and selling, but it would also maximize the timber and non-timber outputs possible with available resources. These critics claim that inefficiencies are involved when the National Forests, with an estimated asset value of $42 billion, are consistently operated at a loss.[5] They argue further that the benefits afforded consumers from increased timber harvests and lower forest-product prices would outweigh the loss of revenues incurred by private forest owners.

II. Current Policies in the Public Forest Sector

Public-forest management policies are guided principally by the Multiple-Use Sustained-Yield Act of 1960, the Forest and Rangeland Renewable Resources Planning Act of 1974, and the National Forest Management Act of 1976. These laws direct the Forest Service to follow the principles of sustained yield, in determining the allowable cut on National Forests. The Multiple-Use Act defines sustained yield as ". . . the achievement and maintenance in perpetuity of a high-level annual or regular periodic output of the various renewable resources of the National Forests without impairment of the productivity of the land." The National Forest Management Act, which amended the Multiple-Use Act but did not materially change the Forest Service's interpretation of sustained yield, states that "the Secretary of Agriculture shall limit sale of timber from each National Forest to a quantity equal to or less than a quantity which can be removed from such a forest annually in perpetuity on a sustained-yield basis."

Harvest determination

In the Forest Service's view, the concept of sustained yield requires that, at the earliest practicable time, an approximate balance be reached between net annual growth and harvest to prevent a decline in the timber inventory. The key to achieving that balance is the establishment of a "regulated forest" with an even distribution of age classes, each of approximately the same acreage. Then, every year, the oldest age class can be cut, with that cut just matching the annual growth of the other classes.

The profile of a fully-regulated forest—the long-term objective of the sustained-yield model—is depicted in Chart I-A and Appendix A. In this example, it is assumed that the forest consists of 210,000 acres of Douglas-fir with the growth characteristics specified later in Table 3. The total forest is divided into seven stands of equal area (30,000 acres), ranging in age from one to seven decades. It is assumed that this type of timber is mature—i.e., ready for cutting—after seven decades under the biological criteria used by the Forest Service. Thus, one-seventh of the total area could be cut every decade, with the growth of the other areas just compensating for that loss of volume. Once harvested, the cutover area would be replanted shortly thereafter and the harvest and replanting cycle continued, leading to a steady periodic output.

The problem with the use of this model in the West is that regulated-forest conditions do not exist in old-growth forests where there is a heavy preponderance of overmature timber. To achieve the desired distribution, large tracts of old-growth timber must be liquidated and restocked with second-growth stands. Under the principle of sustained yield, the key forest-management question concerns the rate at which old-growth timber should be liquidated to convert the forests to a regulated state—a state where growth and cut would be in approximate balance. The U.S. Forest Service has adopted a very conservative harvest policy, based on a non-declining even-flow strategy, which critics contend allows timber to grow far past the point of optimal financial maturity.

Under present Forest Service policy, the first step toward determining the allowable cut for any given National Forest is to determine the appropriate land base upon which the cut would apply. The fundamental unit is not the entire National Forest but rather the segment available for timber production known as "commercial" forest land—that is, the portion remaining after the subtraction of non-forest land, unproductive forest land, "productive deferred" and "productive reserved" lands. The productive reserved component includes designated wilderness and scenic and geologic areas which otherwise would qualify for the commercial component. The productive deferred component includes all areas under study for possible inclusion in the reserved category. Under the present harvest-determination system, the withdrawal of productive land for wilderness or wilderness-study classification thus reduces the area available for determining the allowable annual harvest.

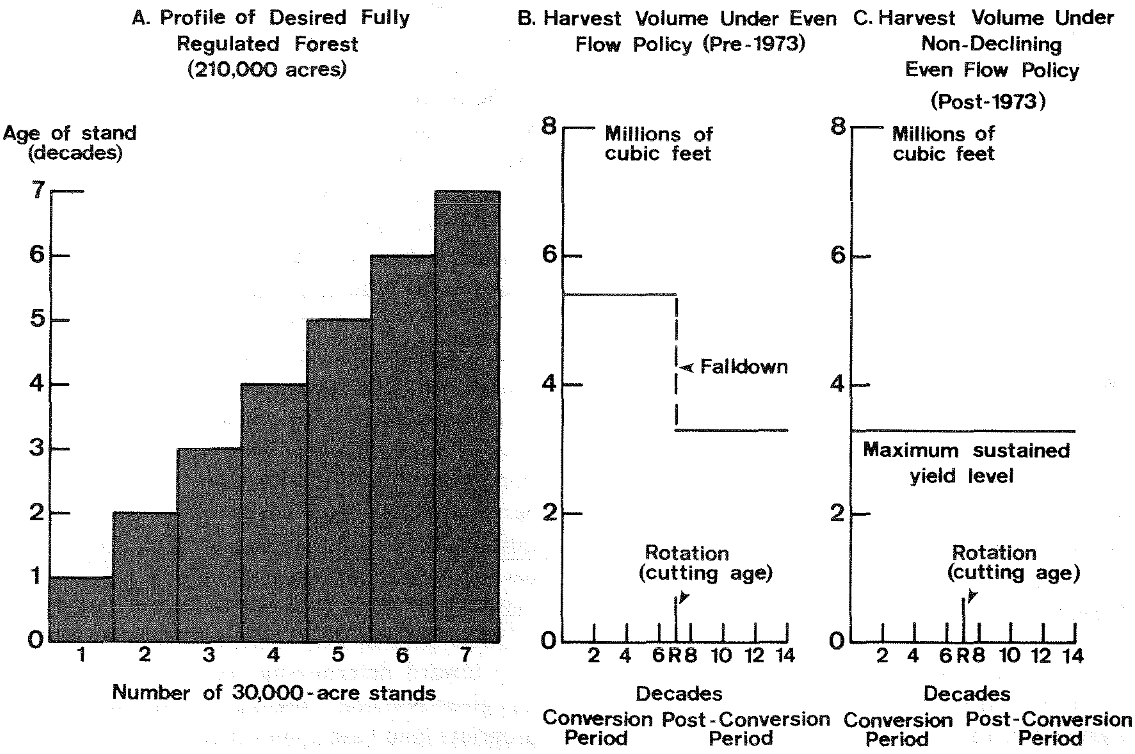
Until recent years, the Forest Service used certain formulas (such as the Hanzlik formula) to determine the allowable cut for each decade in the "commercial" areas of old-growth forests. More recently, it has shifted from the formula approach to the use of a linear programming model—Timber Resources Allocation Method (Timber Ram)—to establish its ten-year allowable cut for each forest. However, this more sophisticated approach has produced similar results to those developed through the old formula approach.

The Hanzlik formula distributes the harvest of old-growth (overmature) timber over one-rotation age—i.e., the cutting age based upon biological maximization—and then adds the expected growth in the decade for which the harvest is being determined.[6] Accordingly:

$$\text{Allowable Cut Per Decade} = (Vm/R) + I$$

Chart 1

FOREST REGULATION UNDER SUSTAINED YIELD (BIOLOGICAL) MODEL[1]



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[1] Assumes biological rotation age of seven decades

Sources: See Appendix A

where: V_m = Volume of mature timber, i.e., timber at or beyond cutting age

R = Length of rotation, i.e., cutting age in decades

I = Increment in total volume, i.e., net new timber growth expected in current decade

This system is designed to convert old-growth timber stands to a regulated state while at the same time providing a regular flow of harvested timber during the conversion period, usually one rotation in length.

Strict adherence to the Hanzlik formula results in a decline, or "falldown," in the average timber harvest level during the post-conversion period, as the inventory of mature timber declines (Chart I-B). To prevent this falldown, the Forest Service in 1973 thus added another constraint to its allowable cut calculation—non-declining even flow—which requires that the allowable cut for any given ten-year period be no higher than can be maintained in perpetuity. That harvest in turn is the maximum sustained yield, i.e., the harvest for a fully regulated forest in the post-conversion period (Chart I-C). The implementation of this regulation caused a sharp decline in the allowable cut on most National Forest lands. The Forest Service's inability to cut overmature timber more rapidly also meant that those forests might never be transformed to a regulated state.

Sustained yield connotes perpetual maintenance of the productive capacity of a forest, without reference to variations in harvest within or among decades. But the Forest Service has interpreted the concept to mean small variations in annual cut, which on average for a ten-year period do not deviate significantly from the long-term average. Moreover, since 1973 it has applied an extreme version of the even flow constraint—non-declining even flow—which forbids significant differences in harvests from one decade to the next. The same philosophy governs the management of other publicly-owned forest lands, such as those administered by the Bureau of Land Management.

The supply of Federal timber under the Forest Service's present policy is depicted by the supply schedule, S_O, shown in Chart 2-A. The most important aspect of this supply function is its unresponsiveness to bid prices, since it is determined on the basis of biological factors which are independent of any cost considerations. It shows that the Forest Service will not sell timber for less than the appraised price, Pc—a price that is not predicated upon its own costs but rather upon the amount it estimates forest-product firms can pay and still earn a satisfactory profit. The Forest Service would be willing to sell up to the full amount of the allowable cut, Qo, for the appraised price, if that price were in fact all that forest product firms were willing to offer. But no matter how much extra purchasers bid for the timber, the quantity offered would remain the same at Qo. In other words, the supply is perfectly inelastic for prices beyond the appraised price Pc. During the past decade, the prices offered for Federal timber typically have been far greater than the appraised price, indicating excess demand for timber at that price. Indeed, empirical studies have verified that the total supply of softwood timber in important Western timber regions—which are heavily influenced by such public policies—is very price inelastic.[7]

The rationale for the Forest Service's non-declining even-flow policy is the maintenance of stable timber prices and stable forest-community employment. Throughout most of this century Forest Service literature has stressed the need to stabilize dependent communities by providing equal or near-equal timber offerings at all times. But many commentators have pointed out that, in a dynamic world of changing technologies and changing economic conditions, an even flow of public timber does not necessarily ensure the realization of those objectives.[8] Employment can be stabilized only if harvests are kept unchanged in both the public and private sectors—an unlikely eventuality when shifts occur in demand. In reality, if demand declines and public harvests are maintained at an even flow, the private sector will be required to make the entire supply adjustment.

In the context of the strong demand conditions that have characterized timber markets over the past decade, an even-flow harvest policy in the public sector may actually result in a greater increase in timber prices than a price-responsive supply policy. As shown in Charts 2-C and 2-D respectively, an upward shift in demand from Do to D_1 with a public even-flow policy would have greater impact on timber prices (Po to Po') than would a shift with a price-responsive harvest policy (P_1 to P_1'). Again, in reality, the private sector is likely to react to an increase in public timber supplies by reducing its own harvest. But unless its actions totally offset those of the public sector—which is unlikely—rising demand will exert a smaller inflationary impact on timber prices with a price-responsive public harvest policy than with an even-flow policy.

Rotation age

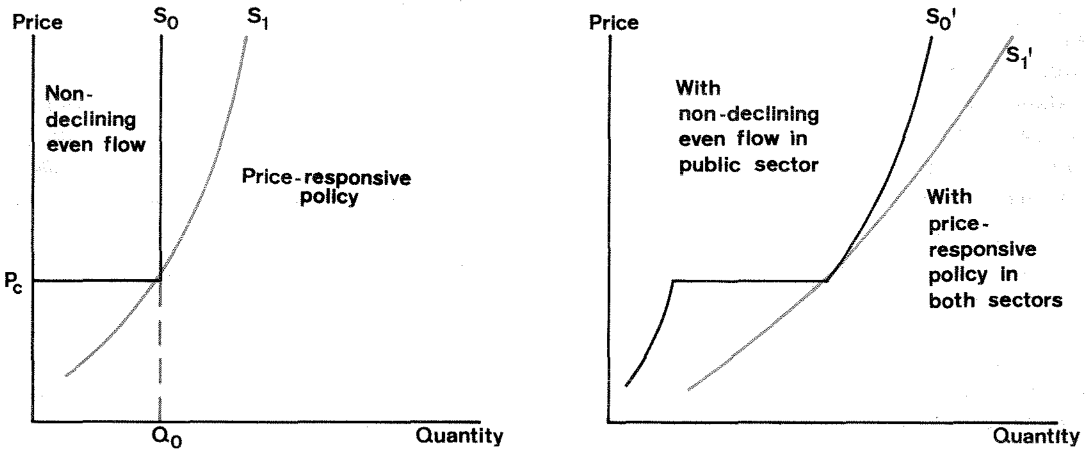
Under any harvest policy, the rotation age—the age at which timber is cut—is a prime determinant of the allowable cut. It determines the

