Where Do We Go from Here?

John C. Bean

Outline

Searching for an effective, politician & lobbyist-proof, way of mitigating climate change

Cap & Trade: Affecting industry directly / but me only indirectly

- Its success with acid rain vs. the complexities of applying it to climate change

Carbon Tax: Affecting ALL directly

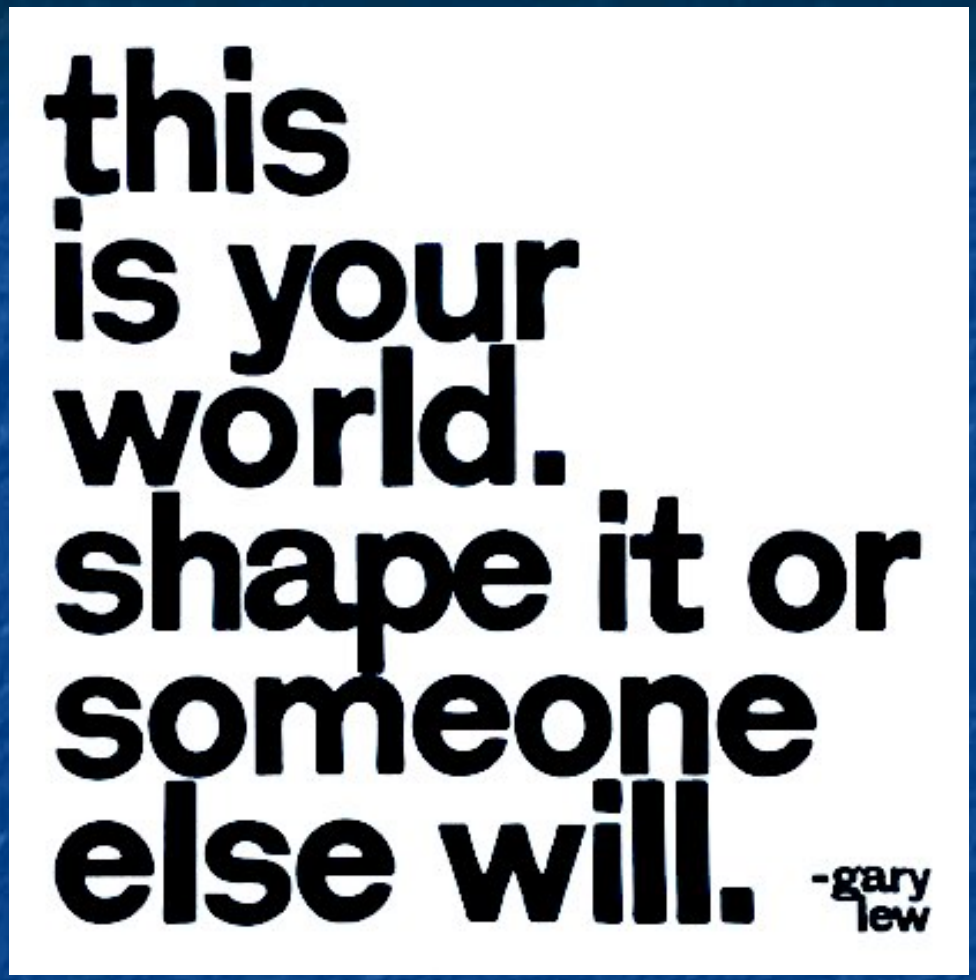
- What tax rate would be required to produce the desired changes?
  - A prediction based on present day energy economics
- What is my personal carbon footprint? => How much tax would I likely pay?
  - Household cost as a function of carbon tax rate and your local energy sources

Would this be justified by what economists call the Social Cost of Carbon?

- Their last two decades of research & debate about this cost
  - My analysis of their data, incorporating more recent climate modeling

(Written / Revised: November 2019

A former student recently sent me this card:



She noted the strong resonance with this class

Which leads me to now pose a final question:

Where Do We Go from Here?

I've described my own early error of fixating upon a **single** energy technology

Which, driven by my research interests, turned out to be solar photovoltaics

But David McKay then taught me the need to consider **entire energy systems**

And that energy systems were now hugely complex and rapidly changing puzzles

David and I have now taught **YOU** a lot about those energy system pieces

Hopefully, that now suggests many ways in which they might be fit together

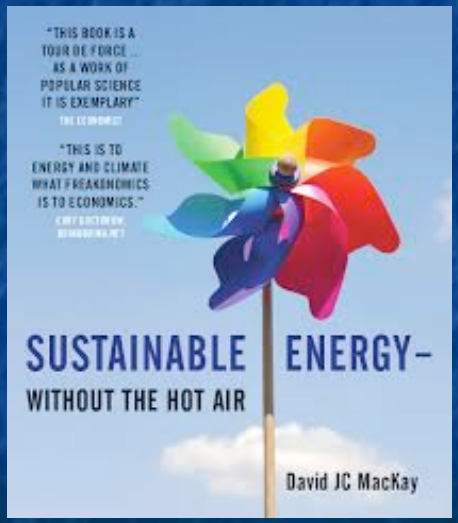
But how do we ensure that anything is now actually **DONE***?*

In his book's final brief chapter, David's closing admonitions were:

1) **"Stop saying NO and start saying YES"** (to specific energy alternatives)

2) Craft your chosen alternatives into **"A plan that adds up"**

3) And then **"Tell all your political representatives"**



I echo David's sentiment, but am increasing troubled with his 3rd recommendation

Sadly, today's politicians are almost always someone who:

1) **DID** manage to eek out some sort of law degree . . . from somewhere

2) Has **NOW** mastered the ability to parrot a set of talking points

3) But is **totally** preoccupied with funding his/her **FUTURE** re-election campaign

≠ People qualified or inclined to study our carefully crafted energy plans

Instead, in their hands our complex plans can easily disappear behind closed doors

Through which only well-moneyed lobbyists have access

And emerge as endlessly complex, carefully loophole-infested bills

That **only** a pack of lawyers can really understand (or exploit)

And I already see rich evidence of highly politicized energy policy:

In MacKay's Britain, where politicians have not only gutted support for sustainables

but even deleted public service webpages about improving household efficiency

Or in power companies successfully lobbying against U.S. sustainability programs

such as the **Clean Power Plan**, **Net Metering** and/or **Feed-in Tariffs**

And here in Virginia where Dominion Power (the state's largest single political donor!)

"convinced" the legislature to adopt a renewables plan that

makes it exceedingly unattractive for homeowners to sell power to the grid

So sorry David, before I toss the responsibility "over the fence" to the politicians

I want a plan that is **REALLY** simple to understand, implement and monitor

I'm not alone in seeking a simple, clean, efficient, transparent solution

The left & the right, businessmen & environmentalists, have all felt a similar need

And this has led to a **LOT** of recent talk about two closely related ideas:

Carbon Cap and Trade **A Carbon Tax**

Evidence for such a meeting of the minds?

Merril Lynch investment brokers: "Those who advocate only command-and-control regulation seem to ignore all of the published data, from the experiences of academics, governments and the private sector, that highlight precisely why emissions trading is a more cost-effective approach to reducing emissions than blunt regulation. Put simply, it is better to reduce emissions in a way that results in lowest costs to society." [1]

The Environmental Defense Fund: "Cap and trade is the most environmentally and economically sensible approach to controlling greenhouse gas emissions, the primary driver of global warming." [2]

1) http://www.fern.org/book/trading-carbon/cap-and-trade-most-cost-effective-way-reduce-emissions
2) https://www.edf.org/climate/how-cap-and-trade-works

Cap and Trade has a longer history, so let's examine it first

It is a governmental approach to decreasing the emission of a certain pollutant

But here the government does not legislate **how** this will be done

It just demands that it **will** be done:

By setting the allowable amount of pollutant emission = The **Cap**

The process starts by surveying ALL present day sources of emission

Then, a company's present day emission of that pollutant => It's year #1 Cap

And it is issued a **permit** for that amount of pollutant emission

But in year #2, quantities in ALL Caps/Permits are ratcheted downward by x%

Following a publically announced, multi-year, decreasing schedule

This, alone, would apply equal pressure on **all** of the pollutant producers

But different companies likely face very different challenges:

Company A, may have only one possible production process

From which the pollutant is an inevitable byproduct

The decreasing Cap would thus drive Company A right out of business

For **Company B**, there might be another possible production process

And investment in that alternative might result in **less pollutant** emission

So Company B could survive the decreasing Cap

Thus caps alone would drive a rapid corporate survival of the fittest

Which could then easily produce massive economic and societal disruption

*That is where The **Trade** comes in:*

Companies are allowed to sell their pollutant emission permits to one another

So **Company A** can offer to buy permits from **Company B**

Those permits (as all permits) still decrease according to The Schedule

And buying these permits is going to add to Company A's expenses

Which will increase the cost of its product

But if **Company A's** **product is essential**, we'll accept that now-increasing price

But we'll sure as heck try to find ways of using **less** of that product!

