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LONG-RUN EFFECTS OF ENVIRONMENTAL REGULATION

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INTRODUCTION

The preceding papers in this volume have considered the effects of environmental regulation on the economy during the past and into the near future. However, it is also important to study the longer run as well as the shorter run implications of such regulations. First, there may be some consequences too small or subtle to worry about in the short run but which may have significant cumulative effects over several decades. Second, environmental policies appropriate for the next few years may require investments and institutional arrangements that are inappropriate from a longer term perspective. This paper attempts to illustrate these points by examining the relationship between the generation of pollutants, environmental regulation, and economic growth over a fifty-year period. In doing so, we draw upon the results of our recent and highly detailed study of these issues.[1]

Long-run economic analysis is very difficult and often quite different from shorter run analysis. First, the nature and determinants of environmental problems are frequently different in the long run as opposed to the short run. For example, during the next five years or so, any economic problems associated with regulation must focus on meeting compliance requirements. Over this five-year period, the effects of changes in the size and composition of the population, in per capita incomes, tastes, technology, and in the nature of economic activities will not be significant. But as the time horizon is lengthened, these more fundamental determinants of economic growth and environmental quality grow in importance.

Long-run analysis is difficult for another reason. As income increases and tastes and technology change over time, the composition of output will change. Because each sector of the economy generates

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1. R. RIDKER & W. WATSON, TO CHOOSE A FUTURE: RESOURCES AND ENVIRONMENTAL CONSEQUENCES OF ALTERNATIVE GROWTH PATHS (1980). Portions of this paper are adapted from this volume; other portions utilized unpublished materials from the underlying study.

a different mix of pollutants and because technological change as well as other factors affect these mixes, the composition of pollutants cannot be expected to remain the same or to maintain the same relationship to aggregate output as they have in the past. In addition, changes in the geographic distribution of population and economic activities can have significant environmental impacts in the long run. In these circumstances, the results of aggregate analysis may be misleading. Despite its greater cost, data requirements, and analytical complexity, a substantial amount of disaggregation is necessary in long-run analyses even if interest is focused on only a few aggregates.

On top of these complexities, there are a vast number of interdependencies and feedbacks to reckon with. If access to one form of energy is restricted, then other forms may be substituted (for example, coal for oil). If restrictions are placed on the use of the automobile, other forms of transportation, with their own array of environmental problems, might become attractive. If wastes are not emitted into the air, they will show up in liquid or solid form. If environmental regulations on some sectors become too costly to meet, the economic activities involved may be moved or substitutes for their output may be found. In truth, everything–from migration patterns and attitudes toward work to economic and political developments in the rest of the world–is related to everything else and these relationships can change in important ways in coming decades.

There is no way any one study can account adequately for all these complexities. As a consequence, our results are limited in several senses. First, our results cannot be considered unconditional forecasts of the future. All we can do is spell out some of the implications of different courses of actions when they occur within specific contexts. Thus, our results cannot be used intelligently to evaluate alternative courses of action without an understanding of all the conditions assumed in their development. While the overall nature of these conditions can be presented in this brief paper, the reader must refer to our longer study for more details.[2]

Second, the analysis is limited mainly to what we call the mass pollutants. These pollutants, referred to in the air and water pollution control regulations as "criteria" air pollutants and "conventional" water pollutants, have been the primary objects of concern in environmental regulations during the past decade. Other environmental problems, many of which will become more important in the future, are briefly discussed in the concluding section.

Third, the focus in our analysis is on direct and indirect effects

2. *Id.*

that can be derived from input-output analysis supplemented by regional analysis and efforts to quantify the direct benefits and costs of different hypothetical levels of environmental controls. The implications of environmental regulations for other social and political issues (for example, land use planning and the distribution of gains and losses from controlling pollution) that might affect the economy are not studied.

METHODOLOGY

Our analysis involves five steps: (1) projecting national economic activity, abatement costs, and point source pollution levels; (2) assigning pollutants from point sources to regions; (3) estimating pollutants from regional transportation, urban runoff, agricultural, mining, and other nonpoint sources; (4) translating estimated pollutant generation into regional ambient air and water pollution concentrations; and (5) estimating regional air and water pollution damage as a function of regional ambient conditions. The appendix discusses the estimating methods used in the various steps.

Three alternative and hypothetical national pollution control policies are simulated in this paper: we refer to them as strict, relaxed, and cost minimizing. The first two (see Table 1) reflect our assessment of a possible range of future EPA regulations, starting from a base of 1975. The strict case is not unlike currently legislated federal air and water regulations; however, we have not assumed that all discharges to water will be eliminated by 1985; nor do we take account of the shift in the policy focus from conventional to toxic water pollutants. The relaxed control policy more nearly approximates actual practice in U.S. environmental policy although it includes weaker rules and allows more time for compliance. In our cost-minimizing case, controls are set at the point where the sum of expected pollution control and damage costs is a minimum.

THE NATIONAL ECONOMY

The basic quantitative assumptions that underlie our analysis are given in Table 2. As can be seen, this scenario projects that real GNP will double between 1975 and 2000 and increase another 60 percent in the subsequent twenty-five years. These increases represent substantial slowdowns from comparable periods before 1975 and result from declines in population and labor force growth rates, changes in labor productivity arising from shifts in the composition of the labor force and of output, and a number of transitional factors related to higher energy prices and environmental clean-up costs. Our assumed

TABLE 1

STRICT AND RELAXED POLLUTION CONTROL POLICIES

Element and Policy	Standards
Water	
Strict	Conventional treatment technology in 1977, advanced treatment technology in 1983.
Relaxed	Conventional treatment technology in 1980, advanced treatment technology for construction begun on or after 1990.
Air–Mobile sources	
Strict	Federal standards for new cars starting in 1978
Relaxed	Federal standards for new cars starting in 1978, *plus* less stringent controls in the period after 2000.
Air–Stationary sources	
Strict	Conventional treatment technology standards by 1977, advanced treatment technology standards for construction begun on or after 1980 *except* control of sulfur oxide for electric utilities to be implemented immediately for high-sulfur fuels and after 1980 for all fuels.
Relaxed	Conventional treatment technology standards by 1978; advanced treatment technology standards for construction begun on or after 1983 *except* control of sulfur oxide for electric utilities starting in 1976 for high-sulfur fuels and for all fuels by 1990, *plus* some relaxation in standards for some pollutants in some sectors.

rate of economic growth may be too high. The lower rates experienced in the 1970s may be more typical. On the other hand, it may be too low if we have underestimated the rate of growth of the labor force.

