COWLES FOUNDATION FOR RESEARCH IN ECONOMICS

AT YALE UNIVERSITY

Box 2125, Yale Station
New Haven, Connecticut 06520

COWLES FOUNDATION DISCUSSION PAPER NO. 615

HOW FAST SHOULD WE GRAZE THE GLOBAL COMMONS?

William D. Nordhaus

January 1982

HOW FAST SHOULD WE GRAZE THE GLOBAL COMMONS?*

by

William Nordhaus

Yale University

Unlike the vast preponderance of planets, earth has been bequeathed a hospitable environment in which to thrive. Up to now, man's activities have affected this environment negligibly. Scientists are becoming convinced, however, that release of carbon dioxide (CO_2) from combustion of fossil fuels will lead to a significant modification of the global climate (see Woodwell).

How should we think about such a destruction of our heritage? Should it be treated as anathema, like bondage? Or should the pace and extent of use of our global commons be subject to the same reasoned balancing of costs and benefits as other economic activities?

The present paper takes the second approach--asking how fast the global economy should allow a buildup of atmospheric CO_2. The first section reviews the current scientific knowledge on this subject, while the second puts this into an optimal growth framework. The third section then presents a numerical example, while the last presents some realistic policy views on the subject.

---

*This paper was presented at the December 1981 meetings of the American Economic Association and is a summary of a fuller discussion in Nordhaus.

010682.Carbon

I. The Carbon Dioxide Problem

The combustion of fossil fuels releases CO_2 into the atmosphere. Through a process of diffusion these emissions are distributed through the oceans and biosphere, but the rate of distribution is so slow that a large fraction of industrial CO_2 remains in the atmosphere for centuries.

The economic impacts of CO_2 arise in two ways, from its impact on production from climatic changes and from policy-induced abatement activities. Starting with the first, it must be emphasized that there are enormous uncertainties about the ultimate impact of a CO_2 buildup. It is generally agreed that as a result of CO_2 elevation the global climate will become warmer, and that this warming will be greatest near the poles. Most climatologists expect major changes in the distribution of other important climatic factors, particularly rainfall and wind patterns, and sooner or later an effect on the level of the oceans--but the changes in particular regions are not known.

Even less is known, however, about the economic impact. In a recent survey (Nordhaus), I concluded that the major impacts would be on agriculture and coastlines. Depending on the scenario, the effect of a CO_2 doubling ranged from minus 12 percent of global GNP to plus 5 percent. These are clearly very large impacts, but they are also very uncertain.

The economic interest in the CO_2 problem lies in the fact that the projected CO_2 buildup is not inevitable. There are many strategies for responding to a CO_2 buildup--ranging from energy conservation or R&D to fuel switching to pickling trees to building dikes. The costs of any effective abatement program are likely to be substantial, for the volume of CO_2 emissions today is enormous, around 6 billion tons per year. On the other hand, few of these strategies are likely to be efficiently provided by the invisible hand of competitive markets.

II. Choice of Alternative Paths

The CO_2 problem presents a classical problem in intertemporal choice. Economic analysis suggest that alternative control strategies be weighed by examining their implications for the consumption (or real income) of different generations.

More technically, we can represent the choice problem as follows. Assume society maximizes the following welfare function subject to constraints.

$$(1) \quad \max_{\{c(t)\}} W = \int_0^{\infty} e^{-rt} u[c(t)]dt$$

$$(2) \quad c(t) = f[E(t)] - h[M(t)]$$

$$(3) \quad \dot{M}(t) = aE(t) - bM(t)$$

where M = increase of mass of atmospheric CO_2 from pre-industrial levels, E = rate of emissions of CO_2 into the atmosphere, W = welfare functional to be maximized, r = pure rate of social time preference, t = time, c(t) = real per capita consumption, and u[c(t)]= utility of real consumption.

Equation (1) states that society seeks to maximize a function that depends only on consumption over time, and not on ethical views about the sanctity of the climate or upon regional distributional concerns. Equation (2) is the production function, which states that consumption depends on emissions and atmospheric concentrations of CO2, while (3) shows how the atmospheric concentration of CO2 builds up over time.