Meanwhile, the income **Company B** got by selling its permits to Company A

could help finance its development of that new less polluting process,

allowing it to convert itself into a new green **Company B**!

The winners?

The Environment: Pollutant emission has decreased according to The Schedule

Company B: Which has recast itself into an new greener form

Company A: Which survived because it has an essential product

But which is still being squeezed by its permits' decreasing emission limits

And by consumers trying to avoid use of its ever more expensive product

All of which has supposedly been accomplished by:

Replacing massive governmental micromanagement / regulation with

The Invisible Hand of a (quasi) free market economic system

= Adam Smith's "unintended social benefits resulting from individual actions" [1]

1) https://en.wikipedia.org/wiki/Invisible_hand

Does Cap and Trade really work?

It was first tested by economists in computer models at the precursor of the EPA: [1]

> "These studies used mathematical models of several cities and their emission sources in order to compare the cost and effectiveness of various control strategies. Each abatement strategy was compared with the "least cost solution" produced by a computer optimization program to identify the least costly combination of source reductions in order to achieve a given abatement goal. In each case it was found that the least cost solution was dramatically less costly than the same amount of pollution reduction produced by any conventional abatement strategy" [1]

The **Bush I administration** then worked with the **Environmental Defense Fund**

Writing a version of C&T into the 1990 Clean Air Act, targeting SO_2 emissions

$SO_2 + H_2O$ => Sulfuric acid => Acid rain => Dead northeastern lakes

The result? A rapid and dramatic reduction in U.S. SO_2 emissions

Leading U.S. & international agencies to label SO_2 C&T a resounding success!

1) https://en.wikipedia.org/wiki/Emissions_trading

Why not just apply Cap and Trade to ALL greenhouse gases?

Well, as cited above, that IS exactly what many suggest

Including many economists, investment houses, and the EDF

However, as applied to all greenhouse gases, Cap and Trade gets very complicated:

1) There are a LOT of different greenhouse gases

2) Cap and Trade depends on precise initial answers to the questions of:

What is each gas's current emission? By whom, in exactly what amounts?

But consider my **Fossil Fuels** (pptx / pdf / key) note set where:

Recent studies suggested that EPA's bottom-up assessment of CH_4 emission:

- Massively understates that greenhouse gas's total emission

- And completely misses "accidental" / "off the books" emissions

from rogue operators within the natural gas industry

So while Cap & Trade minimizes **later** *governmental micromanagement*

It depends on **up front** *governmental micromanagement:*

First, to acquire accurate information on which to base the overall capping schedule

Second, to determine size of a **massive number** of company-by-company permits

=> Hugely complex computations and negotiations

Almost certainly occurring behind closed doors in marathon processes

Which, I fear, reopens possibility of massive well-funded corporate lobbying efforts

Aimed at special corporate dispensations, blunting and/or corrupting results

It's claimed this is exactly what's happening to EU's greenhouse gas C&T program

E.G., a Carnegie Mellon study "Cap and Trade is Not Enough" which concluded:

Facing economic stagnation, the EU has backed off their C&T targets

Effectively undercutting the whole program

1) http://www.cmu.edu/gdi/docs/cap-and-trade.pdf

Further, Cap and Trade lets "us" get off rather easily

As discussed in my lectures on power consumption in transportation and housing:

"Our" personal transportation and housing choices

account for nearly half of the U.S.'s

(spectacularly) high energy consumption

Thus, as the majority of that energy production relied on greenhouse gas emissions,

"our" personal choices drive almost **half** of the total U.S. greenhouse emissions

Nevertheless, Cap and Trade has almost no **directly perceivable** effect upon us:

Above, we got hit only via the increasing cost of Company A's product

Wouldn't a program **confronting us with the consequences of our choices**

produce dramatically quicker and larger reduction in greenhouse gas emissions?

Pogo, by Walt Kelly, Post Hall Syndicate

Leading to idea of a more even-handed and visible **Carbon Tax**

It's ~ **a negative value added tax** where, for any step in a product's production

that (at least eventually) produces greenhouses gases,

a tax is added proportional to the amount of greenhouse gas released

If CO_2 is released, add a tax in proportion to that CO_2 weight

If another gas is released, scale the tax up or down

Based on the ratio of that gas's greenhouse impact relative to CO_2

Economists (vague on combustion?) talk of tax per equivalent tonne of **C burned**

Scientists talk of tax per equivalent tonne of **CO_2 emitted**

One tonne of Carbon burned => (44/12) tonnes of CO_2 emitted

Based on the relative atomic masses of C (= 12) and CO_2 (= 44)

(1 tonne = 1000 kg ~ 1.1 "tons" - an antiquated, now virtually abandoned, primitive unit)

So the idea's simple - But I had trouble putting it into perspective!

Because it seemed to raise all of these hard-to-answer questions:

1) How big would the tax have to be in order to drive down greenhouse emissions?

Heck! MacKay discusses tax rates from **$7 to $900** per CO_2 tonne!!! [1]

2) How would a certain level of tax affect **ME** personally?

Requiring **ME** to figure out: How much greenhouse gas am **I** responsible for?

3) What would be the larger/longer-term impacts of the tax upon our economy?

Which leads economists to ask: What is the true **"Social Cost of Carbon**?"

= Idea that if the **true/complete cost** were actually charged,

free market's **Invisible Hand** could then find the optimum solution

I'll now try to figure out the answers to those questions

1) David J.C. MacKay, Sustainable Energy without the Hot Air, page 224 / Figure 29.2

What size tax is required to drive down greenhouse gas emissions?

Throughout this class we've noted that onshore **wind energy** is thriving:

Now 5% of U.S. power, and our preferred target for new energy investment

While in contrast, **solar energy** is struggling:

Less than 1% of U.S. power

With even that number dependent on government subsidies/programs

In present day ~ free-market energy system, difference **must** be due to economics:

Levelized cost of energy (LCOE) from wind **IS** competitive

Levelized cost of energy from unsubsidized solar **IS NOT** competitive

LCOE difference, added to fossil fuels, should make THEM non-competitive!

= Plausible target value for an effective carbon tax

*Recent LCOE data from **Power Plant Economics** (pptx / pdf / key) notes:*

	EIA	Lazard
Sequestered IGCC Coal	119.1	143 [1]
Natural Gas CC (CCGT)	50.1	42-78
Natural Gas Peaking (OCGT)	85.1	156-210
Hydroelectric	61.7	
Nuclear	92.6	112-183
Biomass - no subsidy (subsidized)	95.3	55-114 (40-112)
Geothermal - no subsidy (subsidized)	44.6 (41.6)	77-117 (64-116)
Wind Onshore- no subsidy (subsidized)	59.1 (48)	30-60 (14-52)
Wind Offshore - no subsidy (subsidized)	138.0 (117.1)	113
Solar PV	63.2 (49.9)	
Si crystalline PV – utility - no subsidy (subsidized)		46-53 (37-42)
Thin Film PV – utility - no subsidy (subsidized)		43-48 (35-48)
Solar Thermal w/o Storage - no subsidy (subsidized)		237
Solar Thermal w/ Storage - no subsidy (subsidized)	165.1? (126.6)?	98-181 (79-140)

1) Lazard gives sequestered IGCC coal as being at the top of their bar = 143 (footnote 11)

Comparing solar LCOE vs. wind LCOE :

2017 value of difference: (LCOE for solar) – (LCOE for onshore wind) =

EIA 2017: ~ 25 $/MW-hour

Lazard 2016: ~ 25 $/MW-hour

Whereas, in preceding years, the EIA reported a difference of more like $50

Difference over **whole time span** contributed to Solar's lower present day use

Thus, lumping these together:

25-50 $/MW-hour difference made solar markedly less competitive

So a carbon tax that forced fossil-fuel power plants to charge that much more

should also make those fossil-fuel power plants markedly less competitive

Or, to accelerate the transition away from fossil fuels,

we might want to set the Carbon Tax rate to twice that value

But we still have to figure out each power plant's carbon production:

We can do this by answering a sequence of science/technology questions:

1) What fraction of each fossil fuel is carbon (by weight)?