The fraction of GNP that is comprised of government expenditures declines over this projection period, primarily because we assume that the defense, education, and public construction shares of GNP will decline. We assume defense to be like expenditures on insurance, which rise less than proportionately to income; the other sectors are expected to decline because of such factors as a decline in population growth and the completion of the federal highway system. Our projected decline in the government's share of GNP does not necessarily indicate a reduction in the economic importance of this sector because its size is not defined to include transfer payments which may continue to grow over time. Indeed, this growth in transfers partly accounts for the rise in the share of GNP derived from personal consumption expenditures over time. The share of invest-

TABLE 2

UNDERLYING POPULATION AND ECONOMIC PROJECTIONS

	1975	1985	2000	2025
Population (millions)	213.9	230.9	250.7	264.9
Labor force (millions)	93.8	108.2	122.3	125.1
GNP (billions 1971$)	1,108	1,589	2,385	3,859
GNP per capita (1971$)	5,180	6,921	9,513	14,568
Private consumption per capita (1971$)	3,202	4,172	6,002	9,651
Percentage of GNP				
Private consumption	61.8	60.6	63.1	66.3
Private investment	14.8	19.1	17.2	17.0
Government expenditure	21.4	20.1	19.6	17.6
Net exports	2.0	0.2	0.1	0.8

ment (private and public and inventory charge) also increases up to about 1990, after which it declines slightly, but never to the 1975 level. A significant portion of this increase results from a growing need to replace old capital equipment in some heavy industries and increased expenditures on energy-producing, energy-saving, and pollution-abating equipment, most of which must be made in the 1980s.

Despite these changes, the composition of output is only modestly affected. Agriculture, mining, and construction continue their slow decline; manufacturing just holds its own (with steel becoming less important and industrial chemicals somewhat more important) and other sectors, such as the personal services, increase their shares. However, all these changes are small and slow.

Some modest changes in the geographic location of populations and economic activities are also assumed. For example, shifts of population and economic activity to the "sun belt" states are continued. Except for primary energy production (which must be located close to energy sources) and nuclear power production (which has other site criteria), historical trends are continued, but at increasingly dampened rates of change. Again, for the most part these changes are small and gradual.

EMISSIONS AND CONCENTRATION LEVELS

Table 3 indicates national emissions levels for various pollutants in 1975 and in future years given this scenario for national economic growth. Gross emissions indicate the levels that would occur in the

TABLE 3

NATIONAL EMISSIONS FOR ALTERNATIVE POLICIES
(millions of tons)

Emission and policy[a]		1975	1985	2000	2025
Particulate matter (PM)					
Gross[b]		98.0	154.4	151.0	227.6
Net	R	24.2	12.2	2.4	2.0
	S	19.5	2.8	1.8	1.4
	M	6.7	5.8	2.0	1.8
Sulfur oxides (SO_x)					
Gross		49.7	63.0	53.1	72.1
Net	R	37.6	40.0	24.8	18.1
	S	32.2	17.0	9.3	6.7
	M	15.6	8.9	9.1	10.6
Nitrogen oxides (NO_x)					
Gross		18.7	21.5	16.4	23.1
Net	R	18.5	18.5	10.8	12.0
	S	17.7	14.6	8.2	8.0
	M	18.4	17.2	12.4	15.1
Hydrocarbons (HC)					
Gross		26.7	19.7	22.0	25.3
Net	R	20.7	9.0	6.7	5.5
	S	19.2	6.5	4.9	3.8
	M	17.2	13.5	11.9	9.3
Carbon monoxide					
Gross		125.4	110.8	135.2	161.2
Net	R	87.2	28.0	15.6	15.4
	S	85.0	22.6	11.6	9.2
	M	124.1	96.1	105.9	128.2
Biochemical oxygen demand (BOD)					
Gross		19.8	22.3	27.0	36.5
Net	R	8.0	7.3	6.2	5.4
	S	7.3	4.0	3.1	2.6
	M	8.9	7.6	7.3	7.6
Chemical oxygen demand (COD)					
Gross		15.7	19.4	25.5	36.4
Net	R	7.2	5.5	4.1	3.7
	S	6.9	2.9	2.4	1.7
	M	5.6	3.8	4.0	6.5
Suspended solids (SS)					
Gross		722.1	635.3	743.9	931.4
Net	R	543.5	544.8	466.4	434.2
	S	510.6	313.7	297.8	326.8
	M	510.6	321.1	307.5	350.7
Dissolved solids (DS)					
Gross		361.7	334.3	401.6	512.5
Net	R	296.0	307.0	212.0	196.0
	S	282.2	149.6	139.8	150.5
	M	282.1	152.5	146.1	159.8

TABLE 3 (continued)

Emission and policy[a]		1975	1985	2000	2025
Nutrients					
Gross		8.5	8.4	8.9	9.7
Net	R	6.0	6.3	6.1	5.1
	S	5.6	4.5	4.3	3.6
	M	5.6	4.8	4.7	4.3
Other[c]					
Gross		5.9	6.9	8.9	11.7
Net	R	4.8	4.0	2.3	1.7
	S	4.8	1.8	1.2	1.4
	M	4.7	2.0	1.3	2.0

[a]Emissions from point sources (industry, electric utilities, and municipal wastewater treatment plants); transportation sources; urban runoff; point emissions and sediment runoff from minerals, ore, and coal mining and milling; and sediment runoff from nonurban construction, forestry, and agriculture.

[b]Gross emissions from mining and nonpoint sources (other than agriculture and urban runoff) are calculated as emissions that would have occurred assuming 1975 control levels in every year after 1975. Gross emissions for agricultural nonpoint sources are emissions that would have occurred if emission control measures in effect in 1975 and subsequent years were to be removed. Gross emissions for point sources and urban runoff are discharges assuming no control in any year.