Chart 2

EFFECT OF SHIFTING DEMAND ON TIMBER PRICES AND OUTPUT UNDER ALTERNATIVE PUBLIC SUPPLY STRATEGIES

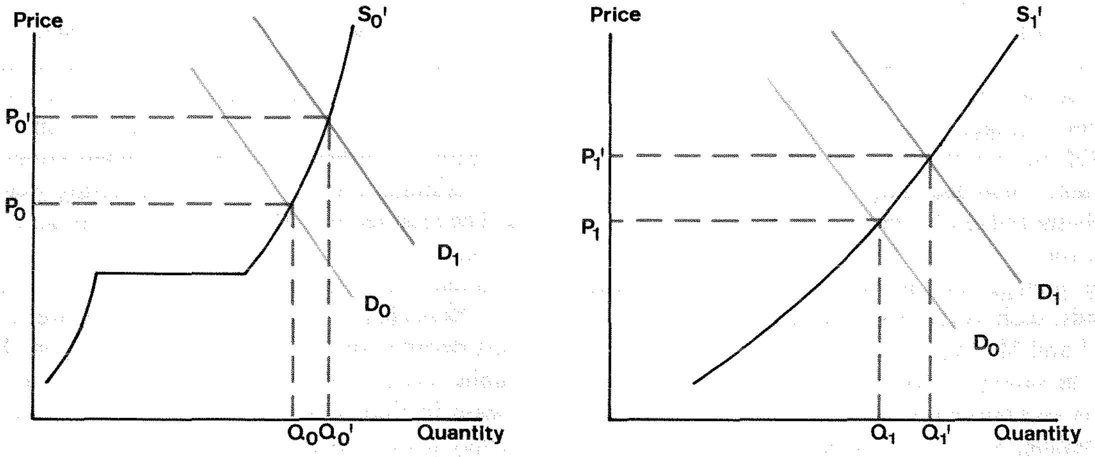
A. Timber Supply Schedule, Public Sector

B. Timber Supply Schedule, Public and Private Sectors



C. Price and Output Response With Public Non-Declining Even Flow

D. Price and Output Response With Both Sectors Price-Responsive



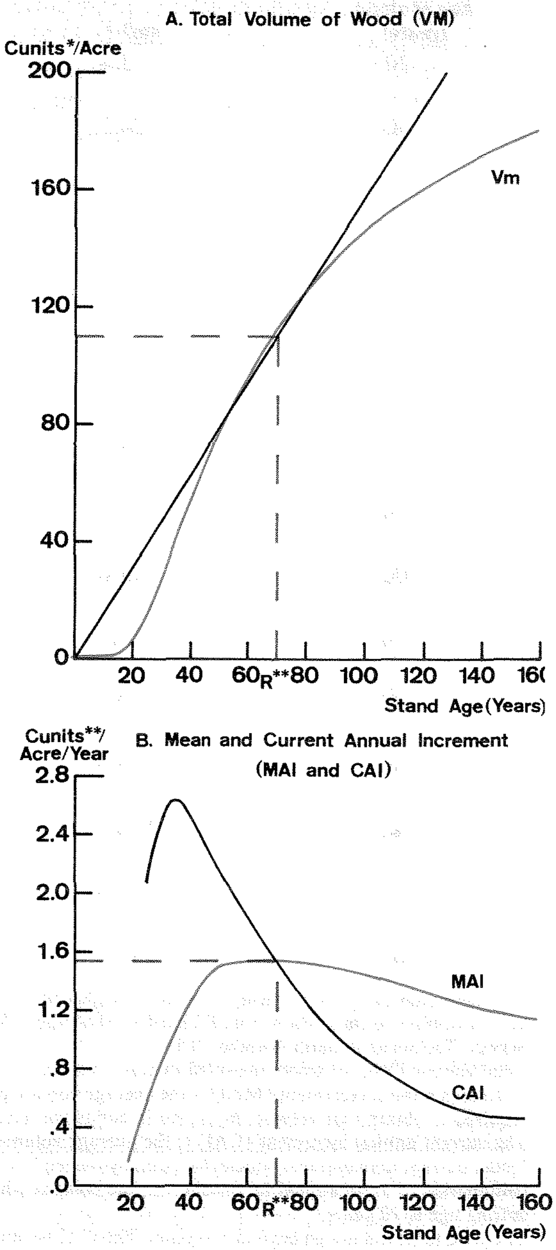
timber that is potentially available for harvest, whether the criteria be biological or economic, although the actual allowable cut may depend upon other constraints such as even flow or maximum economic return. The rotation age is also a key determinant of the rate of return earned on forest capital. Forest growing stock is forest capital: as a stand of trees grows in volume, it also appreciates in value. The period of time that a stand of trees is permitted to grow before the asset is converted to cash determines the economic return to the owner.

Nonetheless, the Forest Service establishes the appropriate rotation age for National Forest timber without reference to economic criteria. The objective is not to maximize economic return but rather the biological yield of the forest at a given level of management intensity. Consider the typical pattern of growth of a natural fully-stocked Douglas-fir stand on a one-acre parcel of land of medium fertility (Table 3). The table shows the relationship between stand age and volume of wood, known as a biological production function or yield curve. This production function also appears in Chart 3-A. The table also shows two other key factors necessary for determining the maximum sustained yield—the program which maximized the harvest of wood over the long-run. The first determinant, the mean annual increment (MAI), is the total capital stock or volume of wood divided by the number of years required to obtain that volume. The second determinant, the current annual increment (CAI), is the change in volume over a given time interval divided by the number of years in that interval. MAI is equivalent to the average physical product, and CAI to the marginal physical product (Chart 3-B).

The appropriate rotation (cutting) age for achieving maximum sustained yield is the age at which the current annual increment is equal to the mean annual increment, that is, where the mean annual increment is at a maximum. In the example shown, the appropriate rotation age is 70 years. This can be clearly seen if a long period, say 420 years, is considered. Cutting every 70 years would give six harvests of approximately 110 cunits each or a total of 660 cunits. (One cunit equals one hundred cubic feet.) No other rotation age would result in as much wood over

Chart 3

DETERMINATION OF CUTTING AGE FOR A ONE-ACRE DOUGLAS-FIR STAND UNDER BIOLOGICAL CRITERIA



*One cunit equals 100 cubic feet.

**R, rotation or cutting age, equals 70 years in this example.

Table 3
Determination of Cutting Age for a One-Acre Douglas-Fir Stand Under Biological Criteria

Age of stand (years)	Vm[1,2]	MAI[3]	CAI[4]
20	3.4	0.17	
			2.08
30	24.2	0.81	
			2.62
40	50.4	1.26	
			2.36
50	74.0	1.48	
			1.98
60	93.8	1.56	
			1.64
70	110.2	1.57[5]	
			1.38
80	124.0	1.55	
			1.10
90	135.0	1.50	
			0.96
100	144.6	1.45	
			0.83
110	152.9	1.39	
			0.70
120	160.0	1.33	
			0.57
130	165.6	1.27	
			0.53
140	170.9	1.22	
			0.47
150	175.6	1.17	
			0.45[6]
160	180.1	1.13	

[1] Normal biological growth (yield) curve for Douglas-fir trees 7 inches in diameter or larger at breast height on fully stocked acre, medium site class. Data from Richard E. McArdle, *The Yield of Douglas Fir in the Pacific Northwest,* U.S.D.A. Forest Service Technical Bulletin Number 201.

[2] Total volume (Vm) of wood measured in cunits per acre. One cunit equals 100 cubic feet.

[3] The mean annual increment (MAI) is the average volume per year—that is, the total volume divided by the number of years required to obtain that volume, measured in cunits per acre per year.

[4] The current annual increment (CAI) is the average volume added each year, measured in cunits per acre per year.

[5] Under current management policies for publicly-owned forest lands, the appropriate cutting (rotation) age is determined at the culmination of mean annual increment, i.e., the point at which the total volume/age is greatest. In this example, appropriate cutting age is 70 years.

[6] The yield table did not go beyond 160 years. The CAI beyond that age is assumed to be zero to simplify the harvest determination example shown in Appendix A.

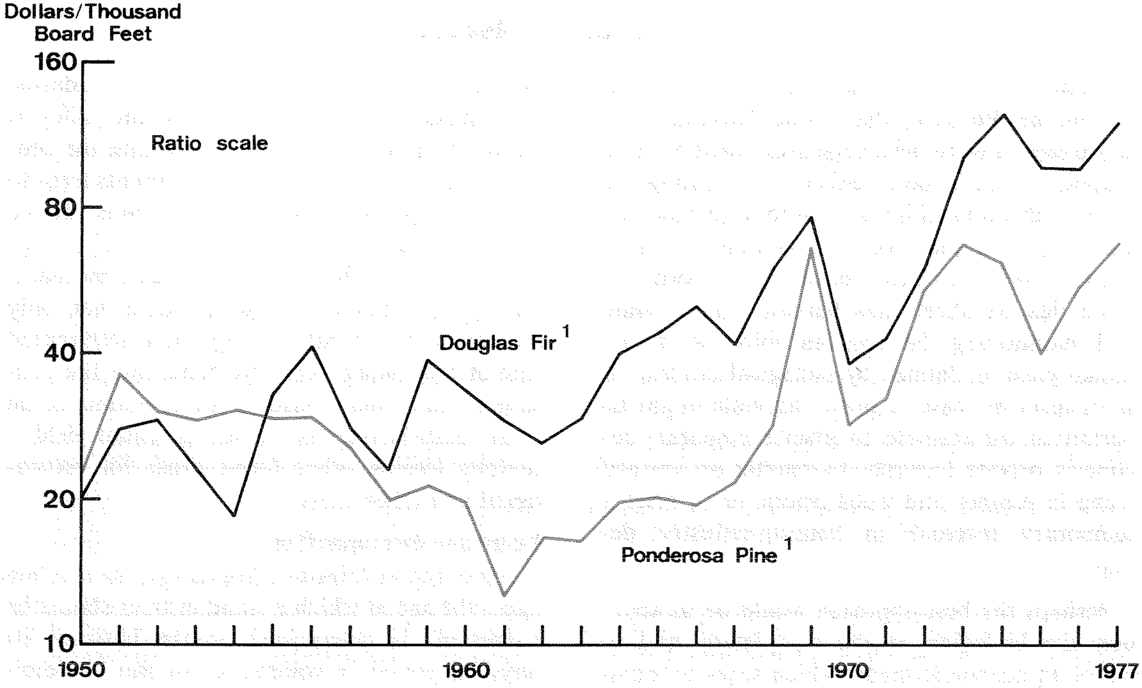
the period. For example, a rotation age of 140 years would give three harvests of 171 cunits each or a total of 514 cunits.

For any given National Forest, the allowable-cut calculation is predicated upon a given intensity of forest management. This refers to a given application of capital and labor to each acre of commercial forest land. The allowable cut can be increased if it can be shown that a more capital- and labor-intensive management "regime" is being introduced as a means of raising prospective forest productivity, i.e., timber growth per acre per year (CAI). For example, "good" management may involve fire protection and seeding and planting to fill in gaps in natural regeneration.[10] "Highest-order" management may involve those practices plus others, such as weeding, fertilization, thinning and genetic stand improvement.

Under current Forest Service policy, the intensification of management practices to bring actual productivity closer to that potentially realizable with fully-stocked natural stands would permit an immediate acceleration in the rate of liquidation of old-growth timber, even though the returns in terms of added growth would not immediately be obtained. This increase in the current allowable cut attributable to increased investment—known as the allowable-cut effect (ACE)—represents a shift to the right in the supply function under a non-declining even-flow policy (Chart 2-A). The approach has been severely criticized by the proponents of an economic approach to public timber management.[11] They argue that it leads to inefficient investment decisions, because the return on a new investment is determined not on the basis of its own growth and revenue potential, but rather on the basis of the increased revenue to be derived from cutting existing old-growth timber.

Chart 4

RELATIVE STUMPAGE PRICES FOR SAWTIMBER
SOLD FROM NATIONAL FORESTS



[1] Actual prices divided by wholesale-price index (1967=100).

Source: U.S. Department of Agriculture, Forest Service, **The Demand and Price Situation for Forest Products.**

Effects on timber prices

The recent movement for change has been motivated by a growing concern over the future cost and availability of public timber if current management policies are continued. In the face of a sharp increase in demand over the 1963–77 period, the competition for available domestic softwood timber supplies has led to an intense price rise, relative to the overall wholesale price index (Chart 4). During that period, the average price for Douglas-fir sawtimber sold on the National Forests in western Washington and western Oregon rose nearly ten-fold, from $27.90 to $230.25 per thousand board feet. Deflated by the wholesale price index, the price of Douglas fir still quadrupled—and a similar pattern was evident in the price of ponderosa-pine sawtimber.

More importantly, U.S. Forest Service projections of softwood timber demand and supply to the year 2000 indicate a continuation of this severe inflation in timber prices.[12] The Forest Service study argues that, with current silvicultural practices and timber harvesting policies, demand is likely to be brought into balance with supply only under the assumption of "rising relative prices," compared with the overall wholesale price index.

The supply forecast suggests that a sharp decline in Western timber harvests will tend to offset an increase in supplies from private lands in the South.[13] This Western decline is expected to occur primarily on private lands, on the basis of the Forest Service's belief—under its biological conception of harvest determination—that private industrial owners will attempt to maintain a closer balance between growth and removals after a period of heavy inventory liquidation. Of course, if these owners respond to rising timber prices, private supplies (and total supplies) from the West could be higher than predicted. Nevertheless, the expected rapid growth in timber demand, together with the past behavior of prices, suggests that price pressures will remain strong if the Forest Service's present harvest policy is continued.

III. An Economic Alternative

Numerous strategies have been suggested to expand the Western public timber harvest, in order to ease upward price pressures. Most of these proposals have involved either 1) increasing the level of silvicultural investment to raise expected annual growth and thus the allowable cut, or 2) relaxing the even-flow constraint to permit a more flexible short-term harvest policy, while still maintaining the long-run objective of sustained-yield as defined by biological criteria. A short-term increase in public harvests might be permitted, for example, to offset a temporary decline in private harvests, to counter an upward trend in lumber and wood prices, or to meet a temporary increase in housing-industry demand.[14]

Perhaps the best approach would be to abandon the biological model completely, and to adopt an economic model which seeks to maximize net financial return, more specifically the present value of future net cash flows. This alternative in effect would subject all forest-management decisions to economic efficiency standards. Economists maintain that the present policy is inefficient in that it does not maximize the economic value of output. Rather, it permits trees to grow far past their point of maximum economic maturity, and thus results in irrational investment decisions. Proper management, by maximizing net financial return, would not only dictate a shorter rotation age and accelerated rate of harvesting—thereby benefiting the consumer—but would also focus investments on those lands having the highest potential yield—thereby freeing other forest areas for recreational and other uses.