Coal = 0.67 [1] Natural Gas = 0.74 [1] Oil = 0.87 [1]

2) How much combustion heat energy is produced per mass of fuel (in kJ/kg)?

Coal = 28,400 [1] Natural Gas = 54,400 [1] Oil = 45,300 [1]

3) What electrical energy is produced (by power plant) per fuel's heat energy?

Coal = 0.37 [2] NG OCGT = 0.37 [3] NG CCGT = 0.61 [3] Oil = ~ 0.4 [4]

NG OCGT = Natural Gas using Open Cycle (single) Gas Turbine

NG CCGT = Natural Gas using Combined Cycle Gas Turbines

1) Rubin, Introduction to Engineering & the Environment, Table 5.1 page 165
2) Example 5.1, Rubin, Introduction to Engineering & the Environment, page 166
3) http://www.powermag.com/pushing-the-60-efficiency-gas-turbine-barrier/
4) "Efficiency in Electricity Generation" - EURELECTRIC *(impossibly long web link)*

Combining these factors for each fuel:

Throwing in factor of 44/12 to convert from mass C burned to CO_2 emitted:

CO_2 Mass / Electrical Energy = [(44/12) (Fuel C Fraction)] ÷

[(Heat Energy / Fuel Mass) (Electrical Energy / Heat Energy)]

In units of grams CO_2 produced per **kW-h** of electrical energy produced:

Coal = 865 NG OCGT = 486 NG CCGT = 295 Oil = 620

Versus final number alone, as found on various websites (in g CO_2/kW-h):

Coal = 989	NG = 803	Oil = 1020	(1)
Coal = 1029	NG = 515	Oil = 758	(2)
Coal = 1039	NG CCGT = 375		(3)
Coal = 840-1200	NG OCGT = 700 NG CCGT = 450	Oil = 780	(4)

1) Rubin, Introduction to Engineering & the Environment, Table 5.2 page 168
2) https://en.wikipedia.org/wiki/Fossil-fuel_power_station
3) https://www.netl.doe.gov/publications/proceedings/01/carbon_seq/1b2.pdf
4) http://bravenewclimate.com/2010/01/09/emission-cuts-realities/

Then extracting a sort of consensus value for each fuel:

Also inserting data on IGCC coal [1] power that I did not have space for above

And converting from kW-h to MW-h (as used in LCOE's)

I conclude that for these fossil fuels, using the indicated power plant technology:

Conventional Coal => **1.0** tonne CO_2 produced / MW-hour of electricity

IGCC Coal => **0.7** tonnes CO_2 produced / MW-hour of electricity

NG OCGT => **0.7** tonnes CO_2 produced / MW-hour of electricity

NG CCGT => **0.45** tonnes CO_2 produced / MW-hour of electricity

Oil => **0.78** tonnes CO_2 produced / MW-hour of electricity

1) From Carbon Fuels lecture: IGCC = Integrated Gasification (of coal) with Combined Cycle (dual turbines)

Then, to make each of these fossil fuels non-competitive:

Wind vs. Solar analysis suggested LCOE's must rise ~ 25-50 $/MW-hour

Most of the above fuels produced roughly 1 tonne CO_2 per MW-hour electricity

Suggesting a **Carbon Tax => 25-50 $/tonne CO_2**

NG CCGT produced half the CO_2, but to pressure it as hard we could double its tax:

Carbon Tax => 50-100 $/tonne CO_2

Or, to speed shift away from fossil fuels, we might just tax **all fuels** at:

Carbon Tax => 100 $/tonne CO_2

My spreadsheet with a range of possible values for tax per CO_2 tonne emitted:

CO2 Tax $/tonne:	12	25	50	100
Delta LCOE $/MW-h:				
Coal	12.24	25.5	51	102
Coal IGCC	8.4	17.5	35	70
NG-OCGT	8.4	17.5	35	70
NG-CCGT	5.4	11.25	22.5	45
Oil	9.36	19.5	39	78

So how will those possible Carbon Tax rates affect **ME***?*

The EIA says average U.S. household uses 911 kW-h of electrical power per month

Which yields an annual household electricity consumption of 10.932 MW-h

Multiplying the table on the previous slide by that number, we then get:

ADDED household cost per year, for a CO_2 Tax per tonne at rate in red:

(for that electrical energy produced via alternate fuels / technologies)

CO2 Tax $/tonne:	12	25	50	100
Delta annual cost:				
Coal	133.8	278.8	557.5	1115.1
Coal IGCC	91.8	191.3	382.6	765.2
NG-OCGT	91.8	191.3	382.6	765.2
NG-CCGT	59.0	123.0	246.0	491.9
Oil	75.4	157.1	314.3	628.6
Nuclear, Wind, Solar, Hydro, Biofuel	0.0	0.0	0.0	0.0

But MY power is generated by a mix of power plant types / fuels

Further, I know that the mix of power technologies and fuels changes state by state

From NPR data[1] in **U.S. Energy Consumption & Production** (pptx / pdf / key) notes:

State	% Coal	% Natural Gas	% Oil
Virginia:	27	28	2
California:		58	
Illinois:	43	2	
Massachusetts:	9	58	3
New York:	3	40	1
Texas:	37	42	
Vermont:			
West Virginia:	96		

NPR did not break down if natural gas power was OCGT or CCGT

So let me assume it is 50% of each

Then, combine the weighting of this table with the preceding table to get:

1) http://www.npr.org/2015/09/10/319535020/coal-gas-nuclear-hydro-how-your-state-generates-power?utm_source=facebook.com&utm_medium=social&utm_campaign=npr&utm_term=nprnews&utm_content=20150910

Added cost of electrical power per average household per year:

For CO_2 tax per tonne in red, and each state's 2014 methods of power generation:

CO2 Tax $/tonne:	12	25	50	100
Delta annual cost:				
Virginia:	59.3	123.5	247.1	494.1
California:	43.7	91.1	182.3	364.6
Illinois:	59.0	123.0	246.0	492.0
Massachusetts:	58.9	122.6	245.3	490.5
New York:	35.2	73.4	146.7	293.4
Texas:	81.2	169.1	338.3	676.6
Vermont:	0.0	0.0	0.0	0.0
West Virginia:	128.5	267.6	535.2	1070.5

Vermont: CO_2 tax has 0$ impact - because their power is 0% fossil fueled

Most other states (with mixes of fossil-fueled and non-fossil fueled electricity):

Added cost / household / year ~ **5 times the CO_2 tax / tonne**

West Virginia (with 96% coal fossil-fueled electricity):

Added cost / household / year ~ **10 times the CO_2 tax / tonne**

What about the impact on MY annual transportation costs?

From website advocating carbon trading to support 3rd world forestry & farming: [1]

Gasoline liberates ~ 0.0088 tonnes CO_2 per gallon burned

Assuming MY car gets 20 MPG

And that I drive (alone) **12,000 miles by car each year**

(meaning that I burn 600 gallons of gasoline per year)

Out and back 5500 mi jet trip emits 2 tonnes CO_2 per passenger

And assuming that I travel **12,000 miles by jet each year**

=> MY added annual transportation costs for the CO_2 tax rates per tonne in red:

CO2 Tax $/tonne:	12	25	50	100
Delta annual cost:				
1 year driving car	63.36	132	264	528
1 year of flights	26.352	54.9	109.8	219.6

1) COTAP = "Carbon Offsets to Alleviate Poverty" organization
http://cotap.org/carbon-emissions-calculator/

Recapping my answers to this point:

Carbon Tax necessary to **NUDGE** power production away from fossil fuels:

~ 25-50 $ / equivalent tonne of CO_2 emitted

Carbon Tax necessary to **SHOVE** power production away from fossil fuels:

~ 50-100 $ / equivalent tonne of CO_2 emitted

Impact on typical American's annual household power bill:

States using totally greenish energy:	0$
States using ~ 50% greenish energy:	~ 5X the CO_2 Carbon Tax Rate above
States using ~ 0% greenish energy:	~ 10X the CO_2 Carbon Tax Rate above

Impact on individual American's annual transportation bill:

For 12,000 automobile miles:	~ 5X the CO_2 Carbon Tax Rate above
For 12,000 jet miles:	~ 2X the CO_2 Carbon Tax Rate above

Total, for resident of 50% state: ~ 12X the CO_2 Carbon Tax Rate

So we seem to be talking ~ $600-1200 per person per year

PLUS the rise in prices of purchased goods/services that also emitted carbon

For which the ultimate payback would be reducing the

presumably much LARGER cost of continued fossil fuel use

Including health and environmental costs from its pollution,

as well as possibly huge costs predicted to accompany global warming

To which some might respond:

But payoff is decades/generations in the future, humans don't think that far ahead!