[c]Includes acids, bases, oils, grease, heavy metals, and pesticides. The heavy metals included here are for ore, coal, and minerals mining, forestry, and nonurban construction. Heavy metals for other sources (including industrial point sources) are included in the suspended and dissolved solids estimates.

absence of any pollution controls. Three different levels of net emissions are also presented, depending on the control policies assumed—R (relaxed), S (strict), and M (minimum cost). While gross emissions in our scenario grow significantly over time, net emissions generally decline, more rapidly under policy S than policy R. The timing of the declines is a reflection of the timing of introductions of policy changes (see Table 1). The minimum cost strategy generally produces emission levels between R and S. There are a few notable exceptions for which emissions under policy M are above both R and S. A plausible explanation is that in the case of those pollutants, society is willing to pay something extra to achieve a reduction in risks of experiencing above-average damage levels over a minimum-cost strategy. An alternative explanation is that the R and S controls are technology-based standards that give only partial consideration to cost impacts. Therefore, R or S can be expected to produce emissions that are different from M.

Table 4 indicates concentration levels likely to be experienced in certain regions (the 243 air quality control regions and 101 watersheds into which the country has been divided). The pattern is simi-

TABLE 4

REGIONAL AMBIENT POLLUTION CONCENTRATIONS FOR ALTERNATIVE POLICIES

Pollutant and policy	1975			1985			2000			2025		
	H	Mn	V	H	Mn	V	H	Mn	V	H	Mn	V
Particulate matter (PM) (μ g/m³)[a]												
R	159.2	54.5	48	80.2	43.7	5	58.3	36.7	0	59.3	36.1	0
S	132.2	52.0	34	77.2	36.7	2	60.3	36.1	0	60.0	35.6	0
M	90.3	40.0	2	88.0	37.9	2	59.3	36.1	0	59.4	35.7	0
Sulfur oxides (SO_x) (μg/m³)[b]												
R	140.4	12.4	36	151.4	10.6	29	88.1	6.8	2	154.3	5.3	3
S	171.3	11.9	37	127.4	6.7	8	71.1	4.5	0	68.2	3.7	0
M	81.4	6.5	1	78.9	4.5	0	53.0	4.4	0	70.0	4.2	0
Nitrogen oxides (NO_x) (μg/m³)[c]												
R	108.3	26.7	2	98.7	26.2	0	62.8	23.3	0	60.7	22.2	0
S	108.3	26.5	2	84.4	25.3	1	53.8	22.7	0	46.7	21.6	0
M	108.3	26.7	2	96.7	25.8	8	82.9	24.3	1	60.8	22.8	0
Hydrocarbons (HC) (1975=100)[d]												
R	100.0	100.0		71.2	34.2		54.1	24.0		43.0	14.8	
S	116.2	105.2		53.0	34.7		39.0	24.3		28.1	13.2	
M	129.8	87.2		107.6	52.1		115.5	40.8		74.0	22.8	

Carbon monoxide (CO) (mg/m^3)[e]												
R	34.8	3.1	59	12.7	2.3	3	7.2	2.2	0	7.2	2.2	0
S	36.0	3.1	57	14.4	2.3	3	8.3	2.2	0	7.1	2.1	0
M	45.6	3.6	65	41.2	3.1	60	43.7	3.2	63	48.3	3.6	64
Water pollution (PDI index)[f]												
R	20.7	1.5	11	18.6	1.3	6	10.0	0.8	3	9.0	0.6	1
S	12.2	1.4	10	6.5	0.7	1	3.3	0.4	0	2.6	0.3	0
M	12.6	1.4	10	10.6	1.1	4	8.4	0.8	2	17.2	0.9	3

The figures in this table refer to 243 air quality control regions (AQCRs) and 101 watersheds.

Note: Column heading abbreviations are: H, highest concentration over all regions; Mn, median concentration over all regions; V, number of regions where indicated standard is violated.

[a]Annual average concentration; primary standard is 75 $\mu g/m^3$.

[b]Annual average concentration; primary standard is 80 $\mu g/m^3$.

[c]Annual average concentration; primary standard is 100 $\mu g/m^3$.

[d]It is not possible to calculate violations for this measure.

[e]Eight-hour concentration; primary standard is 10 mg/m^3.

[f]The PDI (prevalence, duration, intensity) index measures ambient water quality based upon expert judgment [J. B. Truitt, A. C. Johnson, W. D. Rowe, K. D. Feigner, and L. J. Manning, "Development of Water Quality Management Indices," *Water Resources Bulletin*, vol. 11, no. 3 (June, 1975)]. Violations are the number of watersheds with PDIs in excess of 5.35. This value is the average PDI in 1975 plus one standard error when policy R is in effect.

lar to that observed for emissions. Between 1975 and 1985 there are substantial declines in median levels and the number of regions in violation of standards under all policies. By 2000, with the exception of carbon monoxide under a least-cost policy, there is virtually no region remaining that is in violation of ambient standards, and by ratcheting up control levels to compensate for increasing gross emissions, this situation can be made to continue through 2025.

ABATEMENT COSTS

Table 5 presents the abatement costs which we have estimated to be incurred under the strict and relaxed standards through the year 2025. These are *not* unconditional forecasts of future abatement expenditures, even though we tried to make the 1975 levels comparable to reported actual expenditures. Since that time, federal air and water pollution control laws have changed in ways we have not attempted to incorporate. As can be seen, these costs rise more rapidly than GNP under both sets of standards. As a percentage of GNP, however, the costs are currently less than 2 percent and do not increase to more than 3 percent before 2020, and then only in the strict case.