Economic determination

Under the sustained-yield concept, the rotation age—the age at which a stand of trees should be harvested—is determined on the basis of its physical growth in volume terms. But by determining the rotation age at the point of maximum "mean annual increment," the biological model ignores the major cost of timber production—the opportunity cost of tying up the owner's capital for the next period. By failing to take account of interest on capital investment this "zero interest model" permits trees to grow past their point of maximum economic maturity.

With timber production, time is one of the chief inputs. Time is required before the timber reaches marketability. Yet timber cut and sold in the future is worth less to its owners than an equal amount available today. For that reason, investors must be ensured of an acceptable rate of return on invested capital to compensate them for foregoing benefits until a later date. Yet in the Forest Service model, timber cut 70 years from now is assumed equal in value with timber cut this year, without any consideration of the housing and other services which this year's cut will provide for the next 70 years.

What rate of return should be used in evaluating public investments? Economists generally agree that resources committed to the public sector should earn as great a return as they would earn in the private sector for investments of comparable risk—the so-called "opportunity cost of capital."[15] But there is less agreement about the amount of risk inherent in the public sector, and about the proper private sector rates to be used in comparing private and public investments.[16] In any case, some interest rate clearly should be included in the investment decision, and future income then should be discounted by that rate to make it comparable to present income.

But what should the investor attempt to maximize to determine the optimum rotation? Different foresters and economists—such as Fernow (1902), Fisher (1930) and Boulding (1935)—have offered various solutions, including forest rent, present net worth over one harvest cycle, and internal rate of return.[17] But Samuelson showed in 1976 that the appropriate economic model for determining timber maturity is the soil- or land-expectation model developed by German forester Martin Faustmann in 1849.[18]

The Faustmann approach to rotation-age determination is basically a "present-value model" that seeks to maximize the present value of the land devoted to timber production. It begins by asking, "How much could an investor afford to pay for an acre of bare land if he intended to use it for timber production? Rather than determining the present value on the basis of the discounted net income resulting from a single harvest, it determines the present value on the basis of an infinitely long series of expected discounted net periodic incomes from the timber. The optimum rotation age thus is the age at which the present value of a perpetual net income stream earned on the land is maximized.

The basic Faustmann formula reads:

Present Value of Bare Forest Land =

$$\frac{\sum_{t=o}^{r} R_t(1+i)^{r-t} - \sum_{t=o}^{r} C_t(1+i)^{r-t}}{(1+i)^r - 1}$$

where: R_t = revenue received at time t
C_t = costs incurred at time t
r = rotation age
i = interest rate

The formula (Appendix B) does not in itself determine the optimum rotation age. Instead, it

Table 4
Douglas-Fir Cutting (Rotation) Ages
Site Index 150 (Medium)

Criteria	**Cutting Age (years)**
Biological Model: Maximize Mean Annual Increment (Table 3)	70
Economic Model: Maximize Land Expectation Value	
Case I (6% and zero)—Table 5*	50
Case II (6% and 2%)—Table 5*	55
Case III (10% and zero)—Appendix C*	41
Case IV (10% and 2%)—Appendix C*	45

*Figures in parentheses refer, respectively, to real rate of interest and annual stumpage price appreciation after adjustment for inflation.

is necessary to calculate present values for perpetual income streams corresponding to various rotation ages, and then to select that age at which the present value is maximized. Two examples illustrate the present-value method of rotation-age determination, using the same yield data for a one-acre Douglas-fir stand as was used in the biological model. The examples illustrate a key point: by introducing an interest rate into the computations, the economic model provides a shorter optimal rotation age than does the biological model.

The calculations are made under several different interest-rate and price assumptions. If we assume a 6-percent real interest rate and no timber (stumpage) price appreciation (after inflation adjustment), we obtain an optimum cutting age of 50 years (Table 4). With a 2-percent annual rise in relative prices, we obtain an optimum cutting age of 55 years—still far less than the 70-year solution derived by applying the biological model. If we use a 10-percent real rate of interest, we shorten the rotation age still further. Indeed, in 1968 hearings of the Congressional Joint Economic Committee, most of the economists testifying advocated an 8-to-10 percent rate of discount for public investment.[19]

In determining the optimal rotation age under economic criteria, the forest manager needs information on the timber inventory and the vol-

Table 5

Determination of Cutting Age for a One-Acre Douglas-Fir Stand Under Economic Criteria*

6% Real Rate of Interest

(R) Age of Stand[1] (years)	Vol. of Wood (Cunits/ acre)	Current Stumpage Price[2] ($ per cunit)	Current Value of Wood ($ per acre)	6% Present Value of Revenue w/no Appreciation[3] ($)	6% Present Value of Revenue w/2% Appreciation[4] ($)	6% Present Value of Costs[5] ($)	6% Land Expectation Value w/no Appreciation ($)	6% Land Expectation Value w/2% Appreciation ($)
20	3.4	0	.00	.00	.00	62.39	−62.39	−62.39
30	24.2	27	653.40	137.85	301.11	57.55	80.30	243.56
40	50.4	43	2,167.20	233.28	592.13	55.48	177.80	536.65
50	74.0	64	4,736.00	271.87	810.96	54.48	217.39[6]	756.48[7]
60	93.8	77	7,222.60	225.78	798.08	53.96	171.82	744.12
70	110.2	87	9,587.40	165.07	696.25	53.67	111.40	642.58
80	124.0	95	11,780.00	112.40	567.16	53.52	58.88	513.64
90	135.0	98	13,230.00	70.20	528.43	53.44	16.76	374.99
100	144.6	99	14,315.40	42.32	312.36	53.39	−11.07	258.97
110	152.9	100	15,290.00	25.20	225.48	53.36	−28.16	172.12
120	159.9	100	15,990.00	14.71	159.77	53.35	−38.64	106.42
130	165.6	100	16,560.00	8.50	112.77	53.34	−44.84	58.93
140	170.9	100	17,090.00	4.90	78.69	53.34	−48.44	25.35
150	175.6	100	17,600.00	2.81	54.96	53.33	−50.52	1.63
160	180.1	100	18,100.00	1.61	38.33	53.33	−51.72	−15.00

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*See Appendix D for revenue and cost assumptions.

[1] R = rotation (cutting) age.

[2] Today's prices for trees of various ages. Assumes no appreciation in the price of timber relative to the wholesale price of other goods.

[3] Six-percent present value of current value of wood per acre every R years in perpetuity.

[4] Six-percent present value of appreciating value of wood per acre every R years in perpetuity, using an interest rate adjusted for appreciation (1.06 ÷ 1.02 = 1.039216).

[5] Costs = Aerial seeding for regeneration = $20/acre, with annual management costs $2/acre/year. Six-percent present value of $20 every R years beginning today and $2 per year in perpetuity.

[6] Under economic criteria, the appropriate cutting age is the age at which land expectation value (net present value) is maximized. Under the assumption of no stumpage price appreciation, appropriate cutting age is 50 years.

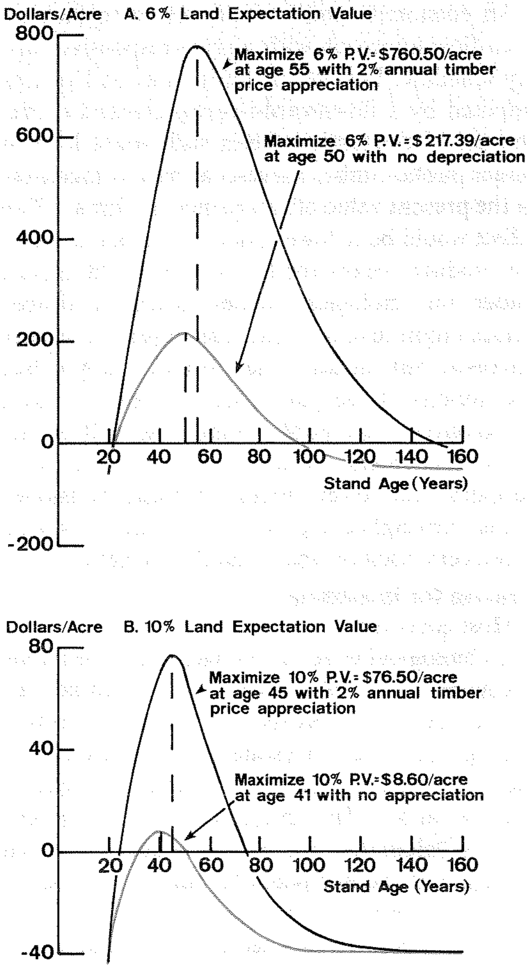
[7] With stumpage price appreciation, land expectation value is maximized at age 55.

ume of wood per acre at various ages—just as he does when operating with the biological model. But the manager also needs estimates of the expected price of trees at different ages, including the price appreciation in excess of the overall inflation rate. He can then convert the biological growth curve to a revenue function by multiplying the volume of wood per acre by the assumed price for timber at each rotation age. Eventually he will be able to calculate the "land-expectation values"—the present discounted value of all net cash receipts, with and without price appreciation, calculated over the infinite chain of cycles of planting and cutting on the given acre of land (Table 5, Appendix C, and Chart 5).

For each interest rate, the age at which the land-expectation value is maximized under each price assumption is the appropriate cutting age. Those values represent the amount investors would be willing to pay for the bare land, under alternative price assumptions, to earn (say) 6- and 10-percent rates of return annually on their investment.

Chart 5

DETERMINATION OF CUTTING AGE FOR A ONE-ACRE DOUGLAS-FIR STAND UNDER ECONOMIC CRITERIA



Harvest scheduling

The land-expectation formula might show that most trees on the National Forests are past their point of maximum economic return, but that does not mean that the Forest Service should begin harvesting its entire stock of overmature timber. For a small forest owner, the economic rotation age is the most important element in the harvest-determination process, because it tells him just when his timber should be harvested. In any given year, to maximize the present value of his forest, the small owner should cut all the trees he owns that are at or above the economic rotation age. But for the National Forests and other very large ownerships, which are large enough to affect the price of timber, such a drastic increase in harvests could seriously depress the price of timber, so that both private forest owners and public agencies would soon be growing timber at a loss.

In imperfectly competitive markets, where large owners can affect the market price, additional data are needed to determine that harvest schedule which will maximize present net worth. In this case, where the forest manager faces a downward-sloping demand curve—i.e., can only sell increased quantities at lower prices—demand forecasts and extraction-cost estimates are even more important than the appropriate rotation age in the harvest-determination process. Given such estimates, we can calculate the present value of net income that would be obtained under various timber harvest schedules, and can select that harvest schedule which produces the highest present value of future net timber returns selected. To calculate present values for a large number of alternative harvest schedules, the assistance of a computer is required. At least one model—The Economic Model for Optimizing The Rate of Timber Harvesting, known as ECHO—has been developed incorporating these economic-maximization principles.[20]

An economic model would act to replace an even-flow approach with a price-responsive supply schedule. Despite the limitations on harvests imposed by a downward-sloping demand curve, the use of economic criteria still would lead to larger public-timber harvests as well as increases in the present value of future income flows.[21] The effect would be to lower prices of timber and forest products below the levels that would prevail under the biological model. Reduced timber prices might lead to reductions in private timber harvests, but unless those cutbacks fully offset the actions of the public sector, forest product firms reliant upon public timber—as well as ultimate consumers—would gain from increased supplies and lower prices. If those consumer gains outweighed the loss of revenue to private producers, society would stand to benefit.[22]

Criteria for investment

Most economists agree that policies based solely on biological criteria will lead to irrational investment decisions. Under the allowable cut effect (ACE), the prospect of increased growth arising from a new investment is a sufficient condition for raising the current allowable cut of mature timber. The return on a new investment thus is calculated not on the basis of its own growth and revenue potential but on the basis of the value derived from cutting existing old-growth timber. Given a decision to replant a nonstocked area of a given National Forest, the allowable cut of old-growth timber could immediately be increased, because it would raise the expected growth of the forest taken as a unit. But under current policy, the returns on that investment would be measured, not by comparing the costs and expected returns on the land where the investment took place, but by comparing those costs with the increased revenues to be derived from cutting more old-growth timber elsewhere in the forest.

In contrast, the economic approach would relate the increased costs associated with a given investment to the value of the increased harvests resulting from the investment. This analysis suggests that investments in better, more accessible sites, should be undertaken first. As prices rise, poorer-quality and less-accessible land should be subjected to more intense management, but at every price some lands would not be worth the investment. Thus, under an economic model, supplies of timber from publicly-owned lands, as well as the intensity of management, would be responsive to price.

Economic criteria thus dictate the removal of unprofitable areas from timber management and production, resulting in a net saving to the public treasury and to society. But since such areas frequently have the physical attributes that are most desirable for wilderness designation—scenic vistas, alpine meadows, lakes and streams—an economic approach to timber management might ensure both more wilderness and more timber production. In those cases where the best timberland possesses desirable, even unique, wilderness characteristics, efficiency criteria would require that the timberland be allocated to its highest valued use—which might be for wilderness preservation when the latter value exceeds foregone timber value.

