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Induced Innovation in Agriculture

and Environmental Quality

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Introduction

The idea that "progress breeds not welfare but catastrophe" (Bury, 1932) is deep-seated. Since the 19th Century, America has felt the tension of technological change, and foreboding at its prospects for Man's place in Nature. Hawthorne's "The Celestial Railroad" (1843) treats the locomotive engine as a symbol of sublime progress toward a celestial garden which leads ultimately toward a demonic catastrophe.

> The sweet breezes of this happy clime came refreshingly to our nostrils; we beheld the glimmering gush of silver fountains, overhung by trees of beautiful foliage and delicious fruit, which were propogated by grafts from the celestial gardens ... The engine now announced the close vicinity of the final station-house by one last and horrible scream, in which there seemed to be distinguishable every kind of wailing and woe, and bitter fierceness of wrath, all mixed up with the wild laughter of a devil or a madman (p. 305).

A similar ambivalence about technology's impact on the environment may be traced through much of modern literature.[1/]

While economists are no strangers to ambivalence, the purpose of this essay is not literary but analytical. It extends the model of induced innovation in agriculture to include the impacts of technology on environmental quality, developing a framework within which both technological optimists and technological pessimists can constructively argue. The elements of this framework are all familiar. Its purpose is to synthesize aspects of the literature on technical choice in agriculture with work on environmental quality.

1/ In The Machine in the Garden: Technology and the Pastoral Ideal in America (1964), Leo Marx traces this theme, weaving social and literary analysis that includes discussions of a wide range of American and English authors.

Part one presents the model of induced innovation in agriculture developed by Hayami and Ruttan (1985) and others. This model explains technological change as responsive to relative factor abundance, which determines factor prices and the choice of agricultural technique. An example is provided using land, water and energy as factor inputs, comparing the adoption of dryland cropping and irrigation-intensive agricultural technologies.

Part two argues that the technology chosen affects the quality of factor inputs. Irrigation technology, for example, may affect the quality of water resources once adopted. A model of such environmental quality effects is presented based on the characteristics of factors, following Lancaster (1966). For purposes of illustration, water quality characteristics are described using an hedonic framework, drawing on studies in which the implicit prices of such characteristics are derived and used to identify inverse demand functions (Freeman, 1979).

Part three explores the problem of the market's failure to reflect the scarcity value of these environmental quality characteristics. If a complete set of markets for them exists, then the market price and implicit price of environmental quality attributes will coincide. If markets are missing (externalities or public goods exist) then they will not coincide and overuse or underuse of the factor (and technology) may result. Where markets are missing, an incentive exists to innovate nonmarket institutions (such as regulations) to accurately reflect the implicit value of the attribute in the use of the factor. Institutional innovations affecting factor use in agriculture are thus linked to the environmental impacts of technological choice.

Part four argues that this model is consistent with Ruttan's (1971) observation that environmental quality is a bundle of characteristics which will be more highly valued as incomes increase. The income elasticity of demand for environmental quality suggests that these characteristics will become increasingly important with increases in economic growth and development, and that where markets for them are missing, especially in high income countries, institutional innovations (such as the Clean Air Act and Clean Water Act) will further impinge on factor valuation, and thus on technical choice in agriculture.

Part five draws together the analysis with some implications for policy. First, environmental quality concerns will increasingly affect the choice of agricultural technique. The relative tendency of high income groups and countries to value environmental quality more than agricultural production has both domestic and international policy implications. Second, the impact of environmental quality on technical choice in agriculture is closely related to missing markets, and institutional innovations will be driven by these market failures. The role of policy is accurately to characterize these market failures, and to propose cost-effective institutional alternatives. Third, policy interventions should be targeted to specific cases in which markets are missing. Both the efficiency and equity of market and quasi-market alternatives should be weighed against regulations as a basis for accurate signalling of technical choices in relation to environmental quality.

Induced Innovation in Agriculture

Technological choice is a function of the relative abundance of factors of production, which determine factor prices and the choice of agricultural technique. This is the "induced innovation hypothesis," first advanced by Hicks (1932) and subsequently elaborated by Fellner (1961, 1962), Kennedy (1964), Ahmad (1966), and Samuelson (1965) among others. In agriculture, the theory has been most fully developed by Hayami and Ruttan (1985) and Binswanger and Ruttan (1978). The induced innovation hypothesis treats technology not as given, but as a dynamic endogenous response to changes in resource endowments and to growth in product demand. Such a dynamic process accounts for the way in which constraints on factor inputs such as land, water, and energy affect the agricultural technology chosen, and how the demand for agricultural output drives the demand for new technology.

Hicks' theory of induced innovation implied that a rise in the price of one factor relative to another (a function of their relative abundance) induces a sequence of technical changes that economizes on the use of the expensive (scarce) factor relative to the use of the other (abundant) factor. Hence, constraints on economic growth imposed by relative scarcity are overcome by technical changes that substitute relatively abundant factor inputs for scarce ones. Criticism of the theory concerned the apparent lack of a microeconomic mechanism triggering this sequence (see Hayami and Ruttan, 1985, pp. 73-114). In response, Binswanger has developed an induced innovation model based on microeconomic reasoning, in which innovation possibilities are triggered by research and development (Binswanger and Ruttan, 1978). More research into new technologies is induced by increases in product demand, which shifts the "innovation possibilities curve." The choice of a specific technique is then guided by relative factor scarcity.

Consider Figure 1, in which land, water and energy are factor inputs, OO and DD are the price lines associated with differing endowments of land and water, the dotted curves IPC_0 and IPC_1 represent innovation possibilities curves and isoquants I_0 and I_1 represent particular agricultural production technologies chosen in situations 0 and 1 respectively. The straight line [W,E] assumes a fixed complementarity between water and energy, based on the reasoning that bringing more water to crop production requires more energy. IPC_0 represents the technological possibilities associated with relatively abundant land and relatively scarce water, such as dryland cropping on the High Plains prior to large scale pumping from the Ogallala Aquifer (see Kneese, 1986). The particular technology in use, I_0, is one in a set of possible techniques falling inside the envelope of IPC_0. I_0 is a cost-minimizing technology when it is tangent at point X to OO. Given the particular factor prices prevailing at OO, L_0, W_0, and E_0 are the implied levels of land, water and energy used by the particular dryland cropping technology I_0.

