The Economics of Climate Change Revisited: Why the Hurry?

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By way of explanation

- I do believe there is a sound economic argument for strong action now to reduced GHG emissions.
- But this is not the mainstream view of economists in the United States.
- In this talk, I will explain the reasons for the difference in perceptions about the economic case for climate action.

Conventional view in Washington

- The conventional view in DC is that
  - Climate change poses relatively little risk to the US in the near term, and may even be beneficial
  - The cost of any large reduction in US emissions would be economically harmful
  - Hence the notion of setting a modest price of carbon and seeing what happens

Stern Review

- Review of economics of climate change commissioned by the Chancellor of the Exchequer, conducted by Sir Nicholas Stern Head of the UK Government Economic Service, released in November 2006.
- Calls for "prompt and strong action….If we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever."

Reception of Stern

- Nordhaus (2006): The Stern Review results are “dramatically different” from existing economic analyses.
- He finds that optimal economic policy for climate change involves modest rates of emissions reductions in the near term. 6% emissions reduction in 2005; 14% in 2050; and 25% in 2100.

Why the difference?

- Thus, there is a fundamental difference in (i) the perception of damages from climate change, and (ii) the sense of urgency about taking action.
- What is the reason for this difference? Is it due to the different treatment of discounting by Nordhaus and Stern?

Factors underlying the interest rate

- Pure rate of social time preference (ρ)
- How much richer the future generation will be (g)
- If they are richer, how much that lowers the value of money to them (η)
- Interest rate is: $r = \rho + \eta g$
  - Nordhaus & Stern both use same η (=1) and similar g (= 1.3%)
  - Nordhaus uses ρ = 2.3-3%; Stern ρ = 0.1%
  - Result is that for Stern r = 1.4%, while for Nordhaus r = 3.6 – 4.3%.

The force of discounting

- With r = 4% (Nordhaus)

  $1 @100 years from now is worth $0.018 today

  $1 @ 200 years from now is worth $0.0003 today

- With r = 1.4% (Stern)

  $1 @ 100 years from now is worth $0.25 today

  $1 @ 200 years from now is worth $0.06 today

Two observations

- The choice of ρ (social rate of time preference) is an ethical judgment, not a matter of economics.
- There are two empirical assumptions underlying the rest of the formula (ηg) that seem incorrect. Altering them would lower the value of the interest rate, r.

Two questionable assumptions

- (A) Climate change does *not* directly affect people's wellbeing; it affects only the production of market goods.
  - If it did affect wellbeing directly, this would add an extra negative term to the formula for r
- (B) People's preferences do not change as they become richer; they don't change their expectations to match their wealth.
  - If preferences do shift, the marginal utility of an extra dollar declines less, and η is lowered.

The effect of model differences

- Moreover, Fujii and Karp (2007) point out that discounting has a much smaller impact in the PAGE model (used by Stern) than the DICE model.
- This is because, in PAGE, a large current expenditure on mitigation doesn’t have so much greater an impact in reducing future income than small current expenditure.
- Therefore, discounting at 4% versus 1.4% makes much less difference in PAGE.

The difference is not just discounting

In fact, it is probably *not* mainly discounting

- Assessment of future damages
  - Stern's assessment of these is much greater
- Assessment of costs of emission reduction
  - Stern's assessment of these is lower
- Treatment of uncertainty
  - Stern includes allowance for risk aversion, views climate policy as partly a matter of insurance

Modeling the costs of mitigation

- The economic costs of reducing greenhouse gas emissions depend crucially on :
  - Decision making behavior by firms and households
  - Technology and technological innovation
  - Institutional behavior and institutional innovation
- Economic models typically do a poor job of accounting for these.

Distinguish 2 types of response

- (A) Move *along* demand and supply curves, based on given technology, preferences, and set of firms in industry.
- (B) Shift *in* demand and supply curves due to changes in technology, preferences, or set of players.

The existing economic models focus mainly on (A). Policy raises price of carbon either through cap or a tax; this raises price of commodities that are carbon-intensive. Provokes adjustment based on shifts in demand and supply. Substitution and price elasticities are key to cost impact.