In essence, then, an economic approach would lead to the segregation of land into two classes. One class would consist of prime timber-growing land, on which timber would be managed to maximize present value. The second class would include those lands less valuable for timber production and/or those with characteristics which could compete with timber in social value. This approach would probably lead to more of both timber production and other forest outputs—including wilderness—because of 1) the accelerated harvesting called for under the economic-efficiency criteria and 2) the concentration of investments on the most productive sites.

IV. Summary and Conclusions

According to Forest Service forecasts, the U.S. demand for softwood timber can be brought into balance with supply over the next several decades only at substantially higher relative prices for forest products—assuming the continuation of current timber-harvesting policies and levels of timber investment. The agency believes that conservation efforts designed to slow down the growth of demand cannot significantly affect the upward pressure on prices. Rather, solutions will have to be sought on the supply side.

Many resource economists, as well as forest-product consumers, believe that National Forests offer an important opportunity for raising total supplies above projected levels in the face of only modest increases in private timber harvests. They argue that the current non-declining even-flow harvest policy places unnecessarily severe constraints on annual harvests from National Forest lands, and fails to accomplish its stated objective of fostering local-community stability. Moreover, that policy leads to an inefficient allocation of available capital and labor for forest management. A more flexible harvest strategy, better tailored to meet the requirements of the market, is needed to alleviate upward pressures on timber and forest-product prices. The solution, in the view of these economists, lies in the use of economic criteria to determine appropriate harvest rates and investments on National Forests. Through this approach, society should be able to obtain both a greater economic return on timber production and a greater set-aside of land for recreation and other uses. Thus, an unduly restrictive and inefficient harvest strategy, rather than environmental pressure, is the true cause of today's apparent shortage of reasonably-priced timber.

Appendix A: A Simplified Example of Forest Regulation in the Public Sector

Problem:

Using the Forest Service's biological criteria for harvest determination, develop a harvest schedule for an old-growth Douglas-fir forest that will convert the existing forest into one with an even distribution of age classes yet still provide a regular flow of harvested timber over time. Assume a simple hypothetical forest with the following characteristics:

Profile of Existing Forest:

Area: 210,000 acres

Age of stands: all trees, 16 decades old

Cutting, or rotation age (R), determined on basis of biological criteria: 7 decades, as shown in Table 3

Growth: assume no growth increment after age 160 years

Profile of Desired Fully Regulated Forest (As shown in Chart 1-A)

Area: 210,000 acres

Age of stands: 1 to 7 decades old, with each age class occupying an equal area of the forest, namely 30,000 acres

Cutting, or rotation age (R), determined on basis of biological criteria, 7 decades, as shown in Table 3

Harvest Determination:

1. *Even-Flow Policy,* Pre-1973 (As shown in Chart 1-B)
   a. Conversion Period:
   In this simplified example—where all stands are assumed to be of equal age (even-aged), growth in all the ensuing decades is assumed to be zero, and the cutting age is 7 decades—the appropriate cutting policy to achieve a regulated forest is to cut 1/7th of the total forest area each decade—a so-called area-control approach. Indeed, the Hanzlik formula $\frac{Vm}{R} + I$, discussed in the text, reduces to an area control formula when there is a large proportion of mature timber, and when I therefore approaches zero. The harvest schedule for each decade of the conversion period would be calculated as follows:

$\frac{\text{Total area}}{\text{Decades in rotation}}$ x Volume per acre for mature timber (160 years)

Solution:

$\frac{\text{210,000 acres}}{\text{7 decades}}$ x 180.1 cunits per acre = 5.4 million cunits/decade

(Note: Volume per acre as shown in Table 3; one cunit equals 100 cubic feet.)

b. Post-Conversion Period:

In the post-conversion period, when the forest is regulated and there are 7 stands of equal area, ranging from 1 to 7 decades in age, 1/7th of the forest area also can be cut, namely that stand containing the trees 7 decades old. Using this same formula, the harvest schedule for each decade of the post-conversion period would be calculated as follows:

$\frac{\text{Total area}}{\text{Decades in rotation}}$ x Volume per acre for mature timber (70 years)

Solution:

$\frac{\text{210,000 acres}}{\text{7 decades}}$ x 110.2 cunits per acre = 3.3 million cunits/decade

(Note: Volume per acre as shown in Table 3.)

2. *Current Non-Declining Even-Flow Policy* (As shown in Chart 1-C)

The allowable cut under a non-declining even-flow policy is that harvest that can be sustained in perpetuity, i.e., the maximum sustained yield. That volume in turn is the harvest for a fully regulated forest, that is, the cut in the post-conversion period. In this example, the cut would be 3.3 million cunits per decade, assuming a given level of management intensity.

Appendix B: Derivation of the Faustmann Present Value Formula

In the article, the objective of the empirical examples was to identify that rotation age, under each set of conditions, at which the present value of the land was maximized. Present values were calculated for net income streams corresponding to various rotation ages. A graph of these values, with corresponding ages on the ordinate, gave an inverted parabola (Chart 5). The highest point on this curve—the point tangential to the horizontal—was identified as the optimum rotation age.

The Faustmann formula, which gives the present value of a perpetual net income stream is derived as follows:

$$\text{Present Value} = \sum_{t=o}^{\infty} \frac{R_t - C_t}{(1+i)^t}$$

where R_t represents revenues at time t

C_t represents costs at time t and

i is the exogenously given interest rate for discounting future income streams.

To introduce rotation age r explicitly, we break up the series on the righthand side, as follows:

$$\text{Present Value} = \sum_{t=o}^{r} \frac{R_t - C_t}{(1+i)^t} + \sum_{t=r+1}^{2r} \frac{R_t - C_t}{(1+i)^t} + \ldots\ldots + \sum_{t=(n-1)r+1}^{nr} \frac{R_t - C_t}{(1+i)^t} + \ldots\ldots + \ldots\ldots$$

$$= \sum_{t=o}^{r} \frac{(R_t - C_t)(1+i)^{r-t}}{(1+i)^r} + \ldots\ldots + \frac{\sum_{t=(n-r)+1}^{nr} (R_t - C_t)(1+i)^{r-t}}{(1+i)^{nr}} + \ldots\ldots + \ldots\ldots$$

$$= \left[\sum_{t=o}^{r} (R_t - C_t)(1+i)^{r-t} \right] * \sum_{n=1}^{\infty} \frac{1}{(1+i)^n}$$

Assuming that the level of cash flows in each rotation cycle is a constant (the assumption may be relaxed if this level increases at some compounded rate over time) as given by

$$\left[\sum_{t=o}^{r} (R_t - C_t)(1+i)^{r-t} \right],$$

we can use the series property

$$\sum_{n=o}^{\infty} \frac{1}{(1+m)^n} = \frac{1}{1-(1+m)^{-n}} = 1 + \frac{1}{(1+m)^n - 1}$$

Therefore, $\sum_{n=1}^{\infty} \frac{1}{(1+m)^n} = \frac{1}{(1+m)^n - 1}$,

which gives us:

$$\text{Present Value} = \frac{\sum_{t=o}^{r} (R_t - C_t)(1+i)^{r-t}}{(1+i)^r - 1}$$

Conceptually, the numerator may be seen as a future-value term. All cash flows within a cycle are transformed to their future values at the end of each cycle. We then have a financial asset which pays a constant amount every r periods in perpetuity.

Appendix C

Determination of Cutting Age for a One-Acre Douglas-Fir Stand Under Economic Criteria (10% Real Rate of Interest)

(R) Age of Stand[1] (years)	Vol. of Wood (Cunits/ acre)	Current Stumpage Price[2] ($ per cunit)	Current Value of Wood ($ per acre)	10% Present Value of Revenue w/no Appreciation[3] ($)	10% Present Value of Revenue w/2% Appreciation[4] ($)	10% Present Value of Costs[5] ($)	10% Land Expectation Value w/no Appreciation ($)	10% Land Expectation Value w/2% Appreciation ($)
20	3.4	0	.00	.00	.00	43.49	−43.49	−43.49
30	24.2	27	653.40	39.72	75.69	41.22	−1.50	34.47
40	50.4	43	2,167.20	48.97	111.16	40.45	8.52[6]	70.71
50	74.0	64	4,736.00	40.69	111.14	40.17	.52	70.97[7]
60	93.8	77	7,222.60	23.80	78.68	40.07	−16.17	38.61
70	110.2	87	9,587.40	12.16	48.41	40.03	−27.87	8.78
80	124.0	95	11,780.00	5.75	28.11	40.01	−34.26	−11.90
90	135.0	98	13,230.00	2.49	14.82	40.00	−37.51	−25.18
100	144.6	99	14,315.40	1.04	7.53	40.00	−38.96	−32.47
110	152.9	100	15,290.00	.43	3.78	40.00	−39.57	−36.22
120	159.9	100	15,990.00	.17	1.86	40.00	−39.83	−38.14
130	165.6	100	16,560.00	.07	.90	40.00	−39.93	−39.10
140	170.9	100	17,090.00	.03	.44	40.00	−39.97	−39.56
150	175.6	100	17,600.00	.01	.21	40.00	−39.99	−39.79
160	180.1	100	18,100.00	.00	.10	40.00	−40.00	−39.90

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*See Appendix D for revenue and cost assumptions.

[1] R = rotation (cutting) age.

[2] Today's prices for trees of various ages. Assumes no appreciation in the price of timber relative to the wholesale price of other goods.

[3] Ten-percent present value of current value of wood per acre every R years in perpetuity.

[4] Ten-percent present value of appreciating value of wood per acre every R years in perpetuity, using an interest rate adjusted for appreciation (1.1 ÷ 1.02 = 1.07843).

[5] Costs = Aerial seeding for regeneration = $20/acre, with annual management costs $2/acre/year. Ten-percent present value of $20 every R years beginning today and $2 per year in perpetuity.

[6] Under economic criteria, the appropriate cutting age is the age at which land expectation value (net present value) is maximized. Under the assumption of no stumpage price appreciation, appropriate cutting age is 41 years.

[7] With stumpage price appreciation, land expectation value is maximized at age 45.

Appendix D: Revenue and Cost Assumptions (Economic Model)

Revenue Assumptions

Age of Stand (Years)	Current Stumpage Price[1] (Dollars/cunit)	End of First Rotation Price[2] (Dollars/cunit)
20	0	0
30	27	49
40	43	95
50	64	172
60	77	253
70	87	348
80	95	463
90	98	582
100	99	717
110	100	883
120	100	1,077
130	100	1,312
140	100	1,600
150	100	1,950
160	100	2,377

Cost Assumptions

Aerial seeding for regeneration = $20/acre

Annual management costs = $2/acre/year

[1] At current (today's) prices, timber 110 years old would sell for $100/cunit; $100/cunit = $200/thousand board feet Scribner. Current stumpage prices are assumed to remain constant after adjustment for inflation.

[2] End of rotation price (with 2% annual appreciation) = Current price x $(1.02)^R$ where R = rotation age.

FOOTNOTES

1. The last comprehensive inventory of U.S. timber resources was conducted by the Forest Service in 1970. Results, as well as an assessment of the long-term supply and demand outlook, appeared in U.S. Department of Agriculture, Forest Service, **The Outlook for Timber in the United States,** Forest Resource Report 20 (Washington, D.C.: U.S. Government Printing Office, 1973). See page 310 for the definition of "commercial forest land." More detailed forest resource statistics, by ownership class and geographical area, are available in the Forest Service publication, **Forest Statistics for the United States, By State and Region, 1970** (Washington, D.C.: U.S. Government Printing Office, 1973).

2. Softwood "growing stock" is more comprehensive than the volume of sawtimber in that it includes trees that are too small for lumber production but suitable for paper. Sawtimber trees must contain at least one 12-foot sawlog or two non-contiguous 8-foot logs, and meet regional specifications for freedom from defect. Unless otherwise specified, the timber inventory, growth and harvest rates discussed in this study refer to growing stock.

3. Marion Clawson, "The National Forests: A Great National Asset is Poorly Managed and Unproductive," **Science** (February 1976), pp. 762-767.

4. For a good summary of this position see, H.R. Josephsen, "Economics and National Forest Timber Harvests," **Journal of Forestry** (September 1976), pp. 605-611.

5. Asset value of standing timber, forest lands and man-made improvements, 1974, as estimated by Marion Clawson, **op. cit.,** pp. 762-764. Charges of inefficiency in public forest management also were made by John Walker in, "Economic Efficiency and the National Forest Management Act of 1976," **Journal of Forestry** (November 1977), pp. 715-718.

6. In determining the allowable cut for a given forest for the first decade, V_m, the volume of mature merchantable timber at or beyond rotation age, is calculated by multiplying the number of acres in each age class at or beyond the rotation age by the volume per acre for each age class at or beyond the rotation age and summing to obtain a grand total. I, current increment (net new timber growth) expected in the first decade, is calculated by multiplying the number of acres in each age class where significant growth is expected by the growth per acre expected in that decade and summing to obtain a grand total. R= number of decades per rotation.

For a description of the traditional methods of determining the allowable cut on National Forests, see LeRoy Hennes, Michael J. Irving, and Daniel I. Navon, **Forest Control and Regulation, A Comparison of Traditional Methods and Alternatives,** U.S. Department of Agriculture, Forest Service Research Note PSW—231 (Berkeley: Pacific Southwest Forest and Range Experiment Station, 1971).