Now suppose that water becomes more abundant relative to land, due to increased extraction from underground water sources, as on the High Plains or in the Central Sands region of Wisconsin during the 1960's and 1970's. This is reflected in the new price line, DD, in which the change in relative factor scarcity is shown. Also assume that the relative price of energy falls compared with land. The change from OO to DD induces research by agricultural engineers and others into a new set of irrigation technologies that are water and energy using, such as center-pivot irrigation

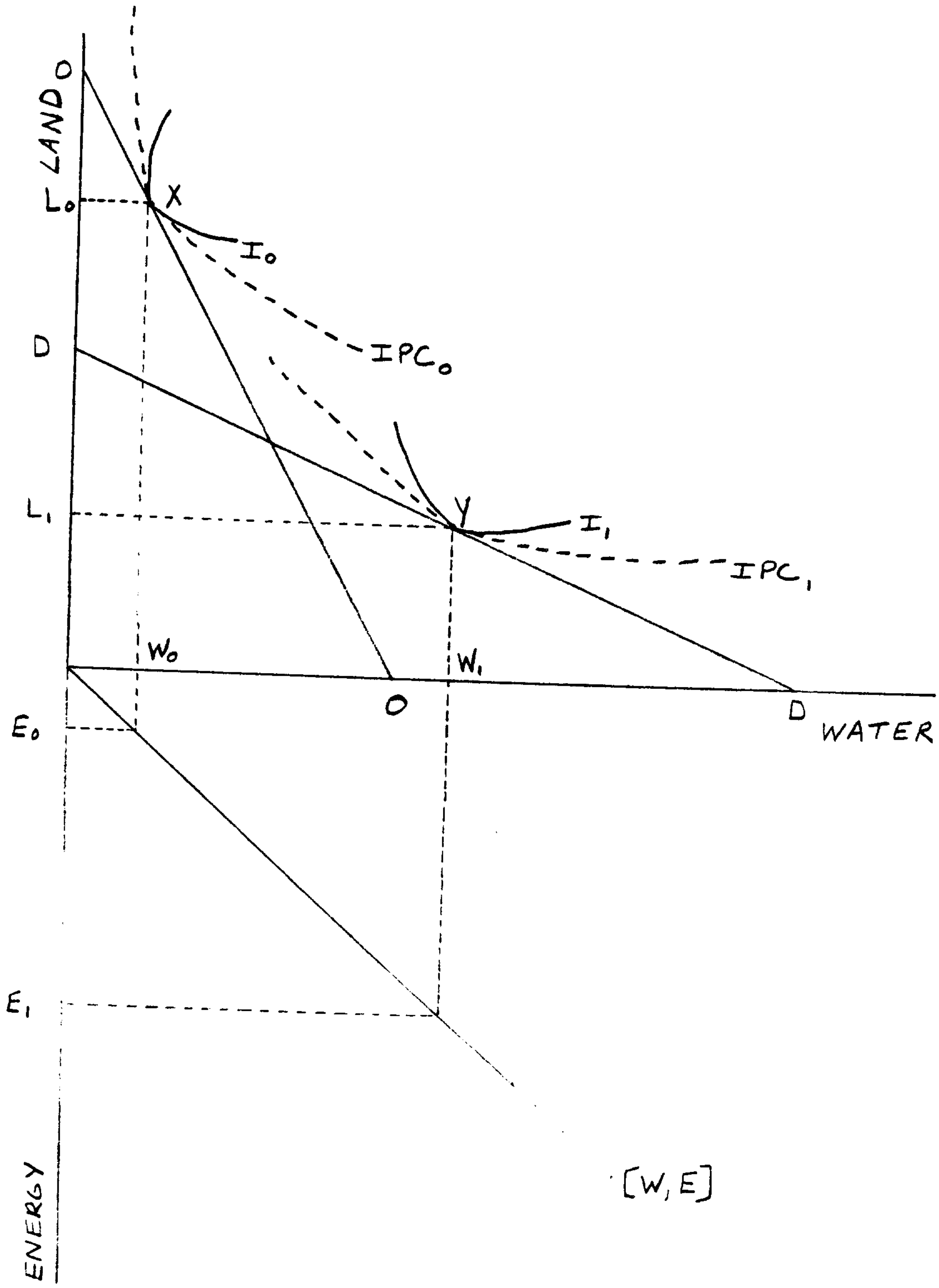

FIGURE 1

INDUCED TECHNOLOGICAL INNOVATION

technology.[1/] This innovation process, reinforced by increased demand for agricultural output, leads to an inward shift in the innovation possibilities curve from IPC_0 to IPC_1, implying efficiency improvements. Within these new innovation possibilities, the particular technology chosen is I_1, at point Y, with L_1, W_1 and E_1 representing the levels of land, water and energy used to produce comparable quantities of output in the new situation.

The overall relationship between factor scarcity and the direction of innovation is shown in Figure 2 (see Binswanger and Ruttan, 1978). Given a fixed production function, relative factor prices are shown by the alternative sets of parallel lines DD, OO and ZZ. Point P is the existing input-output combination. As in Figure 1, OO represents relatively abundant land and scarce water, DD relatively abundant water and scarce land, and ZZ represents an intermediate situation.

If it is assumed that research can alter the existing input-output combination in any of three directions, represented by the arrows a, b and c, then this opportunity set defines the innovation possibilities. Each arrow indicates the distance by which a given innovation moves the input-output combination from reference point P. Hence, activity a is highly water-saving, activity c is highly land-saving, and activity b is an intermediate innovation. If water is cheap relative to land (factor price line DD), then water-using activities such as c will result in greater cost reductions than

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1/ First developed in 1950, center-pivot irrigation consists of a series of water sprinklers mounted on a six-inch pipe that is in turn supported by a row of seven or more mobile towers. Water is pumped through the pipe from a source, and the towers carry the system around the center pivot. Compared with dryland cropping, center-pivots are water using, energy intensive and land and labor saving (Mackenzie, 1983, p. 5).

