DYNAMIC ENVIRONMENTAL TARGETS AND TECHNOLOGICAL PROGRESS

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CONTENT

Summary

This paper analyzes socially optimal responses of environmental targets (i.e. targets on pollutant flows) to different types of technological progress. With reference to a simple macroeconomic model including production, pollution generation, and pollution treatment, a socially optimal temporal sequence of environmental targets is derived. In this context, it is shown that different technological improvements (e.g. increases in labor productivity or improvements in the pollution technology of the production activity) require different dynamic target responses. Moreover, every technological improvement representable by the model calls for a "intertemporal target reversal", i.e. a change in the environmental target's direction of movement through time.

Zusammenfassung

Diesert Artikel analysiert die optimalen Reaktionen umweltpolitisher Zielsetzungen auf verschiedene Arten des technologischen Fortschritts. Anhand eines einfachen makroökonomischen Modells der Produktion, Umweltverschmutzung und Umweltreinigung wird ein optimaler dynamischer Pfad der Residuenströme abgeleitet. In diesem Zusammenhang wird gezeigt, daß die verschiedenen Arten des technologischen Fortschritts unterschiedliche optimale Residuenpfade hervorrufen. Weiters bewirkt jede Art des technologischen Fortschritts eine intertemporale Umkehr des optimalen Residuenpfades.

1. Introduction

The purpose of this paper is to examine how environmental targets should optimally respond to different types of technological progress. The environmental targets considered here pertain to the flow of harmful residuals (e.g. particulates in the air, phenols in the water, and solid litter on land) from consumption, production, and pollution treatment activities. We are concerned with macroeconomic implications of setting these targets, in particular, with the influence these targets exert on an economy's allocation of scarce resources between (a) the production of consumption goods and (b) the treatment of residuals. Social welfare is augmented by consumption and reduced by pollution. The environmental targets should be set so as to elicit the optimal relation between the production and treatment activities. We show that the optimal target levels depend on the technologies whereby scarce resources are transformed into consumption goods, treatment services, and residual flows. The analysis below indicates that the optimal response of the targets to technological progress depends on which of the technological relations undergoes improvement.

We assume that the residuals are long-lived, whereas the consumption goods are not. Certainly, many of the seriously harmful residuals (such as lead, nitrogen oxides, sulfates, halocarbons, asbestos, mercury, DDT, PBC's, cadmium and nickel) have much longer life spans than most consumer nondurables and even most consumer durables. We suppose that social welfare depends on the <u>flow</u> of consumption, but on the <u>stock</u> of residuals. Consequently, the policy maker who seeks to maximize social welfare through the imposition of environmental targets faces an intertemporal problem. For environmental targets affect the flow of residuals (directly) and the flow of consumption (indirectly, since the use of scarce resources in treatment activities preempts their use in production activities). The present imposition of environmental targets affects social welfare in the present and in the future.

Accordingly, the analysis below indicates that the optimal reactions of environmental targets to technological progress should be dynamic. In other words, the target levels at one point in time should depend on the target levels at other points in time. We distinguish among short-run, medium-run, and long-run movements of the targets. It will be shown that a one-shot change of a technological relation does not call for a one-shot target adjustment, but for a temporal sequence of target adjsutments.

The various types of technological progress, which initiate the chain reactions of target adjsutments, will be treated as exogenously given. The endogenous determination of technological change lies beyond the scope of this paper. The types of technological progress to be considered are
(a) reductions in average residual flows from consumption, production, and pollution treatment activities,
(b) reductions in marginal residual flows from consumption, production, and pollution treatment activities, and
(c) expansions in the economy's capacity to provide consumption goods and pollution treatment services.

Although the optimal environmental target responses to these types of technological progress are quite varied, they do have one thing in common: none of the responses consists of monotonic target changes through time. For example, it will be shown that a reduction in the marginal residual flow from the production activity calls for a short-run rise and a medium-run fall of the environmental target. On the other hand, a reduction in the marginal residual flow from the treatment activity calls for the opposite target movements.

None of the technological changes above requires the environmental target to move in the same direction over the short and medium run. In other words, technological progress should invariably elicit "intertemporal target reversals".

Different types of technological progress call for different target responses and these, in turn, have different impacts on environmental quality and economic activity. We shall inquire which types of technological progress are associated with improvements in environmental quality (as measured by the stock of residuals) and which are associated with deteriorations, which stimulate production and which have the opposite effect. Although the various types of technological progress all lead to intertemporal target reversals, these reversals do not all cause the level of production to switch its direction of movement through time (i.e. they are not all responsible for "intertemporal production reversals"), nor do they all induce the level of pollution treatment to switch its direction of movement (i.e. they do not all elicit "intertemporal treatment reversals"). We shall examine which types of technological progress call for production and treatment reversals. To gain a concise overview of these possibilities, the optimal responses to technological progress are presented in terms of four policy paradigms. The paradigms differ with regard to the intertemporal reversals they describe.

We are not concerned with the ways in which environmental targets are implemented -- whether they are achieved through taxes, direct contrls, or reassignments of property rights. Thus, our analysis applies equally to command, free-market, and mixed economies. For all these economies, the incentive structure may be such that the social welfare costs of pollution are not fully internalized by the individual economic agents. Consequently, pollution may be excessive and environmental targets are required.

The model we use to portray the environmental target responses to technological progress is a deterministic one.

The important issues of risk and uncertainty -- with regard to the policy maker's knowledge of technological changes, of the allocation of scarce resources, of the economic repercussions of environmental target setting -- lie beyond the scope of this paper.

The next section contains a simple macroeconomic description of the technological relations linking production, consumption, pollution, and pollution treatment. In Section 3 this description is used to construct a model of optimal environmental targets. This model is related in spirit to the conventional theory of environmental standards, e.g. D'Arge and Kogiku (1973), Forster (1973), Keeler, Spence, and Zeckhauser (1972), Mäler (1974), Plourde (1972), and Smith (1972). With this model, the stage is set for our analysis, in Section 4, of the optimal reactions of environmental targets to the various types of technological progress. Finally, Section 5 contains an overview of the policy implications and some concluding remarks.