7. For an analysis of the supply response in the Douglas-fir region see, U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, **Timber Trends in Western Oregon and Western Washington,** Research Paper PNW5 (Portland: Pacific Northwest Forest and Range Experiment Station, October 1963), page 75.

8. See, for example, Emmett F. Thompson, "Traditional Forest Regulation Model: An Economic Critique, **Journal of Forestry** (November, 1966), pp. 750-752. Also, Thomas R. Waggener, **Some Economic Implications of Sustained Yield As a Forest Regulation Model,** Contemporary Forestry Paper Number 6 (Seattle, Washington: Institute of Forest Products, May 1969); and John T. Keane, "Even Flow—Yes or No?" **American Forests** (June 1972), pp. 32-37.

9. The total volume of wood, or timber inventory, in this example has been labelled Vm rather than K, i.e., capital stock, to distinguish the biological model from the economic model, where physical volumes are converted to values.

10. There are many gradations in intensity of forest management when wood production is the primary objective. Staebler has distinguished six management levels: 1) average management, 2) good management, 3) high-order management, 4) high-order management plus fertilization, 5) high-order management plus fertilization plus thinning, 6) strategy 5 plus genetic improvement. High-intensity management usually refers to at least strategy 6. For definitions of these levels, see George R. Staebler, "Concentrating Timber Production Efforts," **Society of American Foresters, Proceedings 1972** (Washington, D.C.: Society of American Foresters, 1973), pp. 74-76.

11. For an explanation and critique of the "allowable cut effect"

(AEC), see Dennis L. Schweitzer, Robert W. Sassaman and Con H. Schallau, "Allowable Cut Effect: Some Physical and Economic Implications," **Journal of Forestry** (July 1972), pp. 415-418. Also, Dennis E. Teeguarden, "The Allowable Cut Effect: A Comment," **Journal of Forestry** (April 1973), pp. 224-226; Dennis L. Schweitzer et al, "The Allowable Cut Effect: A Reply," **Journal of Forestry** (April 1973), pp. 227, 357, and 360; Barnie Dowdle, "Some Further Comments on the Allowable Cut Effect," **Forest Industries** (November 1976), page 52.

12. The Forest Service timber supply-demand forecast to the year 2000 first appeared in U.S. Department of Agriculture, Forest Service, **The Outlook for Timber in the United States.** That forecast was later updated by the Forest Service in U.S. Department of Agriculture, Forest Service, **The Nation's Renewable Resources—An Assessment, 1975.** The forecast incorporated in this study is the updated version.

13. Numerous studies in addition to **The Outlook for Timber in the United States** have attested to the decline in Western timber harvests expected over the next few decades. See, for example, Donald R. Gedney, Daniel D. Oswald and Roger D. Flight, **Two Projections of Timber Supply in the Pacific Coast States,** U.S.D.A. Forest Service Resource Bulletin, PNW-60 (Portland: Pacific Northwest Forest and Range Experiment Station, 1975) and John Beuter, K. Norman Johnson and H. Lynn Scheurman, **Timber for Oregon's Tomorrow: An Analysis of Reasonably Possible Occurrences,** Research Bulletin 19 (Corvallis: Forest Research Laboratory, School of Forestry, Oregon State University, 1976).

14. For an example of the first proposal see, Robert J. Marty, "Economic Effectiveness of Silvicultural Investments for Softwood Timber Production," Appendix D, **Report of the President's Advisory Panel on Timber and the Environment** (Washington, D.C.: U.S. Government Printing Office, 1973), pp. 145-55, and U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, **Douglas-Fir Supply Study, Alternative Programs for Increasing Timber Supplies from National Forest Lands** (Washington, D.C.: U.S. Government Printing Office, 1969). For an analysis of various short-term flexible harvest strategies and their application to public-forest lands in Oregon under the management of the Bureau of Land Management, see Robert Nelson and Lou Pugliaresi, **Timber Harvest Policy Issues on the O & C Lands** (Washington, D.C.: U.S. Department of the Interior, Office of Policy Analysis, March 1977). The "price control" option also has been analyzed by Darius M. Adams, in his study, **Effects of National Forest Timber Harvest on Softwood Stumpage, Lumber and Plywood Markets, An Econometric Analysis,** Research Bulletin 15 (Corvallis: Forest Research Laboratory, Oregon State University, 1977), pp. 41-44.

15. For a clear analysis of this point see, William J. Baumol, "On the Social Rate of Discount," **The American Economic Review** (September 1968), pp. 788-802. Also see his presentation, "On the Discount Rate for Public Projects," in **The Analysis of Evaluation of Public Expenditures: The PPB System,** A Compendium of Papers Submitted to the Subcommittee on Economy of the Joint Economic Committee, 91st Congress, 1st Session (Washington, D.C.: U.S. Government Printing Office, 1969), pp. 489-503.

16. For a good summary of this debate see, John V. Krutilla and Anthony C. Fisher, **The Economics of Natural Environments, Studies in the Valuation of Commodity and Amenity Resources** (Baltimore: John Hopkins University Press for Resources for the Future, 1975), pp. 60-65.

17. B. E. Fernow, **Economics of Forestry** (New York: Thomas Y. Crowell and Company, 1902); Irving Fisher, **The Theory of Interest** (New York: Macmillan, 1930), particularly pp. 161-165; Kenneth Boulding, "The Theory of a Single Investment," **Quarterly Journal of Economics** (1935), pp. 475-494.

18. Paul Samuelson, "Economics of Forestry in an Evolving Society," **Economic Inquiry** (December, 1976), pp. 466-492. For other analyses of the application of financial maturity models to timber harvesting, see William A. Duerr, John Fedwik and Sam Guttenberg, **Financial Maturity: A Guide to Profitable Timber Growing,** Technical Bulletin Number 1146, U.S. Department of Agriculture (Washington, D.C.: U.S. Government Printing Office, August 1956); Mason Gaffney, "Concepts of Financial Maturity of Timber and Other Assets, **Agricultural Economics Information Series 62** (Raleigh: North Carolina State College, 1957). Also William B. Bentley and Dennis Teeguarden, "Financial Maturity: A Theoretical Review," **Forest Science** (1965), pp. 75-87 and Harold Bierman, Jr., "The Growth Period Decision," **Management Science** (February, 1963), pp. B303-B309.

19. This conclusion appeared in Subcommittee on Economy in Government of the Joint Economic Committee, Congress of the United States, **Economic Analysis of Public Investment Decisions: Interest Rate Policy and Discounting Analysis** (Washington D.C.: U.S. Government Printing Office, 1968), page 16.

20. The basic concepts for this model were developed by John Walker, **An Economic Model for Optimizing the Rate of Timber Harvesting,** Ph.D. Dissertation (Seattle: College of Forest Resources, University of Washington, 1971).

21. This result is discussed by George A. Craig and John T. Keane, "Economic Analysis: A Better Way to Guide Federal Timber Programs," **Forest Industries** (November, 1977), pp. 80-81.

22. For an analysis of this concept see, Hans M. Gregersen and Thomas W. Houghtaling, "Economics and National Forest Timber Harvests-Additional Considerations," **Journal of Forestry** (January, 1977), pp. 28-29.

Pollution Control Legislation and the Capital Appropriations/Expenditure Lag

David Condon*

During the past decade, Congress has passed a major body of legislation to regulate industrial air, water, and solid-waste pollution. This legislation encompasses the Radiation Control for Health and Safety Act (1968), The National Environmental Policy Act (1969), the Clean Air Act Amendments (1970), the Occupational Safety and Health Act (1970), and the Federal Water Pollution Control Act (1972).[1] Virtually all private industry in the nation has been affected by this proliferation of government regulations. Thus, the private sector's capital-investment requirements for pollution-control equipment could reach $112 billion over the decade 1972–81. Again, six industries (non-ferrous metals, steel, paper, chemicals, petroleum, and electrical utilities) have allocated more than 10 percent of their total plant-equipment expenditures for pollution control and abatement during the 1972–76 period. And again, firms might have to invest $31 billion simply to meet the 85-decibel noise limit which the Environmental Protection Agency has recommended for work areas.[2] Costs of this magnitude should increase the rates of return required on new investment, and thus could tend to reduce the total amount of capital formation in the economy.[3]

Because pollution-control standards may—indeed, will—change in the future in some unknown way, business firms have hesitated to make forward commitments. This basic uncertainty, along with the necessity of preparing environmental-impact reports, has tended to delay new construction projects and to lengthen construction periods. As one noted economist said when discussing Dow Chemical's decision to drop its plans for a massive petro-chemical complex: "We have created a nightmare with the permit process. The problem is having some certainty as to what rules are and will be. Right now, you get a permit, or you take a couple of years and you think you've got a permit, and then you really haven't: you've got another two years."[4]

Since 1967, five industries (petroleum, chemicals, paper, steel, and nonferrous metals) have accounted for over 40 percent of all required industrial spending on pollution control.[5] This article attempts to measure the extent to which pollution-control standards have protracted the investment processes for industries. The evidence suggests that the time lag between capital appropriations and final expenditures for those industries as a group has been extended at least four quarters, with spending of roughly 15 percent of initial capital appropriations occurring over the additional quarters. The evidence also suggests that a considerable alteration in the time pattern of plant relative to equipment spending has taken place over the past decade.

Section I presents a model for the investment process. Section II presents the framework for our statistical model, and Section III provides the estimated results. Section IV presents a summary and conclusions.

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I. The Investment Process

Assume an initial condition of long-term equilibrium, where the capital stock is adjusted to a given state of technology and to given supply-and-demand conditions in product and factor markets. Then, let the industry's desired stock of capital increase for some reason—perhaps due to a fall in interest rates or to an increase in demand for the product. The adjustment to a new equilibrium will not be immediate, and capital investment will not be concentrated at one point in time but rather spread over a period of time. The available evidence indeed indicates that the investment response to a change in demand for capital stock is distributed over several years.[6] It takes time to plan capital outlays, arrange for financing, let construction contracts, order equipment, build or manufacture the ordered items, and construct the new facilities. In addition, business firms in an uncertain world are often reluctant to adjust production facilities immediately and fully to new market conditions. "They prefer to make a partial initial adjustment and wait to see if the new conditions persist before undertaking further expansion."[7]

Given the lag between changes in desired capital and final investment expenditures, the investment process can be characterized as a sequence of separate stages. The first stage involves a change in the demand for capital stock, and encompasses the initial capital budgeting and planning process. The second stage covers the appropriations process in which the capital budget is disaggregated and "tested by individual project." When top management authorizes a capital appropriation, it decides either to corroborate or change the capital budget. The approval of capital appropriations therefore formalizes planning decisions for each block of capital spending.[8] The third stage involves the letting of contracts for plant and equipment. Then, in the final stage, funds are expended for received capital goods.

Since the second stage encompasses a formalized business-planning process—involving continuous spending decisions and changes in those decisions—we assume that actual capital expenditures accrue entirely from previous appropriations. In other words, an expenditure (denoted here as E_t) is a weighted average of past appropriations made during the second stage. If w_i is the proportion of projects initiated in time t and completed in time t + i, then

$$E_t = w_0A_t + w_1A_{t-1} + \ldots + w_iA_{t-i} \qquad (1)$$

where A_t is the appropriation made in time t. The weights w_i are non-negative and, in the absence of cancellation of appropriations, sum to unity.

II. Development of Model

We use multiple correlation to estimate the weights w_i, where an expenditure at time t is determined by past appropriations. We assume that an appropriation made more than n periods past can be neglected, so that equation (1) can be rewritten as

$$E_t = \sum_{i=0}^{n} w_iA_{t-i} + e_t \qquad (2)$$

where it is customarily assumed that the exogenous variables A_{t-i} are independent of the error term e_t. However, multiple correlation will yield unreliable results when successive observations A_t, A_{t-1}, . . . , etc. are too collinear, as is the case with the quarterly Conference Board data used in this study. In order to reduce the difficulties of multi-collinearity, we assume that final expenditures accrue entirely from previous appropriations made during the second stage in the investment process and restrict $w_i = 0$ for $i = -1$. Secondly, since we assume that an appropriation made more than n periods ago will have only a negligible effect on E_t, we restrict $w_i = 0$ for $i = n + 1$. Finally, we introduce the hypothesis that the successive weights w_i lie on a polynomial of degree k.[9]

In the final form, our statistical model includes a constant term and a variable defined as the ratio of opening-quarter appropriations backlogs (BL) at time t over expenditures at time t − 1.[10] The constant term is included because the capital-appropriations survey data contain an allowance for overstatement and understatement,[11] and also because some companies included in the survey report only major expenditures as appropriated.[12]

The (BL_t/E_{t-1}) variable compensates for the delayed spending resulting from changes in the business cycle by shifting the lag distribution, $\left(\sum_{i=0}^{n} w_i A_{t-i}\right)$, forward—i.e., it raises the estimated values of the initial weights and lowers the values of the later weights.[13] "Postponements may also occur after the formal approval by the board of directors. Then, as the survey is presently constituted, we would not be formally aware of it. However, if such development were to become widespread, as in a recession, for example, it would show up as a relative rise in the backlog of appropriations with declining expenditures and commitments."[14] The ratio not only reflects these cyclical changes, but also adjusts for the delayed expenditures resulting from the unanticipated impact of the energy crisis.[15]

Autocorrelation has been a problem with previous studies using capital appropriations and expenditures data.[16] To correct for this problem, we transformed the data using the Cochrane-Orcutt iterative technique. The final form of our equation thus is

$$E_t = C + b(BL_t/E_{t-1}) + \sum_{i=0}^{n} w_i A_{t-i} + u_t. \quad (3)$$

where quarterly Conference Board data on capital appropriations, expenditures, and appropriations backlogs are seasonally adjusted and in constant dollars.