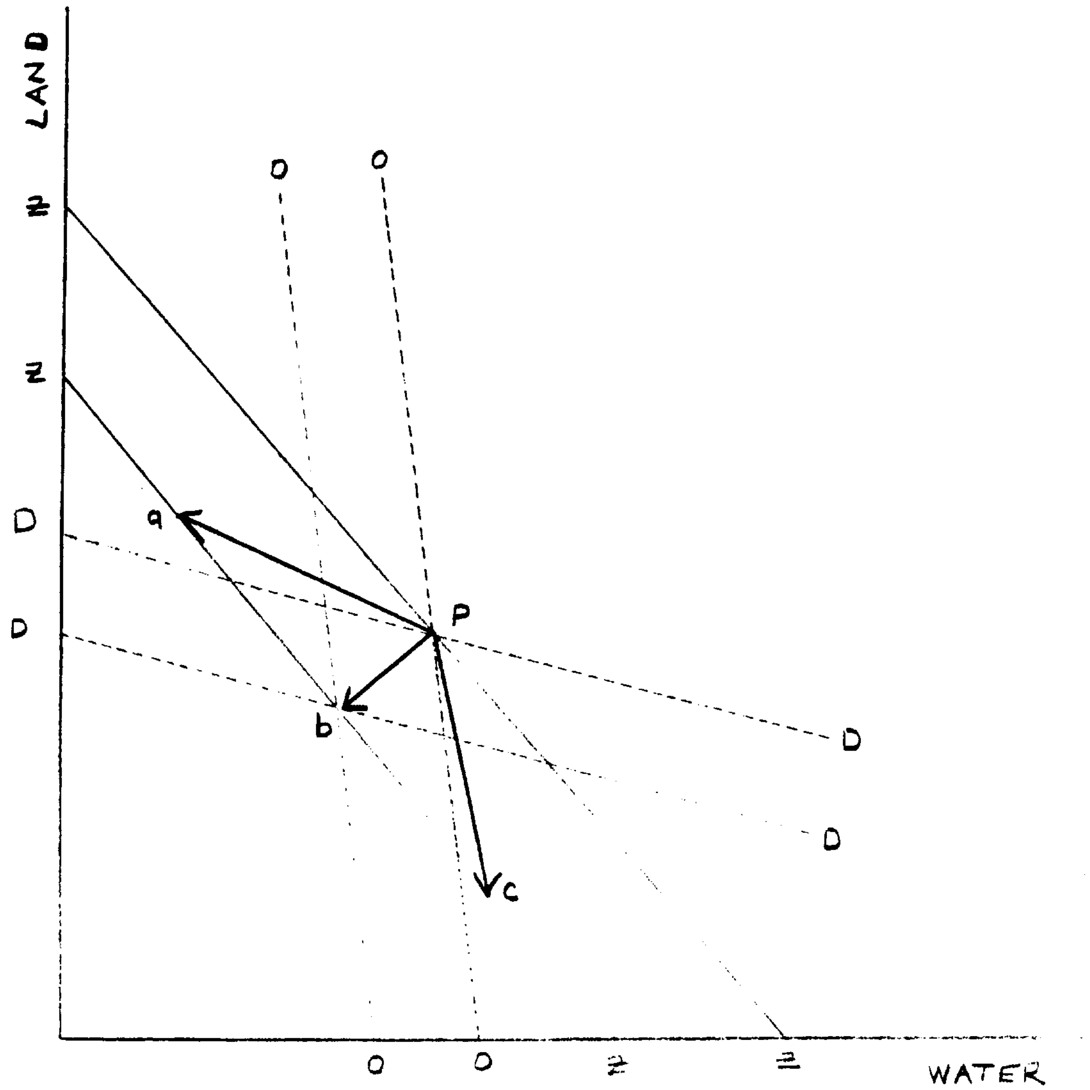

FIGURE 2

INNOVATION ACTIVITIES AND FACTOR PRICES

water-saving activities such as a. If relative factor scarcities shift the price line from DD to ZZ, and from ZZ to OO, water-saving and land-using activities such as b and a are increasingly preferred to water-using and land-saving technologies such as c. These results follow from the fact that the expected benefit from an innovation activity is the sum of reductions in input requirements weighted by the price of each factor. Water saved times its price, plus land saved times its price, will induce cost-minimizing agents to adopt water-using and land-saving technologies whenever water is cheap relative to land. Binswanger and Ruttan (1978) and Hayami and Ruttan (1985) develop full models of this process, taking into account not only changes in factor prices but product prices, scale of output, innovation costs, and market size.

Criticisms of the induced innovation hypothesis have been advanced because it is often interpreted to depend on accurate signaling of resource scarcity by market prices. As the above analysis emphasizes, it is relative scarcity, rather than market prices, which is the fundamental basis of the theory. Market prices may not reflect this scarcity due to externalities or other market failures. However, these market failures themselves create incentives to innovate institutions which allow actual (or perceived) relative scarcities to be reflected (for a discussion see Crosson, 1986, and comments by Runge). The theory of induced technological innovation in agriculture must therefore be augmented by treating institutions as well as technology as endogenous.

It was this realization that led Hayami and Ruttan to the complementary concept of "induced institutional innovation." Institutions "are the rules of society or of organizations that facilitate coordination among people by helping them form expectations which each person can reasonably hold in dealing with others" (Hayami and Ruttan, 1985, p. 94). The demand for this coordination arises from the need for assured benefits streams, now and in the future, in the form of rules of exclusion and inclusion which institutions supply (Runge, 1984a, 1984b).

In the absence of dictatorship, institutions must generally result from collective action of one sort or another. Collective action involves the innovation of new rules regulating individual and group behavior. The supply of such new rules will be influenced by the cost of achieving consensus and/or suppressing opposition (Olson, 1965). In some cases, this may mean developing new property rights in connection with factors of production including land, water, or energy. In other cases, especially where externalities and public goods are concerned, collective action in the form of other nonmarket institutions may be required, in which substantial political costs must be incurred to enact new taxes, subsidies or other rules and regulations.

The remainder of this paper is devoted to the interaction of technological and institutional innovations, in which technical choices induce institutional reforms in laws and regulations affecting agriculture. The demand for institutional change is often derived from technological change, as the discussion of environmental regulation below will show. The key element linking technological choice and institutional innovation in the model below is not only the relative scarcity of factors measured in terms of quantity, but the effect of initial choices of technology, such as center-pivot irrigation, on the _quality_ of factor inputs.[1/] By accounting for such

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1/ This linkage, especially in the case of water quality, was suggested by S.V. Ciriacy-Wantrup (1961).

qualitative effects, the induced innovation model is expanded and enriched. At the same time, where these qualitative impacts are unreflected in market prices, a reason is provided why technical choices in agriculture are not guided by market institutions alone. Quality effects of technical choice may be an important form of missing market. The institutions induced by these missing markets, including environmental regulations, may increasingly constrain the choice of agricultural technique.

Technological Choice and Environmental Quality

Consider a two-stage model of technological choice in agriculture. Let there be two types of activity. The first is agricultural production using land, water and energy to produce food; the second is consumption. There are two types of agents: farmers and consumers. Some agents (farmers) are both producers and consumers. Consumers demand food produced by farmers. They also consider the quality of land and water direct consumption goods giving rise to utility. Farmers and consumers may both consider water as a consumption good while farmers also consider it as a factor input. The consequence of producer-consumer externalities resulting from this interdependence will be considered below.

