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Need Economic Development be Hazardous to the Health of the Chesapeake Bay?

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Abstract *This paper adds environmental and mass balance relationships to an economic model in order to explore the welfare implications of alternative patterns of regional development. It concludes that improvements in welfare can be achieved by selecting those types of economic activity which yield high ratios of economic benefit per unit of pollution generated. Methods are examined for achieving selectivity in designing economic development programs to capture the benefits of development while protecting environmental resources.*

I. Introduction

Is Economic Development Compatible with Environmental Quality?

A fundamental problem in efficient management of estuaries is dealing with the multiple jurisdictions involved (Oates and Mueller, 1986). Despite this intergovernmental problem, state and local governments concerned about environmental protection must explore the internal options open to them for efficient management of their valuable estuarine resources. But these same regions have also traditionally acted vigorously to accelerate the process of economic development. The purpose of this paper is to explore relationships between regional environmental and developmental goals and to examine options available to regional governments for achieving high levels both of environmental quality and of economic development.

The proposition is advanced that the application of traditional economic concepts has much to offer in the analysis of these issues, and that the extension of economic analysis to include relevant concepts from the physical sciences such as mass balance and elementary thermodynamics can provide additional insight into the relationships between environmental and developmental goals.

Section II raises the question of what criteria can appropriately be applied to regional economic development plans in order to determine whether or not specifically proposed projects and programs contribute positively to improving regional economic welfare. For this purpose a set of conditions for evaluating improvements in regional welfare is developed.

Since one of the conditions for improvement involves an environmental sector, Section III develops a basic mass balance model of material flows for an estuarine region and examines recent empirical estimates of waste flows for the Chesapeake Bay. Section IV examines the policy implications for a region seeking to achieve high levels of both economic development and environmental quality. Section V examines instruments for managing regional economic development. Section VI is a summary.

II. Criteria for Improvement in Regional Welfare

In order to identify those aspects of regional economic development which can reasonably be said to improve economic welfare, we develop a three-sector set of conditions for regional welfare improvements. The proposed conditions include a private income criterion, a public finance criterion, and environmental criteria. These criteria are summarized in Figure 1. The criteria are designed to be applied by decision makers and analysts on a before and after basis in order to determine whether or not any proposed development project or program would improve regional welfare.

In the private sector, welfare improvement is measured on a per capita rather than total basis in order to emphasize that welfare can conceivably decline if population increases at a greater rate than does real income. An improvement in private welfare is assumed to occur if the effect of a project is to raise per capita real income (Y_{t+1}/P_{t+1}) above its level in the base period (Y_t/P_t). It should be noted that the use of an average per capita income measure of welfare in the private sector fails to record potentially important changes in income distribution which might result from a development project.

I. *Private Sector Criterion*

$$Y_{t+1}/P_{t+1} > Y_t/P_t$$

Y = personal income
P = population
t = time period

II. *Public Sector Criterion*

$$\frac{R_{t+1} - G_{t+1}}{P_{t+1}} > \frac{R_t - G_t}{P_t}$$

R = revenue of local government
G = expenditure of local government

III. *Environmental Criteria*

Necessary Conditions:

$B > D$ or,
$B > C$

B = environmental benefits
D = environmental damage
C = cost of environmental restoration

Sufficient Conditions:

If $D > C$, environmental quality be restored
compensation be paid for environmental damage
If $C > D$,

Source: Based upon John H. Cumberland "A Regional Interindustry Model for Analysis of Development Objectives, *Regional Science Association Papers,* Vol. VVII, 1966, pp. 65–94.

Figure 1. Development criteria for an estuarine region conditions for an improvement in regional welfare

In addition to the per capita income criterion, reduction in local unemployment may also be regarded as an important goal for improvement in regional welfare. However, since reduced unemployment is usually accompanied by reduction in government expenditures (G) for welfare payments, and usually by an increase in per capita income as well, it is not formally listed here as a separate welfare criterion, important though this goal is for regional welfare improvement.

