DISCOUNTING CLIMATE CHANGE
PLANNING FOR AN UNCERTAIN FUTURE

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I- Climate Change as Investment

All serious economic decisions, public or private, require consideration of the future. Typically, a decision is made today, which requires some costs today or in the near future, In the hope of returns in the future. This pattern is characteristic of investments, and much of life is made up of investments, large or small . Investing in machinery or structures is a typical case. There is a relatively large initial expenditure, which, by itself, is a cost, something to be avoided. It is followed, if all goes well, with a period of time in which there are profits. Similarly, an individual investor can buy securities, stocks or bonds or nowadays sophisticated derivative securities. These are bought with the prospect of future income, derived from subsequent sales of the securities or from income rights, dividends or interest, associated with them, or from payments contracted for on the maturity of the securities, whether bonds or options.

The key characteristics of these returns are that they occur in the future and that they are, usually, uncertain. At least part of the initial investment costs are incurred now, and they are known.
How does the investor decide whether it is worthwhile to invest?
He or she is making a comparison between two unlike magnitudes, expenditures and incomes that differ in date and usually in the degree of uncertainty.

Of course, people are making comparisons between disparate magnitudes all the time. Everyone has to, make a choice between buying more clothes and buying more furniture. The willingness of individuals to, choose one or the other is both governed by and reflected in the prices of the two goods. Similarly, the choice between present and future incomes, even though both seem to be measured in the same units, is reflected in the prices paid for these incomes. These are in fact essentially interest rates or discount rates. Incomes of varying degrees of uncertainty will also be valued differently. Under simple conditions, of two incomes with the same average magnitude, the one with the lower variability will be valued higher. Thus, if the dividends on a common stock have the same expected value as the interest on a bond, buyers will typically prefer the bond if the prices of the two were the same. Hence, typically, the stock price will be below that of the corresponding bond in order to induce buyers to hold some stocks.

The interest rates and the market discounts for uncertainty thus play a vital role in determining the volume and especially the direction of investment. High interest rates induce individuals to prefer investments that pay off rapidly, for at those rates the present value of a long-deferred payoff is low, even if the value at the time of payment is high.

Setting the correct rate of interest Is therefore very important for private investment. It is or should be equally important for public investment. Public investments are those made to provide for future public goods. By public goods, I mean those that are desirable but for one reason or another are not readily supplied by the market. One characteristic reason for public provision of goods is that they create what have come to be called *externalities*. An externality occurs when one individual's activity affects the productivity or well-being of others without being mediated through a well-functioning price system. Air pollution provides a classic example. My burning fuel releases sulphur dioxide, ozone, and other noxious gases which frequently do cause others to suffer annoyance in breathing and even ill-health and death. If I had to buy the right to pollute the air from the potential victims, we could assume that the market will balance appropriately the gains from combustion against the losses from inhaling the polluted air. But for obvious reasons appropriate markets do not e3dst. Hence, the need for public policy to avoid pollution.

Another externality has come to public attention. It is the one variously referred as the "greenhouse effect" or "global warming." Currently, the preferred term in international political discourse is, "climate change." and I will use primarily use that term. This is an externality on a genuinely global basis. Other forms of air or water pollution can have consequences over ranges of ten or twenties of kilometers, perhaps hundreds in the case of acid rain or pollution of major waterways. But climate change is a world-wide phenomenon; carbon dioxide create by combustion in one place circles the world in a few days.

I am an economist, not a physicist, and I cannot pretend to give a fully reliable account of what is, in any case, a very complex issue in its details. I will just say enough to highlight the issues relevant to economic analysis and, in particular, to, the theme of this lecture, the discounting of future benefits and costs. It has been known since the middle of the nineteenth century that the temperature of the Earth's surface is maintained by a balance between incoming and outgoing radiation. The Earth is warmed by the Suns rays, the energy of which is mainly in the visible and ultra-violet frequencies. The Earth in turn radiates energy but mostly in the form of lower-frequency radiation, the infra-red bands. Air (oxygen and nitrogen) itself is transparent to both high- and low-frequency radiation. If the atmosphere contained nothing but air, the radiation from the Earth would be so rapid that the Earth's surface would be much colder, and life would not be viable. However, the atmosphere contains several gases, notably, water vapor, carbon dioxide, and methane, which are transparent to, high-frequency radiation but which absorb low-frequency radiation and then re-radiate it back to the Earth. This process is similar to that in a greenhouse, where glass is similarly transparent to the incoming solar radiation but absorbs. and re-radiates the infra-red radiation from the plants and floor.