However, this picture is somewhat misleading in two senses. As Figure 1 indicates, we assume that abatement expenditures are not spread smoothly over time. Under the strict policy, they rise rapidly from 1975 to a peak in 1979 of more than 2.6 percent and remain high until 1983, when they fall to 2.2 percent. This period, during which the majority of the legislated standards must be met, involves the most rapid rate of expansion of projected abatement expenditures during the fifty-year period covered by this study, and those expenditures explain a substantial portion of the increased requirements for environmental spending noted for this period. Thereafter, abatement expenditures grow more smoothly over time, except for several peaks and troughs that can be explained by the timing of additional regulations and equipment replacement cycles. Additional new source regulations for point sources are assumed to be imposed for the strict policy beginning in about the year 2000. In the case of relaxed policy, it is assumed that the additional new source standards are delayed until about the year 2010.

Parenthetically, it can also be noted that shifts in assumptions about population and economic growth rates (compare the alternative projections provided in Figure 1) do not appear to have as significant an impact on the percentage of GNP devoted to abatement as does a change in policy (compare the strict and relaxed standards in Table 5).

TABLE 5

PROJECTED ANNUALIZED ABATEMENT COSTS FOR SELECTED YEARS
(billions of 1971 dollars)

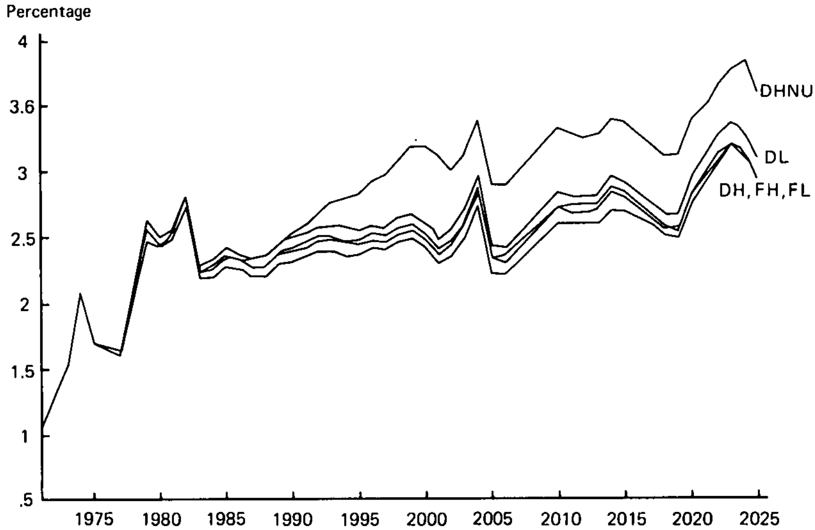
	Strict standards				Relaxed standards			
	1975[a]	1985	2000	2025	1975[a]	1985	2000	2025
Air pollution	4.1	14.3	20.5	36.1	3.5	11.1	17.0	30.1
Mobile	1.2	7.4	11.4	10.8	1.2	7.4	11.2	9.6
Electric utilities	1.1	3.4	3.2	3.7	1.0	1.4	1.4	3.3
Water pollution	9.3	27.6	36.3	86.8	7.7	17.2	23.4	52.3
Industrial point sources	4.9	13.4	17.4	57.1	4.7	8.4	13.4	38.8
Electric utilities	0.3	0.6	0.9	2.0	0.2	0.3	0.4	0.7
Municipal wastewater	3.7	12.4	16.3	25.9	2.8	7.7	8.2	11.3
Urban runoff	. . .	2.2	4.0	6.9	. . .	0.8	1.2	2.0
Nonpoint sources	. . .	2.2	2.4	2.3	. . .	0.2	1.2	1.5
Agricultural sediment	. . .	1.0	0.9	0.8	. . .	0	0	0
Construction sediment	. . .	0.4	0.3	0.4	. . .	0.2	0.3	0.4
Forestry sediment	. . .	0.1	0.2	0.4	. . .	0	0.2	0.4
Acid mine sediment	. . .	0.7	1.0	0.7	. . .	0	0.7	0.7
Thermal pollution	0.4	1.2	1.7	1.8	0.1	0.8	1.3	1.4
Solid waste	0.6	1.1	1.7	2.3	0.6	1.1	1.7	2.3
Sulfur sludge	0	0.5	0.3	0	0	0.3	0.2	0
Land reclamation	0.4	0.3	0.4	0.6	0.4	0.3	0.4	0.6
Radiation	0.1	0.2	1.1	2.0	0.1	0.2	1.2	1.9
Onsite	–	–	0.1	0.1	–	–	0.1	0.1
Offsite	–	0.2	1.1	1.9	0.1	0.2	1.1	1.8
Total	14.5	44.0	60.3	127.8	12.3	30.2	43.9	87.2
Percentage of GNP	1.3	2.8	2.5	3.3	1.1	1.9	1.8	2.3

Note: Three dots (. . .) indicate that data are not available or are not separately reported. A dash (–) indicates that the amount is nil or negligible.

[a]Costs for 1975 are derived from the model and therefore may differ from actual costs.

FIGURE 1

Abatement resource costs as a percentage of GNP, assuming strict controls. Actual figures for 1971–75 are indicated by the lower line. Note: D (census series D) indicates population growth from 214 million in 1975 to 368 million by 2025. F (census series F) indicates population growth from 214 million in 1975 to 265 million by 2025. H (high) indicates GNP growth from $1,108 billion (1971 dollars) in 1975 to $6,212 billion in 2025. L (low) indicates GNP growth from $1,108 billion (1971 dollars) in 1975 to $3,859 billion in 2025.



Second, while these percentages never become so large that they would be difficult to finance in the aggregate, their impact on individual sectors can be quite substantial. This can be seen in Figure 2 and Table 6, which assume that the standards specified in Table 1 will be met by certain dates and that capital for this purpose will be put in place over a four-year period prior to these dates.[3] If abate-

3. For example, the pattern shown by the chemical industry in Figure 2 is explainable in the following terms. The 1976 peak in expenditures occurs under strict standards because of efforts to apply conventional treatment standards; the 1982 peak happens when this sector moves from conventional treatment to advanced treatment technology standards on all equipment; and the expenditure increases starting in 1990 reflect replacement of earlier abatement investments plus the cost of converting to coal for process heat. Under relaxed enforcement, the 1976 peak is delayed until 1979; the 1982 peak is shifted to 1989, and it is smaller because only new plants are involved. The increases starting after 1990 also are delayed and smaller. These standards are compatible with environmental legislation up to but not after 1976. The large increase in abatement investments after 1990 results from the assumption that both the strict and relaxed standards will have to be upgraded over 1985 levels by 2000 and that this turn of the screw will be quite expensive.