Sticky-fingered politicians would just use this as an excuse to add more taxes!

What's the evidence that fossil fuel use or global warming **will** be so expensive?

Reacting to those objections:

James Hansen's modest Carbon Tax proposal:

James Hansen is an environmental scientist who used to work for NASA

At NASA he and his colleagues studied the atmosphere

Which got them into the subject of global warming

Which then got them into big trouble with the Bush II administration

Bush II officials (with high-level NASA cooperation?) tried to gag these scientists

Preventing any contact with the press and censoring their presentations

Which is an eye-opening history I urge you to further investigate [1-3]

But today's relevance is that Hansen now advocates a unique Carbon Tax

countering both human short-sightedness AND government's sticky fingers

*1) **New York Times:** http://www.nytimes.com/2006/01/29/science/earth/29climate.html?_r=2&pagewanted=print&*

*2) **Scientific American:** http://www.scientificamerican.com/article/nasa-climate-scientist-james-hansen-quits-to-fight-global-warming/*

*3) **Union of Concerned Scientists:** http://www.ucsusa.org/our-work/center-science-and-democracy/promoting-scientific-integrity/james-hansen.html#.VroQGTZx6_U Page 1 of 4*

Hansen's "Carbon Tax and 100% Dividend" proposal: [1]

Hansen suggests an immediate carbon tax on the order of $100 / tonne CO_2

Which he estimates might cost the typical American $1200 per year

Which is dead on my preceding estimates for a level

that should SHOVE us toward diminished fossil fuel use

But he would guarantee that we get all that tax back, almost immediately

Specifically: We would each be sent a $100 refund check each month

Actually, he suggests a direct bank deposit

I doubt practicality of that, especially for many poorer citizens

But while we'd all get the same FIXED MONTHLY REFUND,

we could reduce our personal Carbon Tax PAYMENT

by choosing goods & services NOT subject to the Carbon Tax

1) http://www.columbia.edu/~jeh1/mailings/2008/20080604_TaxAndDividend.pdf

=> Revenue & tax neutral behavior-modification tool only!

But by raising U.S. costs, wouldn't we just INVITE foreign imports?

At least from countries that do NOT also impose a Carbon Tax?

Well, China has also become **extremely** concerned with air pollution

But yes, countries like India now seem unable to deal with this challenge

So let me modify Hansen's proposal - Apply his tax to ONLY:

- Fossil Fuels **- Electrical Power**

And apply this "Hansen/Bean" tax regardless of the fuel/power country-of-origin:

At U.S. Carbon Tax rate, minus Carbon Tax rate applied in country-of-origin

This would be easy, transparent and fair (to **all** of the countries involved) AND

This would still affect our two biggest sources of greenhouse gases!

OK, that's a climate activist's proposed solution

But climate activism is controversial, at least in the United States

So let's go back, instead, to the type of questions economists ask, such as:

1) What would continued use of fossil fuels really cost?

2) What level of carbon tax would accurately recover those costs?

Economists try to answer such questions through the concept of an **Externality**:

"An externality is an effect of some activity on an entity (such as a person) that is not party to a market transaction related to that activity." [1]

"In economics, an externality is the cost or benefit that affects a party who did not choose to incur that cost or benefit." [1]

I.E.: **The full cost of an action may NOT be represented by its market price**

1) https://en.wikipedia.org/wiki/Externality

An **externality** *as defined via classic Supply and Demand curves:*

Red = Supply line of quantity vs. price

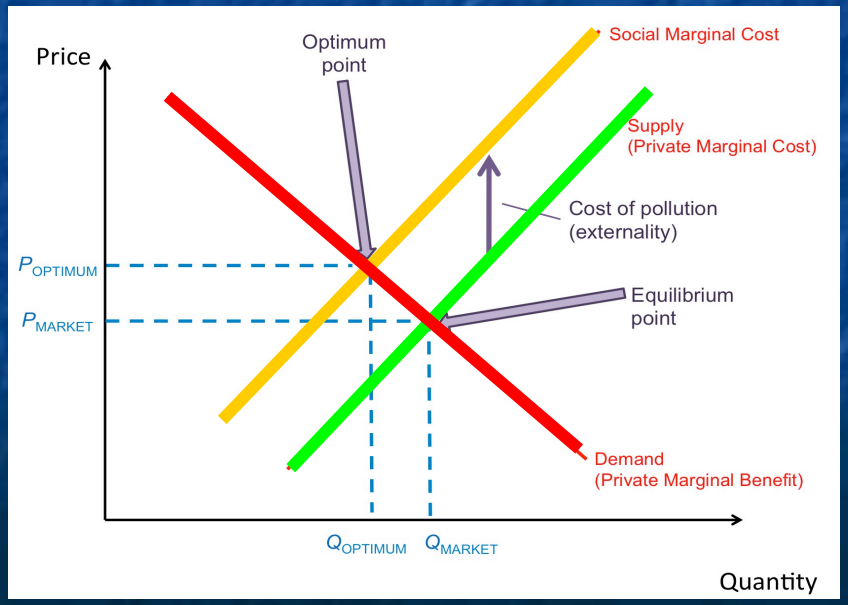
Green = Demand line of quantity vs. price

} Intersection => **Market Cost**

But **Yellow = Social Marginal Cost** = Complete cost to society vs. quantity

Intersection of social marginal cost line and the supply line

=> More economically accurate value for true **Social Cost** of the product



Market Cost – Social Cost = Externality

(here there is a "negative externality")

Products with **negative externalities** *are considered to be* **subsidized**

Merriam-Webster defines subsidy as:

> "Money that is paid, usually by a government, to keep the price of a product or service low or to help a business or organization to continue to function (or) a grant by a government to a private person or company to assist an enterprise deemed advantageous to the public"

The energy industry is ABSOLUTELY RIDDLED with subsidies!

Some of which are well known, such as subsides for solar energy

Some of which are hidden, such as **huge** tax breaks for fossil fuel production

And then there are a raft of ongoing, non-governmental, subsides

Such as allowing industries to pollute the air

without paying for that pollution's health and environmental costs

And lurking subsidies, such as not charging them for future costs of sea level rise

Economists believe that **subsidies** *effectively subvert the economic system*

Leading them to take the lead in trying identify **all** such energy industry subsidies

An example of which was the 2015 International Monetary Fund publication:

"IMF Working Paper: How Large Are Global Subsidies?" [1]

Which concluded that, worldwide:

Fossil fuels receive a $5.3 trillion annual subsidy = 6.5% of global GDP

But of that, only $500 billion came via **explicit** government spending & tax-breaks

Which economist's refer to as being: **Pre-tax subsidies**

The much, much larger, but hidden, balance came from:

Post-tax subsidies = "failure to internalize negative externalities"

= Not taking product's full impacts (and thus true costs) into account

1) https://www.imf.org/external/pubs/ft/wp/2015/wp15105.pdf

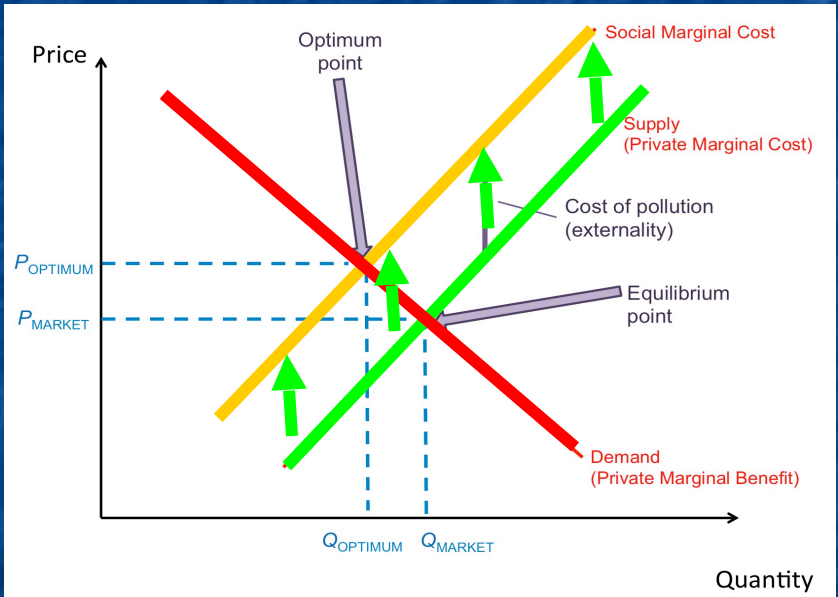
Economists argue that all such "Externalities should be Internalized!"