2. A Description of Technological Relations

Consider an economy in which the only factor of production is labor (L) and the only produced outputs are a consumption good (Q), a pollution treatment service (T), and a harmful residual (R). The consumption good is nondurable; it lasts only one instant of time. There are three types of economic activity: (1) a production activity in which labor is used to produce consumption goods and harmful residuals, (2) a treatment activity in which labor and harmful residuals are used to produce harmless residuals and some harmful residuals, and (3) a consumption activity in which consumption goods are transformed into harmful residuals. In addition, there is a natural treatment activity in which nature -- through dispersion, dilution, chemical decomposition, and biodegradation -- transforms harmful residual concentrations into harmless concentrations.

Assuming that the marginal social utility of consumption is always positive, it follows that the entire output of Q must be consumed in a socially optimal state of the economy. Thus, Q may be used to represent both the level of consumption and the level of production.

The labor force may be divided into two categories, L_Q devoted to the output of Q and L_T devoted to the output of T. The technological relation between each component of the labor force and its respective output may be described by the following production functions:

$$(1) \quad Q = f_1(L_Q), \qquad f_1' > 0,\ f_1'' < 0;$$

$$T = f_2(L_T), \qquad f_2' > 0,\ f_2'' < 0.$$

The size of the labor force is exogenously given at $\bar{L}$. If we assume that the social utility of consumption always exceeds the social disutility of work, then it is socially optimal for the labor force to be fully employed. (For if there was unemployment, it would be possible to raise Q and T so that the consumption flow would rise and the residual stock would remain unchanged. Yet this possibility implies a social welfare gain.) Thus, $L_Q + L_T = \bar{L}$ in a socially optimal state of the economy.

Given full employment, the two production functions above may be combined to derive a production possibility frontier describing the maximal combinations of Q and T which may be produced with the given labor force:

$$(2) \quad T = F(Q), \qquad F' < 0,\ F'' < 0.$$ [1]

The overall stock of residuals is denoted by R; the overall residual flow is $\dot{R} = (dR/dt)$. The residual flow may be divided into two categories: $\dot{R}_Q$ and $\dot{R}_T$, the former generated by the production and consumption activities and the latter generated by the treatment activity. The corresponding pollution technologies may be described as follows:

$$(3) \quad R_Q = g_1(Q), \qquad g_1' > 0, \; g_1'' > 0;$$

$$R_T = g_2(Q), \qquad g_2' > 0, \; g_2'' > 0$$

(i.e. equal incremental increases in Q and T generate successively larger increases in residual flow).

Let T_N be the amount of harmful residuals cleansed by nature. We assume that nature's treatment activity depends on the overall stock of harmful residuals deposited in the environment:

$$(4) \quad T_N = f_3(R), \qquad f_3' > 0, \; f_3'' < 0$$

(i.e. equal incremental increases in the residual stock elicit successively smaller increases in the flow of residuals cleansed by nature).

Let treatment services (both anthropogenic and natural) be measured in such a way that one unit of treatment service corresponds to one unit of residual cleansed. The net residual flow is defined as the residual flow generated by production, consumption, and treatment minus the residual flow cleansed through anthropogenic and natural treatment:

$$(5) \quad \dot{R} = \dot{R}_Q + \dot{R}_T - T - T_N.$$

Inserting Equations 2, 3, and 4 into Equation 5 yields the following transformation function, which describes the technological relation linking the net residual flow to production and the residual stock:

$$(6) \quad \dot{R} = g_1(Q) + g_2(F(Q)) - F(Q) - f_3(R)$$

$$= k(Q,R).$$

The properties of this transformation function may be derived from the properties of its component functions:

$$(7) \quad k_Q > 0, \quad k_{QQ} > 0;$$
$$k_R < 0, \quad k_{RR} > 0;$$
$$k_{RQ} = 0.$$[2]

This statement of our economy's production and emission possibilities underlies the optimal control model of the following section. In that section we formulate the policy objectives with regard to consumption and pollution and then choose the optimal environmental target from the feasible options described by the transformation function.

3. A Model of Dynamic Environmental Targets

At every instant of time, social welfare is assumed to depend on the consumption flow and the residual stock:

$$(8) \quad U = U(Q,R),$$

where $U_Q > 0$, $U_{QQ} < 0$,

$U_R < 0$, $U_{RR} < 0$, and $U_{RQ} = 0$.

Since present consumption, production, and treatment activities generate residuals which affect future social welfare, the policy maker must optimize an intertemporal welfare function. To avoid the difficulties of evaluating the terminal-time residual stock, we assume that the policy maker's time horizon runs from the present into the infinite future. Furthermore, we assume that utilities at different points in time are additive and that the discount factor is invariant through time. Then the policy maker's objective functional is

(9) $W = \int_0^\infty e^{-rt} \cdot U(Q,R)\, dt,$

where r is the discount factor and t=0 stands for the present instant of time.

The policy instrument is an environmental target, Ψ, on the net flow of harmful residuals through time. The lower the environmental target, the lower Q and the higher T must be in order for the net residual flow to satisfy the target. (In other words, the environmental target determines the allocation of labor between the production sector and the pollution treatment sector.) By setting the environmental target at $\dot{R} = \Psi$, the policy maker uniquely determines the levels of production and anthropogenic treatment.

The policy maker uses the environmental target to maximize the objective functional 9. The resulting social optimum may be characterized by a unique Q and T. Since there is a unique, monotonically increasing relation between the level of the environmental target and the level of production, the same social optimum could be achieved if Q were the policy instrument. In fact, it will be mathematically convenient to use Q for this purpose and to infer the optimal dynamic path of the environmental target from the optimal dynamic path of Q.

Thus, the policy maker's problem may be formulated as follows:

(10) Maximize $W = \int_0^\infty e^{-rt} \cdot U(Q,R)\, dt$

subject to $\dot{R} = k(Q,R)$,

where Q is the control variable and R is the state variable.[3]

The current-value Hamiltonian is

$$H = U(Q,R) + \mu . k(Q,R),$$

where μ is the current-value shadow price of residual emission.