We can solve (1) to (3) by standard variational techniques. It is useful to examine not only the paths of emissions and concentrations, but also the "shadow price of CO2" -- q(t). In what follows, q(t) represents the incremental cost in terms of consumption of increasing CO2 emissions, as well as the incremental damage done by an additional unit of CO2 emissions. Thus in a steady state optimal path

$$(4) \quad q^* = f'(E^*) = h'(M^*)\,[a/(r+b)] \;.$$

Equation (4) states that the CO2 shadow price is equal to both the marginal cost of reducing emissions as well as the discounted cost of the atmospheric concentration from one unit of emission.

More generally, we can calculate the optimal abatement path during transitions to steady state. Here again, the shadow price, q(t) , must equate discounted costs and benefits of CO2 abatement in terms of consumption:

$$q(t) = f'[E(t)] = \int_0^{\infty} re^{-(r+b)} \, , \, \frac{u'[c(v)]}{u'[c(t)]} \, h'[M(v)]dv \;.$$

There are a wealth of possible paths for optimal CO_2 buildup depending on the exact parameters. We illustrate here only a simplified case. Assume that there is a saturation level of CO_2 concentration, M^*, such that for CO_2 concentrations up to M^* there is no damage from increased CO_2, but that when M passes M^* the cost becomes catastrophic (it should be emphasized that this is an unrealistic assumption). Further assume that the marginal cost of CO_2 abatement is constant at a fixed level. In this case, it is easily shown that the shadow price $q(t)$ rises exponentially at the CO_2 discount rate--i.e. the real interest rate on goods plus the CO_2 disappearance rate (b) in the transition phase when M is less than M^*. Thus, if the steady state shadow price is $50 per ton CO_2, if the CO_2 discount rate is 5 percent, and saturation occurs in 2052, today's shadow price would be $1.64 per ton.

III. A numerical example

In Nordhaus, I calculated illustrative optimal CO_2 paths under alternative assumptions. These calculations require estimates of all the parameters in equations (1) to (3) above. In these calculations, I have modified the equations to allow for a period of growth at rate g for T years, after which the economy is in steady state. Moreover, the discount rate of goods is 13 percent per annum during the transition period, but 1 percent in steady state; the abatement cost function is quadratic; and a doubling of CO_2 concentrations is assumed to lower world GNP by 3 percent.

Figure 1 summarizes the results. On the left hand side of the Figure is the optimal shadow price, while on the right hand side is the CO2 control rate. The current control rates are in the 20 percent range for any but the most robust growth trajectories. The current shadow price on CO2 ranges from around $10 per ton for modest growth paths up to $70 per ton for rapid growth path. Again, the speculative nature of these results should be stressed.

It is worth noting that current policy discussions should focus on the current CO2 shadow price. Today's decisions concern the amount of abatement that should occur today as well as the kinds of R&D that society should begin. These decisions will, in our optimal plan, be completely determined by today's shadow price and its trajectory over the next few years.