It should be noted that these measures of welfare improvement are explicitly local in nature, and are not intended to be global criteria. For example, an inflow of new population, whether employed or not, which lowers per capita income in the region, thus reducing per capita regional welfare might well represent an improvement in the welfare of the in-migrants, and an improvement in national welfare. However, the assumption here is that individual regions have the means and the right to improve local welfare so long as they do not injure residents of other regions in so doing. This view seems justified by the fact that if all regions were to adopt the welfare criteria listed here, and to develop the means of implementing them, national welfare would improve. The model with its limited number of parameters abstracts from reality in order to focus attention on a few policy variables and to explore criteria for regional welfare improvement. The model is intended to aid policy makers in identifying types of policies and programs which do and which do not serve to improve welfare.

The private sector personal income criterion is based on a per capita concept, to draw attention to the fact that mere job creation does not necessarily add to regional welfare unless the jobs go to those previously unemployed in the region. If wage rates for the new jobs are below the average of those already existing in the base period, and if the new jobs are filled by migrants into the region, not only does per capita income fall, but lower incomes coupled with potentially lower tax revenues from new residents and increased public expenditure could weaken the public sector and generate additional regional welfare losses.

The public sector criterion, also on a per capita base, is formulated to emphasize that development generates not only tax revenue (R) but also raises expenditure requirements (G) for new enterprises and for any new labor force they may attract into the region. Unless the new enterprises themselves generate revenue in excess of the governmental services they require, and the added labor force satisfies the same condition, mere attraction of new business fails to meet the public sector criterion. Obviously "adding to the tax base" is a necessary but not sufficient criterion for economic development projects and policies. An improvement in the public sector is assumed to occur if the proposed development (and associated new work force) generates a more favorable net balance of public sector revenue (R) over associated local government expenditures (G) per capita than existed before the proposed development:

$$\left(\frac{R_{t+1} - G_{t+1}}{P_{t+1}} > \frac{R_t - G_t}{P_t}\right)$$

This public finance criterion is not intended to suggest that accumulating surpluses is a desirable goal of development but merely that if a development project weakens the capability to maintain the previous level of public sector services, regional welfare is lowered.

The environmental sector criteria for regional economic development should be linked with the regional mass balance model and equations presented below. The central relationships are that added population with both its production and consumption activities generate added gross residuals and waste. Even if added waste treatment is undertaken, this can only change the form and not the mass of gross residuals. Added population and economic development therefore must reduce environmental quality in the region and in the estuary, unless special conditions exist.

In order for economic development to generate environmental improvement, the criteria in Figure 1 suggest that the economic benefits (B) from gains in the private and public sectors must exceed the added environmental damages (D), or the resulting cost of environmental restoration associated with the project (C) must be less than the resulting economic benefits. It is conceivable, but unlikely, that a development project will improve environmental quality without creating environmental damage. In the general case, however, environmental restoration or protective treatment must be undertaken.

The sufficient conditions for achieving environmental improvement (after the necessary conditions have been met (B > D or B > C) are that environmental restoration activities be undertaken, provided that the cost of doing so is less than the damage prevented (D > C), or, if restoration costs exceed damages (C > D) losers must be compensated (see Figure 1).

Since few development projects can meet the criteria for environmental improvement, it is difficult to meet all the necessary conditions for an unequivocal improvement in regional welfare. This would require an actual improvement in one or more sectors without a deterioration in any sector. However, development projects may generate sufficient economic benefits in the private and/or public sector that the benefits outweigh the resulting environmental damage. In this case, a benefit-cost improvement will have been achieved. A benefit-cost improvement can be converted into a Pareto-like actual regional improvement if compensation is made by the from sectors with gains to the sectors with losses. It is important to note that significant Pareto relevant losses and gains to individuals may also occur within the three sectors shown here, but these are not considered in the simple model.