In the first stage, relative factor scarcity determines technical choices for producers. In the terms considered above the relative scarcity of land, water and energy can be used to explain research into alternative technologies such as center-pivot irrigation. In the Central Sand Counties of Wisconsin, for example, unreliable rainfall, low water-holding capacity of the soil, high commodities prices, and abundant underground water sources encouraged University of Wisconsin research during the 1950's and 1960's into the application of new irrigation technologies and subsequently rapid adoption of center-pivots. In 1974 irrigated acreage in these counties was 10 times what it was in 1945, while from 1974 to 1977 alone irrigated acreage grew by 60 percent. During the same period, acreage irrigated with center-pivot technology increased nationally by 61.9 percent (Sloggett, 1979).[1/]

1/ Once such choices are made and capital is tied up in them, they persist until new relative factor prices are clearly established. These concerns have led Frederick (1980), among others, to argue in favor of careful attempts to accurately evaluate changing water and land scarcities. However, even perfect foresight with respect to quantitative scarcity would be insufficient if qualitative considerations entered individual utility functions.

A second stage effect of a technological choice such as center-pivot technology is on the quality of factors, such as water, that enter individual utility functions as direct consumption goods. Center-pivot irrigation, for example, affects the quality of water as a consumption good for non-agricultural purposes. In the case of Wisconsin, the coarse-grained sandy soils of the Central Sand Counties hold less than an inch of water per foot, and are quite permeable in most areas, where groundwater is near the surface. Hence, although the quantitative abundance of water as a factor of production encourages irrigated crop production, it also encourages irrigation at levels which have contributed to leaching of nitrate through the sandy soils and into groundwater sources (Griffin and Bromley, 1981). This leaching has led to nitrate contamination of local water supplies, reducing the quality of water, despite the fact that quantity has remained largely unaffected. Although the example is specific, the phenomenon is general: technical choices in agriculture may affect the quality of factors and thus the physical environment. As Saliba (1985) observes, quality and quantity of groundwater are not separable, making careful appraisal of specific water quality characteristics crucial to the evaluation of alternative agricultural production techniques.

In order to capture these impacts of technological choice on consumption, we need to define factors that also serve as direct consumption goods in terms of their characteristics. Following Lancaster (1966), the characteristics of water may be treated as a bundle of the form:

(1) $Z_w = (z_1, z_2, \ldots, z_j, \ldots, z_n)$

where Z_w is a vector of consumption (and/or production) characteristics defining water resources and $(z_1, \ldots, z_j, \ldots, z_n)$ are particular characteristics such as salinity, rate of flow and nitrate levels. The use of such characteristics models to measure qualitative differences giving rise to utility in the consumer choice literature is well-developed (see Deaton and Muellbauer, 1980, pp. 243-272; Ladd and Suvannunt, 1976). For purposes of illustration, I shall use an application of these models pioneered by Griliches (1971) and widely used in the literature on environmental quality. This is the hedonic price estimation model.

The hedonic technique is a method for estimating the implicit price of characteristics such as water quality. If water is differentiated by its degree of nitrate pollution, for example, then one of its characteristics (z_j) might be the level of nitrates. Letting W represent water as before, and Z_w its vector of quality characteristics in a given area (such as the Central Sands or High Plains), if water quality varies from place to place, the differences in these characteristics will be revealed in its price <u>if a market for water exists.</u> Even if water is a public good, or externalities indicate missing markets, the implicit price of water quality characteristics may be revealed if water is weakly complementary with a good which is traded in private markets (Maler, 1974). A typical example is the estimated impact of water quality characteristics on property values in which a market for property is presumed to exist. Because this approach is widely used, it will be briefly developed here (for expositions, see Freeman, 1979; Feenberg and Mills, 1980).

Assume that each consumer derives utility from consumption of the characteristics of a composite commodity, water quality characteristics, and a flow of other characteristics from property. To the potential consumer of property, the flow of services from it is a function of characteristics such as distance from metropolitan areas, soils, etc. Let Z_D be the vector of distance characteristics and let Z_S be the vector of soil characteristics in the area in which the property is located. Finally, let Z_w be the level of water quality, defined in terms of individual characteristics (such as nitrate levels) that are relevant to consumer choice. We may then state the flow of services from property as

(2) $P = P(Z_D, Z_S, Z_w)$.

If it is assumed that the area under study constitutes a single property market with sufficient variation in these characteristics to show measurably different responses, and that individuals are informed and free to choose property based on its characteristics, then it is possible to infer inverse demand functions for water quality characteristics from preferences revealed in the property market.

The price (or rent) of a given parcel i of property, R_i, can be expressed as a function of the vectors of characteristics for that site

(3) $R_i = R(Z_D, Z_S, Z_w)$

Recall that

$$Z_w = (z_1, z_2, \ldots, z_j, \ldots, z_n)$$

where z_j is a specific characteristic such as water nitrate levels, and z_1, z_2, etc. are other water quality characteristics.

The hedonic procedure is first to estimate an hedonic function for (3) which explains the price (or rent) of property in terms of its various characteristics. The partial derivative $\frac{\partial R_i}{\partial Z_w}$ gives the implicit marginal price of water quality on characteristics property values:

$$\frac{\partial R_i}{\partial Z_w} = \begin{bmatrix} \frac{\partial R_i}{\partial z_1} \\ \frac{\partial R_i}{\partial z_2} \\ \frac{\partial R_i}{\partial z_j} \\ \frac{\partial R_n}{\partial z_n} \end{bmatrix}$$

Note that $\frac{\partial R_i}{\partial z_j}$ gives the implicit marginal price of nitrate levels on property values. In principle, equilibrium results when marginal willingness to pay by consumers for a given characteristic z_j or vector of characteristics Z_w is equal to the marginal implicit price.

To derive the inverse demand function for water quality characteristic j (nitrates) on property parcel i, it is necessary to combine the implicit prices revealed for water quality with the usual determinants of demand: consumers' income and tastes and preferences. If it is hypothesized that consumers' demand price (willingness to pay) for water quality is a function of Z_w, income M, and other variables affecting tastes and preferences, including Z_D and Z_S, then the demand function may be expressed as weakly separable in the property market, so that the prices of goods other than property can be omitted from the willingness to pay for property parcel i (Freeman, pp. 124-125). The equilibrium condition equating the implicit marginal price of water quality to marginal willingness to pay for characteristic j then gives willingness to pay (WTP) for water quality on property parcel i as

(4) $WTP_{ij} = \frac{\partial R_i}{\partial z_j} = f(Z_w, Z_D, Z_S, M)$

The conditions for estimating this willingness to pay function are quite strict, and have led to numerous criticisms of the hedonic method and alternative proposals for the measurement of environmental quality (Brookshire et. al., 1982; Hanemann, 1980; Mendelson and Brown, 1983; Caulkins, et. al., 1984).[1/] All such measures seek to capture qualitative determinants of demand as well as income effects.