Which, translating into English, seems to mean that they should be eliminated

Green "Supply – Private Marginal Cost" line would then RISE to overlay

Yellow "Social Marginal Cost" line

=> **A simple, but now accurate, Supply vs. Demand problem**



Or, falling into geek-speak, we would do away with **G I G O**:

"Garbage in" (misinformation) => "garbage out" (inefficient economic solutions)

What does IMF identify as (largely invisible) "post-tax" externalities?

It's tally of negative externalities due to fossil fuels:

Global Warming = $219.19 billion

Local Air Pollution = $206.56 billion

Congestion = $147.10 billion

Accidents = $58.26 billion

Road Damage = $9.48 billion

Forgone Consumption Tax Revenue = $45.32 billion

Or, for the U.S. alone (per year):

(Visible) Pre-Tax U.S. Fossil-Fuel Subsidies = $13.29 billion

(Largely invisible) Post-Tax U.S. Fossil Fuel Subsidies = $699.18 billion

But critical IMF data was drawn from an almost inaccessible OECD report

We wanted to see the source data!

Luckily, it turns out that economists are really bugged by "negative externalities"

Because they subvert the "invisible hand's" generation of economic solutions!

Economists have thus studied energy's negative externalities for ~ two decades

And they have generated a large and accessible body of (pre-IMF) research

about both **past AND future** hidden costs of fossil fuels

Further, they used this research to compute the **Social Cost of Carbon (SCC),**

which, ideally, should now be added to the cost of fossil fuels

= Which we could now do by imposing a carbon tax!

But what is this social cost of carbon (as estimated by economists)?

Wikipedia cites it as $48 / tonne C (=> **$12 / tonne CO_2**)

MUCH less than the behavior-modifying tax we discussed earlier!

So would our earlier "effective" carbon tax = An economic travesty?

We found that a 50-100 $/tonne CO_2 tax would strongly curtail carbon emissions

But if true societal cost of those carbon emissions is 12 $/tonne CO_2

We'd be grossly distorting the operation of the economic system

=> Inefficiencies, waste, unnecessary pain & suffering, etc.

So let's look at how economists came up with 12$/tonne CO_2 figure:

Wikipedia cites key publication with first author identified as "Yoh"

Who turns out to be head of the IPCC committee that compiled the study

Key work cited in that study is by **German economist R.S.J. Tol** who:

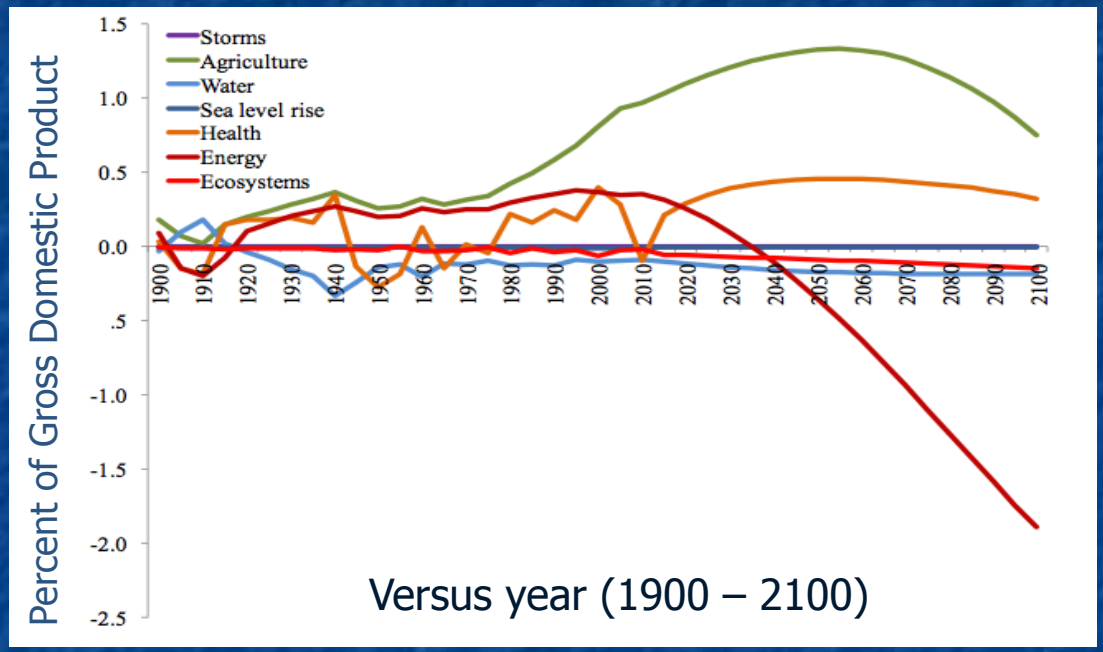
1) **FIRST** did his own research on Social Cost of Carbon (~ 1995-2005)

2) **THEN** reviewed the SCC work of **dozens of other economists**

Both roles AND their timing turn out to be very important!

Tol's summary of a SCC computations by all economists

Components of SCC, expressed as percentages of Gross Domestic Product:



http://www.copenhagenconsensus.com/sites/default/files/climate_change.pdf

Things economists think could **benefit** from climate change:

Agriculture (1900-2100), Energy (< 2025), Health (most of 1900-2100)

Things economists think could be hurt by climate change:

Energy (> 2025), Ecosystems (post ~ 2000), Sea Level Rise (1900-2000)

The economists' reasoning: [1]