The first-order conditions are

$$(11) \quad \frac{\partial H}{\partial Q} = Q \quad \Rightarrow \quad \mu = -(U_Q/k_Q)$$

$$(12) \quad -\frac{\partial H}{\partial R} = \dot{\mu} - r.\mu \Rightarrow \dot{\mu} = \mu.(r-k_R) - U_R$$

$$(6) \quad \frac{\partial H}{\partial \mu} = \dot{R} \quad \Rightarrow \quad \dot{R} = k(Q,R).$$

Substituting 11 into 12,

$$(13) \quad k_Q \cdot (\frac{U_R}{U_Q}) + (r-k_R) = \left[\frac{U_{QQ}}{U_Q} - \frac{k_{QQ}}{k_Q} \right] \cdot \dot{Q},$$

where $\dot{Q} = (dQ/dt)$. Equation 13 may be rewritten as

$$(14) \quad \dot{Q} = \left(\frac{Q}{\sigma^U_{QQ} - \sigma^k_{QQ}} \right) \cdot \left[(\frac{U_R}{U_Q}) \cdot k_Q + (r-k_R) \right]$$

$$= h(Q,R),$$

where σ^U_{QQ} is the elasticity of marginal utility from consumption with respect to consumption (i.e. $(U_{QQ}/U_Q) \cdot Q < 0$) and σ^k_{QQ} is the elasticity of marginal net resiudal flow from consumption (and production) with respect to consumption (i.e. $(k_{QQ}/k_Q) \cdot Q > 0$). We assume that these elasticities are constants.

Equations 6 and 14 yield the time paths of the residual stock and the production flow, respectively, which satisfy the first-order conditions for social optimality. These paths are illustrated in Figure 1. The $\dot{R}=0$ function is upward-sloping since $-(k_P/k_Q) > 0$ and the $\dot{Q}=0$ function is downward-sloping since $-(h_P/h_Q) < 0$. The stationary state, in which $\dot{R} = \dot{Q} = 0$, is denoted by (R^*, Q^*). The non-stationary states are indicated by arrows.

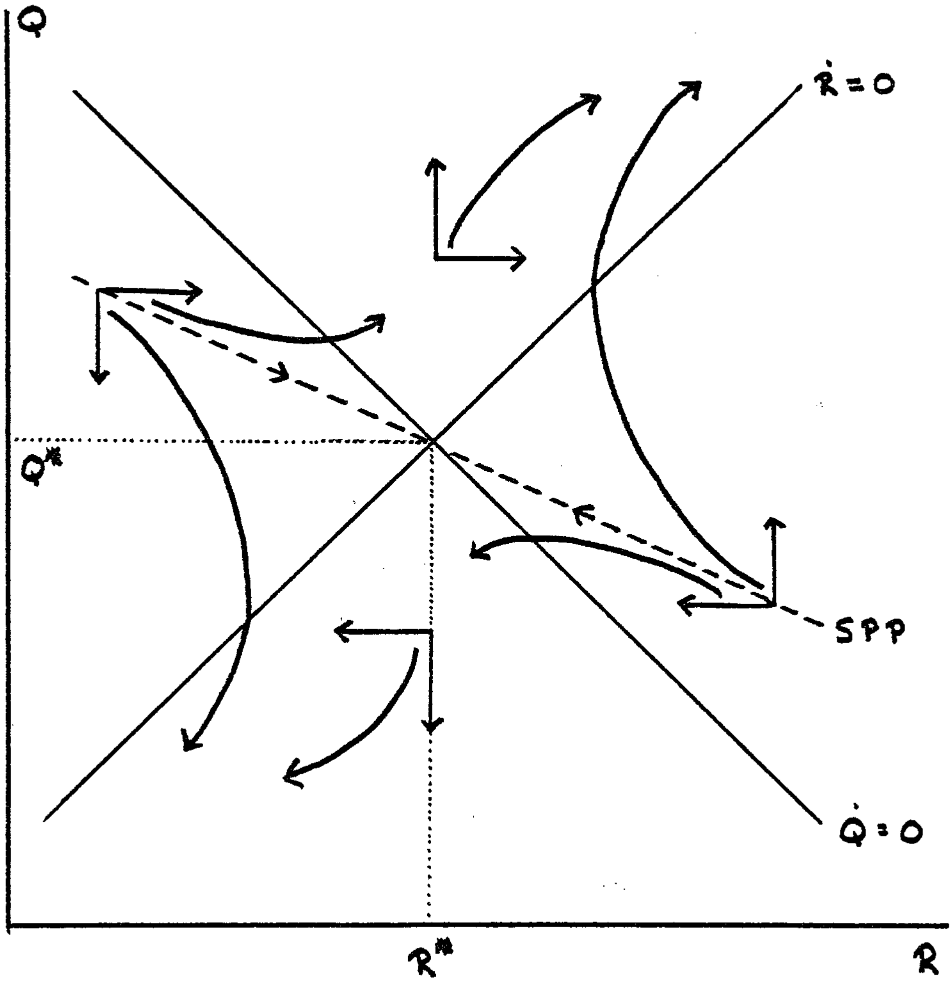

FIGURE 1

Not all the time paths for R and Q generated by Equations 6 and 14 satisfy the sufficient conditions for social optimality. It can be shown that there exists only one economically meaningful path for Q and R which satisfies both the necessary and sufficient conditions. This path, the "saddle-point path" (SPP in Figure 1), leads to the stationary state. It is downward-sloping.

At the initial instant of time, the policy maker inherits the residual stock R_O. The initial level of the environmental target must be selected so that the corresponding level of production, Q_O, places the economy on the saddle-point path. From then on, the environmental target must be set so that the residual stock and the consumption flow remain on the saddle-point path. Given this model of dynamic environmental targets, we are now in a position to examine how these targets respond to different types of technological progress.

4. The Optimal Responses of Environmental Targets to Technological Progress

In the previous section, the optimal environmental target path was derived with respect to a given set of technological relations linking production, pollution, and pollution treatment. In general, a change in these technological relations calls for a new optimal target path. This section is concerned with the environmental policy guidelines implied by the switch of target paths in response to various types of technological progress.