For the purposes of this exposition, the key objective is to relate the literature on the estimation of environmental quality characteristics to the induced innovation model of technological choice. If technological choice in agriculture creates environmental quality effects, and these effects have implicit prices for consumers of water, then such qualitative effects can be estimated by the hedonic or some other method. The crucial point is that the impact of agricultural producers' choices on the quality of consumption may in turn affect the market for factors such as water to the producers themselves. The mechanism leading from consumers' demand for water quality characteristics back to producers' choice of technique may be the market or other institutions depending largely on the extent to which implicit prices are revealed by the market mechanism itself. Where they are not, a market failure or missing market is said to exist, and nonmarket signals may prove more significant than market signals.

1/ As Freeman notes (1979, pp. 125-127) non-linearity in equation (3) is required for (4). If all consumers are identical, then incomes and utility functions do not vary across consumers, and the willingness to pay function (4) is identical with (3). Where these two special cases do not hold, the supply side of the market for water quality must be examined. Harrison and Rubinfeld (1978) argue that if the supply of a good such as air or water quality is perfectly inelastic with respect to price or willingness to pay at each property location, then quality is independent of consumers' willingness to pay, and equation (4) is a fully identified demand curve, at least in the short and intermediate run.

Market Failure and Institutional Innovation

The market is an institution, one in a set of institutions that coordinates expectations of outcomes by signaling the intentions of agents. Markets do this through price signaling. Although it comes as no surprise to non-economists, there are institutions other than the market that also provide coordination, supporting and often complementing the functioning of markets themselves. Whenever markets fail accurately to signal agents, an incentive exists to innovate non-market institutions that will do the job of coordination. Of course, these signals may involve more than the equation of marginal values. Not only efficiency but equity must often be assured. This signaling, whether by markets or by non-market institutions, is not costless. Although this point is most often made in connection with government institutions (eg. Wolf, 1979), markets too are not free of charge. Absent the convenient artifice of the Walrasian auctioneer, markets require their own costly forms of collective action to function. In reality, the auctioneer must be both appointed and paid.

It is well known that a full set of markets for water quality characteristics does not exist. If the implicit price of water quality characteristics is fully reflected either in the price of water itself, or in some weakly complementary private good such as property values, we can argue that these implicit price signals are a sufficient basis for the allocation of water quality according to willingness to pay. Property values can signal the implicit marginal value of water quality to consumers of property, and act, in equilibrium, to efficiently allocate environmental quality characteristics. However, the implicit price of water quality characteristics is <u>not</u> generally fully reflected in property values. And a market (or markets) for water quality characteristics themselves is (are) likely to be missing. In such cases, the signaling process performed by the price system, including implicit prices estimated by hedonic methods, will not equate marginal willingness to pay with this marginal implicit price.

$$(5) \quad WTP_{ij} \neq \frac{\partial R_i}{\partial z_j}$$

The reasons for these missing markets are potentially large (see Saliba, 1985). Even if the quantitative scarcity of water is accurately signaled to agricultural producers, leading to the adoption of efficient irrigation technologies, there need be no assurance that the qualitative impacts of this choice of technique on water quality are accurately signaled either to farmers or consumers. Because qualitative effects are often more difficult to measure and perceive, there is reason to believe that markets for them are indeed missing on grounds of imperfect information (see Dahlman, 1979; Runge and Myers, 1985).

In the face of such missing markets, an incentive is created by the disequilibrium reflected in inequality (5) to develop institutions capable of achieving a level of efficiency unachievable by existing institutions alone.[1/] This incentive to innovate institutions arises because marginal willingness to pay for water quality is greater than its marginal implicit price as reflected in property values. The result is that government subsidies, taxes, or regulations on property may be innovated in order to achieve the equivalence between willingness to pay and water quality's marginal implicit price.

1/ A familiar result in environmental externalities theory is that there exists a correspondence between a tax-subsidy scheme to internalize a (Pigouvian) externality and a particular set of regulations which will achieve the same effect (see Dales, 1968; Baumol and Oates, 1975).

Of course, the development of these institutions is not costless. As Buchanan and Stubblebine originally emphasized, costs may exceed benefits, and the missing market may be Pareto-irrelevant. However, the fact that it is irrelevant on the grounds of Pareto-efficiency does not obviate the possibility that institutional innovations may arise from concerns of equity or fairness (Runge and von Witzke, 1986). If farmers are perceived as receiving an inequitable share of the benefits of water resources and consumers' willingness to pay for water quality exceeds its marginal implicit price as signaled by the market, then even if the costs of institutions assuring this equity exceed their benefits, equity or fairness may be used to justify collective action to constrain the subsequent technological choices of agricultural producers.

Consider the following sequence. Extensive irrigation leads to nitrate pollution of groundwater. Despite continued abundance of water as an agricultural input, declining water quality affects some consumers' health.[1/] If consumers value water quality highly, and are willing to pay for it at levels in excess of those reflected in property values, this disequilibrium creates incentives for institutional innovation in the form of taxes, subsidies, or regulations that constrain groundwater or fertilizer use by agricultural producers, in effect raising the relative factor price of water in production. If enacted, these measures reduce farmers' incentive to continue water-using irrigation methods. New research is stimulated into less water-using irrigation techniques, inducing a new round of water-conserving

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1/ The primary health effects associated with nitrate pollution are methemoglobinemia (Blue baby syndrome) and gastric cancer (see Griffin and Bromley, 1981).

technological innovations, such as drip-irrigation. In Figure 3, the effect is equivalent to a shift from price line DD, reflecting relative factor abundance for water, to a new one such as ZZ (also shown in Figure 2 above). Figure 3 shows how a new round of research responding to the new regulatory or tax-subsidy constraints then induces innovation possibilities such as IPC_2, and new techniques such as I_2.

This may be thought of as a third stage in the process of induced innovation, triggered by missing markets for environmental quality characteristics. These missing markets feed back to affect subsequent choices of agricultural technique. In effect, institutional changes are consumers' response to the environmental quality impacts of agricultural technology. These impose costs on producers, altering relative factor prices and inducing subsequent changes in agricultural technology. Both technology and institutions are thus endogenously linked to changes in the relative scarcity of factors and changes in environmental quality.[1/]

The range of possible institutional innovations is large, and need not include coercive government action or regulation. In the case considered here, the relative costs of various institutional alternatives affecting water quality may make centralized government regulation far less attractive than local water users associations and/or the use of quasi-market or newly created market institutions (Anderson, et. al., 1983). In short, the relative costs of these institutional alternatives are as relevant as they

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1/ In the case of irrigation, recent evidence confirms declining U.S. rates of increase in its use, although the exact causes require further investigation. According to a recent USDA study by Sloggett (reported in Agweek, 1986, p. 58): "Higher costs are making farmers take a closer look at conservation, including ways of recovering irrigation runoff and use of low-pressure center-pivot irrigation systems."