In summary, for an unequivocal improvement in regional welfare, an actual improvement must occur in at least one of the two sectors without a deterioration in any of the sectors. For a potential Pareto-like improvement to occur, an improvement in one or more of the criteria sectors must be achieved with a magnitude larger than the sum of losses in any sector. In order to transform a potential improvement into an actual Pareto-like improvement, sectors with losses must be compensated by sectors with gains.

In order to explore the opportunities for designing regional development programs in which environmental damage is maintained at low levels in comparison with benefits from economic development, we next examine the material flows within a regional economy using mass balance concepts.

III. A Regional Mass Balance-Environmental Model

A highly simplified model of the principal economic and material flows in a region is shown in Figure 2. A set of equations accompanying the diagram in Figure 2 is shown in Figure 3. An early version of this type of model is found in Kneese, Ayres, and d'Arge (1970). The economic module (X) is based upon the traditional gross regional product accounting system. The rest of the model is based upon elementary principles of thermodynamics and mass balance using the central concept of conservation of mass and energy. The flows shown in Figure II emphasize materials, but they can be expanded to include the parallel concept of energy flows. Correspondence between the economic activities and the material flows results from the fact that all economic activities, including production and consumption, involve the processing of materials whose mass remains constant. All production activities generate flows of waste (W_Q) and deliveries to consumption (Q). All deliveries to consumption also eventually become waste (W_C). Therefore, all inputs (M) to production and consumption activity eventually become waste. Therefore, all materials (M) going into production and consumption activities eventually become waste ($W_C + W_Q$) after appropriate lag times.

Figure 2 shows all economic activities generating wastes (which can be gasses, particulates, liquids, or solids), in the gross residual output account (G). Aside from the limited amount of waste which is recycled as inputs, or directly discharged to the environment, most wastes then go through some sort of waste treatment processes. An important insight provided by the mass balance approach is that all waste going into waste treatment processes (G) also emerges as waste (T), though presumably waste of a less damaging nature. The waste treatment module shows that except for outputs which are recycled, waste treatment activities discharge all of their inputs either to the air (A), to the water (W), or to the land (L).

In an estuarine region, all waste flows potentially flow into the estuary. For example, in the 64,000 square mile basin of the Chesapeake Bay system, all streams and rivers eventually flow into the Bay. Airborne waste (A), depending upon many factors including wind direction, may flow out of the region or may be discharged partially into the waters of the Bay. Waste discharged onto the land (L) may remain entrapped, but may also seep into the waterways and eventually into the estuary.

All wastes which flow into the estuary are potentially subject to the environmental treatment provided by natural processes. Some nutrients are recycled and become inputs into biological systems. Other wastes may be converted into valuable resources through oxygenation, assimilation, dilution, transportation, and other transformation processes. The capability of the estuary to provide these benefits depends on many factors including its water flow, salinity, water temperature, pollution burden from other regions, the nature of its biota, and other factors.

However, as noted in Figure 2, those wastes reaching the estuary which cannot be sufficiently assimilated by environmental processes remain to cause damages to water quality, and to the natural resources within the estuary. Damage to marine resources may limit their quantity or quality, thus imposing economic costs on those activities which use these resources as inputs. Finally, in an open system, some water, marine resources, and pollution flow out of the region.

Harvested marine resources (N) and non-marine resources from the region (K) are combined ($N + K = R$) with imports (I) to make up the total mass of material inputs (M) to the regional economy, with which the flow analysis began ($M = R + I$).