To reduce emissions on large scale with limited economic cost, the California experience suggests we will need (B) as well – conservation, new technology. These are not well accounted for.

The time dimension and costs

- What difference does it make to the cost if one reduces GHG emissions by 20%
  - In 1 time period (say, 2020)
  - In successive steps between now and 2020?
- In existing economic models it makes no difference: the marginal cost is the same.
- But that is not empirically plausible
  - Adjustment cost
  - Changing stock of physical capital
  - Changing stock of knowledge and institutional capital
- To be policy relevant, economic models will need to reflect this

The significance of damages

- Both the level of damages from climate change and the slope of the damage function – how much damages increase as emissions rise – play a crucial role in determining the economically optimal
  - (1) level and timing of abatement
  - (2) choice of policy instrument (carbon tax versus cap on emissions)

Damages from climate change

- I believe the damages for the US implied by DICE model – ½ of 1% of GNP for a 2.5C warming – are too low. They certainly should be doubled and perhaps quadrupled.
- In addition the damages for the US increase with the amount of temperature change more rapidly than represented in DICE.

TABLE 1: MODEL COVERAGE OF IMPACTS

TYPE OF IMPACT	DICE/RICE	FUND	JORGENSON
MARKET - Impacts on flows of inputs & outputs			
Agriculture	Yes	Yes	Yes
Forestry	No (b)	Yes	Yes
Fishery	No(a)	No(a)	Yes
Related processing industries	No(a)	No(a)	Yes
Energy	No (b)	Yes	Yes
Construction	No (b)	No(a)	No(a)
Water	No (b)	Yes	Yes
Recreation, tourism	No(a)	No(a)	No(a)
Labor supply/number of consumers	No(a)	No(a)	Yes
Disruption of production - extreme events	No(a)	No(a)	No(a)
Response costs to deal with extreme events	No(a)	No(a)	No(a)
MARKET - Impacts on stocks of assets			
Forced obsolescence of capital due to changed climate	No(a)	No(a)	No(a)
Damage to coastal and loss of land from sea level rise	Yes	Yes	Yes
Damage to property from extreme events	Yes	No(a)	Yes
NONMARKET			
Human health and life	Yes	Yes	No(a)
Amenity	Yes	No(a)	No(a)
Ecosystems, species, landscapes	Yes	Yes	No(a)
CATASTROPHIC CONSEQUENCES OF CLIMATE CHANGE	Yes	No(a)	No(a)

NOTES

(a) = Item not covered

(b) = Item covered and calibrated to be zero for 2.5° C warming in USA, but non-zero for larger temperature increases or for other regions

TABLE 2: NORDHAUS & BOYER ESTIMATE OF ECONOMIC IMPACT OF 2.5˚ C WARMING IN THE U.S. -- ANNUAL WILLINGNESS TO PAY PER U.S. HOUSEHOLD (2006$)	
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NONMARKET SUBTOTAL*	$195
MARKET + NONMARKET TOTAL*	$321

NOTES

Applies impacts as % of 1990 GDP from Nordhaus and Boyer (2002 Table 4.11) to 2006 mean household income of $66,570. Damages are positive, benefits are negative.

* Total does not add due to rounding in original

Damages from climate change: why DICE underestimates them

- Some important categories of damage are omitted.
- The categories of damage that are included are under-estimated.
- I will illustrate the latter with regard to impacts on
  - agriculture
  - water
  - coastal areas
  - energy
  - health.

Climate Change and Agriculture

- The most heavily analyzed sector in climate economics literature.
- Also the most divergent range of estimates e.g., from loss of 25% in value of US ag output to *gain* of 20%.

Interactions between climate & crop growth

Complex, non-linear, not unidirectional, and multidimensional:

- Temperature
  - Effects on yield
  - Effects on quality
- CO_2 fertilization
- Crop ET (crop water need)
- Weeds, pests
- Ozone

- Existing literature focuses just on temperature and CO2 fertilization; focuses on crop yield, not quality, especially major grain crops.
- Other effects largely ignored so far.