This is the standard theory of what is called the radiation balance of the atmosphere; it is what I learned in my training as a weather forecaster in World War II. What makes it an object of policy is that the carbon dioxide (and also the methane) in the atmosphere are not the product of natural forces only. They are also the result of human activity, in the case of carbon dioxide, of combustion, which always creates carbon dioxide as a by-product. Human activity has always included fire, but the importance and magnitude of combustion has been vastly increased by the Industrial Revolution. The concentration of carbon dioxide in the atmosphere has in fact more than doubled over the last century.

It is not a new idea that the increased carbon dioxide content of the atmosphere due to industrial activity will cause global warming through the greenhouse effect. The lecturer in my weather course mentioned it in 1942 as a natural implication of the general theory, and the prospect had been raised by the great Swedish chemist, Arrhenius, in the 1890's. However, while the theory is unquestioned, the quantitative implications are much less clear. There is more to, the process than I have described: there are interactions with cloud cover, which also has a greenhouse effect, with growing vegetation, particularly trees, and with the oceans. The net effect becomes complex and difficult to analyze. In fact, whether the Earth's surface is significantly warmer than it was a century ago is still a matter of debate. In any case, the doubling of the carbon dioxide content of the atmosphere has been accompanied by at most a mild increase in temperature.

Nevertheless, there is a widely, though not universally, accepted scientific consensus that with present trends, including the rapid industrialization of the developing countries, the Earth's surface will be 3 to 5 degrees Celsius warmer by 2050 than it is today. It should be added that die effect in different parts of the world will be different. The estimates of the economic and social implications of this warming are equally uncertain. A general view among economists is that the average effect throughout the world is probably not more than about 2% of world income, but that some regions may be affected very strongly and that there is some risk that that the average effect will be large, for example, if enough of the Antarctic ice cap melts to raise the sea level considerably.

There are two important lessons to be drawn from. these remarks. One is that the effect of combustion is long- lasting. It adds to the carbon dioxide content of the atmosphere permanently (or almost so). Hence, present combustion produces damage for the indefinite future; and preventing combustion is an investment, in that the benefits in terms of avoided damages last into the indefinite future. Second, the effects are very uncertain. They may be very small; they may be very large; they may differ very much by region, so that they are large in some areas and small in others. There is considerable evidence, for example, that mean world temperature fell by only about 2 degrees C. during ice ages in Europe and North America.

There are two kinds of actions to forestall, climate change and its possible adverse consequences. One is abatement, preventing climate change by reduction in the generation of carbon dioxide. The other includes mitigation and adaptation, both of which are steps to minimize the adverse effects of whatever climate change does take place. Mitigation steps might include dikes to prevent the

incursion of higher sea levels, increased air-conditioning, or migration to cooler or higher areas. Adaptation includes such actions as growing different crops or changing the methods of crop culture to take account of the changed climate. Mitigation and adaptation steps are taken more contemporaneous1y with the problems they address. They have less the nature of an investment than abatement activities. I will concentrate on the evaluation of abatement activities.

Primarily, abatement requires some or all of the following: reduction of industrial output, electric power, and transportation; increase in the efficiency of combustion, so that less fuel is needed per unit output. and switches in fuels to those emitting less carbon dioxide per unit of energy generated. Natural gas has lower carbon dioxide per unit of energy than oil, and oil has less than coal. Nuclear energy emits no carbon dioxide whatever.

As I have already pointed out, abatement is an investment activity. The costs are borne now; the benefits in terms of reduced concentration of carbon dioxide last into the indefinite future. In fact, the benefits will not start being consequential for thirty to forty years. The reason is that moderate temperature increases will have very small effects on human welfare; the costs of temperature increase will rise more than proportionately to the warming.