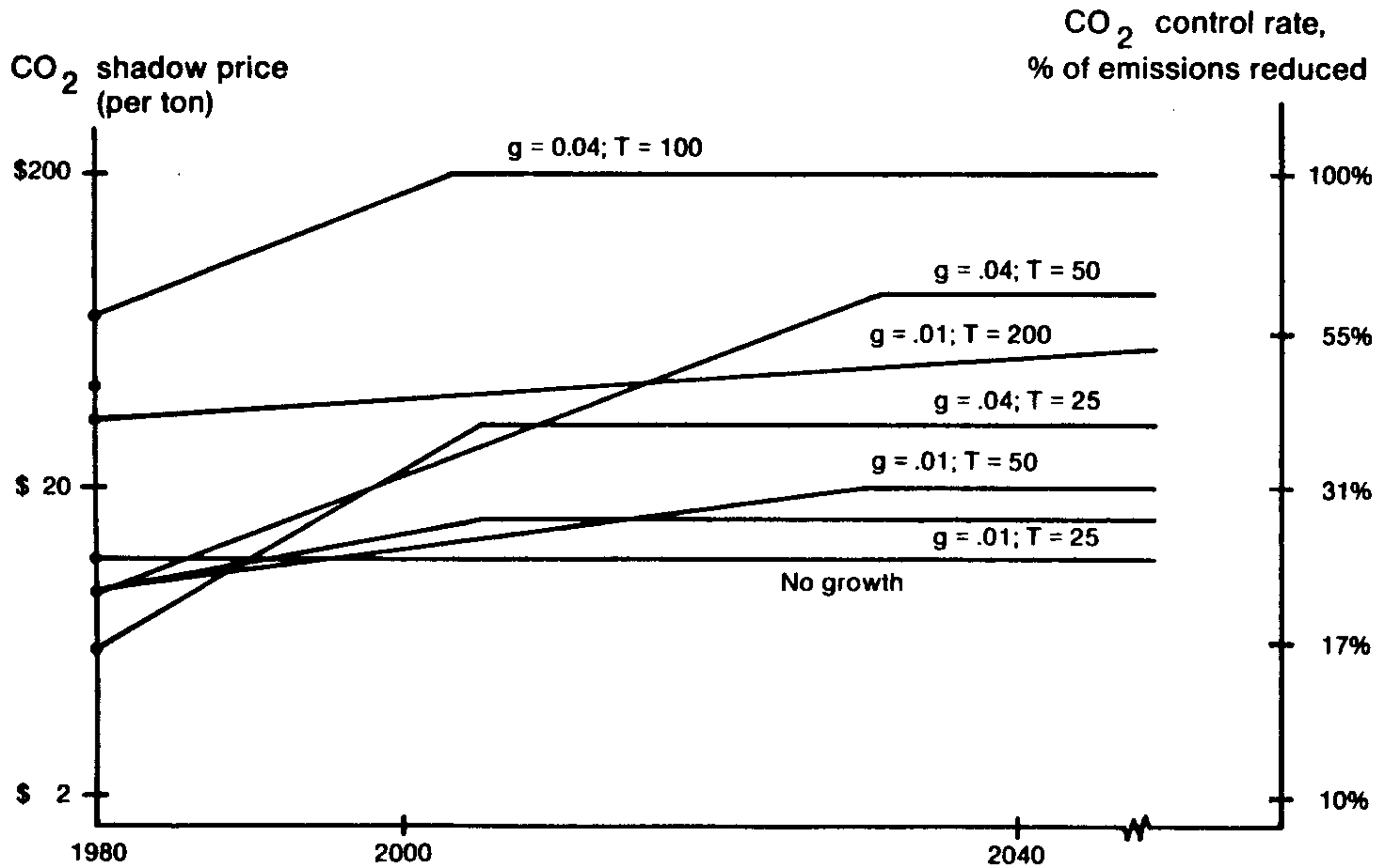

Figure 1. Calculated trajectory of optimal carbon shadow price (left scale) and control rate (right scale) for different economic growth patterns.

IV. Realistic considerations

Up to now the CO_2 problem has been viewed here as a pure exercise in optimal economic growth. In this final section realistic considerations of policy and politics are considered.

The externality problem. An important source of inefficiency in market systems arises from the presence of "externalities." It would be natural to suppose that the incentives for nations to regulate effectively would apply to CO_2 as to other pollutants, such as sulfur oxides. This supposition would be much too optimistic. Most externalities are ones that are internal to nations; in such a circumstance, the balancing of costs and benefits of pollution control by a nation's government may lead to policies that approximate an efficient solution.

The CO_2 problem is different from conventional pollutants because it is an externality across space and time. Once in the atmosphere, CO_2 disperses across the globe and has a half-life of centuries. In such a situation, a CO_2 control strategy would be effective only if major nations were farsighted and successfully negotiated a global policy. While such an outcome is possible, there are few examples where a multinational environmental pact has succeeded—the nuclear test ban treaty being the most prominent. Other clearly recognized international problems—whales, acid rain, undersea mining—provide a career for negotiators but little concrete agreement.