- When attention is thus restricted, estimated, climate change impact on yield can well be positive:
  - Fertilization effect is positive
  - Cooler areas benefit from warming

Three factors

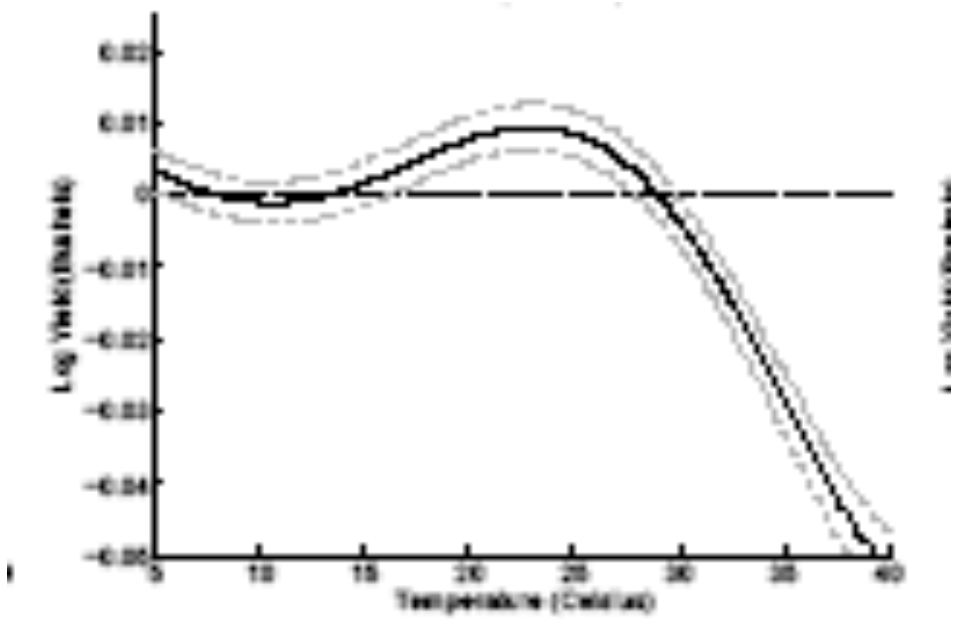
- Characterization of temperature change
  - Annual, seasonal, monthly, daily
  - Global, US, California, Central Valley
- Assumed shape of relationship between temperature and yield
  - Symmetric, hill-shaped
  - Asymmetric, mesa-shaped
- Allowance for economic adaptation

Characterization of temperature change

HOW TO CHARACTERIZE THE CHANGE IN TEMPERATURE, 2070-2099, USING HADCM3			
		EMISSION SCENARIO**	
		A1fi	B1
Change in global average annual temperature		4.1	2
Change in statewide average annual temperature in California*		5.8	3.3
Change in statewide average winter temperature in California*		4	2.3
Change in statewide average summer temperature in California*		8.3	4.6
Change in LA/Sacramento average summer temperature		~10	~5
*Change relative to 1990-1999. Units are ˚C			

Schlenker & Roberts (2006)
Relation of Temperature and Crop Yield

- Relationship is not symmetrical; it is distinctly asymmetric, fairly flat at first and then sharply declining beyond an upper threshold.



Details matter!

- Should one look at impact on yield or profit? (Latter may be harder to measure – need economic profit, not accounting profit).
- Should one look at the impact of weather on current profit, or of climate on long-run profit? Is the former necessarily an upper bound on the latter?
  - Not if there are adaptations that work in short-run but not long run (e.g., storage, groundwater depletion).

Details matter!

A finding of little or no impact of weather on yield or current profit is highly sensitive to:

- Monthly temperature versus degree days.
- Daily average temperature versus daily maximum and minimum temperature.
- Degree days over $34^{o}C$ as well as degree days between 8^{o} and $32^{o}C$
- Taking simple average of weather stations in a county versus using weather on a 2.5x2.5 mile grid and then weighting by crop acreage.