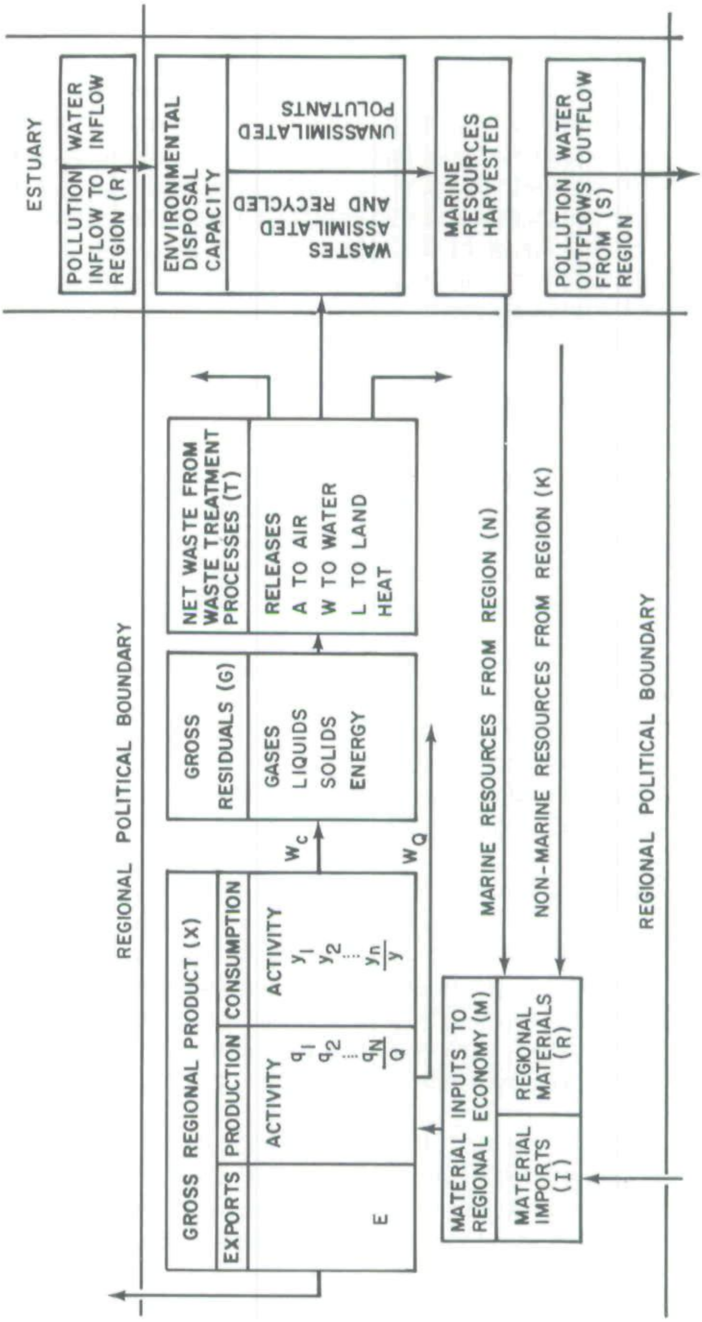

Figure 2. Principal material flows and mass balance of a region.

Material Inputs Into The Regional Estuary

$M = R + I$

M = Material inputs into the regional economy
R = Materials inputs from the region
I = Materials imported from other regions

Material Processing—Gross Regional Product

$Q = M$

Q = Material outputs of production process

Output From Productive Processes

$Q = Y + E + W_Q$

Y = Deliveries of outputs to consumers and final demand to consumers, investors and government
E = Exports from the region
W_Q = Waste from production processes

Output from Consumption Processes

$Y = W_C$

W_C = Total mass of waste from consumption and from final demand processes (= total mass of inputs to consumption)

Output of Wastes: Gross Regional Waste Output

$G = W_Q + W_C$

G = Gross residuals = total waste produced by regional economy
W_Q = Waste from production process
W_C = Waste from consumption process

Waste Treatment Processes

$T = G$

T = Secondary waste from treatment processes. Mass of output from waste treatment process = $\sum$ inputs to waste treatment (= G)

Discharge of Wastes from Treatment Processes

$T = A + W + L$

A = Treatment wastes discharged into the atmosphere
W = Treatment wastes discharged into water resources
L = Treatment wastes discharged to land or underground

Discharge of Wastes Into Estuaries

$U = F + W + \theta A + \pi L$

U = Total waste reaching the estuary
W = Wastes from region discharged to water courses
F = Waterborne wastes flowing into estuary from other regions
θA = Fallout and rainout into estuary from airborne waste
πL = Seepages and leakage into estuary from waste discharges to land
θ = Proportion of regional airborne waste falling into estuary
π = Proportion of wastes discharged to land which eventually reaches estuary