The multilateral bargaining is severely complicated by the likelihood that some major countries will benefit from the CO_2

buildup. Some analysts believe that agricultural production in the USSR and Canada will be enhanced by the warmer climate. Given that these two countries (and the former's allies) burn 25 percent of the world coal, it is hard to see how a CO_2 strategy can succeed without them. On the other hand, as it is unlikely that the western nations will compensate the USSR for participating in a CO_2 pact, it is hard to see why the Soviet bloc would participate. Finally, given that some major CO_2 producers do not participate, it is hard to envisage the others, including LDCs, making a major sacrifice. Thus the differences in country experience is likely to doom an international agreement.

Alternative control techniques. Scientists have given scant attention to the techniques that would be useful for controlling CO_2. There are basically two kinds of control devices--prices and quantities. In the former, a "carbon tax" would be placed on all net sources of CO_2, basically burning of fossil fuels. In the quantity approach, emission stardards would be placed on technologies.

An efficient control program is one in which each individual has an incentive to reduce emissions up to the point where further reductions cost more than the benefits of emission reductions. Particularly for cases such as CO_2, such a property is much more easily realized using prices than quantities. This is so because the benefits of emission reduction are uniform across regions and technologies, while the costs of CO_2 abatement vary widely. By using a uniform CO_2 tax, the incremental cost of CO_2 reductions will be uniform across CO_2 producers.

A price-type scheme for abating CO2 might run as follows. Nations would first agree on a strategy for controlling CO2--something like the framework outlined here in much greater detail and regional and temporal disaggregation. The program would include both a target emissions reduction and a shadow price which reflects that reduction. <u>The shadow price that comes out of the optimal program is the appropriate carbon tax</u>.

In this scheme, individual nations would be committed to take steps to assure that the carbon tax was reflected in fuel and other prices. In a market economy like the U.S., such a commitment would be naturally fulfilled by pricing a $10 per ton excise tax on coal, lesser amounts on oil and gas. Nations that have nationalized coal or energy industries would place consumption taxes on products in proportion to CO2 emissions resulting from their production.

The carbon tax will, of course, grow in real terms over time depending on the discount rate as illustrated in Figure 1. In addition, as new knowledge becomes available, new calculations would require changes in the carbon tax.

<u>Issues involving uncertainty</u>. We have emphasized that the CO2 problem is loaded with uncertainties of all kinds. A common approach for many real world economic problems involving uncertainty is to use the "best guess" and proceed as if the world were certain. Such an approach is not appropriate under two general conditions----when the effects of actions are highly nonlinear or when the uncertainties are likely to be resolved with the passage of time.

On the first condition, I am aware of no convincing evidence that the effects of CO_2 are highly nonlinear. Possible exceptions are the melting of the Arctic sea-ice pack and disintegration of the West Antarctic ice sheet. Either event would surely have highly nonlinear effects but we do not have clear prior knowledge of when the event will occur. However, if our prior judgment of the probability of such discontinuous events is a linear function of CO_2 concentration, then from a decision-maker's perspective the expected consequences are linear and the presence of uncertainty does not change the best guess strategy markedly.

The second condition--reduction in uncertainty over time--is surely significant for the CO_2 strategy. The passage of time, as well as scientific research, will narrow the uncertainties about the parameters of an optimal strategy. In a decade or so, for example, we may have more secure knowledge about whether a CO_2 buildup will be beneficial or not, as well as about the costs of CO_2 abatement. If so, the best investment to ameliorate the CO_2 problem today is probably to expand our CO_2 knowledge.

In sum, the presence of uncertainty is per se not a reason for either accelerating or slowing programs for the control of CO_2. It is simply irrational to say we should wait for further information before we act; or that we should act purely because the consequences of inaction may be grave. Unless there is substantial asymmetry in the structure of the costs or benefits, or in the way in which uncertainties are resolved over time, we should act now on the best guess (or certainty equivalent) basis.

<u>References</u>

Nordhaus, William D., "Thinking About Carbon Dioxide: Theoretical and Empirical Aspects of Optimal Growth Growth Strategies," paper prepared for U.S. Department of Energy, available as Cowles Foundation Discussion Paper No. 565, October 1980.

Woodwell, George M., "The Carbon Dioxide Question," <u>Scientific American</u>, January 1978, pp. 34-43.