Economic adaptation

- The extent to which a physical change in yield translates into a corresponding change in output supplied depends on
  - Supply and demand in market for product and in related markets
  - Other responses and adaptations
    - Change planting/harvest dates
    - Change cropping pattern
    - New seed varieties
    - Change land use
    - etc

Two approaches to incorporating adaptation

- Combine crop yield model with some model of economic market behavior.
  - Led to estimates of loss to US agriculture ranging from $1.1 billion to $17.5 billion.

- Ricardian Approach (Mendelsohn, Nordhaus and Shaw, 1994) [MNS]. Regress farmland value directly on climate variables. In theory, allows for adaptation to a greater extent.
  - Gain of $2.5 billion, $24 billion.

- The difference was widely attributed to the economic effect of adaptation.

- In fact, it arises from some flaws in MNS's statistical analysis of their data involving their failure to control adequately for irrigation (Schlenker, Hanemann and Fisher 2005).
- Irrigation breaks the link between precipitation where crop is grown and the amount of plant growth.
  - In Iowa, 22" of growing season precip, 100% of crop water need for corn
  - In California, 1.5" of growing season precip, 5% of crop water need for cotton.
- Therefore, need to analyze irrigated areas separately from rainfed areas.

- When MNS analysis is repeated just for rain fed areas of US, instead of a gain for these areas of $2.3 billion, there is a loss of $11 billion.
- Irrigated areas need individual analysis based on a measure of their water supply; but there clearly is a net loss:
  - Increased crop demand for water
  - Reduced supply of water
- There is no evidence that, when correctly implemented, Ricardian approach yields substantially different estimates of loss from models of agricultural market models.

Adaptation

- Adaptation will clearly occur and will mitigate loss.
- But adaptation will not be costless, will not occur instantaneously, and may not be perfect when it does occur.
- Thus there are likely to be costs:
  - Interim loss prior to adaptation
  - Cost of adaptation
  - Long-run loss if adaptation is not perfect
- These costs have not been well tallied in the existing literature.
- We do not yet have a realistic representation (or understanding) of adaptation. This is where research is needed.

Water Supply

- Not just precipitation but also runoff (which is sensitive to temperature).
- Not just annual precipitation. Timing of precipitation matters
  - Precipitation during the growing season.
  - Can have both more winter precipitation and more summer time drought.
  - With snow-reliant systems, what matters is water stored in snow pack at the beginning of spring. Can have more winter precipitation and less water supply available for springtime and summertime use unless costly extra storage is developed.
- Temperature is often the more powerful influence on effective water supply than precipitation.
- With water supply, the cost is mainly the infrastructure for storage, conveyance and treatment, not water per se.

Water supply impacts, continued

- Key fact of future impacts of climate change is that they are superimposed on a larger population, possibly more prone to live in vulnerable locations.
  - Climate change exacerbates the stress caused by population growth and changes in land use.
  - Climate change causes an *intensification* of extreme events.

Water, continued

- Because of population growth, urban demand for water in Southern California will be 60% larger in 2085 than now. Climate change reduces effective supply by 10-20%.
- Compared to without climate change in 2085, with A1Fi shortages that require rationing occur twice as frequently (1/3 instead of 1/6 of years) and are more intense (1/3 greater loss of consumer’s surplus).
- Thus, looking at the median or average year is misleading.

Water: institutional dimension

- Rights to divert surface water in the US West are rights to divert in specific time period, typically April – September.
- With climate change and melting of snowpack in snow-dependent systems, this streamflow will decline significantly.
- Will water rights adjust? If not, what happens to water transfers?

Social/economic dimension to flood losses

- Flood damage tend to dwarf costs of sea-wall construction.
- But existing cost estimates focus on property damage and (some) government expenditures. But they omit costs associated with:
  - Business disruption and economic dislocation
  - Injury, illness and loss of life
  - Misery and loss of well-being from being flooded

The official estimate of damage from Katrina is $125 billion; other estimates are $250-350 billion.

Accounting for capital assets

- There is large amount of infrastructure along the coast that is vulnerable and needs to be tallied.
  - Katrina affected 172 wastewater treatment plants and 1,000 water supply systems, as well as roads, bridges, pipes, powerlines,etc.