Parameters for our distributed-lag regression model are estimated for the five industries—singly and in the aggregate—which have accounted for over 40 percent of all industrial anti-pollution spending since 1967. These industries—petroleum, chemicals, paper, steel, and nonferrous metals—are classified as "Regulated" industries. The data cover the sample period 1953 I – 1976 IV and two subperiods—one preceding, and one following, the passage of pollution-control legislation (1953 I – 1976 IV and 1967 I – 1976 IV).

Following estimation of coefficients, a test is performed to determine whether there is a significant change in coefficient values between the two subperiods. The regression model is then reestimated for each industry and the industry aggregate, to determine whether the number of elements in the lag distribution (n) increased between the two subperiods.

Because of the probability that changes in estimated lag distributions reflect factors which are independent of pollution-control legislation, estimated results for "Regulated" group are compared with estimated results for a "Control" group of industries that have been minimally affected by pollution-control standards—specifically, electrically machinery, other nondurables, textile mill products, and transportation (excluding motor vehicles). These were the four industries in the McGraw-Hill pollution-control expenditures survey which maintained the lowest percentages of anti-pollution spending to total capital expenditures over the 1970–76 period.[17] Pollution-control expenditures amounted to 4.1 percent of total capital spending for the "Control" group from 1970 to 1976, versus 14.0 percent for the "Regulated" group and 5.4 percent for all industries surveyed by McGraw-Hill.[18] Pollution-control expenditures as a percentage of capital spending for individual industries (and group aggregates), and also as a percentage of total industrial anti-pollution spending, are presented in Appendix Tables A1 and A2.

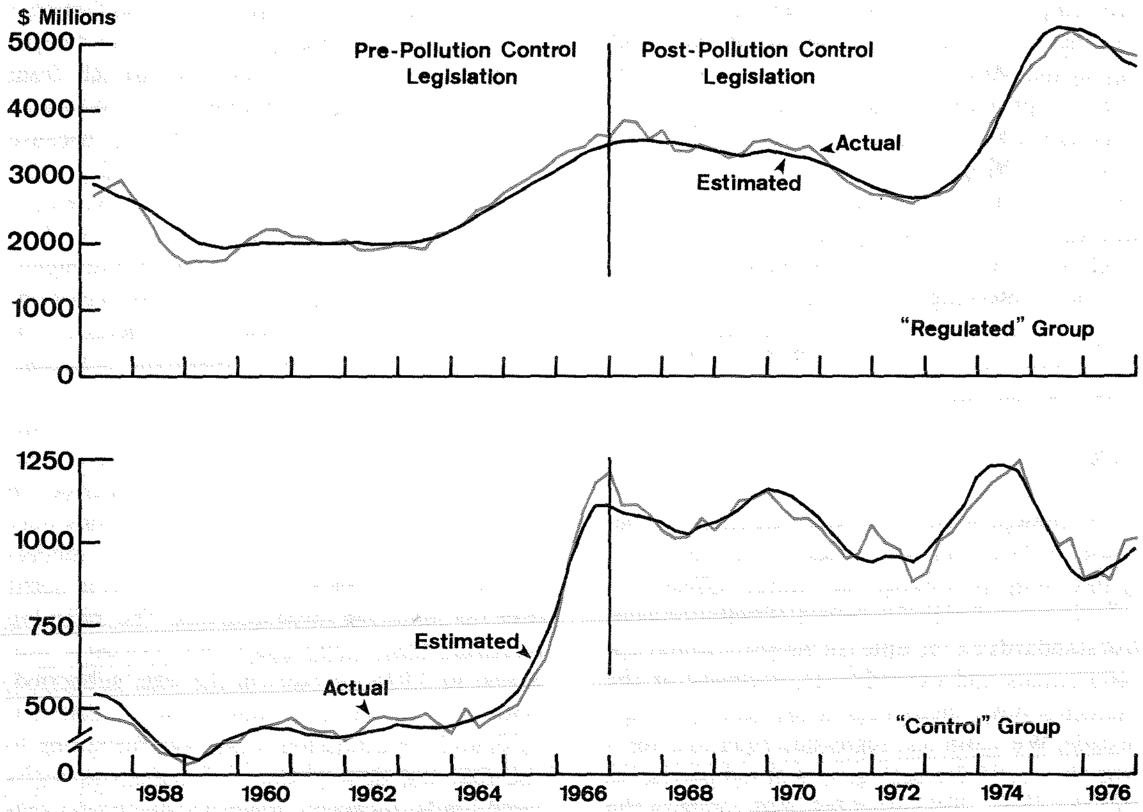
The industries in the "Control" group were not completely unaffected by pollution-control regulations. In other words, these regulations have accounted for a portion of a change in the time lag between capital appropriations and final expenditures for that group. Adjusting increases in the lengths of the "Regulated" group lag-distribution will therefore cause a slight understatement of the extent to which pollution-control standards have protracted the investment process.

III. Empirical Results

Before estimating the coefficients (w_i) and determining values for n pertaining to each industry and aggregate, we had to make an arbitrary decision regarding the value of k (the degree of the polynomial).[19] The initial value was set at 4 and $n = 6, 7, \ldots, 19$ were tested for each industry and aggregate for the 1953 I – 1976 IV sample period. From among these 15 estimated distributed lags, one was chosen as "best" for each industry and aggregate using the following two criteria: (1) $\bar{R}^2$ (the coefficient of multiple determination adjusted for degrees of freedom), and (2) elimination of those distributed lags whose later weights are negative. Once the "best" distributed lag was selected for each industry and aggregate, the process was repeated for the two aggregates setting $k = 2$ and 3 to determine if there was an improvement in $\bar{R}^2$. In both cases, $\bar{R}^2$ deteriorated for those values of k. All results reported in this study are therefore derived using 4th degree polynomials.[20] Actual expenditures and values estimated using the "best"

Chart 1

ESTIMATED AND ACTUAL CAPITAL EXPENDITURES



distributed lag regressions are plotted for the "Regulated" and "Control" aggregates in Chart 1.

Since we hypothesize that the investment process for "Regulated" industries has lengthened as a consequence of pollution-control standards, it follows that any such alteration should be reflected in a change in estimated coefficient values between the two subperiods. Using the same values for n determined for the "best" distributed lag regressions over the entire sample period 1953 I – 1976 IV, coefficients are reestimated for each industry and aggregate over the two subsamples. These individual regressions are used to test this hypothesis as against the null-hypothesis (equal coefficients in both subperiods).

A comparison of the sums of squared residuals from the regressions estimated for the entire sample period with those estimated for the two sub-samples yields $F^5_{61} = 10.22$ for the "Regulated" aggregate and $F^5_{61} = 3.44$ for the "Control" aggregate, with an F^5_{61} – critical = 2.12 at the one-percent level of confidence.[21] The F-tests thus support the alternative hypothesis, which denotes a change in coefficient values between the early and later subperiods. The alternative hypothesis was also accepted at the one-percent level of confidence for each of the individual industries composing the "Regulated" and "Control" aggregates. Since both groups exhibit significant alterations in coefficient values between subperiods, we may conclude that investment activity is affected by other factors besides pollution-control regulations. However, these regulations must be responsible for at least some of the change in estimated coefficient values, because the "Control" industries are not completely free from their direct and indirect effects.

Next, we estimate the impact of pollution-control standards on the time lag between capital appropriations and expenditures, exclusive of the impact of other factors operating during the last decade. We again test regression equations for n = 6, 7, . . . , 19 for both groups of industries, select the "best' distributed lag, and compare the changes in the mean lags and in the orders of the estimated distributed lags between the two subperiods.[22] The two criteria specified earlier are used in selecting the "best" distributed lags for each industry and aggregate. Regression results for the early and later subperiods are presented in Tables 1 and 2, while plots of the "best" distributed lags are shown in Chart 2.

The results indicate a shift from an inverted "v" shaped distribution in the early period to a bi-modal distribution in the later subperiod. This suggests that an appropriation in the 1953–66 subperiod led to a symmetrically distributed set of expenditures over time for plant and equipment, while an appropriation in the 1967–76 subperiod led to quite a different distribution. In this later period, we see an initially higher percentage of expenditures on equipment—indicated by the left-skewed distribution in six of the individual industries as well as the "Regulated" aggregate—with a longer, and in the case of both group aggregates, a somewhat separate distribution reflecting delayed expenditures for plant. This explanation is consistent with the fact that the plant share of total appropriations for "Regulated" industries (except petroleum) fell from 25.93 percent in the early subperiod to 20.96 percent in the later subperiod. Again, because spending for plant involves longer and greater capital outlays than spending for equipment, it follows that final appropriations for new plant are subject to relatively longer delays and higher postponement rates because of all the uncertainties that have characterized the past decade—including the uncertainties attendant pollution-control regulations.

In the case of the "Control" aggregate, an estimated 100 percent of appropriations were spent by the eighth quarter in the early subperiod. In contrast, only 81 percent of appropriations were spent by the eighth quarter in the later subperiod, with an estimated 13.5 percent being spent over the following three quarters. The mean lag increased from 3.302 quarters in the early subperiod to 3.936 quarters in the later subperiod. Both the number of periods in the lag distributions and the estimated mean lags pertaining to the four individual "Control" industries registered similar increases. Electrical machinery registered the smallest increase, and transportation equipment the largest increase, between the two subperiods.

In the case of the "Regulated" aggregate, an

Table 1
"Best" Distributed Lags
Early Subperiod (1953.I – 1966.IV)

	"Regulated" Group						"Control" Group				
	"Regulated Aggregate"	Primary Iron and Steel	Primary Non-Ferrous Metals	Chemicals & Allied Products	Paper & Allied Products	Petroleum	"Control" Aggregate	Electrical Machinery & Equip.	Other Non-durables	Textile Mill Products	Transportation Equipment[2]
c	355.156	67.327	49.587	139.083	−12.140	−22.358	−48.561	38.723	−9.536	−0.393	59.227
	(1.135)	(0.744)	(1.669)	(3.080)	(−0.465)	(−0.173)	(−0.651)	(1.187)	(−0.720)	(−0.047)	(5.907)
BL/E_{t-1}	−74.209	−5.170	−3.446	−21.066	5.652	7.560	4.926	−9.217	−1.723	0.153	−14.678
Weight[1]	(−0.913)	(−0.633)	(−1.599)	(−1.706)	(0.945)	(0.143)	(−0.390)	(−1.842)	(−1.347)	(0.137)	(−3.267)
0	0.048	0.035	0.058	0.075	0.032	0.083	0.111	0.133	0.012	0.076	0.102
	(1.032)	(0.749)	(3.148)	(3.017)	(0.934)	(1.224)	(4.974)	(9.270)	(1.384)	(3.758)	(2.993)
1	0.114	0.070	0.095	0.127	0.067	0.162	0.157	0.179	0.127	0.155	0.205
	(2.784)	(1.517)	(4.893)	(6.064)	(1.891)	(2.891)	(8.734)	(12.745)	(3.588)	(11.572)	(6.500)
2	0.168	0.099	0.113	0.154	0.098	0.206	0.161	0.170	0.224	0.206	0.234
	(8.012)	(3.152)	(8.343)	(11.482)	(4.521)	(5.481)	(15.320)	(21.194)	(6.380)	(10.518)	(7.737)
3	0.190	0.119	0.118	0.157	0.120	0.200	0.145	0.134	0.255	0.214	0.173
	(7.309)	(4.117)	(8.716)	(8.713)	(7.192)	(4.797)	(7.966)	(15.069)	(6.210)	(9.604)	(8.101)
4	0.176	0.129	0.112	0.139	0.131	0.147	0.123	0.090	0.204	0.176	0.061
	(5.161)	(3.229)	(5.820)	(7.090)	(5.115)	(3.833)	(5.547)	(6.242)	(3.444)	(11.092)	(1.223)
5	0.128	0.127	0.099	0.106	0.129	0.068	0.102	0.054	0.105	0.107	
	(4.275)	(2.845)	(4.358)	(6.854)	(4.504)	(1.610)	(5.488)	(3.256)	(2.591)	(3.813)	
6	0.063	0.114	0.080	0.064	0.114	0.001	0.086	0.033		0.034	
	(2.341)	(2.814)	(3.668)	(3.615)	(4.944)	(0.026)	(4.231)	(2.269)		(0.920)	
7	0.007	0.091	0.059	0.025	0.090		0.071	0.028			
	(0.264)	(2.459)	(3.099)	(1.191)	(4.699)		(2.264)	(2.358)			
8		0.062	0.038		0.059		0.047	0.037			
		(1.478)	(2.174)		(2.240)		(1.489)	(2.298)			
9			0.017		0.026			0.047			
			(1.247)		(0.486)			(2.194)			
10								0.042			
								(2.228)			
Σ lag Coefs.	.897	0.880	.794	.849	.871	.871	1.000	.952	.931	.971	.777
Mean Lag	3.120	4.403	3.768	3.012	4.402	2.435	3.302	3.265	2.515	2.740	1.853
RHO	.42	.52	.69	.25	.56	.44	.70	.35	.63	.13	.00
$\bar{R}^2$	.98	.85	.97	.98	.96	.87	.98	.97	.86	.97	.97
D.W.	1.49	1.88	1.27	1.66	1.85	2.00	2.31	2.22	1.36	1.81	2.00
S.E.	77.01	52.77	10.00	23.03	12.90	66.70	23.91	16.85	6.25	6.31	12.14