To formulate the policy problem as simply as possible, suppose that the economy is initially at its socially optimal stationary state and then a technological improvement occurs. The new set of technological relations is associated with a new optimal stationary state. How must the environmental target change through time in order to induce the optimal transition from the old to the new stationary state?[4]

The temporal changes of the environmental target may be divided into short-run, medium-run, and long-run changes. In the short run, the residual stock remains unchanged, but the environmental target and the flows of production and treatment services are free to vary. In the medium run, the residual stock is free to vary as well, but the new stationary state is not attained. In the long run, the entire transition from the old to the new stationary state takes place.

Different technological changes call for different dynamic paths of the environmental target. These paths, in turn, give rise to different temporal sequences in production and pollution treatment. The various kinds of technological progress may be characterized in terms of four policy paradigms. These paradigms describe the short-run, medium-run, and long-run movements of (a) the environmental target, (b) the level of production, (c) the level of anthropogenic treatment, and (d) the level of the residual stock.

The first paradigm is generated by a "neutral" improvement of labor productivity in the production and treatment activities, i.e. a rise in labor productivity which shifts the production possibility frontier ($T=F(Q)$) outwards without changing its slope (F_Q).[5] This technological improvement permits the given labor force to produce more than the original bundle of goods and treatment services. The labor which is no longer needed to produce this bundle may be referred to as labor "released" by the technological improvement. It is possible to allocate the released labor between the production and treatment sectors in such a way that, for any given value of the residual stock, the production of Q rises while the net flow of residuals remains unchanged. Thus, the $\dot{R}=0$ function shifts upwards in R-Q space, as shown in Figure 2. Since the improvement in labor productivity leaves F_Q (and therefore also k_Q) unaffected, the $\dot{Q}=0$ function remains unchanged. The stationary state shifts from point α to point γ in Figure 2. The saddle point path shift upwards from SPP to SPP'.

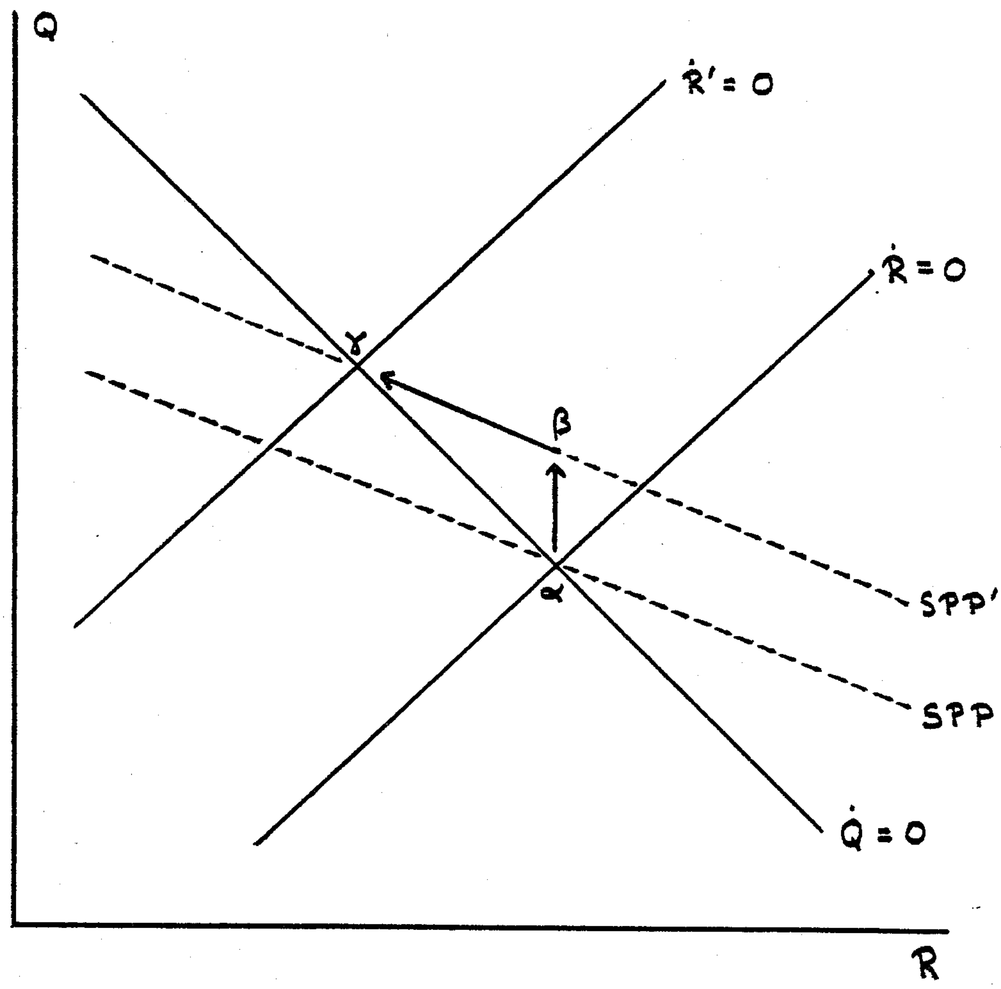

FIGURE 2

In the short run, the environmental target must be adjusted to move the economy from point α to point β . While the net residual flow is zero at point α , it is negative at point β . Thus, it is clear the the environmental target must be lowered in the short run (i.e. the net residual flow must be reduced). Furthermore, the movement from point α to point β implies a rise in the level of production. In order to achieve a fall in the net residual flow despite a rise in production, it is necessary for the level of pollution treatment to rise. In sum, the labor released by this technological improvement must be allocated to both the production sector and the treatment sector.

In the medium run, the environmental target must be adjusted to move the economy along the saddle-point path SPP_2 from point β to point γ . In the process, the level of production rises steadily. This development is possible only if labor is transferred from the treatment sector to the production sector. Hence, the level of pollution treatment must decline. The rise in Q, the fall in T, and the fall in nature's treatment service (due to the fall in the residual stock) all imply an increase in the net residual flow. Hence, it may be inferred that the environmental target must be raised over the medium run in order to elicit the movements above. However, the rise in the target should be small enough to ensure that the residual flow cleansed always exceeds the residual flow treated (since the residual stock should fall over the medium run). As the treatment sector contracts relative to the production sector, the residual stock falls by smaller and smaller amounts per unit of time.