Sources of Materials Inputs from Region Into Regional Economy

$R = N + K$

N = Regional marine resources input
K = Regional non-marine resources input
M = Material inputs into regional economy

$M = R + I$

As above

Figure 3. Regional mass balance equations estuarine waste loadings and environmental quality

At this point some empirical information on the material flows of metallic wastes in the Chesapeake Bay can be examined. These data in Table 1 drawn from the recent EPA study of the Chesapeake, are only one component of wastes discharged to water courses (W) in the Chesapeake region. These data have the advantage that they can be approximately related to some of the categories in the materials balance model discussed above. The industrial wastes correspond roughly to wastes generated by production processes, and municipal wastes are largely those from consumption processes.

Wastes generated in the Susquehanna approximate wastes flowing into the estuary from outside the region. Wastes from atmospheric sources (sometimes termed cross-media wastes) originate partly from within and partly from outside the region. Wastes from shore erosion and other sources are at least partly unrelated to economic activities. Although Table I shows more than 6,000 tons of metal annually being discharged into the Chesapeaks Bay system these raw figures on emissions are less significant for Bay management than is the ambient metal content, and more significantly, the effects of its toxicity on the biota of the Bay. These heavy metals constitute a serious threat to the health of the Bay, especially since the EPA Chesapeake Study (1983) indicates that with slow and incomplete flushing, a large percentage of total emissions never leaves the Bay, but remains in the system for long periods of time.

As yet, few studies exist which establish a dose-response relationship between pollutants and damage to the biota (Kahn and Kemp 1985; Grigalunas, Opaluch, French, and Reed 1986). However, despite the large areas of uncertainty and incomplete knowledge, the thousands of tons of heavy metals, other toxic substances, and excess nutrients identified by the EPA Chesapeake Bay Study as damaging to the Bay, must be regarded as probable causes of serious economic and environmental losses. A large portion of these emissions results directly and indirectly from economic activity. It is therefore important to examine the extent to which it is possible to achieve the advantages sought from economic development while protecting estuaries and other environmental resources from detrimental pollution externalities. The next section examines some of these possibilities.

IV. Need Gross Regional Product Equal Gross Regional Pollution?

This mass balance perspective of the impact of economic activity upon estuarine resources emphasizes the extreme difficulty of protecting environmental quality at high levels of economic development. This raises serious questions about the ability to design development strategies which would meet the requirements listed in Figure I for assuring that economic development would unequivocally improve welfare in a region.

The greatest difficulty in assuring that development would improve welfare is found in meeting the environmental criteria. These environmental criteria require that either the development generate economic benefits in the private and public sector greater than the environmental damage or that the economic benefits be greater than the cost of environmental restoration. Meeting at least one of the above conditions is necessary for a potential Pareto improvement. In order to convert a potential Pareto improvement into an actual improvement, it is nec-

Table 1
Discharges of Metals into the Chesapeake Bay System
1980 by Source (tons/year)