How rapid is the adaptation?

What do we assume about the timeliness of sea wall protection? Consider Katrina:

- In 1955, USACE starts planning for flood protection in New Orleans.
- In 1962, USACE completes comprehensive flood protection plan. No action is taken.
- 7 weeks after Hurricane Betsy in 1965, Congress authorizes construction of New Orleans Flood Defense System at cost of $80 million and with completion date of 1978.
- When Katrina hit in 2005, the cost was over $700 million and the projected completion date was 2013, with likelihood of further postponement.
- The two portions of the flood defense system that failed most comprehensively when Katrina hit were officially rated as 90% and 98% complete.

Energy

- Climate change affects supply as well as demand.
- On demand side, there is a mixed effect: winter heating is reduced, while summer cooling rises. But the effect is not necessarily symmetric or offsetting.
  - Summer cooling is peak demand, winter heating is baseload.
  - This is a behavioral response, not an engineering one. The change in demand is not necessarily proportional to the changes in heating and cooling degree days.

Energy costs

- Existing energy cost estimates focus on operating costs not capital costs of supply.
  - Effect of warming on peak cooling demand becomes important
  - Depending on transmission capacity, reduced heating demand in one region doesn't costlessly offset increased cooling demand in another.
- A key behavioral adaptation on the demand side is air conditioning.
  - Retrofitting existing housing stock is more expensive than equipping new buildings.
  - These costs are typically not included.

Energy supply

- Energy supply is vulnerable to climate in ways that have generally been overlooked so far:
  - Drought affects hydropower.
  - Warm river water temperature reduces cooling.
  - Warm air temperature reduces carrying capacity of power lines.
  - Extreme events (wind storms, ice, hurricanes) affect production and distribution.

Human health

- Direct consequences of heat versus cold.
- Vector-borne disease

Extreme heat vs cold

- A mixed effect: less winter mortality, more summer mortality.
- In general, more people die in the winter than the summer. But the pathway is not the same. In winter, few die from direct exposure to cold; most mortality is from infectious disease (flu, etc). In summer, the issue is direct exposure to extreme heat.
- It is not clear what is the net effect on mortality. Result depends on some key issues:
  - How extremes are handled (distinguish > 110^{o}F, >100^{o}F, and > 90^{o}F).
  - Nighttime temperature may be significant
  - Need several hot days in a row
  - Interaction with humidity and ozone,
  - Thus, daily average temperature may not be a sufficient statistic.

Health effects, continued

- Harvesting is an important question: is this merely premature mortality advanced by a few weeks or months? If so, what is the policy significance?
- Adaptation, including improvement in public health systems and emergency response capacity, are key factors.
- These costs have not generally been assessed.

Quality of life

- DICE model uses an oversimplified statistical analysis to conclude that there will be a substantial net increase in outdoor recreation in the US.
- It values this so as to generate a large net benefit from climate change.
- This ignores substitution: what will occur is a switch from one type of leisure/ recreation activity to another, rather than a net increase in leisure.
- At first, people will surely miss their old activities (e.g., skiing) and there will be some welfare loss: they are giving up what they preferred to do.

Preference adaptation

- For some of the non-market amenity impacts, preference adaptation is of importance.
  – Interim loss while people face changed environment.
  – Then they get used to it (their preferences adapt) and there is little or no loss.
  – The magnitude of the interim loss is the major factor.
  – This is where research is needed.

The gaps in the existing impact literature

- In summary, existing literature
  - Understates coastal impact
  - Understates agricultural impact
  - Wrongly assumes no net impact on water supply, energy, or other market sectors
  - Ignores disruption from extreme weather events
  - Assumes no cost for health impacts
  - Ignores nonmarket impacts on quality of life, human well-being, natural environment or ecosystems.