As with private investment, justification of a public investment depends on a comparison of future benefits with present cons. In this case, the benefits are indeed very much in the future. For the purpose of illustration, I will assume a delay of fifty years. More precisely, an abatement policy requires a stream of annual cons beginning today in order to, achieve a stream of annual benefits beginning fifty years from now.

If we use an interest rate to, discount future benefits, we can see that the sensitivity of investment decisions to the particular choice of interest rate is greater the greater the delay. First note that I will refer to the real rate of interest, that is, the market rate of interest less the rate of inflation. This is to permit us to, measure future benefits at constant prices, specifically, at today's prices. Let me illustrate the effects of varying the rate of interest on the evaluation of future benefits. If we use 1% as the interest rate, then a dollar of benefit 50 years from now is worth $.61 today. In other words, it is just worth a cost of 61; cents today to achieve a dollar's worth of benefits 50 years hence. But if the interest rate were 40/6, a dollar of benefits 50 years hence would have a present value of only 14 cents; an interest rate of 5% would drastically reduce the present value of a dollar 50 years hence to 8 cents. At 10% the present value of a dollar would be considerably less than 1 cent. Clearly, with high rates of interest, we are very unconcerned about anything short of a major catastrophe.

II Thinking About Appropriate Rates of Interest

Serious discussion about the rate of interest appropriate to public investments has gone on since the 1950% at least. The initial focus in the United States was on water resources, which have been a major item of public investment since the beginning of the 20th century. Historically, the two major types of water development have been irrigation and flood control. In the 1950's, it was agreed that each water resource project should subject to a benefit-cost

analysis. Of course, the idea and basic logic of benefit-cost analysis is to be found in the classic paper of Jules Dupuit in 1844, with special reference to French bridges and highways, and was developed greatly from 1939 to the early 1960's by Maurice Allais, Pierre Massé, Marcel Boiteux, and others at the Corps des Mines and Electricité de France. But I do not think there was much discussion how to choose the appropriate rate of interest.

There are basically two different strands of thought which have to be drawn together to give some judgment as to appropriate rates for discounting benefits. One may be termed valuation of the future; it asks questions about our judgments, how much do we care about future generations, how much do we care about our future selves. Since it will concern benefits to others, valuation of the future is at least in part an ethical judgment.

The second strand is the notion of *opportunity costs*. There are alternative ways of providing for the future. Given that we are going to make an investment, we could, instead of spending resources on abatement of pollution, save and invest in the production of private goods. This will not prevent global warming, but it will make future generations better off than they would otherwise be and possibly compensate them fully. Suppose, for example, there is a high rate of return in the private sector. This implies that drawing resources from private investment to finance abatement of carbon dioxide production will involve the sacrifice of a large amount of private goods in the future. This diversion implies a high price for avoiding climate change.

Let us examine the opportunity cost argument in more detail. Basic to the existence of alternative investment possibilities is the clearly established fact that production over time generally yields more output than input, although the output emerges later.

In principle, whatever amount we desire to put aside for the future can be spent on either abatement or on private investment. (Actually, as we shall see, this proposition may not in fact be true, but, for the moment, let us follow its implications.) Both abatement and private investment benefit the future, one by minimizing climate effects, one by producing more ordinary goods. We should, it would appear invest at the higher rate of return. If in fact we both save and abate, the rates of return in the two activities should be equal.

The apparent implication of the opportunity cost argument is that the rate of return on private investment is the appropriate rate to be used for discounting the future in evaluating public investment. Since pretax real rates of return in the corporate sector are estimated at 10% or more, this policy would imply little regard for the future relevant to abatement policies for meeting climate change. The argument, I will claim, is flawed, but it has been officially accepted by the United States Office of Management and the Budget. However, probably very little public investment has in fact been stopped by this policy.

Let me return to the more fundamental approach, based on valuation of the future. On what basis do we form judgments about the value of future benefits and costs.

One way of posing this question is to ask why the interest rate is not zero. After all, the future is basically like the present. If we consider the problem as an ethical issue, we have to ask why these future individuals should not be treated just as we are. Why does the mere displacement in time change one's values?