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[1] Distributed-lag weights for quarters

[2] Excluding motor vehicles

Table 2
"Best" Distributed Lags
Later Subperiod (1967.I – 1976.IV)

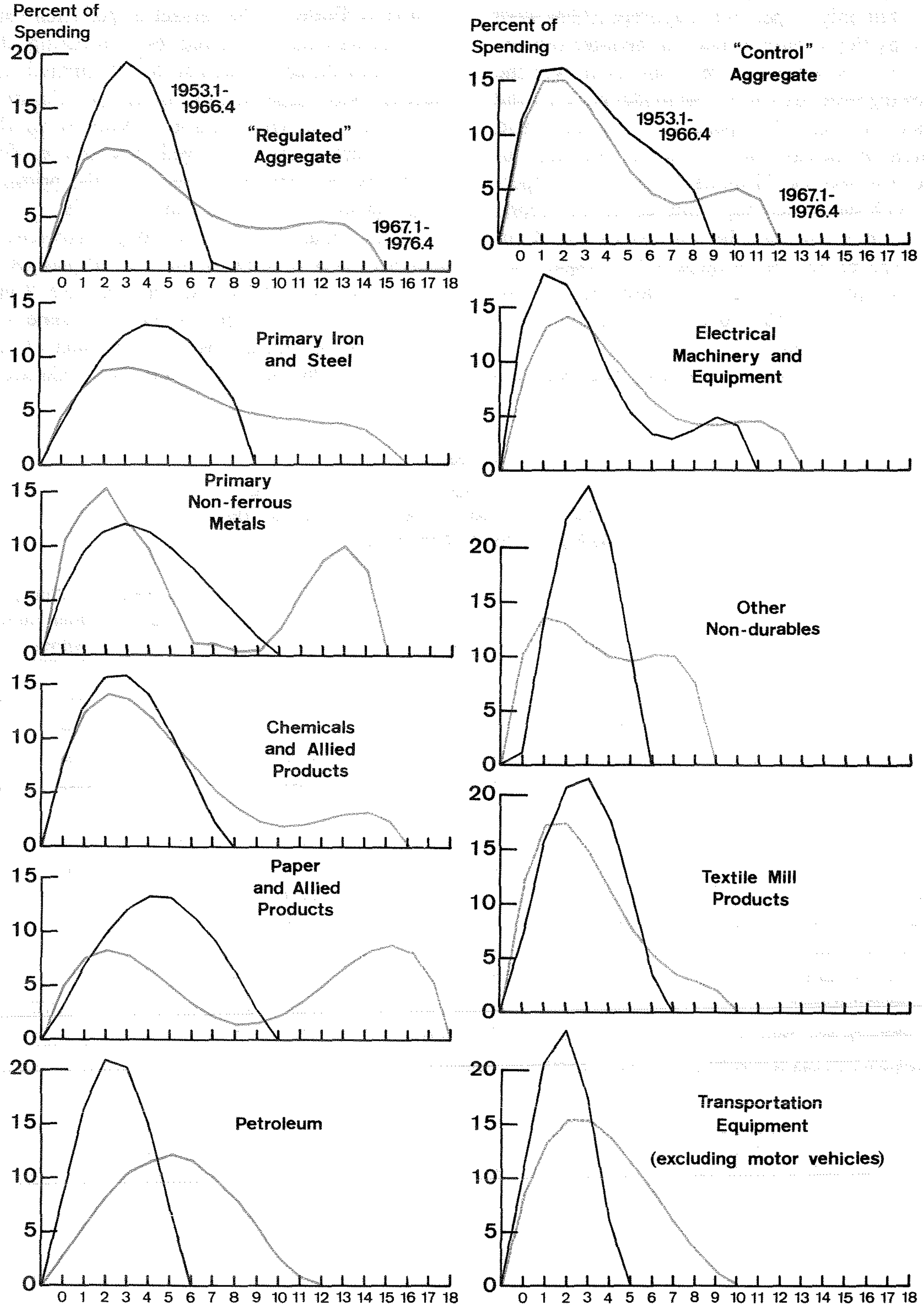
	"Regulated" Group						"Control" Group				
	"Regulated Aggregate"	Primary Iron and Steel	Primary Non-Ferrous Metals	Chemicals & Allied Products	Paper & Allied Products	Petroleum	"Control" Aggregate	Electrical Machinery & Equip.	Other Nondurables	Textile Mill Products	Transportation Equipment[2]
c	7.123	−14.258	88.847	9.439	80.882	−1.517	−35.519	−141.047	31.056	3.241	17.941
	(0.028)	(−0.135)	(3.194)	(0.171)	(0.756)	(−0.018)	(−0.136)	(−0.558)	(2.125)	(0.086)	(0.324)
BL/E_{t-1}	−58.508	−0.042	−19.900	−20.751	−11.586	−11.700	−5.323	11.868	−8.326	−2.994	−2.800
Weight[1]	(−1.452)	(−0.006)	(−4.887)	(1.412)	(−1.327)	(−0.653)	(−0.398)	(0.738)	(−2.370)	(−1.128)	(−0.531)
0	0.066	0.046	0.103	0.080	0.051	0.024	0.105	0.090	0.102	0.123	0.083
	(7.266)	(5.720)	(9.018)	(10.906)	(3.403)	(1.493)	(5.142)	(3.879)	(4.954)	(5.057)	(2.031)
1	0.100	0.073	0.132	0.123	0.076	0.052	0.148	0.131	0.134	0.172	0.131
	(8.493)	(6.696)	(10.027)	(12.497)	(3.537)	(2.750)	(5.778)	(4.296)	(6.513)	(6.306)	(3.288)
2	0.112	0.087	0.152	0.138	0.083	0.079	0.148	0.140	0.129	0.173	0.151
	(10.621)	(8.197)	(11.761)	(15.156)	(3.677)	(5.437)	(6.689)	(4.772)	(8.790)	(7.281)	(6.896)
3	0.109	0.090	0.121	0.135	0.077	0.102	0.126	0.128	0.112	0.147	0.150
	(14.737)	(10.498)	(14.767)	(20.218)	(3.750)	(12.014)	(7.683)	(5.042)	(7.697)	(5.964)	(7.585)
4	0.096	0.086	0.096	0.118	0.064	0.116	0.096	0.106	0.099	0.111	0.135
	(20.891)	(13.104)	(14.210)	(30.145)	(3.563)	(15.398)	(7.420)	(4.582)	(5.984)	(3.927)	(4.217)
5	0.080	0.079	0.049	0.096	0.048	0.120	0.066	0.082	0.095	0.076	0.112
	(16.479)	(12.908)	(5.490)	(28.682)	(2.905)	(11.372)	(5.374)	(3.506)	(6.597)	(2.661)	(3.200)
6	0.064	0.070	0.011	0.072	0.033	0.114	0.046	0.061	0.099	0.050	0.084
	(10.001)	(10.100)	(1.040)	(14.708)	(1.999)	(10.004)	(3.566)	(2.525)	(7.921)	(1.934)	(2.901)
7	0.051	0.061	0.010	0.051	0.022	0.099	0.036	0.047	0.100	0.035	0.056
	(7.393)	(7.882)	(0.940)	(8.321)	(1.300)	(10.773)	(2.442)	(1.879)	(5.783)	(1.364)	(1.853)
8	0.043	0.053	0.001	0.034	0.016	0.077	0.038	0.042	0.076	0.027	0.031
	(7.191)	(6.583)	(1.715)	(5.534)	(0.986)	(11.395)	(1.851)	(1.492)	(4.219)	(0.950)	(0.739)
9	0.039	0.048	0.003	0.023	0.017	0.051	0.045	0.042		0.019	0.012
	(8.942)	(5.599)	(0.419)	(4.522)	(1.085)	(5.213)	(1.661)	(1.283)		(0.787)	(0.299)
10	0.040	0.044	0.023	0.019	0.024	0.025	0.050	0.046			
	(7.531)	(4.464)	(1.971)	(4.856)	(1.542)	(1.837)	(1.653)	(1.197)			
11	0.043	0.042	0.056	0.020	0.036	0.006	0.040	0.046			
	(4.873)	(3.401)	(2.950)	(4.328)	(2.000)	(0.495)	(1.705)	(1.184)			
12	0.046	0.041	0.086	0.025	0.052			0.034			
	(3.735)	(2.680)	(3.426)	(3.485)	(2.190)			(1.204)			
13	0.043	0.039	0.098	0.031	0.068						
	(3.242)	(2.253)	(3.727)	(3.190)	(2.243)						
14	0.030	0.033	0.076	0.032	0.082						
	(3.009)	(2.007)	(3.942)	(3.143)	(2.243)						
15		0.021		0.024	0.087						
		(1.865)		(3.188)	(2.247)						
16					0.080						
					(2.252)						
17					0.053						
					(2.260)						
Σ lag Coefs.	.971	.918	1.045	1.018	.976	.871	.948	.999	.951	.939	0.950
Mean Lag	5.498	6.179	5.251	4.863	8.653	5.033	3.936	4.441	3.700	2.918	3.424
RHO	.526	.53	.13	.13	.80	.25	.22	.61	.06	−0.15	.37
$\bar{R}^2$	.99	.96	.91	.98	.91	.97	.83	.84	.92	.74	.91
D.W.	1.49	1.97	2.01	2.03	1.49	1.72	1.83	1.78	1.95	2.03	1.89
S.E.	85.93	27.54	27.56	27.949	22.46	58.55	38.73	33.48	13.49	11.89	16.90

[1] Distributed-lag weights for quarters

[2] Excluding motor vehicles

Chart 2

"BEST" DISTRIBUTED LAGS OF ESTIMATES



estimated 90 percent of appropriations were spent by the seventh quarter in the early subperiod —but only 68 percent of appropriations were spent by the seventh quarter in the later subperiod, with 28 percent more being spent over the following seven quarters. The modal period—the period of greatest expenditures—is the third quarter in the early subperiod, but the distribution then becomes bi-modal in the later subperiod, with peak spending centered in the second and twelfth quarters. In contrast to the "Control" aggregate, the "Regulated" aggregate has its first spending peak in the later period centered to the left of the mode pertaining to the earlier sample period.

The increases in the order (Δn), the mean lag ($\Delta\Theta$), and the total percentage of expenditures delayed in the later subperiod ($\%E_D$) are presented in Table 3. The impact of pollution-control regulations is derived by comparing the values calculated for each of the "Regulated" industries with those calculated for the "Control" aggregate. The paper industry shows by far the largest percentage of delayed expenditures, followed by primary nonferrous metals, primary iron and steel, petroleum and chemicals.

All the industries in both groups experienced increases over time in the number of periods in their respective lag distributions. Because "Control" industries were subject to at least some pollution-control regulations, some portion of the increases in the number of periods in "Control"

Table 3
Estimated Total Changes in Θ, n, and $\%E_D$ Between Subperiods, and Portion of Change Due to Pollution Control Regulations

	Early Subperiod		Later Subperiod		Total Change		Total Share Delayed Expen.	Portion of Change Due to Pollution Control Regulations[1]		
	n	Θ	n	Θ	n	Θ	($\%E_D$)	Δn	$\Delta\Theta$	($\%E_D$)
"Regulated" aggregate	7	3.120	14	5.498	7	2.378	28.4	4	1.744	14.9
Primary iron and steel	8	4.403	15	6.179	7	1.776	26.8	4	1.142	13.3
Primary non-ferrous metals	9	3.768	14	5.251	5	1.483	33.9	2	0.849	20.4
Chemicals and allied products	7	3.012	15	4.863	8	1.851	20.8	5	1.217	7.3
Paper and allied products	9	4.402	17	8.653	8	4.251	48.2	5	3.617	34.7
Petroleum	6	2.435	11	5.033	5	2.598	25.8	2	1.964	12.3
"Control" aggregate	8	3.302	11	3.936	3	0.634	13.5			
Electrical machinery and equip.	10	3.265	12	4.441	2	1.176	8.0			
Other non-durables	5	2.515	8	3.700	3	1.185	27.5			
Textile mill products	6	2.740	9	2.918	3	0.178	8.1			
Transportation equip. (excluding motor vehicles)	6	1.853	9	3.424	5	1.571	29.5			

[1] Represents difference between "Regulated" group and "Control" aggregate.

group lag distributions can therefore be attributed to the direct and indirect effects of those regulations. We therefore hypothesized that (ceteris paribus) the higher ratio of an industry's anti-pollution spending to its total capital spending, the larger the increase over time in the number of periods in the lag distribution—and the higher the percentage of appropriations spent over protracted periods.