FIGURE 2

Investments for selected industrial sectors, 1975–2000.
A, chemicals; B, steel; and C, electric utilities.

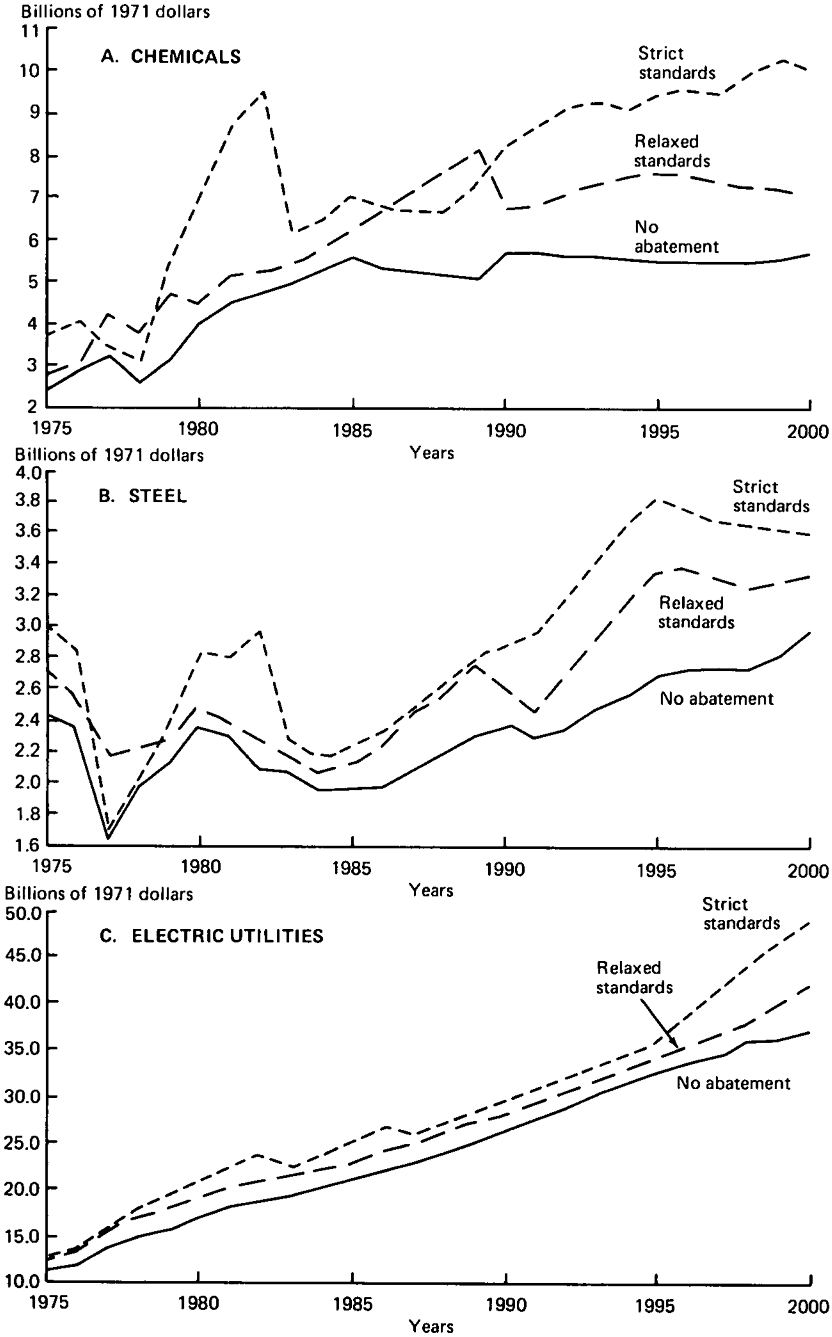


TABLE 6

ABATEMENT INVESTMENT AS A PERCENTAGE OF TOTAL INVESTMENT FOR SELECTED PURPOSES, 1976–2025

Industry	Control standard[a]	1976–80	1981–85	1986–90	1991–95	1996–2000	2001–05	2006–10	2011–15	2016–20	2021–25
Average for the economy[b]	R	3.4	2.6	3.1	2.8	3.1	4.4	3.6	4.2	3.9	4.3
	S	4.8	4.9	3.7	4.7	5.9	5.9	6.5	7.9	7.3	8.1
Transportation[c]	R	1.4	2.6	2.4	2.3	2.2	2	1.9	1.8	1.8	1.8
	S	2.3	2.6	2.6	2.5	2.2	2	1.8	1.7	1.7	1.7
Electric utilities	R	10.7	9.3	8.1	5.4	8.2	13.3	7.1	6.3	5.6	5.4
	S	15	16.6	10.7	8.8	19.8	15.2	9.5	7.8	6.9	8.3
Municipal water treatment[d]	R	27	21.9	1.2	0.7	1.1	1.4	1.7	1.5	12	7.2
	S	34.8	27.4	11.6	10.6	10.8	10.9	11	21.7	17.7	10.8
Industrial chemicals	R	21	9.2	27.5	22.1	24.7	27.6	31.9	33.6	36.7	42.3
	S	31	33.9	26.4	37.8	44	38.9	49.3	57.1	56.1	56
Petroleum refining	R	24.9	8.4	20.2	35.8	26.9	80.8	51	60.6	47.4	50.6
	S	28.6	22	27	49.6	38.6	87	67.2	68.5	66.7	80.1
Steel	R	10.7	5.9	13	15.3	16	12.5	14.2	25	22.1	23.3
	S	12	16.8	14.7	27.4	24.6	18.5	30.4	46.3	40.1	40.3
Aluminum	R	9.4	4.4	7.5	11.2	20.9	16.7	14.2	14	18.4	15.6
	S	10.1	8.3	11.3	18.6	28.5	22.8	20.8	22.1	26.3	23.3

TABLE 6 (continued)