Two reasons have been given in the economic literature for discounting the future, originally by the Austrian economist, Eugen von Böhm-Bawerk about 1887. The first, which we may term the wealth effect, is that we expect the future generations to be better off than we are. After all, in the advanced world, at least, we have experienced several centuries of steady growth in income per head. We expect that an additional unit of goods to be valued less in the richer societies of the future. Therefore, an investment which gives one unit of goods in the future in exchange for one unit of goods in the present would not be acceptable. Hence, future goods have to be discounted.

What is the discount rate implied by the we alth effect? A little analysis suggests that it is the product of two numbers, the growth rate in *per capita* income and the responsiveness of valuation to, changes in income. Some rather thin evidence suggests that this responsiveness is of the order of 1.5 or 2. The growth rate of per capita income in most countries has been of the order of 2% per year over a long period. This would yield the conclusion that the interest rate due to the wealth effect alone would be about 3% to 4%. Of course, we do not know that the growth rate will continue to be 2%. Those who emphasize the effects of natural resource scarcity will see lower growth rates in the future. But others will argue that the effects of the enormous improvements in information technology have yet to be realized in productivity, and the world faces a period of more rapid growth. My view is that 2% is a fairly conservative estimate of the per capita growth rate.

The wealth effect is relatively uncontroversial as to principle, though the quantitative magnitudes are in dispute. A second reason advanced for discounting the future may be termed, *pure time preference*. Suppose there were no growth in per capita income. Would it still be reasonable to discount the future? The point has been very much disputed by economists and philosophers. Even for an individual contemplating his or her own future, it has frequently been held that it is at best a deficiency to, value future benefits less than present ones, "faulty telescopic vision," in the words of A. C. Pigou. These words were strongly endorsed by his brilliant younger colleague, Frank Ramsey, in his major paper on the theory of saving, in 1928. But elsewhere, in a less formal, mode, Ramsey remarked that he was not depressed by the fact that life would eventually be extinguished by the cooling of the Sun, for that event would have little present value at even modest rates of interest. The ethical and even descriptive argument is that future individuals are very much like those now living and that an individual will think of his or her own future as equally worthy of support with the present.

Other economists. have tended to doubt the thesis of zero pure time preference. I find an argument first advanced by the Dutch-American economist, Tjalling Koopmans, in 1960 to be very persuasive. Put simply, it observes that a zero time preference makes investment and savings decisions insensitive to the

needs of any one generation. Concretely, as we shall see, zero time preference implies unacceptably large savings rates.

To understand this, it must be recognized that the two approaches to discounting the future, opportunity cost and valuation of the future are not independent of each other. Suppose we value the future highly, that is, the interest rate implied by our values is low. Then we should be willing to invest a lot in each way of benefiting the future. This will be observed as a high saving rate. Put another way, the higher the value put on the future, the more any generation should sacrifice for the future.

We can perform a thought-experiment: how much saving would be implied if we assumed no time preference? Consider Koopmans's original argument. Imagine that we are in a stationary economy. In each period, there is a steady flow of goods which can only be consumed in that period. The present generation is presented with an investment opportunity which will not recur. For each dollar invested, it will yield a fixed positive income throughout the future. This income may be very small compared with the initial investment, but it will last forever. If there is no time preference, how much should the present generation invest? It should invest its entire income, leaving it completely destitute; at least it should reduce itself to the lowest level compatible with sheer survival. Any loss in welfare to the present generation, no matter how small, will be made up by the benefits to an indefinitely large number of generations, no matter how small the gain to each may be.

The reference to lasting forever may sound fanciful; after all the Earth will not be habitable for ever. But the underlying argument is only slightly changed if we consider a long but finite future. If we assume that the investment will yield only 1% return per year, then the present generation should sacrifice 90% of income if the investment continues to pay off for 3,000 years or so.

I do not believe most of us will find these conclusions acceptable. We do not believe that any one generation should be called upon to make such sacrifices, no matter how long the period which receives some benefit. It is true that the Koopmans argument is biased in one way; only the present generation has the opportunity to make an investment. We cannot call on future generations to, help, because the assumptions preclude that. Nevertheless, it seems to me to, be a compelling argument. An ethical argument that all generations should be treated equally should, if valid, yield reasonable results for cases which are conceivable, even if not realistic.