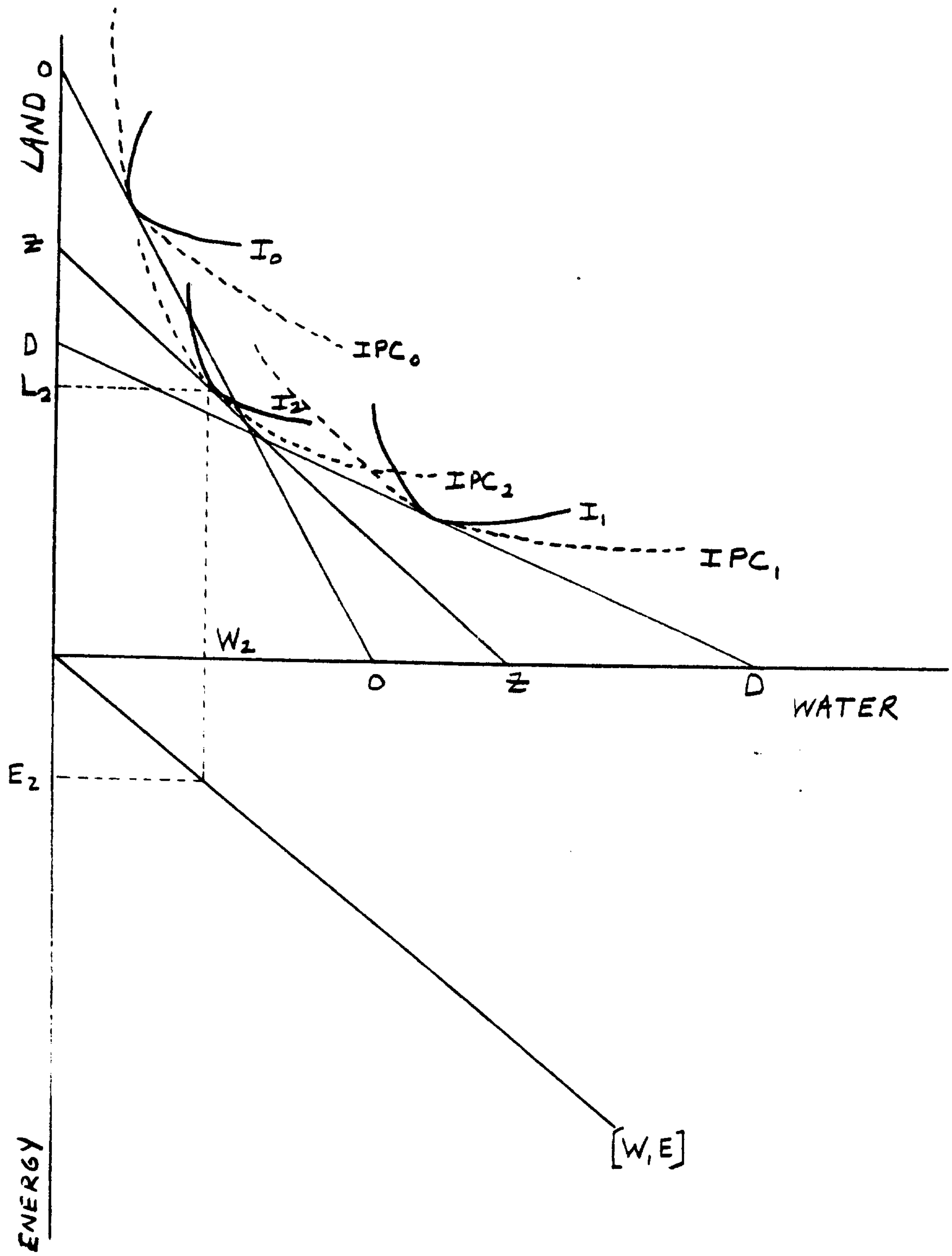

FIGURE 3

INDUCED TECHNOLOGICAL INNOVATION

are in the choice of technology. However, because institutional choices involve collective actions that may be affected, indeed dominated, by considerations of equity rather than efficiency, governmental rather than non-governmental institutions may often be chosen despite their costs in efficiency terms.[1/] Considerations of equity and fairness are also linked to the distribution of income within and across societies.

1/ Ruttan (1971, p. 712) has stated: "Redirection of technical effort in response to the rising economic value of environmental services will involve complex interaction between technical and institutional change. Extension of the theory of induced innovation to include the process of institutional innovation adds significantly to our understanding of this process. It seems consistent with historical experience to view institutional change as resulting from efforts of economic units (households, firms, bureaus) to internalize the gains and externalize the costs of economic activity and efforts by society to force economic units to internalize the costs and externalize the gains. Where internalization of the gains of innovation activity are difficult to achieve, institutional innovations involving public sector activity become essential" [emphasis in original].

<u>Changes in Income and the Demand for Environmental Quality</u>

Ruttan (1971) has argued that environmental quality is a bundle of characteristics that will be more highly valued as incomes increase.

> [I]n relatively high-income economies the income elasticity of demand for commodities and services related to sustenance is low and declines as income continues to rise, while the income elasticity of demand for more effective disposal of residuals and for environmental amenities is high and continues to rise. This is in sharp contrast to the situation in poor countries where the income elasticity of demand is high for sustenance and low for environmental amenities. The sense of environmental crisis in the relatively affluent countries at this time stems primarily from the dramatic growth in demand for environmental amenities (pp. 707-8).

Two important implications follow from this argument. First, by Engels' Law, demand for food production ("sustenance") at higher income levels will be proportionately less than for other goods. If environmental quality is a superior good, as Ruttan argues, then as relative demand for agricultural output falls with increases in income, demand for environmental quality will rise. This argument applies to the demand side only, but is reinforced on the supply side by Smith (1975), who has emphasized that the irreversibility of losses in environmental quality characteristics makes them even more scarce over time, raising their relative implicit value. Second, this argument should be valid both across countries (as Ruttan intended it) as well as <u>within</u> countries, so that higher income groups should demand more environmental quality characteristics, ceteris paribus, than lower income groups. The rising income elasticity of demand for environmental quality characteristics I will distinguish as Ruttan's Law, although Hirsch (1976) also holds a claim.[1/]

These implications are helpful in explaining recent trends in the environmental regulation of agriculture. Before exploring them from a policy perspective, however, the significance of changes in income will be related to the model developed in previous sections.