	Cadmium (CD)	Chromium (CR)	Copper (CU)	Iron (FE)	Lead (PB)	Zinc (ZN)	Manganese (MN)	Nickel (NI)	Total
INDUSTRIAL									
Eastern Shore	0.4	0.6	4.5	—	—	—	—	—	5.5
James	3.0	17.1	16.5	8.0	9.9	47.0	—	9.9	111.4
Patuxent	—	0.02	—	—	0.04	—	—	—	0.06
Potomac	3.6	95.8	78.1	—	93.8	290.8	—	98.4	660.5
Rappahanock	—	—	—	0.04	—	—	—	—	0.04
Susquehanna	64.4	379.4	386.4	—	172.3	828.9	—	226.8	2058.2
West Chesapeake	12.7	58.9	65.3	4116.7	46.6	63.3	—	—	4413.5
York	0.02	0.9	0.2	—	0.3	1.6	—	—	3.0
TOTAL	84.1	552.7	551.0	4174.7	322.9	1231.6	—	335.1	7252.2
MUNICIPAL									
Eastern Shore	0.1	0.8	1.6	32.2	1.3	3.5	—	—	39.5
James	6.6	67.0	53.1	375.1	43.7	305.5	—	60.6	911.6
Patuxent	0.05	0.6	1.1	21.4	0.9	2.3	—	—	26.3
Potomac	2.8	39.7	54.9	736.4	50.9	144.8	—	21.5	1051.0
Rappahanock	—	0.2	0.3	6.1	0.2	0.7	—	—	7.5
Susquehanna	7.1	42.1	42.9	—	19.2	92.2	—	25.2	228.7
West Chesapeake	6.5	24.7	36.0	541.1	21.7	46.7	—	—	676.7
York	—	0.1	0.1	2.2	0.1	0.2	—	—	2.7
TOTAL	23.1	175.2	190.0	1714.5	138.0	595.9	—	107.3	2944.0
ATMOSPHERIC	3.3	—	30.8	95.8	37.4	907.9	24.3	27.6	1127.1
SHORE EROSION	1.3	107.1	37.4	73,804	36.1	123.9	—	—	74,110
NEC	7.7	12.1	9.9	330,808	122.3	69.3	—	—	331,089
TOTAL	120.	847	819	410,657	657	2929	24	470	416,523

Source: Based upon EPA Chesapeake Bay Study: A Framework for Action. Flows entering the Chesapeake from the Susquehanna and Potomac Rivers have been allocated between industrial and municipal sources on the basis of figures estimated for total waste flows in the Bureau of Business and Economic Research.

essary either to restore environmental quality (if this costs less than the value of the environmental damage), or to compensate those who are injured by the environmental damage (if the cost of restoring environmental quality exceeds the value of the damage). Thus the principle of using some of the economic gains from economic development to compensate the victims of environmental damage is worthy of serious consideration (especially in cases where the damage is greater than the cost of restoring environmental quality).

Consideration of the mass balance principle illustrates the difficulty of completely restoring environmental quality to the level which would be experienced in the absence of economic growth, since all economic activity generates waste, and waste once produced cannot be destroyed. But though waste cannot be eliminated, it can be treated. Treatment and other options suggested by Figure 2 can be used to reduce the damage from waste by economic activity.

The materials flow and mass balance model in Figure 2 and the accompanying equations in Figure 3 indicate that the generation of waste is inseparable from the processes of production, consumption and economic development. However, these constraints also suggest that development and waste generation need not necessarily lead to pollution since several escape mechanisms exist. One obvious mechanism for reducing the environmental impact of economic activity is to run gross residuals through waste treatment processes. However, increasing empirical evidence is accumulating to confirm the mass balance principle that waste once generated cannot be removed, only transformed. One of the most dramatic examples of this phenomenon is provided by the case of advanced waste water treatment for removing nutrients from sewage. The Blue Plains Treatment Plant on the Potomac, one of the most advanced in the world, now generates approximately 1,000 tons of sludge daily, for which no completely satisfactory disposal methods have yet been devised. With expanding population in the Chesapeake region, increasing resort to advanced waste water treatment is only a temporary remedy, since the sludge disposal burden can be expected to become more serious.

Another escape from pollution by wastes from economic activity is provided by nature itself. The symbolic presentation of the estuary in Figure 2 indicates that its water inflow and outflow plus biological processes in the estuary are potentially capable of providing environmental waste treatment. These consist, besides transport of waste outside the region, of assimilation, dilution and biological reconversion of wastes into re-usable resources. One of the remarkable features of an estuary is that it not only can produce marine resources, but with proper management, it can convert some, but not all, forms of waste into economic and environmental resources, provided that it is not overloaded. The assimilative capacity of the estuary depends upon such factors as the amount and quality of the incoming water, its temperature and biota, and the rate at which it can flush pollutants out of the estuary. Thus the pollution potential of gross regional production depends upon relationships between the physical characteristics of the estuary and its waste loadings generated by the local economy.