To supplement this argument, I have considered growth models of a more reasonable nature, those in which the future also has opportunities for investment. There is no one agreed-on model which gives good clue as to the relation between investment in one period and subsequent returns, so I tried several. The results are different for different models, but they agree that in the absence of pure time preference, the savings rates are much higher than those observed and much higher than I think most people would judge reasonable.

I conclude therefore that our ethical and empirical conclusions strongly lead to the existence of a pure time preference which is greater than zero, perhaps

about 1%. I therefore that a reasonable figure for total time preference, taking account both the wealth effect and pure time preference, is between 4% and 5%. This is a higher figure than some analysts are willing to concede, but nearly as high as the figures based on opportunity costs.

III. Risk and the Discounting of Public-Goods

I have still left a puzzle, the apparent contradiction between the opportunity cost and valuation of the future. If it is possible to earn 10% return by private investment, how we can use the rate of 5% to discount public projects. Remember, we are assuming that the outputs of the public projects, in this case, the benefits from reduced climate change, have already been measured to make them comparable to private goods. Hence, it would appear that we can do better for future generations by investing in the private sector under these assumptions, unless the return in the public sector is 10% or more.

There are two different arguments which explain the discrepancy, and both are of importance. One is the presence of risk in private investments, the other is the public character of investment to avoid climate change.

First, let us discuss private risks and their implications. Private investments are in general risky.
But in addition these risks are only incompletely insurable. Devices like common stocks are ways of spreading risks, but it is intuitively clear that significant risks remain. An individual investor can reduce risks by diversifying his or her portfolio, but risk remains. Therefore, private returns in the corporate sector have to contain an element of compensation for the risks undergone. This can be stated as a *risk premium* of the return as an excess over the risk-free rate of interest. Of course, the return from the common stock is not a fixed amount but an uncertain magnitude; what is meant is that on the average the realized return exceeds the true or risk-free rate of interest by the risk premium. This difference is made manifest if an investor seeks to, achieve a return which genuinely avoids all risks, including those of inflation. This can more or less be accomplished in the United States by buying Treasury bills (with maturities of 90 days or less); the average real rate that could have been achieved over a long period of time was slightly over 1%. More generally, we find that long-term government bonds, which are riskless at least in nominal term yield real rates in the neighborhood of 2 1/2% or 3%. These figures are well below the average return in the corporate sector, yet they remain in demand. Obviously, the difference is a risk, premium (apart from some tax considerations).

It is clear that, while the opportunity cost must be considered, it must be properly assessed. To the extent that it includes a compensation for private risks, it must be adjusted downwards.

I also call attention to the second aspect mentioned before, that abatement to avoid climate change is a public investment. It is an investment to achieve a public good, not one that can be attained through the market.
Therefore, we expect that the investment will go beyond private investment, not merely displace it. If it did only displace private investment, then use of the opportunity cost would be reasonable. In fact, however, abatement cons will be

largely financed by a reduction in consumption. Whatever means are used to reduce the burning of fuel, the immediate effect will be to reduce the consumption of fuel or of the goods produced by fuel. It is therefore the willingness to reduce consumption that is relevant. This willingness is what I have called valuation of the future. The opportunity cost argument is really only marginally relevant; it is valid only for that part of the abatement costs which result in a reduction of private investment, a proportion which is likely to be small.

Raising the issue of risk in private investment reminds us that there is also a risk in public investment. Indeed, as I stressed at the beginning, there is an extraordinary degree of uncertainty. The underlying science is not well understood, the climatic consequences for particular regions are certainly poorly predictable, and the economic and social consequences of a climate change will depend on many factors including the ingenuity of the future generations. With all these factors, two main points can be made.

(1) Since the consequences are spread all over the world, there is at least some possibility of insurance, with some regions being able to help out others. Whether this possibility can really be implemented is a matter to, be worked out in the future. If it could, there would be a reduction in uncertainty for everyone.

(2) It must be stressed that the abatement programs; are a way of reducing uncertainty. The uncertainty of benefits is an uncertainty about the consequences of not engaging in abatement activities. Therefore, here the benefits of abatement include a reduction of uncertainty and hence of the risk premium. We can consider this either an addition to the benefits or a reduction in the interest rate.

To conclude, it would appear that, if we try to discount the expected gain, we should be using a figure of about 4%. This is in the middle of the range of interest rates that have been proposed.