Recall that the inverse demand function derived from the hedonic equation of marginal willingness to pay for water quality characteristics such as nitrates (j) on a given property parcel (i) can be expressed as a function of the environmental and other characteristics of the parcel (Z_w, Z_D, Z_S) as well as income (M).

$$WTP_{ij} = \frac{\partial R_i}{\partial z_j} = f(Z_w, Z_D, Z_S, M)$$

Estimation of this willingness to pay function allows empirical testing of Ruttan's Law that willingness to pay for water quality is an increasing function of changes in income. If equilibrium between marginal willingness to pay and the marginal implicit price of environmental quality is not achieved due to missing markets, yet changes in income are significant explanatory factors in the demand for water quality characteristics, one can

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1/ In Social Limits to Growth (1976), Hirsch argued that "positional goods," including environmental quality, are (1) scarce in some absolute or socially imposed sense and (2) subject to congestion or crowding through more extensive use. If positional goods remain in fixed supply as other goods become more plentiful, their price will rise, in the same way suggested by Smith (1975). The tendency for positional goods to increase in price, Hirsch (p. 28) observes, "will be reinforced if rising incomes increase the demand for them faster than for material goods." This is to be expected (1) because the use of them involves not only effort but time, a complementary superior good; (2) because primary material needs including food have already been satisfied at some threshold. The combined effect of these influences "is that goods and services sharing some or all of the characteristics of positional goods attract an increasing proportion of family expenditure as family income rises."

speculate that higher income consumers and countries will have the greatest incentive to call for institutional innovations to correct for these missing markets.

Interestingly, this should be the case regardless of the particular institutional innovation sought as a remedy. If income is a significant explanatory variable, it can be interpreted to suggest that debates over environmental quality characteristics, and remedies for missing markets, will revolve (in high income circles) not around whether something should be done to equate willingness to pay and the implicit value of environmental quality, but what should be done in terms of the costs (and equity) of alternative institutional arrangements. Some may favor government regulation over market or quasi-market solutions, and others may have a preference for regulation. But environmental quality will be a consensus objective - at least among high income groups.

Correspondingly, international debate over environmental quality will occur primarily between high income countries (such as Canada, Western Europe and the United States) rather than between low income countries. Within countries such as the U.S., the debate over institutional alternatives will be conducted primarily between "competing elites," represented by groups such as the Heritage Foundation on the one hand, and Worldwatch Institute on the other, with the Nature Conservancy and Sierra Club somewhere in the middle. These groups will all reflect upper income preferences for environmental quality, but their preferred solutions may vary from newly created markets ("privatization") to direct government regulation.

In contrast, as incomes rise, the growing weakness of demand for agricultural products compared with environmental quality suggests that the value of agricultural output will fall relative to the implicit price of environmental quality. The case on efficiency grounds for intervention to correct for missing markets in agriculture will be weakened as the case for intervention to correct for missing markets in environmental quality characteristics is strengthened (see Myers, 1986). We may think of this as the interaction of Engel's Law and Ruttan's Law. Granting the importance of equity considerations relative to efficiency suggests that transfers may continue to the agricultural sector, but that these transfers may be increasingly undercut by a realization of the comparative efficiency gains that could result from withdrawing transfers from agricultural producers who harm the environment. This suggests that as incomes rise the relative share of political resources devoted to agriculture - not only by government but by private voluntary or lobbying groups - can be expected to fall in relation to those devoted to environmental quality.

Finally, this analysis suggests that whenever markets for environmental quality characteristics are perceived to be missing and institutional innovations are undertaken, the relative factor prices facing agricultural producers may be altered, leading to new directions for agricultural research and technology that reflect the higher value given to these environmental quality characteristics (see English, et. al., 1984). The Clean Water Act provides just one example of such an institutional innovation. Recent examples of changing technological possibilities partially induced by changing institutional constraints include no-till cultivation practices, integrated pest management, and a variety of more environmentally benign herbicides and pesticides.

Implications for Policy

An analytical approach has been developed to describe endogenous changes in agricultural technology and their relationship to environmental quality. Three observations with relevance for policy result. First, environmental quality concerns will encroach on agricultural technology choices to an increasing extent in higher income countries, but will have less effect in lower income countries if Engel's Law and Ruttan's Law are valid. Second, this encroachment will affect the choices of technique of agricultural producers through market institutions in some cases, and through non-market institutions in others, depending on the extent to which markets are missing and the particular policy response. Third, the linkage between growth in incomes, food demand, and the demand for environmental quality suggests that growth in incomes will create endogenous incentives to reduce the harmful environmental impacts of agricultural technology. Whether these incentives are sufficient to avoid irreversible environmental damages from technological innovation in agriculture is largely a question of policy design and execution. Each of these observations will be considered in turn.

In a recent policy analysis, Batie, Shabman, and Kramer (1986) argue that output expanding agricultural technology is increasingly perceived to be a threat to environmental quality. In part as a result, institutions innovated solely to support the income of producers engaged in output expansion during earlier periods are now considered misdirected. Erosion and other environmental damages resulting from full-scale planting in response to international demand, together with the growth of the environmental movement, are identified as major causes of the shift in perception.

The model developed above provides a framework within which to interpret this shift from an economic perspective. Technological innovations of the 1970's, which responded to the increased food demands (in large part of lower income countries), prevented domestic adjustments which Engel's Law would have dictated if U.S. farmers had produced solely for domestic markets. Yet as agricultural output (and technology) responded to the export market boom, Ruttan's Law was also operating, creating increasing demands for environmental quality as incomes rose. The perception that market forces in agriculture failed to account adequately for environmental quality characteristics led to support for institutional innovations including environmental legislation such as the Clean Water Act, creating a new set of constraints for agricultural producers which conflicted with the maximum output objectives associated with Earl Butz' famous incantations to plant "fencerow to fencerow."

These environmental quality constraints entered the 1985 Farm Security Act in the form of cross-compliance, strict sodbuster language, and the acreage retirement provisions of the Conservation Reserve Program. Such institutional innovations were in large part the result of lobbying by environmental interest groups with new and significant interests in policy. Although difficult to measure, it would appear that as these groups gained influence, the general farm organizations' overall strength declined, almost in inverse proportion. The consequence of these institutional changes is a new set of constraints on agricultural technology. While considerable disagreement remains over agricultural policies, there is surprisingly strong consensus around environmental quality as a policy objective inside and outside of agriculture. Evidence of willingness to pay through higher taxes for improvements in environmental quality at levels in excess of those reflected by current policy are strongly supported by surveys conducted by Resources for the Future (1980) and others.