Comparing the short-run and medium-run responses to the technological improvement, we find that the environmental target does not change monotonically through time. The target falls in the short run, but rises in the medium run. We call this change of the direction in which the environmental target moves an <u>intertemporal target reversal</u>. The movement of the target does not cause the production flow to change its direction of movement, i.e. there is no intertemporal production reversal. Yet it does give rise to an intertemporal treatment reversal: the treatment activity expands in the short run and contracts in the medium run.

Broadly speaking, the movement of the environmental target should induce a greater reduction of the residual flow in the short run than in the medium run. In fact, with the passage of time the residual stock is reduced by less and less while the production flow rises. In this sense, the dynamic path of the environmental target ensures that pollution objectives are given temporal priority over consumption objectives. This temporal priority is induced through the intertemporal target reversal.

In the long run, the entire transition from point α (the old stationary state) to point γ (the new stationary state) is completed. Naturally, the net residual flow is zero at both points. Yet at the new stationary state a greater residual flow is generated through production and consumption and a smaller residual flow is cleansed by nature than at the old stationary state. Hence, the level of anthropogenic pollution treatment must be higher at the new stationary state than at the old one. Thus, it is evident that the short-run expansion of the treatment sector must outweigh its medium-run contraction. Not all of the released labor which enters the treatment sector in the short run leaves this sector in the medium run.

The socially optimal responses to a "neutral" improvement of labor productivity may be summarized in the following proposition:

Proposition 1: Given a "neutral" improvement in labor productivity (which shifts the production possibility fronter outwards without changing its slope),
the socially optimal response of the environmental target is

characterized by the following intertemporal target reversal: the target falls in the short run and rises in the medium run. The optimal target path induces no intertemporal production reversal: production rises in the short and medium run. Yet the optimal target path does given rise to the following intertemporal treatment reversal: the level of the treatment service rises in the short run and falls in the medium run. Over the long run, the flows of production and treatment both rise and the residual stock falls.

The second paradigm is generated by a "neutral" improvement in pollution technology, i.e. a downward shift in the pollution function $\dot{R}_Q = g_1(Q)$ or $\dot{R}_T = g_2(T)$ -- Equations 3 -- which leaves the slope of the function unchanged. As in Paradigm 1, the original bundle of goods and treatment services can be produced with a smaller input of labor and it is possible to use the released labor to raise the production of goods while maintaining the original flow of residuals. Hence, the $\dot{R}=0$ function shifts upwards in R-Q space, but the $\dot{Q}=0$ function remains unchanged (since the slopes of the pollution functions remain unaffected by the technological change). The optimal transition from the old to the new stationary state may be illustrated by the same figure as that describing Paradigm 1 (i.e. Figure 2).

As in Paradigm 1, the environmental target must be lowered in the short run while the level of production rises. Yet unlike Paradigm 1, the level of the treatment service falls in the short run. This is evident from the following considerations. As result of a "neutral" improvement in the pollution technology, the original amount of treatment services can be provided with less labor, but the ordignal amount of goods require the same amount of labor as in the initial state. Only if all the labor released by the treatment sector were to return to this sector in the short run, would the level of the treatment service be unaffected by the technological change. However, as shown in Figure 2, some of the released labor is required to raise the level of production in the short run. Thus, the level of the treatment service must fall in the short run.

In the medium run, there is a continued rise in the level of production, which is achieved through a transfer of labor from the treatment sector to the production sector. Hence, the level of the treatment service must continue to fall. These developments may be induced by a steady rise in the environmental target. It is apparent that the medium-run adjustments are qualitatively identical with those of Paradigm 1.

In the long run, the level of production rises and the residual stock falls (as in Paradigm 1). Yet in contrast to Paradigm 1, the level of pollution treatment falls.

In sum,

Proposition 2: Given a neutral improvement in pollution technology (which shifts the pollution function $\dot{R}_Q = g_1(Q)$ or $\dot{R}_T = g_2(T)$ downward without changing its slope), the socially optimal response of the environmental target is characterized by the following intertemporal target reversal: the target falls in the short run and rises in the medium run.
The optimal target path induces no intertemporal production reversal: production rises in the short and medium run.
The optimal target path also induces no intertemporal treatment reversal: the treatment service falls in the short and medium run.
Over the long run, the flow of production rises, the flow of pollution treatment falls, and the residual stock falls.

Clearly, the difference between the optimal responses to a neutral improvement in labor productivity and the optimal responses to a neutral improvement in pollution technology lies in the dynamic behavior of the anthropogenic treatment service. The former technological change calls for an intertemporal treatment reversal; the latter does not. The former requires a long-run expansion of the treatment sector; the latter requires a long-run contraction.

The third paradigm is generated by a drop in the marginal residual flow from the pollution treatment service, i.e. a drop in g_2'.[6] This technological improvement causes the $\dot{Q}=0$ function to shift downwards in R-Q space, as demonstrated by the following equations. From Equation 6 it is evident that

$$(15)\quad k_Q = g_1' - (1-g_2') \cdot F'.$$

Thus,

$$(16)\quad \frac{\partial k_Q}{\partial g_2'} = F' < 0.$$

From Equation 14 we obtain

$$(17)\quad \frac{\partial \dot{Q}}{\partial k_Q} = \left(\frac{Q}{\sigma^U_{QQ} - \sigma^k_{QQ}}\right) \cdot \left(\frac{U_R}{U_Q}\right) > 0.$$

Consequently, by Equations 16 and 17,

$$(18)\quad \frac{\partial \dot{Q}}{\partial g_2'} = \frac{\partial \dot{Q}}{\partial k_Q} \cdot \frac{\partial k_Q}{\partial g_2'} < 0.$$

Thus, a drop in the marginal residual flow from the pollution treatment service raises $\dot{Q}$, ceteris paribus.
Equation 14 also yields

$$(19)\quad \frac{\partial \dot{Q}}{\partial Q} = \left(\frac{Q}{\sigma^U_{QQ} - \sigma^k_{QQ}}\right) \cdot \left[U_R \cdot \frac{k_{QQ} \cdot U_Q - U_{QQ} \cdot k_Q}{(U_Q)^2}\right] > 0$$

(whenever $\dot{Q}=0$). Hence, a fall in Q is required to neutralize the effect of a drop in g_2' on $\dot{Q}$. In other words, the $\dot{Q}=0$ function falls in R-Q space.[7]