Agriculture benefits because plants grow better with more CO_2 to consume

Until late this century when heating + drought knock back their growth

Energy consumption **initially drops** because of its decreased use for heating

Until ~2025 when warming **massively increases** air-conditioning energy

Health benefits from decreased impact of tropical diseases such as

Malaria, Dengue Fever . . . as jungles and wetlands dry out

Ecosystems are damaged from ~2000 onward,

But financial impact is miniscule compared to benefits above

Sea Level Rise costs are similarly minimal

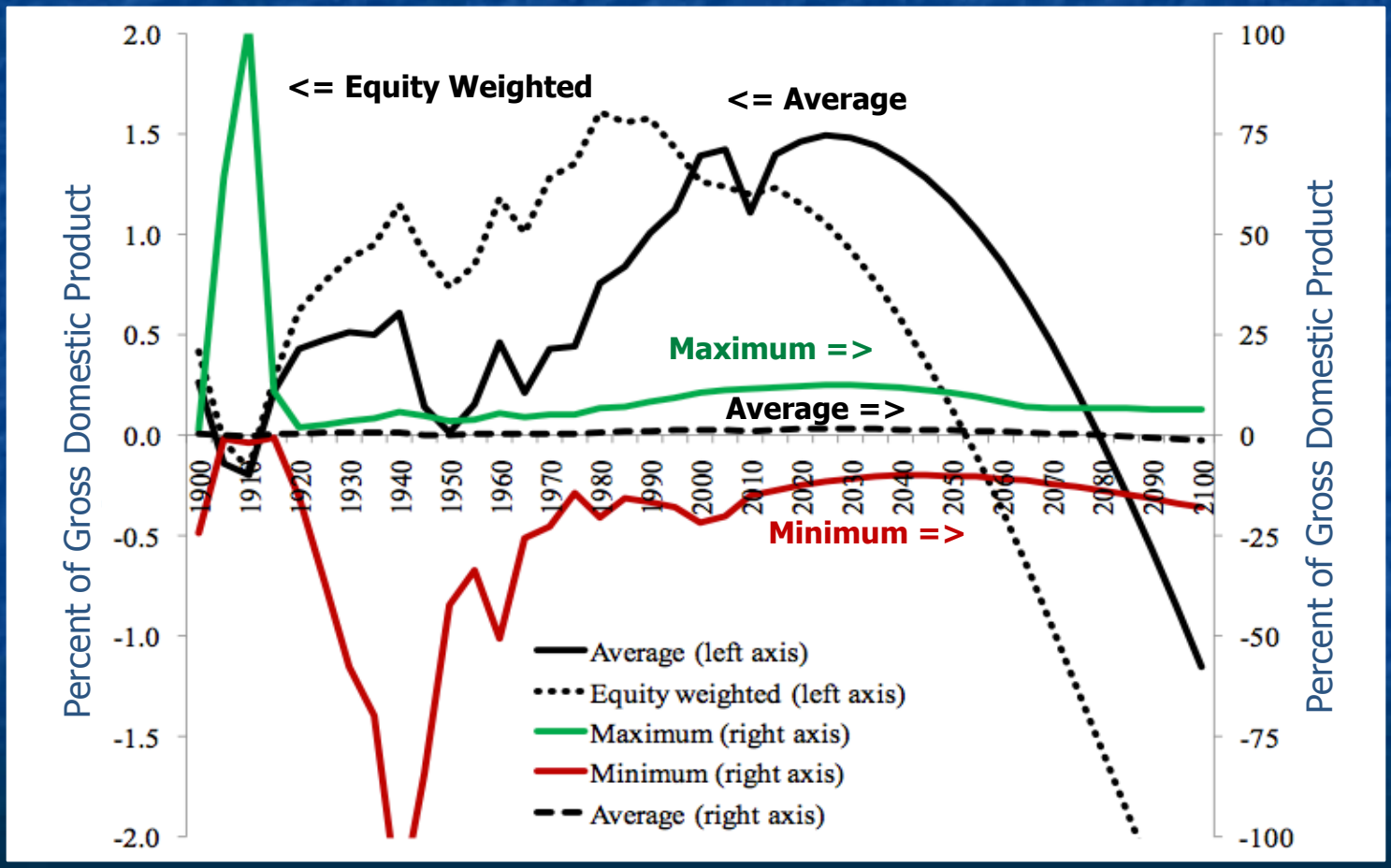
Actually thought to be smaller in 21st century then in mid 20th century!

1) Estimates of the Damage Costs of Climate Change, Environmental and Resource Economics 21, pp. 135-160 (2002)

Do you have problems with any of that?

You are in good company: Economists **massively disagree with each other**

As revealed by study's alternate plots of TOTAL SCC cost, 1900-2100:



http://www.copenhagenconsensus.com/sites/default/files/climate_change.pdf

Disagreement is also apparent in this table from one of Tol's reviews

Different table lines = SCC results calculated by different economists

Note not only differences in cost numbers but even difference in signs!

Table 1

Estimates of the Welfare Impact of Climate Change

(expressed as an equivalent income gain or loss in percent GDP)

			Worst-off region		*Best-off region*	
Study	*Warming (°C)*	*Impact (% of GDP)*	*(% of GDP)*	*(Name)*	*(% of GDP)*	*(Name)*
Nordhaus (1994a)	3.0	−1.3				
Nordhaus (1994b)	3.0	−4.8 (−30.0 to 0.0)				
Fankhauser (1995)	2.5	−1.4	−4.7	China	−0.7	Eastern Europe and the former Soviet Union
Tol (1995)	2.5	−1.9	−8.7	Africa	−0.3	Eastern Europe and the former Soviet Union
Nordhaus and Yang (1996)[a]	2.5	−1.7	−2.1	Developing countries	0.9	Former Soviet Union
Plambeck and Hope (1996)[a]	2.5	2.5 (−0.5 to −11.4)	−8.6 (−0.6 to −39.5)	Asia (w/o China)	0.0 (−0.2 to 1.5)	Eastern Europe and the former Soviet Union
Mendelsohn, Schlesinger, and Williams (2000)[a,b,c]	2.5	0.0[b] 0.1[b]	−3.6[b] −0.5[b]	Africa	4.0[b] 1.7[b]	Eastern Europe and the former Soviet Union
Nordhaus and Boyer (2000)	2.5	−1.5	−3.9	Africa	0.7	Russia
Tol (2002)	1.0	2.3 (1.0)	−4.1 (2.2)	Africa	3.7 (2.2)	Western Europe
Maddison (2003)[a,d,e]	2.5	−0.1	−14.6	South America	2.5	Western Europe
Rehdanz and Maddison (2005)[a,c]	1.0	−0.4	−23.5	Sub-Saharan Africa	12.9	South Asia
Hope (2006)[a,f]	2.5	0.9 (−0.2 to 2.7)	−2.6 (−0.4 to 10.0)	Asia (w/o China)	0.3 (−2.5 to 0.5)	Eastern Europe and the former Soviet Union
Nordhaus (2006)	2.5	−0.9 (0.1)				

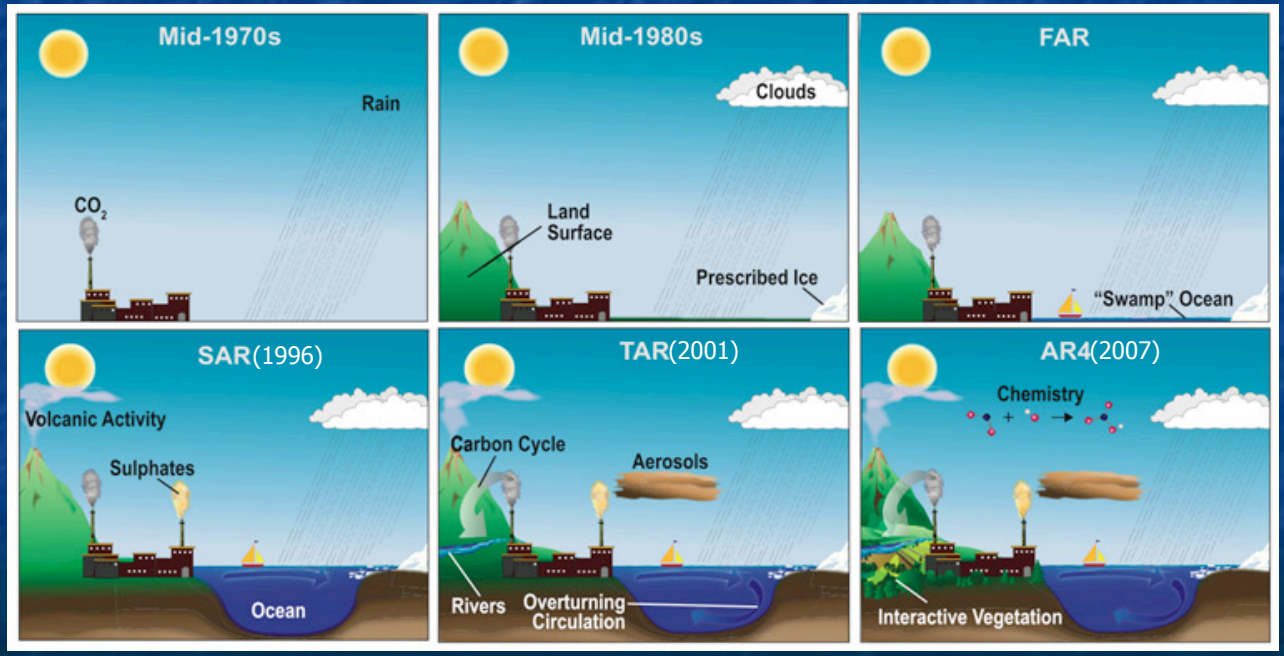
http://www.ssc.wisc.edu/~walker/wp/wp-content/uploads/2012/09/Tol2009.pdf

But "elephant in the room" may actually be the DATE of those studies:

Key cross-field review article (giving SCC, component by component) was:

Estimates of the Damage Costs of Climate Change,
Journal of Environmental and Resource Economics 21, pp. 135-160 (2002)

But that was **well before** the maturation of our climate change models!



(For discussion of those models see my lecture on Climatology and Climate Change)

The economists WERE aware of the this problem:

As Tol, himself pointedly acknowledged in his 2009 SCC review paper: [1]

"In a survey article I co-authored more than a decade ago on the social costs of climate change, we suggested that all aspects of the problem were roughly known, and that research would be complete within a few years.

This view turned out to be so overoptimistic as to be entirely mistaken."

1) Tol 2009: J. Economic Perspectives 23(2), pp. 29-51(2009)

*He also acknowledged that they'd NOT considered **catastrophic** change:*

"Examples of extreme climate scenarios include an alteration of ocean circulation patterns . . . (which) could lead to a sharp drop in temperature in and around the North Atlantic . . .