Level and slope of marginal damages

In conclusion:

- I believe the damages for the US implied by Nordhaus' DICE model – ½ of 1% of GNP for a 2.5C warming – are too low. They certainly should be doubled and perhaps quadrupled.
- In addition the damages for the US are likely to increase with the amount of temperature change more rapidly than represented in DICE.
  - Thresholds are key to damages.
  - The more thresholds crossed, the more sharply damages increase.

The ethical dimension

- Treating distributional issues
  - Between generations
  - Between rich and poor countries
  - Between regions within a country
- Windfall gains versus losses
- Uncertainty

These are all important areas for research

Paternalistic altruism & discounting

- Future generations may be richer than us. Also, we don't know their preferences. Why should we spend our money to give them a better environment?
- They may not be interested in inheriting a non-climate-change environment. Their preferences will have adapted to whatever is familiar to them.
- For us to want to preserve the present environment for them to enjoy is an act of paternalism on our part.
- But, so be it ???

Distribution: a social welfare function oriented to the status quo?

- Above all, climate change creates winners and losers.
- Economists typically employ the Kaldor-Hicks (Potential Pareto Improvement) social welfare function: all that matters is whether aggregate gain outweighs aggregate loss, regardless of to whom this occurs, and regardless of the status quo. Is this appropriate?
- Should windfall gains count equally with windfall losses, or should the latter be weighed more heavily.

Uncertainty

- There is a powerful argument that climate change should be viewed through the prism of risk management.
- In that case, a key question is whether public policy should embody a degree of risk aversion.
  - These are mainly non-monetary, non-market outcomes, and cannot well be hedged in financial markets.
  - Stern allows for uncertainty and risk aversion, in a particular way. DICE does not. This is a major reason for their divergent assessments.
  - This point has been strongly emphasized by Weitzman in several recent papers.

Weitzman (2007)

- Weitzman focuses on risk and risk aversion.
- In economics, if a person is risk-neutral, he values uncertain consequences by their expected value.
- But, if he is risk averse he discounts uncertain benefits and augments uncertain costs by a risk premium.
- The risk premium depends in general on
  - The degree of risk aversion
  - The magnitude of the uncertainty

- Weitzman shows that the combination of risk aversion regarding future consumption and a fat tail for the potential reduction in this due to adverse climate change impacts can generate a very large risk premium – possibly infinite in some cases.
- It turns out that the PAGE model used by Stern has risk aversion applied to *all* potential impacts.
- Nordhaus allows for risk aversion in the case of catastrophic events such as collapse of the thermohaline, but *not* for any other impacts.

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Framing the policy decision

- Choosing the level of emissions
- Choosing the policy instrument

Choosing the level of emissions

- Balance benefits of emission reduction (damages avoided) against costs of emission reduction (reduction in economic output). PROMOTED BY THE US

- Define an unacceptable ("dangerous") level of GHG concentration (e.g. >550ppm). Reduce emissions sufficiently to stay below this level or to stabilize at this level. ADOPTED BY THE EU

The balancing approach

- Makes a heavy demand on quantitative analysis, including economic analysis to quantify benefits and costs over a time frame to 2100 or 2200.
  - Raw difficulty of projecting economy and society so far into the future
  - Issue of discounting
  - Issue of uncertainty
    - Are we correctly accounting for all future damages as well as all costs?

The “imperative” approach

- Reflects an assumption that there is a sharp threshold effect, whereby marginal damage increases sharply once concentration passes a certain level.

- Economics then enters the analysis only with regard to determining the most cost –effective way to attain the given amount of emission reduction.

Differences between US & EU

- Policy makers in the EU seem to have adopted the imperative approach, while the policy discussion in the US leans more towards the balancing approach. Set an emission tax and then live with whatever reduction occurs.
- This reflects
  – A difference in policy objective
  – A difference in underlying assessment of costs and benefits

Price versus quantities

- Weitzman (1974) famously addressed this issue. In the face of uncertainty, the two instruments perform differently.
  - Price leads to uncertainty about amount of emission reduction. But, whatever emission does occur, will be achieved efficiently (at least total cost).
  - Quantity regulation generates certainty about reduction in emissions; but the amount of reduction may turn out ex post to have been non-optimal.
- Which instrument is preferred depends on which is the more serious error.
- Weitzman relates this to the relative slopes of the marginal benefit and marginal cost curves.