Since most estuarine regions are open subdivisions of larger political units, exporting and importing across local boundaries offer additional but limited opportunities for reducing the impact of pollution from economic activity. As shown in Figure 2, some of the material inputs into the local economy may be imported. If these materials are produced under pollution-intensive conditions like energy production, importing them is the equivalent of exporting pollution to the regions from which they are imported. Similarly, if the consumption of some materials like coal is pollution-intensive, shipping these materials outside the region for consumption, rather than using them internally, is the equivalent of exporting pollution. Legal, political and ethical considerations impose limits on the export of pollution. Other possible methods not shown in Figure 2 exist for reducing pollution, such as recycling of residuals and improving technology in waste treatment processes.

However, one of the most direct and basic methods available for reducing pollution from economic activities is through managing the magnitude and composition of the economic components of the gross regional product. Production activities $q_1, q_2, \ldots q_n$ and consumption activities $y_1, y_2, \ldots y_n$ are identified in Figure II to indicate that their size and composition varies from region to region and, to some extent, are subject to decision making within the region. Given whatever the assimilative capacity may be for the region, the size and composition of the production and final demand activities is then the basic determinant of the pollution loadings within the region. This analysis recognizes that the gross residuals generated by the local economy can be mitigated by technical treatment processes. However, the efficiency of waste treatment is still subject to the laws of mass balance, and even treated waste can overwhelm the regenerative powers of the estuary. So dilution and even treatment are not necessarily satisfactory solutions to pollution. Eventually, as treated and untreated wastes mount up against the environmental constraints on the ability of the estuary to accept further wastes, environmental protection will require selectivity in managing the magnitude and composition of economic activities in the region. In Figure 2, regional economic production activities are disaggregated ($q_1, q_2, \ldots q_n$) to emphasize that the amount and composition of wastes generated depend directly upon the type of economic activity attracted to the region. Some industries produce much less pollution per dollar of economic benefit than do others. Achieving the benefits from economic development with minimal damage will require local governments to exercise management options. The next section will summarize some of the opportunities available to state, county, and municipal governments for managing regional economic development processes.

V. Instruments for Managing Regional Economic Development

Recent economic literature has devoted extensive attention to the analysis of policy instruments for reducing external diseconomies from pollution emissions. Important examples include the proposals developed by Oates (1986) and those developed by Opaluch and Kashmanian (1985) dealing with the "bubble approach" and the use of CERCLA or "Superfund" damage assessments regulations, (Grigalunas, Opaluch, French, and Reed 1985) which could provide economic incentives to reduce pollution. These measures deserve serious consideration within the states and localities surrounding the Chesapeake Bay. However, in addition to reducing current pollution, additional opportunities exist for preventing future pollution, through judicious management of regional economic development strategies. Therefore, this paper attempts to make the case that at least in regional development where polllution externalities and common property problems are pervasive, welfare losses can be reduced and benefits increased by limited local government intervention, especially at the state level, for the specific purpose of exercising selectivity in the attraction of economic activities which meet personal income, public finance, and environmental criteria for raising the quality of development.

Objections can properly be raised that local governments face legal and other limitations on their rights to exclude any legitimate economic activity, regardless of its effects on average income, fiscal balance, or environmental quality. However, state governments engage in a wide range of activities to promote, subsidize, and regulate economic activities of many types. A partial list of state activities affecting the magnitude and compensations of economic activities includes numerous programs for revenue bonds and other subsidies, operation of port authorities, management of transportation programs, regulation of natural resources, management of power plant siting programs, and protection of environmental quality. County and municipal governments exercise even more control over economic development through land use planning and zoning.