The drop in g_2' also affects the slopes of the $\dot{R}=0$ function and the $\dot{Q}=0$ function. Yet this influence has no bearing on the qualitative conclusions of our analysis. Thus, it is ignored in Figure 3, which portrays a downward shift of the $\dot{Q}=0$ function

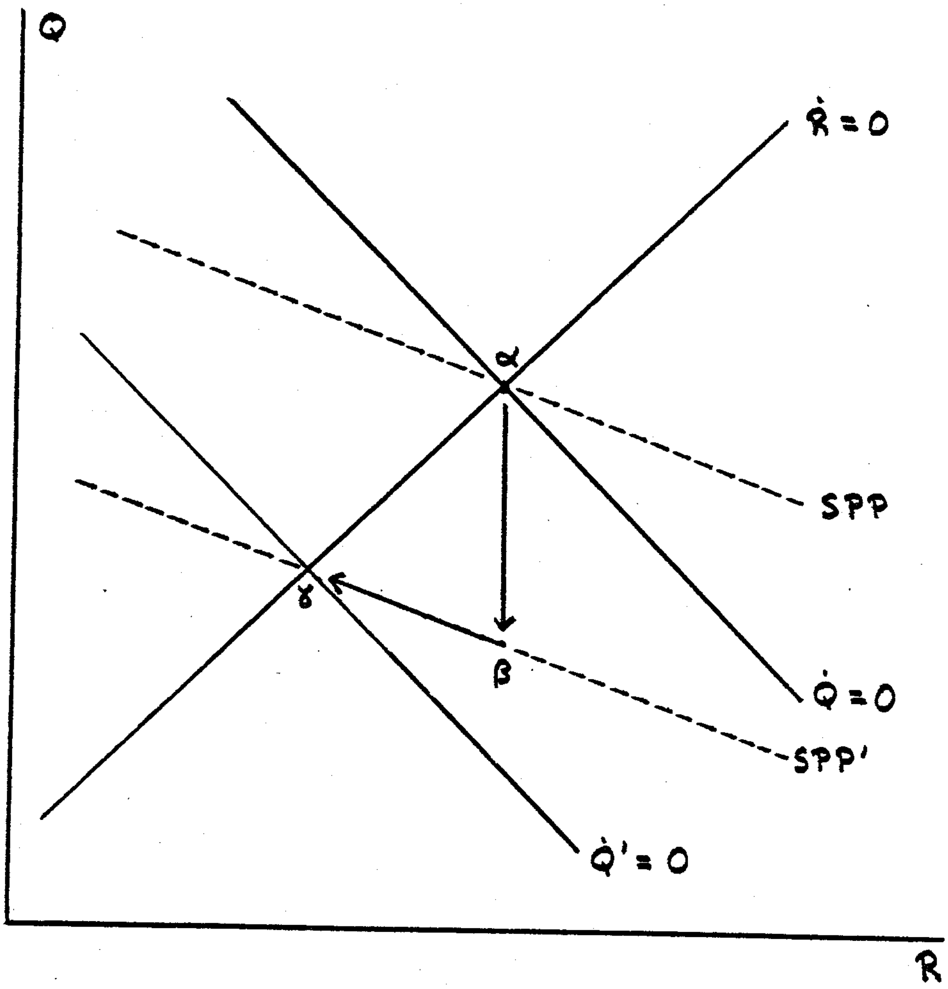

FIGURE 3

and an unchanged $\dot{R}=0$ function.

The optimal short-run movement of the economy extends from point α to point β in Figure 3. Since the net residual flow is zero at point α and negative at point β, the environmental target must be lowered. This adjustment induces a transfer of labor from the production sector to the treatment sector (for the consequent fall in Q and rise in T reduces the net residual flow).

In the medium run, the economy optimally moves from point β to point γ. As shown in Figure 3, this movement implies a rise in the level of production. Hence, labor must return to the production sector from the treatment sector, thereby causing a decline in the level of the treatment service. In order to induce this new transfer of labor, the environmental target must be raised. Yet the rise of the target must remain small enough to permit the residual stock to fall throughout the medium run.

Once again, we note that an intertemporal target reversal is the optimal response to technological progress. Yet in contrast to Paradigms 1 and 2, this movement of the environmental target gives rise to an intertemporal production reversal. In response to a drop in the marginal residual flow from the treatment service, the treatment sector expands at the expense of the production sector in the short run and the production sector expands at the expense of the treatment sector in the medium run. We recall that, in the first two paradigms, the treatment sector does not expand at the expense of the production sector in the short run; instead, both sectorsexpand simultaneously. Hence, it is clear that in Paradigm 3 pollution objectives are given even <u>more stringent temporal priority</u> over consumption objectives than in Paradigms 1 and 2.

The optimal responses to a drop in the marginal residual flow from the treatment service may be summarized as follows:

<u>Propostion 3</u>: Given a drop in the marginal residual flow from the pollution treatment service, the socially optimal response

of the environmental target is characterized by the following intertemporal target reversal: the target falls in the short run and rises in the medium run.
The optimal target path induces the following intertemporal production reversal: production falls in the short run and rises in the medium run.
The optimal target path also induces the following intertemporal treatment reversal: the treatment service rises in the short run and falls in the medium run.
Over the long run, production falls and the residual stock falls as well.

The fourth (and final) paradigm is generated by a drop in the marginal residual flow from consumption or production, i.e. a drop in g_1'.[8] This technological improvement may be represented by an upward shift of the $\dot{Q}=0$ function in R-Q space, as indicated by the following considerations. From Equation 15 we obtain

$$(20) \quad \frac{\partial k_Q}{\partial g_1'} = 1 > 0.$$

Equation 20, together with Equation 17, implies that

$$(21) \quad \frac{\partial \dot{Q}}{\partial g_1'} = \frac{\partial \dot{Q}}{\partial k_Q} \cdot \frac{\partial k_Q}{\partial g_1'} > 0.$$

Equation 21, together with Eqaution 19, indicates that the $\dot{Q}=0$ function must shift upwards in R-Q space.[9] The drop in g_1' also changes the slopes of the $\dot{R}=0$ and $\dot{Q}=0$ functions; yet this influence does not affect the conclusions of our analysis and will be ignored below.