Industry	Control standard[a]	1976–80	1981–85	1986–90	1991–95	1996–2000	2001–05	2006–10	2011–15	2016–20	2021–25
Cement, concrete, and gypsum	R	14.7	4	12.4	14.1	15.5	17.8	17.5	30.6	31.7	28.7
	S	13.3	10.8	20.1	26.9	25.6	26.2	37.3	50.8	51.7	47.6
Paving plus asphalt	R	75.6	33	48.4	98.5	94	34	96.3	95	100	98.9
	S	78.6	49.3	65	99.1	95.8	49	98.6	97.6	100	99.6
Pulp mills	R	28.7	11.8	18.6	62.2	40.5	27.2	56.4	85.3	59.2	57
	S	28.1	19.5	41.2	81.5	54.8	46.8	82.6	92.8	73.7	75.4
Grain mill products	R	38.1	9.3	22.4	47.7	36.9	32.6	69.6	62	50.5	69.4
	S	39.5	23.4	30.9	60	47.7	49.6	85.1	78.2	71.5	85.5
Grain handling	R	9.4	2	14.9	10.4	10.1	14.7	7.4	26.6	14.9	20.8
	S	9.8	5.6	23.8	12.8	18.6	18.8	18.4	46.8	26	43

[a]R = relaxed pollution control standards; S = strict pollution control standards.

[b]Total abatement investment as percent of total investment in the economy.

[c]Total investment for this sector is the value of all transport equipment produced in the indicated period plus investment for abatement.

[d]Total investment for this sector is the expenditures on water treatment to meet the standards in force up to 1972 plus investment for controls above 1972 levels.

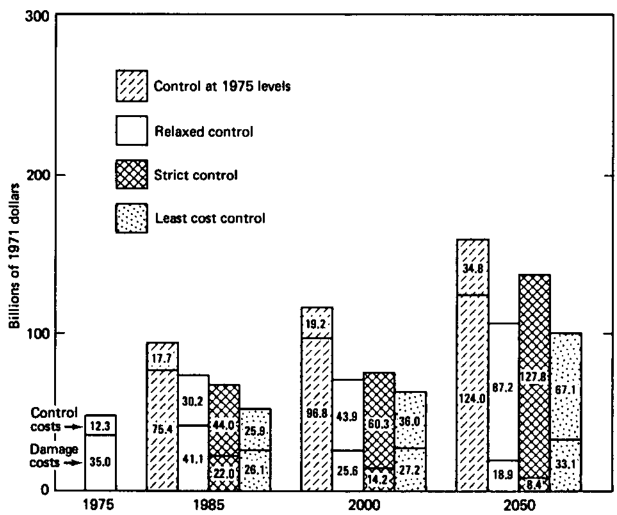
ment investments were added along with other investments in the normal course of expanding capacity, a less erratic and more manageable pattern of expenditures would have emerged. But the benefits to companies of delaying implementation as long as possible are so large that this outcome may be as unlikely in the future as it has been in the past. Indeed, given loopholes built into current legislation and judging from recent trends, we may observe substantially greater delays in implementing standards than those built into the relaxed case. To avoid this result, new ways would have to be found to force compliance and to help industries over these transition problems.

COMPARISON OF DAMAGE AND CONTROL COSTS

Our exclusive concern with control costs to this point is misleading. We ought to be concerned with *total* pollution costs, that is, pollution damage costs as well as pollution control costs. Figure 3 sums the two types of costs for different years and control policies. As can be seen, if environmental controls were kept at their 1975 level, pollution emissions and damage resulting from them would grow dramatically over time. If either the relaxed or strict policies were applied—both of which incorporate increasingly strict controls over time—control costs would increase rapidly, but damage costs would

FIGURE 3

Pollution control and damage costs for alternative environmental policies.



be reduced, with the result that total costs increase much more slowly. The principal difference between the relaxed and the strict standards during the first twenty-five years of the projection period is not in the total costs of pollution, but in the way these costs are allocated between damage costs on the one side and abatement or control costs on the other. The least-cost policy tends to have lower control costs in all years and higher damage costs in later years than does a relaxed policy because in no case does it allow for efforts to reduce risks by increasing controls beyond the point of minimum total cost.

Based on our assumed pattern of pollution control expenditures and damages, this diagram can be interpreted as indicating that it is better to opt for the strict policy during the first twenty-five years of the projection period and a relaxed policy thereafter. But it should be remembered that an additional benefit of more strict controls, which has not been quantified in monetary terms, is the reduced probability of instances where damage costs rise above the average or expected values incorporated into this figure. In other words, it might be worth some increase in total costs to avoid a small chance of very large environmental damages. An ethical question of how best to allow costs to occur is also involved; if total costs are nearly the same, we would prefer to spend more on controls to avoid more damages, since these often fall on third parties.

Another way in which to summarize the results of our simulation experiments is to construct a simple index of per capita welfare. We start with consumption per capita and subtract direct consumption expenditures for abatement and pollution damages per capita (see Table 7). The much larger portion of pollution control expenditures paid for directly by businesses has already been taken into account because these expenditures reduce the portion of output that can go to consumption. A least-cost pollution control policy would lead to the highest per capita welfare over time. A strict policy is, again, seen

TABLE 7

INDEXES OF PER CAPITA ECONOMIC WELFARE FOR VARIOUS POLLUTION CONTROL POLICIES

Control policy	1975	1985	2000	2025
Relaxed controls	1.0	1.33	1.96	3.20
Strict controls	1.0	1.34	1.95	3.17
Least-cost controls	1.0	1.36	1.97	3.22
Controls at 1975 levels	1.0	1.30	1.91	3.14

to be better than a relaxed policy during the first twenty-five years of the projection period; thereafter, the relaxed policy has higher welfare levels. While these welfare indexes do not include values for risk reduction inherent in different policies and therefore understate the welfare value of the strict policy, our general conclusions are not affected by this omission.