- The marginal benefit of abatement curve is steep if there are serious threshold effects.
  - Then it makes a big difference to the damages if one achieves a bit more or less abatement.
- If the marginal cost of abatement curve is steep, there can be a big efficiency loss from a bit too much abatement.
- Consequently, quantity regulation is better than price regulation if the marginal benefit curve is steeper than the marginal cost curve, and vice versa.
- So, what is the case with climate change?

- Pizer (2002) and Newell & Pizer (2003) apply this analysis to climate change (a “stock” pollutant), and find that the marginal benefit curve is very flat relative to the marginal cost curve.
- They conclude that this favors the use of a price instrument – a carbon tax – rather than a quantity control (e.g., the Kyoto limit on emissions). This supports the US view.
- Their analysis is summarized in the following diagram.

[Pizer, J. Pub. Econ. 2002]

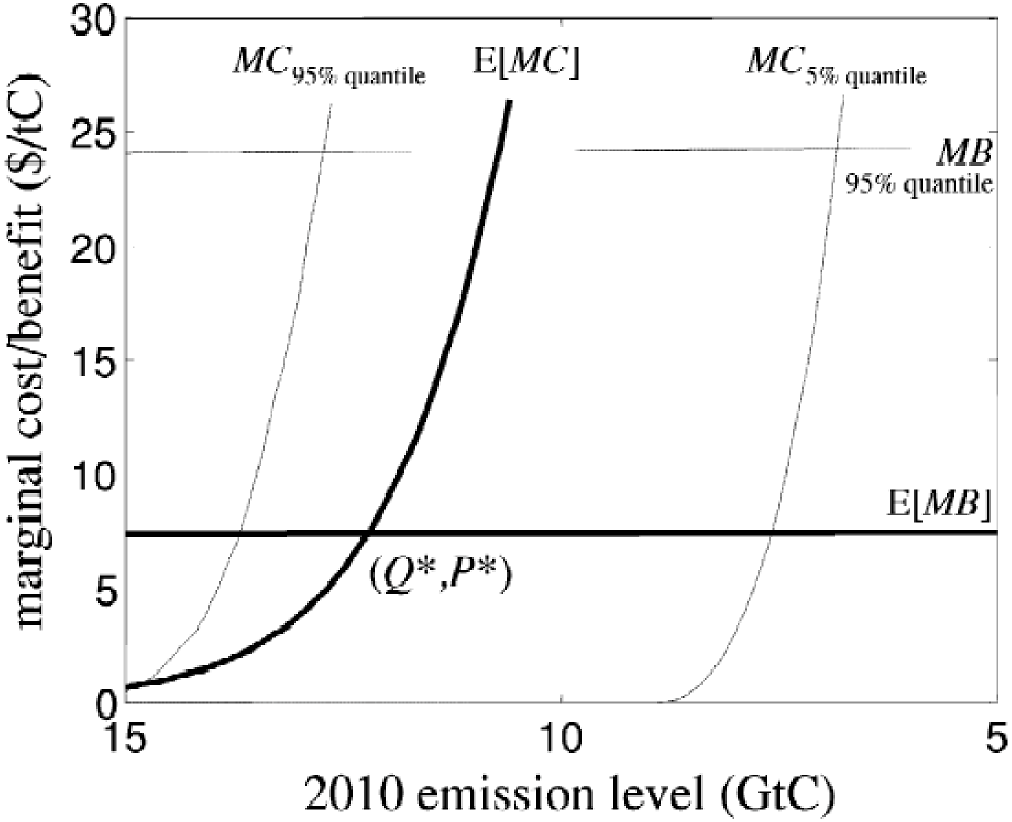

Fig. 2. Distribution of marginal costs and benefits in 2010. (The 5% quantile of marginal benefits overlaps the x-axis.).

What's wrong with this picture?