Figure 4 illustratesthe optimal responses to a drop in the marginal residual flow from consumption or production. It is apparent that this paradigm is the dynamic obverse of Paradigm 3. In the short run, the environmental target is raised and, as result, production expands while anthropogenic treatment contracts. In the medium run, the environmental

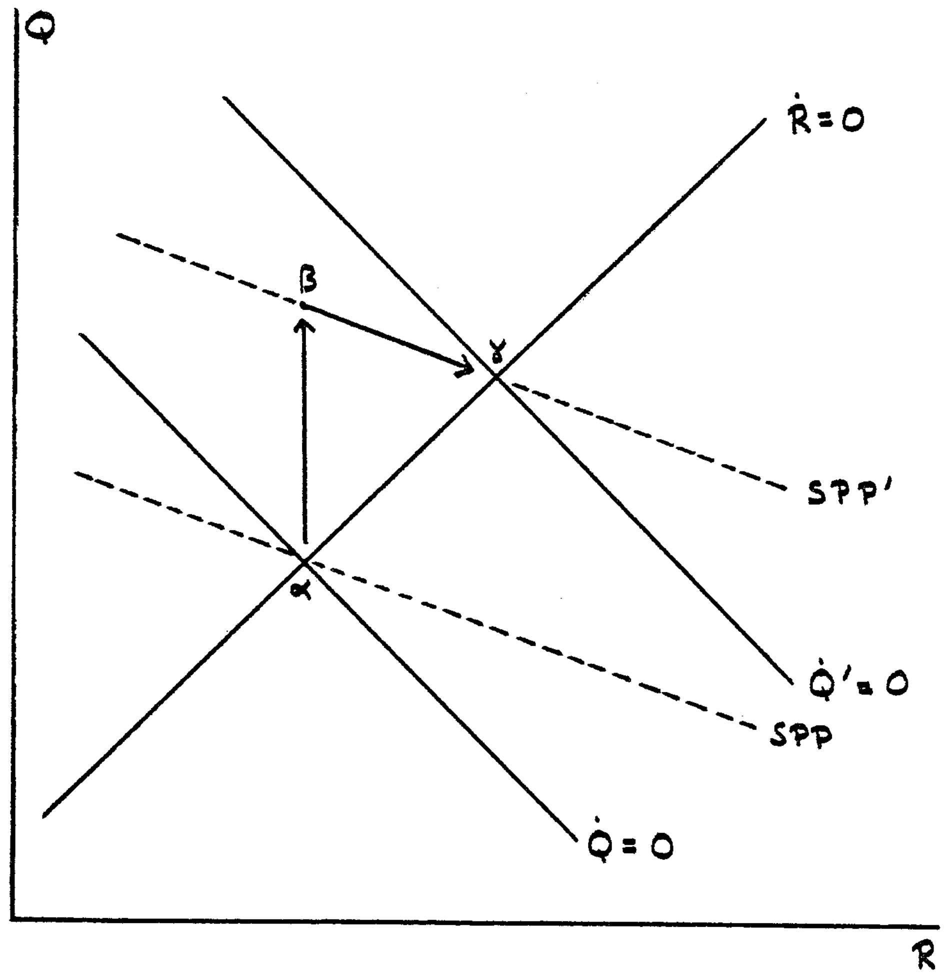

FIGURE 4

target is lowered and thus production contracts while anthropogenic treatment expands.

It is significant to note that whereas pollution objectives are given temporal priority over consumption objectives in Paradigms 1 - 3, consumption objectives are given temporal priority over pollution objectives in this paradigm. These priorities are induced through the movement of the environmental target. The environmental target reversal portrayed in this paradigm is the obverse of the environmental target reversals portrayed in Paradigms 1 - 3.
The optimal responses of Paradigm 4 may be described as follows:

Proposition 4: Given a drop in the marginal residual flow from consumption or production, the socially optimal response of the environmental target is characterized by the following intertemporal target reversal: the target rises in the short run and falls in the medium run.
The optimal target path induces the following intertemporal production reversal: production rises in the short run and falls in the medium run.
The optimal target path also induces the following intertemporal treatment reversal: the treatment service falls in the short run and rises in the medium run.
Over the long run, production rises and the residual stock rises as well.

The four paradigms described in this section each concern a different type of technological progress. It has been shown that different types of technological progress call for different responses of the environmental target, production, and anthropogenic pollution treatment. These responses have a well-defined, complex dynamic structure: intertemporal reversals play an important role.

5. Conclusions

This paper has examined the socially optimal responses of environmental targets to various types of technological progress. In a sense, the most basic conclusion of the paper is that the optimal target responses are dynamic. A one-shot technological improvement should not be met by a one-shot target adjustment, but by a temporal stream of target adjustments. Secondly, the dynamic properties of the optimal target responses depend on which technological relations undergo improvement. Different technological changes may call for different dynamic target paths. Thirdly, the optimal target responses to all types of technological progress representable in our analysis are characteriyed by intertemporal target reversals. Some, but not all, of these target reversals lead to intertemporal production reversals and intertemporal treatment reversals.

Four types of technological progress have been considered: (1) a neutral improvement in labor productivity, (2) a neutral improvement in pollution technology, (3) a drop in the marginal residual flow from the pollution treatment service, and (4) a drop in the marginal residual flow from consumption or production. The optimal responses of the environmental target, production, and anthropogenic pollution treatment have been described in terms of four corresponding policy paradigms. These paradigms may be characterized in terms of the intertemporal reversals they describe.

(a) Intertemporal target reversals: The first three paradigms involve a short-run fall and a medium-run rise of the environmental target;yet the fourth paradigm involves a short-run rise and a medium-run fall of the environmental target.

(b) Intertemporal production reversals: The first two paradigms contain no intertemporal production reversals (in particular, production rises over the short and medium run), whereas the last two paradigms contain such reversals (in particular, the third paradigm involves a short-run fall and a medium-run rise of production and the fourth paradigm represents the dynamic obverse).