FEEDBACK TO THE MACROECONOMY

Implicit in our procedure for entering investment requirements into our model (including investments to adjust to higher energy prices and investments for abating pollution) is the assumption that aggregate savings will increase to the extent necessary to finance this investment. This assumption may be unrealistic, at least for the decades of the 1980s and 1990s, when, according to our assumptions, the investment share of the GNP must remain above 21 percent. Since World War II, an investment rate (defined to include public construction and inventory accumulation) reaching 21 percent was achieved in only two years, 1950 and 1951.

If the investment rate cannot be increased to the required levels, the growth in labor productivity and hence in the GNP is likely to be less. A rough indication of the extent of the slowdown that might occur can be obtained by referring to other work of ours in which the private fixed investment rate was constrained to a maximum of 18 percent of the GNP.[4] Interpolation of those results indicates a reduction in GNP of between 4 and 12 percent starting in the mid-1980s when the additional energy and abatement investments are made to fit within an overall investment constraint of 18 percent of GNP. About one-fourth of the fall in GNP can be directly attributed to the investment requirements for pollution abatement.

These results suggest to us that in the end, the operation of the financial markets plus monetary and fiscal policy may be the most important factors in determining whether pollution control policy (along with adjustments to high energy prices) can be implemented without major disruptions. If fiscal and monetary policy mechanisms do not encourage savings to increase substantially and on a sustained basis over what they have been historically, the results could be serious.

4. Ridker, Watson & Shapanka, *Economic Energy and Environmental Consequences of Alternative Energy Regimes: An Application of the RFF/SEAS Modeling System*, in MODELING ENERGY-ECONOMIC INTERACTIONS: FIVE APPROACHES 135 (C. Hitch ed. 1977).

CONCLUSIONS AND QUALIFICATIONS

We have demonstrated that it is possible to simulate the long-term implications of environmental policy for the economy with an analysis that accounts for economic growth, increased population, and technical change. Under the assumed policies and assumed tides of economic and population growth, environmental damages resulting from the mass pollutants covered in this analysis are likely to remain the same or fall over time despite the growth in the economy and greater number of people at risk. Pollution control costs, though never a large percentage of GNP, will increase over time relative to both population and economic growth. The net effect is that total pollution costs (damage plus control costs) as a percentage of GNP or of consumption will decline slowly over time, and net economic welfare will increase. Thus, overall, the long-run impacts of pollution control on the national economy appear to be favorable given the assumptions of our analysis.

There are, however, a number of qualifying factors which should be kept in mind in judging this result. First, the policies we have analyzed are based on uniform national emission standards. In fact, some regions will be "overcontrolled," while others could experience deterioration in environmental quality; and some industries will find the costs of meeting regulations rising rapidly, while others will not be seriously burdened. Differential standards for special regions and some means of easing the transition for especially hard-hit sectors and regions would be worth serious consideration.

A related consideration stems from the fact that we have considered only aggregate packages of pollution control policies. If this analysis had been conducted in terms of individual pollutants, we would have found that the aggregate policies labeled "strict" and "relaxed" contain controls that are too strict for some pollutants and too lax for others.

Third, investments for pollution abatement and for energy-efficient capital (in response to high energy prices) may reduce macroeconomic growth if savings are not sufficient to finance these "extra" capital requirements. Some means of reducing national consumption and increasing savings will probably be necessary in the 1980s and 1990s to smooth the transition. This is, incidentally, a conclusion we could not have arrived at had our analysis been shorter term or less comprehensive.

Fourth, our analysis has focused mainly on mass pollutants at the national level. Other environmental problems may pose difficult choices in specific localities—for example, control of soil erosion, location of power plants, and land requirements for solid waste disposal and mining. Local constraints may increase costs by requiring remote siting or unusual protective measures. The cumulative effect of local decisions could be a significant reduction in the national economic growth rate.

Fifth, uncertainty about eventual environmental pressures may also result in slower economic growth. In some cases, one can point to only potential problems—acid rain, global warming from CO_2 buildup, difficulties in disposing of nuclear wastes, loss of topsoil—that are likely at some point to cause damages and possibly require costly adjustments. In still other cases—for instance, increasing population densities relative to resources in general but especially to land and water—the perception of growing environmental pressures may mean more regulations and conflicts, and the closing off of economic options.

To sum up, if the costs and damages we have assumed here are accurate, it appears that substantial control of the common mass pollutants can be achieved without undue interference with the national economy (and, in fact, can add to national economic welfare) as long as fiscal and monetary policy bring about some increase in savings and as long as hard-hit regions and sectors are helped. On the other hand, the picture for other environmental pressures is more worrisome. Our ignorance about some of these additional problems is profound. We frequently do not know what the environmental consequences of past human actions have been, let alone what present or future human behavior might bring. Nor do we know how long we may have to solve some problems before passing a possibly critical ecological threshold. For example, we do not seem to have reached the point today at which we need to restrict the use of some forms of energy, but we may not know until after the fact that we have reached that point. If less environmentally damaging forms of energy, for example, solar or fusion, come into use rapidly enough, we may never reach that point. By causing us to overreact or not react at all, our ignorance may make adjustments very costly. Had such costly adjustments due to ignorance been accounted for in our analysis, macroeconomic growth rates would probably be lower than we assumed at the outset.

APPENDIX

Estimates of national economic activity are derived using the national components of the Strategic Environmental Assessment System/Resources for the Future modeling systems (SEAS/RFF). This is a set of interlinked models, the core of which is a dynamic input-output model of the U.S. economy developed by Clopper Almon at the University of Maryland.[5] Its national economic accounting structure consists of 185 sectors delivering commodities to each other and to various final consumers (households, investors in fixed capital and inventories, government, and net exports). In addition, there are 364 side equations dealing with product and technology mixes within these sectors. The purpose of these side equations is to provide more detail for projecting pollution levels and abatement costs. All coefficients linking producing sectors with each other and with consumers are subject to change over time, some on the basis of econometrically fitted equations with time trends or lagged variables, but most on the basis of exogenously specified changes in technology, tastes, relative prices, supply constraints, and so on, determined on the basis of special studies.