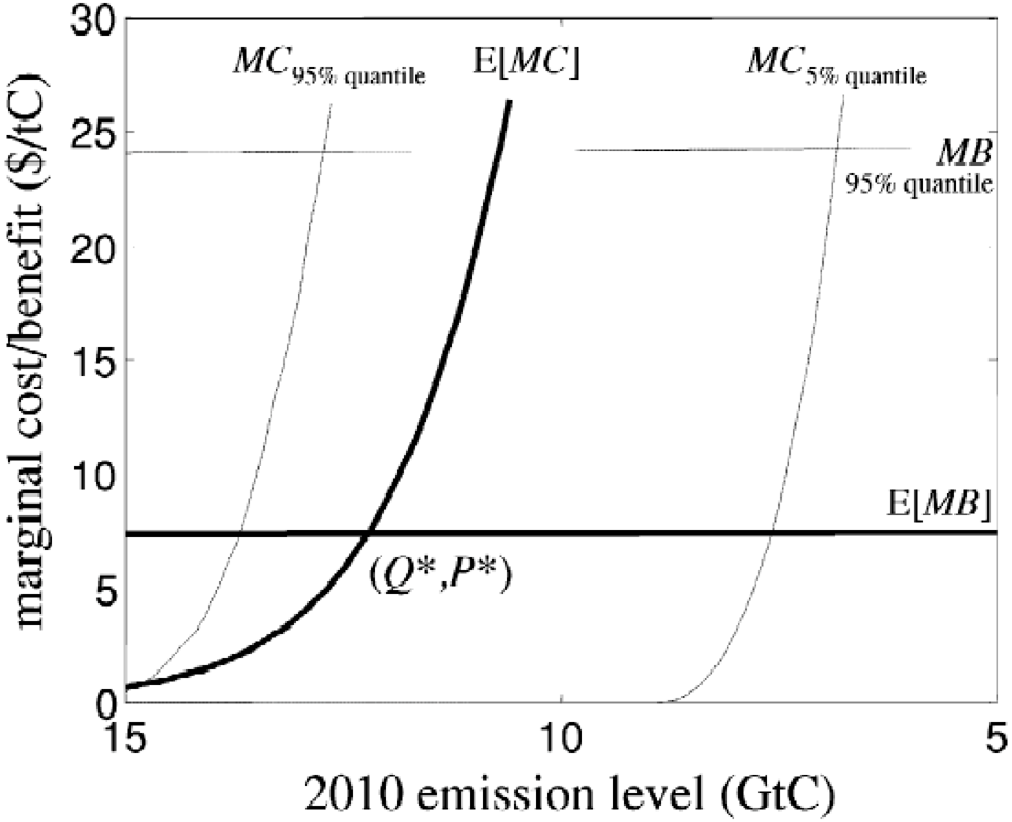

Fig. 2. Distribution of marginal costs and benefits in 2010. (The 5% quantile of marginal benefits overlaps the x-axis.).

What is wrong:

- 1) They conduct an annual analysis, and this may not be appropriate. The issue is *not* reducing emissions in one isolated year. If it were, clearly
  - Marginal benefit is low: a single year contributes relatively little to stock of CO_2 in atmosphere.
  - Marginal cost of reducing emissions 20%, say, in one year is high.
- What is lacking is analysis of a multi-year policy commitment. This may reverse the relative slopes of marginal benefit and marginal cost.

- 2) The original Weitzman analysis of prices vs quantities has certain limits. By using quadratic functions for costs of abatement and damages from pollution, it generates a certainty equivalent effect. The result is that uncertainty regarding the damages from pollution, and risk aversion, have no impact on the choice between prices vs quantities.
- If one changes the structure of the damage function and/or adds risk aversion, this appears to strengthen the case for quantity controls.

Conclusion

1. The US economic concensus understates the damages of climate change and overstates the economic cost of reducing emissions.
2. These are largely empirical questions, although there is also a moral dimension which the economic concensus wrongly ignores.
3. The consequence is to understate the arguement for strong early action.
4. The analysis of prices vs quantities favors a carbon tax mainly because of the assumptions made in framing the analysis; some different assumptions could reverse the conclusion.

Thank you

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