(c) Intertemporal treatment reversals: The second paradigm contains no intertemporal treatment reversal (in particular, the treatment service falls over the short and medium run), whereas all other paradigms contain such reversals (in particular, the first and third paradigms involve a short-run rise and a medium-run fall of the treatment service and the fourth paradigm represents the dynamic obverse).

Intertemporal target reversals serve an important purpose: they dictate a pattern of temporal priorities between the policy maker's pollution objectives and consumption objectives. Each type of technological progress examined above requires that such temporal priorities be set; hence, each type of technological progress calls for an intertemporal target reversal. In the first three paradigms the pollution objectives are given temporal priority over the consumption objectives; in the fourth paradigm the opposite is the case.

Whenever an intertemporal target reversal is sufficiently pronounced to induce an intertemporal production reversal (as in Paradigms 3 and 4), the temporal priorities are set with particular stringency. In these cases, the optimal level of production does not follow a monotonic time path in response to technological progress. "Stabilization policy" -- which aims to eliminate fluctuations in national output -- is misplaced here; the occurence of technological progress should occasion the policy maker to <u>induce</u> a fluctuation in the level of production, not to prevent it.

Needless to say, the policy recommendations contained in this paper are completely at variance with actual environmental programs implemented thus far. In practice, environmental targets tend to be set rather inflexibly through time. Rarely is provision made for a temporal sequence of target changes as part of a single environmental strategy. Environmental targets are usually not responsive to technological progress. Certainly, provision is not made for systematic differences in the target responses to different types of technological change. Besides, intertemporal reversals of environmental targets are unheard of in environmental policy making.

However, the argument of this paper is too simple to serve as a basis for fundamental criticisms of present environmental policy. Our analysis focuses primarily on one salient characteristic of pollution through economic activities: that the welfare effects of residual emissions are commonly long-lived in comparison with the welfare effects of consumption. This characteristic is responsible for the dynamic nature of the environmental targets described above. Yet other characteristics which are of general significance in the formulation of environmental policy -- such as the influence of environmental targets on technological progress, the administrative costs of changing the levels of environmental targets, the role of risk and uncertainty in the formulation of environmental targets -- are not subjects of our analysis. Certainly, consideration of these matters may require that our policy recommendations be amended. This possibility presents itself as an area of future research.

Yet regardless of whether such amendments are necessary, it is useful to inquire which characteristics of pollution generation lead to which desiderata of environmental policy. Our analysis serves this purpose. It tells us that insofar as the longevity of residual effects (relative to consumption effects) on social welfare is important, the environmental target responses to technological progress must be dynamic and, in particular, must embody intertemporal reversals.

F O O T N O T E S

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1. The second production function may be written as

$$T = f_2(\bar{L} - L_Q).$$

Inverting the first production function,

$$L_Q = f_1^{-1}(Q), \text{ where } (f_1^{-1})' > 0 \text{ and } (f_1^{-1})'' > 0.$$

Thus, $T = f_2 \left[\bar{L} - f_1^{-1}(Q) \right] = F(Q)$.

$$F' = -f_2' \cdot (f_1^{-1})' < 0 \text{ and}$$

$$F'' = -f_2' \cdot (f_1^{-1})'' + (f_1^{-1})' \cdot f_2'' \cdot (f_1^{-1})' < 0.$$

2. $k_Q = g_1' - (1-g_2') \cdot F'$.

If we make the plausible assumption that the antropogenic treatment activity generates a smaller flow of harmful residuals than it cleanses (viz, $g_2' < 1$), then $k_Q > 0$.

$$k_{QQ} = g_1'' - (1-g_2') \cdot F'' + g_2'' \cdot (F')^2 > 0.$$

$$k_R = - f_3' < 0.$$

$$k_{RR} = - f_3'' > 0.$$

3. In addition, the nonnegativity constraints, $Q \geq 0$ and $R \geq 0$, and the constraint $Q \leq f_1(\bar{L})$ (i.e. that the actual production of Q cannot exceed the amount which would be produced if the entire labor force were devoted to its production) must be satisfied. In this paper we consider only interior optima, for which these constraints hold as inequalities.

4. The assumption that the economy is originally in a stationary state is of expository convenience in describing the transition path from the old to the new stationary state. If the economy were originally at an arbitrary point along the saddle-point path, a different transition path would be required; yet this path could be readily deduced from our analysis.
5. This paradigm may also be generated by a "neutral" improvement in nature's assimilative capacity, i.e. an upward shift in the natural treatment function ($T_N = f_3(R)$) which leaves the slope of this function unchanged. There are a variety of ways in which nature's "treatment technology" can be improved by man. Two prominent examples are organizational improvements concerning the location of polluting factories and reformulations of environmental controls with regard to the permissible times during which residuals may be emitted. Aside from these "disembodied" technological changes, a variety of inventions (e.g. those pertaining to smoke stacks)may also induce an increase in nature's assimilative capacity.
6. This paradigm may also be generated by a rise in the marginal rate of transformation from Q into T, i.e. a rise in F'.
7. The $\dot{Q}$=O function also falls in response to a rise in F'. From Equation 15 we obtain

$$\frac{\partial k_Q}{\partial F'} = -(1 - g_2') < 0.$$

Given Equation 17, it is thus apparent that

$$\frac{\partial \dot{Q}}{\partial F'} = \frac{\partial \dot{Q}}{\partial k_Q} \cdot \frac{\partial k_Q}{\partial F'} < 0.$$

This result, along with Equation 19, implies a fall in the $\dot{Q}$=O function in R-Q space.
8. This paradigm may also be generated by a fall in the marginal rate of transformation from Q into T, i.e. a fall in F'. Moreover, a technological improvement which leads to a rise in nature's marginal rate of residual treatment (i.e. $f_3' = k_R$) generates this paradigm as well. In Footnote 5 we considered the possibility of augmenting nature's

assimilative capacity through technological improvements.

9. It is apparent from Footnote 7 that the $\dot{Q}=0$ function also rises in response to a fall in F'. A rise in k_R has the same effect, because,

$$\frac{\partial \dot{Q}}{\partial k_R} = -\left(\frac{Q}{\sigma^U_{QQ} - \sigma^k_{QQ}}\right) > 0$$ (as implied by Equation (14)) and

$$\frac{\partial \dot{Q}}{\partial Q} > 0$$ (by Equation (19)).

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