These changing valuations and institutions are also being felt in the redirection of research priorities toward more environmentally benign agricultural technologies, including no-till cultivation, more bio-degradable pesticides and herbicides, integrated pest management, and, as suggested by the example above, more water-conserving forms of irrigation technology.

If the above analysis is accurate, these pressures will be felt less at lower levels of income both within and across countries. Within the U.S. and other high-income countries, this suggests a "competing elites" model of environmental policy. Debates over environmental policy will be drawn in terms of what markets for environmental quality characteristics are missing, and what forms of institutional innovation are best able to replace them, not about whether to do anything at all. Competing elites can be expected to range along a continuun from those favoring market and quasi-market solutions to those favoring direct government regulation and control.

Negotiations between high income countries such as Canada, the United States and the nations of Western Europe will also increasingly involve environmental quality issues. Recent discussions over acid rain are an example, suggesting how environmental quality impacts of (industrial) technology induce demands for institutional innovation which may in turn trigger new rounds of research and technological innovation to reduce SO_2 emmissions and improve air and water quality.

In lower income countries, however, the demand for environmental quality characteristics will take second place to the demand for agricultural output. This reversed emphasis is typified by some of our major agricultural export competitors, such as Brazil. Like the U.S. in its own early period of economic growth and expansion, lower income countries reveal less interest in environmental quality than in expanded agricultural production, and are likely to impose far fewer constraints on their agricultural sectors in its name.[1/] This is unfortunate both for environmental quality in the Third World, and for competing U.S. agricultural producers, who will be forced to bear the additional costs that tastes wrought of higher incomes bring as their technologies adjust to stricter environmental regulations.

In the long run, however, international comparative advantage in agricultural production will be on those soils that are both productive and resistant to erosion losses, implying fewer offsite damages to water quality (Larson, et. al., 1983). As the demand for environmental quality grows, it can work constructively to shift production onto those lands on which the United States' comparative advantage is greatest. Policies such as the Conservation Reserve Program must therefore be targeted so as to protect both on-site productivity and minimize off-site damages (Crosson and Stout,

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1/ This generalization seems more valid at the level of national policy than for individuals in Third World countries. A 1981 study of water supply and the impact of quality characteristics on Bengali villagers, for example, found that "for drinking water, quality is a powerful determinant of the attractiveness of a water source, distance is not a powerful determinant for any of the income groups [in the study], and conflicts over access to drinking water sources adversely affect the choices exercised by poor families." Even in a village economy, however, systematic differences were found between income groups' preferences for water quality for drinking and non-drinking uses. The inclusion of these water quality considerations has important implications for the choice of technology, and argues strongly "against a water supply program, like the existing UNICEF program, which is exclusively devoted to installation of tubewells." These programs have "assumed that the most important factor governing the use of a drinking water source is the distance of the source from the home," rather than water quality characteristics (Briscoe, et. al., 1981, p. 180).

1983). The fact that Engel's Law and Ruttan's Law are working together in the U.S. and Europe also suggests that conservation acreage retirement programs are in the long-term interests of both, and can be made a constructive basis for future agricultural policy cooperation and negotiations. The same pressures leading to the encroachment of environmental interest groups on the agricultural policy process in the U.S. are responsible for the growing influence of the "Green" parties in Western Europe. Since both the U.S. and EC are chronic overproducers of grain, an opportunity exists to use environmental quality as a basis for surplus stock reductions.

A second observation concerns the relative capacity of new institutions to respond to missing markets for environmental quality. From a policy perspective the issues are (1) which markets are missing? and (2) what are the most efficient and equitable institutions to deal with them? Issue (1) is an empirical matter, based on the examination of specific environmental quality characteristics in relation to particular agricultural technologies. In the case of nitrate pollution of ground water, for example, Saliba (1985, p. 1234) argues that "ground water contamination is more than a technical problem; it is also one of resource misallocation, unrevealed values concerning water quality, and distorted incentives related to water use." If these symptoms of market failure exist in a given case, then issue (2) becomes relevant: What can be done? In the case of water quality, alternatives range from newly invented markets, as proposed by advocates of privatization (eg. Anderson, Burt, and Fractor, 1983) to direct control over groundwater pumping by state agencies (eg. Henderson, 1984). The implicit value attached to environmental quality characteristics, if it can be discovered, will be important to determining willingness to pay for those policy alternatives. However, the choice among alternatives will be guided by considerations of equity as well as efficiency. These are issues about which individuals equally concerned with environmental quality may nonetheless disagree. Institutional solutions seldom are uniquely determined. Again quoting Saliba:

> Suppose households significantly increase bottled water purchases following publicity regarding nitrates in the city water supply. It may be inferred that many consumers are willing to pay at least the cost of bottled water to avoid nitrates in drinking water. These inferential values can be compared to the costs of imposing fertilizer management restrictions on agriculture to determine which approach more efficiently resolves nitrate externalities - bottled water for households or regulation of farm practices. The distributional effects of these two alternatives on consumers and farmers vary greatly and would likely become the focal point of policy discussion (1985, p. 1235).

While the hedonic approach discussed above offers one method of eliciting willingness to pay, a variety of other approaches exist and are rapidly being refined. The particular technique employed is less important than recognition of the fact that environmental quality characteristics do have value for which individuals seem willing to pay. Estimates of this willingness, especially where markets are missing, will be important in determining the costs of various institutional alternatives.

A final issue is whether endogenous pressures inducing technical and institutional change suggest that problems of environmental quality will "take care of themselves." This interpretation of the induced innovation model is erroneous. The theory of induced technological and institutional change provides a basis for interpreting decisions that have occurred and are in the process of occurring. But that individuals respond rationally to constraints is hardly a policy prescription in itself, especially where missing markets and differences over the costs and equity of institutional alternatives remain. There is nothing in it that suggests complacency over our capacity for institutional solutions to problems of environmental quality. The correct interpretation, in my view, is that because the value attached to environmental quality characteristics in the high income countries of the West is high and getting higher, rewards will go to successful innovators of agricultural policies that recognize and respond to these values. I am optimistic that policymakers, and the research community generally, will respond to this demand in the high income countries. Of greater concern is the low value that may be attached to harmful environmental quality characteristics by poorer nations, and the poor among us, who bear a disproportionate share of its burdens. But in relation to primary material goods, such as food, can we blame them? The way to environmental quality, if Ruttan's Law is valid, is through increases in income, which may require not only growth, but redistribution.

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