To test this hypothesis, we first compute the mean lag (δ) of the percentage of appropriations spent over protracted periods in the later (1967–76) subperiod, using the formula

$$\frac{\sum_{i} i\, w_i}{\sum_{i} w_i}.$$[23]

Next we derive the industry rankings for the mean lag (δ) and for the ratio of antipollution spending to total capital spending (Table 4). Our hypothesis is strongly supported by the Spearman rank correlation coefficient (rho), which is computed to be .75 and is significant at the 2.5-percent level.[24]

Table 4
Ranking of Industries According To (1) Anti-pollution Expenditures/Total Capital Expenditures and (2) Mean Lag (δ)

Industry	**Anti-pollution Share of Total Capital Spending (%)**[1]	**Rank**	**Mean Lag (δ)**	**Rank**
Primary iron and steel	13.1	3	3.604	3
Primary non-ferrous metals	18.3	2	3.437	4
Chemicals and allied products	9.0	5	4.543	2
Paper and allied products	20.0	1	5.062	1
Petroleum	9.4	4	2.078	6
Electrical machinery and equip.	3.2	8	1.425	9
Other non-durables	2.9	9	1.916	7
Textile mill products	5.5	6	1.802	8
Transportation equip. (excluding motor vehicles)	4.6	7	2.142	5

[1] Based on annual data from Appendix Table A1

IV. Summary and Conclusions

The basic hypothesis tested in this paper is that the investment process for industries which have incurred heavy anti-pollution expenditures has been prolonged, partly because of the permit process itself and partly because of the increased investment uncertainty engendered by both the unpredictability of future legislation and the case-by-case application of pollution controls. Parameters for a distributed-lag investment function incorporating capital appropriations and final expenditures were estimated for two groups of industries for the sample period 1953 I–1976 IV, which covers the periods before and after the implementation of pollution-control legislation. The first of the two groups is composed of five industries which accounted for more than 40 percent of all industrial anti-pollution spending over the past decade. Because of the probability that some portion of an observed increase in the appropriations/expenditures time lag is due to factors independent of pollution-control legislation, parameters were also estimated for a second group composed of four industries negligibly affected by pollution controls. Estimated parameters for both groups were tested to determine structural changes in our investment model between the subperiods. The evidence suggested that there is a change in estimated coefficient values between subperiods for both groups.

In order to estimate the impact of pollution-control standards on the time lag between capital appropriations and final expenditures, estimated changes for the minimally-affected group were used to adjust the estimated increases over time in the mean lag and in the number of periods between appropriations and expenditures for the five industries heavily affected by pollution-control standards. Empirical evidence indicates that, for the five heavily-affected industries, roughly 15 percent of appropriated expenditures were delayed over a period of four quarters due to uncertainty and the permit process. The paper industry experienced the most severe delays, with 34.7 percent of expenditures postponed over a period of five quarters, while petroleum suffered the smallest delays, with 12.3 percent of expenditures postponed over a period of two quarters. Empirical evidence also supports the hypothesis of a strong positive correlation between the a priori estimate of the degree of pollution-control impact on an industry, as indicated by the ratio of anti-pollution to total capital spending, and the actual percentages of expenditures delayed as a result of pollution-control standards.

Direct pecuniary costs of course are involved in satisfying government mandated regulations. But in addition, the lengthening of the time frame of investment spending because of pollution-control standards represents an important secondary cost on industry through its tendency to lower the rate of capital formation.

Table A1
Pollution Control Expenditures As Percentage of Total Capital Spending by Industry, 1970–76*

	1970	1971	1972	1973	1974	1975	1976	Average 1970–76
"Regulated" aggregate	7.7	12.2	14.5	15.1	13.7	16.8	15.5	14.0
Primary iron and steel	10.3	12.8	12.3	11.7	9.3	14.9	11.5	13.1
Primary non-ferrous metals	8.1	10.3	15.3	18.0	28.3	25.5	20.4	18.3
Chemicals and allied products	4.9	8.2	10.9	10.2	7.3	8.9	12.3	9.0
Paper and allied products	9.3	20.6	23.3	22.8	16.6	21.9	25.7	20.0
Petroleum	6.0	9.0	10.7	12.7	7.2	12.8	7.5	9.4
"Control" aggregate	3.8	3.2	3.1	3.7	4.1	4.5	6.1	4.1
Electrical machinery and equipment	2.3	2.3	2.8	3.7	2.3	4.2	4.8	3.2
Other non-durable goods	5.5	1.0	5.0	3.1	2.2	1.4	2.2	2.9
Textile mill products	2.3	3.3	2.6	3.5	5.4	8.9	12.6	5.5
Transportation equipment (excluding motor vehicles)	5.0	6.2	2.0	4.3	6.4	3.5	4.0	4.6
All surveyed industries	3.1	4.0	5.1	5.7	6.2	6.8	7.1	5.4

Table A2
Pollution Control Expenditures as Percentage Of Total Industrial Anti-Pollution Spending by Industry, 1967–76*

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Average 1967–76
"Regulated"Aggregate	43.2	43.7	45.7	38.6	43.0	36.3	36.5	33.5	48.4	43.9	40.9
Primary iron and steel	12.2	10.5	10.7	8.2	6.7	4.3	3.6	3.5	7.2	9.1	6.6
Primary non-ferrous metals	4.0	1.4	2.5	4.0	3.4	4.0	5.3	9.5	8.2	5.2	5.9
Chemicals and allied products	8.6	9.6	8.4	6.8	8.7	8.4	8.0	6.0	7.2	9.6	7.9
Paper and allied products	8.8	7.7	8.6	6.1	7.9	7.1	7.5	6.2	8.4	9.8	7.9
Petroleum	9.6	15.0	15.6	13.5	16.2	12.5	12.2	8.3	17.5	10.2	12.7
"Control" Aggregate	7.6	8.2	5.3	5.6	3.6	3.4	3.3	2.4	2.4	3.2	3.4
Electrical machinery and equipment	1.6	4.7	1.9	2.1	2.1	1.4	1.8	0.9	1.2	1.5	1.6
Other non–durable goods	0.5	0.9	0.9	0.6	0.5	0.1	0.1	0.2	0.1	0.1	0.3
Textile mill products	4.9	1.8	1.9	2.4	0.4	1.3	0.8	0.5	0.3	0.4	0.8
Transportation equipment (excluding motor vehicles)	0.6	0.8	0.6	0.5	0.6	0.4	0.4	0.7	0.8	1.2	0.7

* Calculations based on "Annual McGraw-Hill Survey of Pollution Control Expenditures," Economics Dept., McGraw-Hill Publications Co.

FOOTNOTES

1. For description of the specific purposes and function of each law, see Murray L. Weidenbaum, **Government-Mandated Price Increases: A Neglected Aspect of Inflation** (Washington, D.C.: American Enterprise Institute for Policy Research, 1975).

2. "Plant and Equipment: Spending for Pollution Abatement To Increase 11 Percent This Year," **Daily Report for Executives,** May 24, 1977; "Regulators: A Rising Clamor Over Noise Limits," **Business Week,** June 30, 1975, p.34.

3. For examples see Leonall C. Anderson, "Is There a Capital Shortage: Theory and Recent Empirical Evidence," **Journal of Finance,** May 1976; Anne P. Carter, "Energy, Environment, and Economic Growth," **Bell Journal of Economic and Management Science,** Autumn 1974; John Cremeans and Frank W. Segel, "National Expenditures for Pollution Abatement and Control 1972," **Survey of Current Business,** February 1975; and Beatrice N. Vaccara, **A Survey of Fixed Capital Requirements of the Business Economy,** 1971-1980 (Washington: U.S. Department of Commerce, Bureau of Economic Analysis, 1975).

4. Gene Conatser (Economist for Bank of America) before the (California) Assembly Permanent Subcommittee on Employment and Economic Development, October 1977. Extract from Laura R. Mitchel, "A Barometer Reading Of California's Business Climate," **California Journal,** May 1977.

5. Calculated from data presented in Annual McGraw-Hill Survey of Pollution Control Expenditures. This 41-percent figure becomes 61 percent if the electric-utilities industry is included in the calculation. However, that industry could not be included because of non-comparability of data.

6. L. M. Koyck, **Distributed Lags and Investment Analysis** (Amsterdam: North Holland, 1954); F. deLeeuw, "The Demand for Capital Goods by Manufacturers: A Study of Quarterly Time Series," **Econometrica** (July 1962), pp. 407-23; T. Mayer, "The Inflexibility of Monetary Policy," **Review of Economics and Statistics** (November 1958), pp. 359-74; R. Eisner, "Investment: Fact and Fancy," **American Economic Review** (May 1963); P.W. Jorgenson and J.A. Stephenson, "Investment Behavior in U.S. Manufacturing, 1947-1960," **Econometrica** (April 1967).

7. B. G. Hickman, **Investment Demand and U.S. Growth** (Washington D.C.: Brookings Institution 1965), p. 33.

8. M. Cohen, "The National Industrial Conference Board Survey of Capital Appropriations," in **The Quality and Economic Significance of Anticipations Data,** Universities—National Bureau Conference 10 (Princeton: Princeton University Press, 1960).

9. For a description of the polynomial distributed-lag regression technique see S. Almon, "The Distributed Lag Between Capital Appropriations and Expenditures," **Econometrica** (January 1965), pp. 178-196. Recent evidence offered by P.J. Dhrymes and others suggests that the imposition of this assumption may cause biases in estimation. Comparison of the sums of squared residuals of an ordinary least-squares regression model against the sums of squared residuals for our polynomial distributed-lag regression indicates no evidence in support of the alternative hypothesis that estimated w_i should be unconstrained. (The results of our tests are presented in Footnote 20).

10. Previous studies (Almon, [9], and J. Popkin, "Comment on 'The Distributed Lag Between Capital Appropriations and Expenditures'," **Econometrica,** Vol. 34, No. 3.) incorporating a cancellations variable in regression equations conforming to the above specification, and also in variable lag specifications, found the variable to be statistically insignificant. This was probably due to the impossibility of determining to which periods' appropriations the cancellations apply. We therefore do not include a cancellations variable in our equation, with the result that the distributed lags will subtract the average cancellation in every quarter.

11. M. Cohen, **op. cit.,** p. 305.

12. M. Cohen, **op. cit.,** p. 305.

13. See Almon, **op. cit.,** p. 190.

14. M. Cohen, **op. cit.,** p. 306.

15. "Regulated" industries are chiefly engaged in primary and intermediate-stage processing, whose production facilities tend to be more energy intensive than the intermediate-and advanced-stage processing industries composing the "Control" group. Hence, the impact of the energy crisis on investment spending could be greater for the "Regulated" group than for the "Control" group. To test this possibility, a dummy variable with a value equal to one during the period 1973I-1976IV and zero elsewhere was included in the two aggregate regressions estimated over the sample period 1953I-1976IV. Although the sign of the dummy variable was negative, as expected, the estimated coefficient was insignificantly different from zero at the 95 percent confidence level. That the dummy variable was statistically insignificant for both the "Regulated" and "Control" aggregates indicates that the backlogs variable effectively adjusted expenditures for the impact of the energy crisis.

16. S. Almon, **op. cit.,** pp. 187-189 and J. Popkin, **op. cit.,** pp. 720-721.

17. McGraw-Hill, **op. cit.**

18. For the period 1967-73, the percentage of capacity shutdowns due to environmental and safety regulations was 0.51 percent for our "Regulated" group, 0.13 percent for our "Control" group, and 0.35 percent for the twenty industries contained in the particular McGraw-Hill survey. (Calculations based on "Annual McGraw-Hill Survey of Pollution Control Expenditures," **op. cit.)**

19. "The choice of an appropriate specification for a distributed lag function. . .is a multiple decision problem of great complexity. No formal statistical procedure is available for such a problem, so that the choice must be made on some basis other than testing of a statistical hypothesis." Jorgenson and Stephenson, **op. cit.**

20. A comparison of the sums of squared residuals of an ordinary least-squares regression model against the sums of squared residuals from our 4th degree polynomial distributed-lag regression yields

$F^{5}_{63} = 1.62$, F^{5}_{63} – critical = 2.36 for the "Regulated" aggregate, and $F^{4}_{64} = 1.58$, F^{4}_{64} – critical = 2.51 for the "Control" aggregate.

Thus, there is no evidence for rejecting our null-hypothesis that the w_i are polynomially distributed. (For a description of this F-test see P. J. Dhrymes, **op. cit.** p. 227-229.)

21. The appropriate test statistics is defined by

$$F[Z, T_1 + T_2 - 2Z] = \frac{SSR_T - (SSR_1 + SSR_2) \,/\, Z}{(SSR_1 + SSR_2) \,/ T_1 + T_2 - 2Z},$$

where T_1 and T_2 are the sum of observations in the early and later subsamples, SSR_T is the sum of observations in the early and later subsamples, SSR_1 and SSR_2 are the sums of squared residuals in the early and later subsamples, and Z is the number of independent variables. For an explanation of this test statistic see F. M. Fisher, "Tests of Equality Between Sets of Coefficients in Two Linear Regressions: An Expository Note," **Econometrica** (March 1970), pp. 361-366. Since three-parameter distributions are estimated by fourth-degree polynomials, the number of independent variables associated with the regression term $\sum_{i=o}^{n} w_i A_{t-i}$ remains constant at 3 regardless of the value of n.

22. The mean lag (Θ) is defined as:

$$\Theta = \frac{\sum_{i=o}^{n} (i+1) \cdot w_i}{\sum_{i=o}^{n} w_i}$$

23. The mean lag (δ) of the percentage of appropriations spent is calculated at 3.912 for the "Regulated" group aggregate and 1.963 for the "Control" group aggregate.

24. A concomitant test of independence, using the alternative hypothesis of positive correlation between the two sets of rankings, is significant at the two-percent level. For a description of these tests, see E. Lehman, **Nonparametrics; Statistical Methods Based on Ranks.** (San Francisco: Holden-Day Inc., 1975), pp. 297-303.

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