In the case of technology, six main areas were emphasized: the substitution of concrete for lumber and steel in construction, increasing use of plastics and aluminum, improved efficiency of transportation equipment and the introduction of electric cars in significant numbers after 2000, process changes in primary metals production (which tend on net to improve efficiency and reduce pollutants), extensive development of communications and its partial substitution for some types of transportation, and energy supply and conversion technology.[6]

A submodel within this system estimates the investment and operating and maintenance costs associated with the control of pollution for 131 abating sectors. The costs calculated by the submodel for a given year create a demand for resources that is reflected through feedbacks which modify the output levels from the affected economic sectors. In turn, these changed output levels result in different sector growth rates from which the abatement costs are calculated during the next year.

National gross pollution levels for point sources (electric utilities, industry, residential and commercial fuel burning and process activities, and municipal sewage treatment) are calculated by applying gross pollution coefficients (units of gross pollution per unit of out-

5. C. ALMON, M. BUCKLER, L. HOROWITZ & T. REINBOLD, 1985: INTERINDUSTRY FORECASTS OF THE AMERICAN ECONOMY (1974).

6. Technical details, more complete discussion of all assumptions, and discussions of limitations are provided in R. RIDKER & W. WATSON, *supra* note 1; Ridker, Watson & Shapanka, *supra* note 4; A. Shapanka, Technological Assumptions and Their Use in Studying the Resource and Environmental Consequences of Population and Economic Growth in the United States (1977) (discussion paper, Resources for the Future, Washington, D.C.).

put) to output and side equation values. Net emissions are calculated as the product of gross emissions and the percent not controlled. These percentages correspond directly with the control levels and timing used in calculating abatement costs. These national point-source pollutants are assigned to regions using employment and population shares from government reports and special industry location studies.

In addition to the aforementioned point sources of pollutants, SEAS/RFF also calculates pollutants for transportation, urban runoff, mining, nonurban construction, forestry, and agriculture. Most of the estimates for these remaining categories–mainly nonpoint sources of pollution–are made at the regional level. In some cases, estimates of nonpoint pollutants are made initially at the national level and are then assigned to regions using appropriate shares.[7]

A three-step procedure is followed to develop our assumed pollution damage costs. Regional pollutants are transformed into ambient concentrations using dispersion models with appropriate transfer coefficients for each region; per capita average damages in dollars are calculated as a function of average per capita exposure; and per capita damages are multiplied by regional population and summed to obtain national damages for aggregated sources. National damage costs over a range of controls are obtained by changing assumed levels for national policy instruments.

Lying behind this procedure is a per capita regional pollution damage function that satisfies two properties. First, the regional damage function is concave upward with respect to exposure. The slopes or concavity of the function are determined by making them equal in a relative sense to the slopes of a few existing empirically estimated damage functions.[8] Second, the function assigns damages to regions so that for the year 1971, when per capita damages are multiplied by regional populations and summed, the result agrees with an exogenous national estimate for 1971 of total national pollution damages.[9] Satisfaction of these two properties is sufficient to determine a

7. Details of the calculations are provided in R. RIDKER & W. WATSON, *supra* note 1.

8. For example, if the empirical functions have slopes that increase by 50 percent as exposure goes from its median level to twice that amount, then the derived functions will also have the same relative change in slope over the same range of exposures relative to the median.

9. An estimate of national air pollution damages for 1971 ($20.2 billion in 1971 dollars) is taken from Gianessi, Peskin & Wolff, *The Distributional Implications of National Air Pollution Damage Estimates,* in THE DISTRIBUTION OF ECONOMIC WELL-BEING 201 (F. Juster ed. 1977). Estimated national water pollution damages for 1971 ($11.1 billion in 1971 dollars) are taken from H. HEINTZ, A. HERSHAFT & G. HORAK, NATIONAL DAMAGES OF AIR AND WATER POLLUTION (1976); Page, Harris & Epstein, *Drinking Water and Cancer Mortality in Louisiana,* 193 SCI. 55 (July 2, 1976).

unique regional per capita damage function that can be used to forecast damages.

Total regional damages are assigned to specific sources in proportion to each source's share in total exposures. In the case of water pollution, special assumptions are made to calculate the impact of sediment discharges by nonpoint sources. A weight for sediment from agriculture was selected so that in 1971 the damage model assigned $350 million of the $11.1 billion national water pollution damages to agricultural sediments. This weight was applied to sediment from other nonpoint sources and held constant for projection purposes.[10] The figure of $350 million was selected because it is roughly the middle of the range of damage estimates from agricultural sediment discharges reported by the best of the studies of this issue so far available.[11] That figure is only for damage associated with the silting of reservoirs and alteration of stream flows; it does not include any estimate for damage to water-based recreation activities. If a larger figure than $350 million had been used—which would have involved selecting a larger weight—less damage would have been assigned to point sources of water pollution, and the conclusions of our analysis could be affected.

In the case of air pollution, the analysis of least-cost controls covers all major sources and the major air pollutants. In contrast, the analysis of water pollution control determines least-cost controls only for electric utilities, industrial point sources, municipal wastewater treatment plants, and urban runoff sources. However, since damage costs depend upon emissions from all sources, assumptions had to be made about controls on the other sources.[12] These controls are kept constant as the model searches for least-cost controls for the indicated point and urban runoff sources.

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10. This procedure was used only for deriving damage estimates for suspended and dissolved solids, the two pollutants associated most directly with sediment runoff. Other pollutants from nonpoint sources are treated exactly like pollutants from any other source; in effect, they are assigned a weight of one for entry into the damage model.

11. J. Wade & E. Heady, A National Model of Sediment and Water Quality: Various Impacts on American Agriculture (1976) (Report 67, Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa).

12. For ore, coal, and minerals milling and mining, it is assumed that all facilities meet conventional treatment technology standards by 1980 and advanced treatment technology standards by 1985. The per unit sediment runoff from mining of ore, coal, and minerals is assumed to be reduced to about one half of its current level by 1985. Sediment runoff from nonurban construction (per unit of activity) is assumed to be one-half and one-fourth of current levels by 1985 and 2000, respectively. Acid mine drainage from abandoned coal mines is assumed to be one-half and one-fourth current levels by 1985 and 2000, respectively. Sediment runoff from agriculture on a per acre basis is assumed to be about two-thirds of its pre-1970 level, beginning in 1975.