Whether or not it is formally recognized, local governments already intervene in economic development processes both in promotional and in restrictive ways through numerous programs. Unfortunately, these programs are usually uncoordinated and may be contradictory. An example is the simultaneous expenditure of millions of dollars to abate pollution, while spending millions more to dredge shipping channels to expand industry which stirs up accumulated toxic substances deposits emitted by industrial ports.

Under well designed guidelines for economic development aimed at Pareto improvement in regional welfare, significant opportunities exist to capture the positive externalities of program coordination while avoiding costly detrimental externalities resulting from typical efforts to maximize quantitative growth.

VI. Summary and Conclusions

Traditional environmental regulatory approaches have suffered from two major weaknesses. First as economists have pointed out in great detail, comand and control regulations fail to capture the efficiencies which could be gained from using incentive based approaches. More pollution control could be achieved at lower cost by using emission charges, transferable discharge permits, and other economic incentive measures. Secondly, traditional regulatory measures inadequately recognize the thermodynamic mass balance implications of economic activity. Since economic activities involve the processing of materials and energy, the growth of population and its accompanying production and consumption activities add inevitably to the generation of the waste burden which must be discharged into the estuary and into the other environmental receptors in the region.

Some important options exist for protecting the estuary. They include export of wastes, importing materials and energy, recycling wastes, environmental assimilation of wastes, and technological treatment of wastes. However, all of these measures for preventing waste generation from developing into pollution damage face serious physical and social constraints. This is especially true of technical waste treatment, which can at best modify the chemical composition of the waste, without reducing its mass-energy magnitude. As economic development becomes more intense, more advanced waste treatment technologies are required to prevent pollution, but advanced treatment technologies merely generate the same mass of waste in what is intended to be less damaging forms. The most effective method of pollution control is to prevent the initial generation of pollution.

The major point of this paper is that cautious guidance of the economic development process offers the best opportunity to achieve the important advantages of economic growth while minimizing its environmental impacts. Since physical laws ultimately limit the scale of economic development and limit development opportunities, estuaries and environmental quality can best be protected by policies of selectivity in economic development. Development options should be carefully chosen in order to meet the region's private sector, public sector, and environmental sector goals in order to avoid mere quantitative growth which can cause losses in regional welfare.

Local, municipal, and state governments can affect regional development through numerous processes and mechanisms which are typically uncoordinated and often contradictory. Comprehensive analysis of the physical aspects of economic development seems to indicate that insistence upon effective environmental policy is also the most effective economic development policy in the long run.

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References

Cumberland, J. H., and L. E. Cronin 1985. A bioeconomic approach to improved fisheries management and pollution control for the Chesapeake Bay. University of Maryland, Department of Economics and Bureau of Business and Economic Research Working Paper, 85–88.

Grigalunas, T. A., J. J. Opaluch, D. French, and M. Reed 1986. Measuring damages to natural resources in estuaries from oil and hazardous substances spills: application of an integrated ocean systems/economic model. Paper presented at the Conference on the Economics of Chesapeake Bay Management II, 28–29 May 1986, Annapolis, Md.

Kahn, J. R., and M. Kemp 1985. Economic losses associated with the degradation of an ecosystem: the case of submerged aquatic vegetation in the Chesapeake Bay. *Journal of Environmental Economics and Management*, 12:246–63.

Kneese, A. V., R. V. Ayres, and R. C. d'Arge 1970. *Economics and the Environment: A Materials Balance Approach*. Washington, D.C.: Resources for the Future, Inc.

Oates, W. E., "Market Incentives for Environmental Protection: A Survey of Some Recent Developments," in Preston, M., and Quandt, R., Eds., 1986, *Prices, Competition, and Equilibrium*. London: Philip Allen.

Oates, W. E., and D. Mueller 1986. The management of the Chesapeake Bay: alternative strategies for decision-making. Paper presented at the Conference on the Economics of Chesapeake Bay Management II, 28 May 1986, Annapolis, Md.

Opaluch, J. J., and R. M. Kashmanian 1985. Assessing the viability of marketable permit systems: an application in hazardous waste management. *Land Economics:* 61, 263–71.