(Or) collapse of the West Antarctic Ice Sheet . . . which would lead to a sea level rise of 5 - 6 meters in a matter of centuries.

(Or) the massive release of methane from melting permafrost . . . which would lead to rapid warming worldwide.

(These) have the potential to happen relatively quickly, and if they did, the costs could be substantial . . .

Effects of sea level rise would increase **ten-fold** should the West Antarctic Ice Sheet collapse.

But the work of Olsthoorn, van der Werff, Bouwer, and Huitema
suggests that this may be too optimistic." [1]

1) Tol 2009: J. Economic Perspectives 23(2), pp. 29-51(2009)

Let me look at just his sea-level-rise cost estimates:

In 2002 he generated this table for impact of century long 1 meter rise in sea level

He noted that this was a **higher** rise than the IPCC **then** predicted:

Table III. Impact of a one metre sea level rise.

	Level prot. (%)	Dryland loss (10^3 km^2)	Dryland value (10^6\$/km^2)	Wetland loss (10^3 km^2)	Wetland value (10^6\$/km^2)	Protection costs (10^9\$)	Emigrants (10^6)
OECD-A	0.77	4.8 (2.4)	1.3 (0.6)	12.0 (8.6)	5.4 (2.7)	83 (74)	0.13 (0.07)
OECD-E	0.86	0.7 (0.4)	13.1 (6.6)	4.0 (2.3)	4.3 (2.2)	136 (45)	0.22 (0.10)
OECD-P	0.95	0.3 (0.4)	13.7 (6.7)	1.0 (1.1)	5.9 (2.9)	63 (38)	0.04 (0.02)
CEE&fSU	0.93	1.2 (2.7)	0.9 (0.5)	0.0 (0.0)	2.9 (1.5)	53 (50)	0.03 (0.03)
ME	0.30	0.6 (1.2)	0.5 (0.3)	0.0 (0.0)	1.3 (0.7)	5 (3)	0.05 (0.08)
LA	0.86	7.8 (7.1)	0.3 (0.2)	50.2 (36.4)	0.9 (0.5)	147 (74)	0.71 (1.27)
S&SEA	0.93	9.3 (9.6)	0.5 (0.3)	54.9 (48.0)	0.3 (0.2)	305 (158)	2.30 (1.40)
CPA	0.93	8.4 (15.1)	0.3 (0.2)	15.6 (17.1)	0.2 (0.1)	171 (126)	2.39 (3.06)
AFR	0.89	15.4 (18.4)	0.4 (0.2)	30.8 (14.8)	0.4 (0.02)	92 (35)	2.74 (2.85)

"OECD A" and "OECD E" refer to North America and Europe respectively:

North America: 1 meter sea level rise => **130,000 displaced persons**

Europe: 1 meter sea level rise => **220,000 displaced persons**

This was then folded into the economists' SCC estimate of 12$/ tonne CO_2

This result **was** based on most elaborate climatological studies available in 2002

But a **decade later** more (& more sophisticated) studies have now been published

Including one published in March 2016 issue of Nature Climate change entitled:

Millions projected to be at risk from sea-level rise
in the continental United States

From that research paper's abstract:

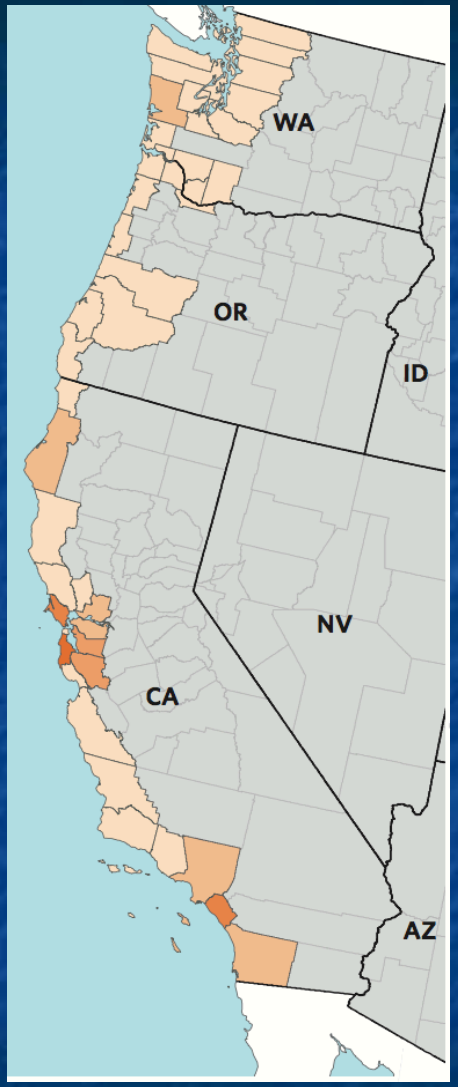
"We find that a 2100 SLR (Sea Level Rise) of 0.9 meter places a land area projected to house 4.2 million people at risk of inundation, whereas 1.8 meters affects 13.1 million people"

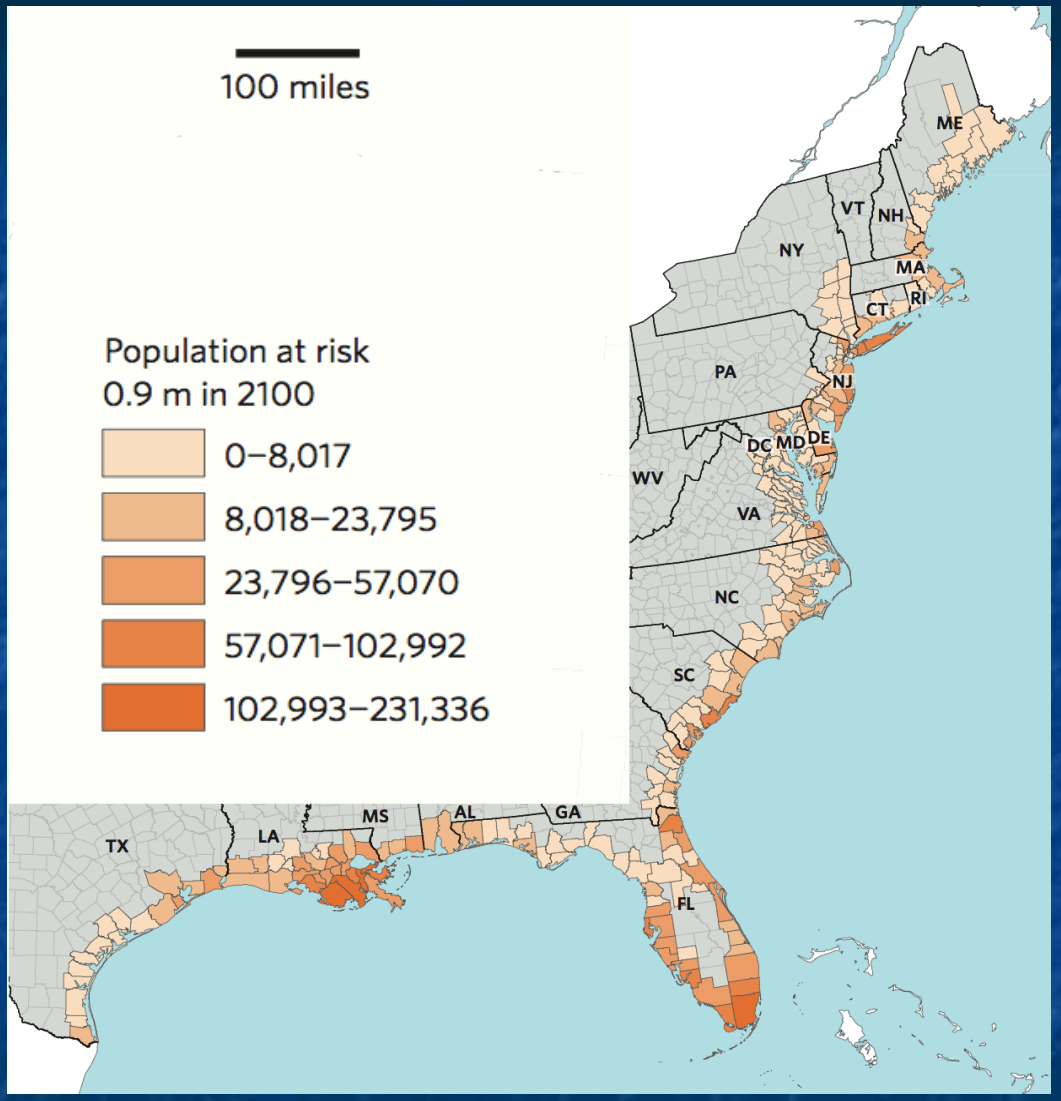
Take a look at that paper's state-by-state predictions:

State-by-state predictions of population affected by sea level rise:

State	Current populations		Projected populations			
	0.9 m SLR in 2100	1.8 m SLR in 2100	0.9 m SLR in 2100	±	1.8 m SLR in 2100	±
AL	14,648	25,326	38,238	7,801	57,303	11,584
CA	94,217	216,174	472,248	98,343	1,046,757	208,343
CT	17,249	39,482	53,566	7,189	128,048	17,947
DC	545	1,257	2,005	410	4,629	948
DE	19,782	35,811	44,597	7,708	76,836	14,061
FL	385,436	1,499,509	1,221,837	236,103	6,057,419	1,216,806
GA	25,061	48,426	93,036	18,683	178,787	37,263
LA	413,646	678,151	846,203	263,827	1,361,792	292,676
MA	38,232	155,335	103,552	13,329	427,549	57,669
MD	30,300	68,667	92,584	14,730	188,624	31,624
ME	6,849	13,233	15,230	1,848	29,028	3,574
MS	12,379	20,075	50,385	10,254	76,901	16,721
NC	59,884	109,756	163,260	27,210	297,917	52,013
NH	3,299	6,211	8,670	1,131	15,432	2,024
NJ	117,553	300,923	308,662	47,436	827,449	137,272
NY	48,933	221,056	198,257	32,543	901,366	159,124
OR	4,374	8,985	12,754	1,903	25,614	4,163
PA	2,537	7,288	9,939	1,858	27,427	5,659
RI	5,188	13,150	14,875	1,646	36,546	3,977
SC	52,443	126,498	163,492	38,527	374,395	86,058
TX	52,600	114,797	173,025	45,306	405,423	106,301
VA	45,521	109,507	181,130	38,072	475,871	102,952
WA	11,178	26,597	43,436	7,229	94,139	16,040
Tot	1,461,854	3,846,214	4,310,981	923,086	13,115,252	2,584,797

Or the same data shown on a U.S. coastal map:





Note that this shows **counties affected** rather than actual flooding boundaries

TWO things have changed from the time of the economist's work:

1) In 2002, IPCC **had** been estimating sea level rises of **less than 1 meter,**

Whereas sea level rises of **up to 1.8 meters** are now seriously discussed

2) For even a 1 meter rise, vastly greater impact is now predicted

Tol 2002: 1 meter rise impacts **130,000** people over whole of North America

New Study: 0.9 meter rise impacts **4,310,981** in the U.S. alone

How could 1 meter rise now threaten ~ 50 TIMES more people?

The answer comes one sentence later in Tol's earlier musings:

"Effects of sea level rise would increase ten-fold should the West Antarctic Ice Sheet collapse. But the work of Olsthoorn, van der Werff, Bouwer, and Huitema [2] suggests that this may be too optimistic: **that we may have overestimated the speed with which coastal protection can be built up"**

2) http://link.springer.com/article/10.1007%2Fs10584-008-9423-z

So discrepancy is not in ***HOW MANY*** *would be affected by a 1 meter rise*

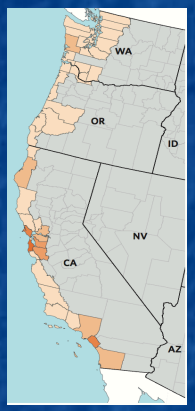
Discrepancy is in **HOW** those people would be affected!

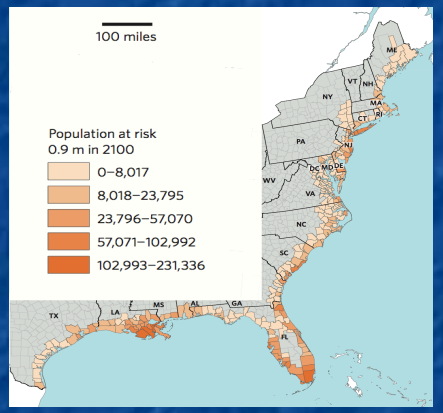
Economists had assumed ocean barriers could prevent ~ all encroachment

Cutting number having to relocate from millions to hundreds of thousands

Was that really EVER plausible

given the length of U.S. coastline?





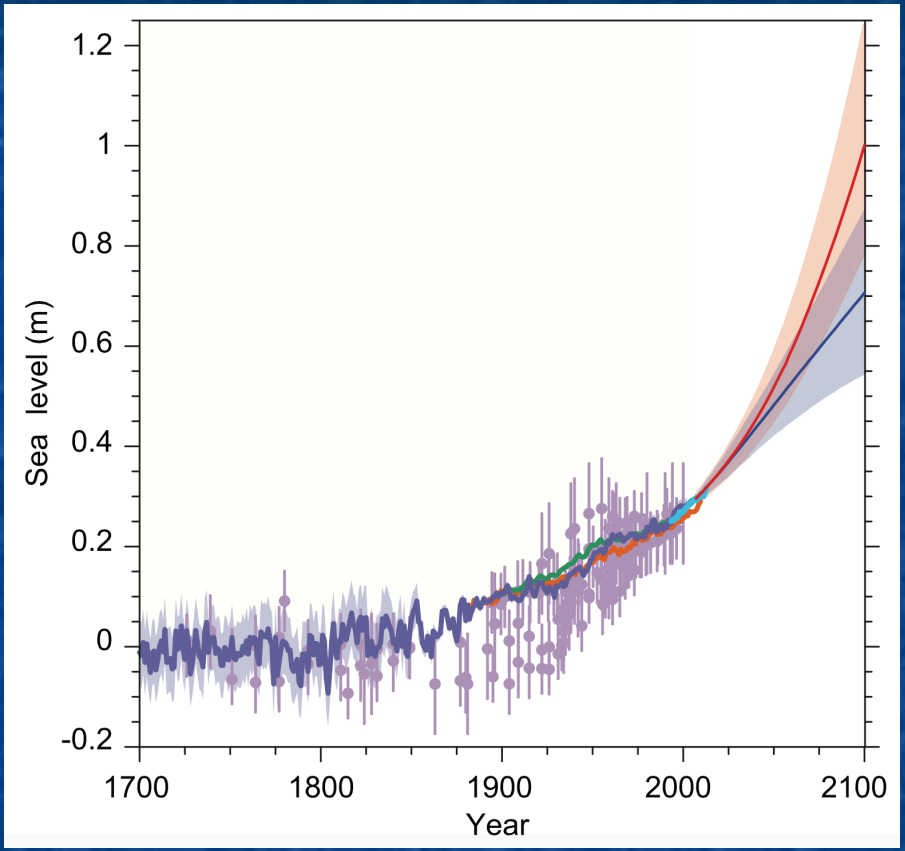
Further, those economists assumed **COST** of such construction would be so palatable

that the total Social Cost of Carbon would still be only 12$ / tonne CO_2

Instead, economists Olsthoorn, van der Werff, Bouwer, and Huitema
(from the the world's premiere dike-building country of the Netherlands)
had warned from the start about the difficulty of holding back the sea!

And it is not just one report:

The IPCC's 5th Assessment (2013) has **also** upped predictions of sea level rise: [6]



1 Meter

Violet ("RCP2.6") = **With** strong international efforts to curb greenhouse gases

Orange ("RCP8.5") = **Without** such efforts

6) https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter13_FINAL.pdf

BREAKING NEWS:

(Relevant news articles I've not yet fully researched and/or verified)

New Elevation Data Triple Estimates of Global Vulnerability to Sea-Level Rise and Coastal Flooding

Princeton University (Nature Communications, October 2019) [1, 2]

Based on new airborne LIDAR mapping data & modeling: "Here we show . . . that 190 million people currently occupy global land below projected high tide lines for 2100 under low carbon emissions, up from 110 million today, for a median increase of 80 million.

Under high emissions (our data/modeling) indicates up to 630 million people live on land below projected annual flood levels for 2100, and up to 340 million for mid-century, versus roughly 250 million at present.

We estimate one billion people now occupy land less than 10 meter above current high tide lines, including 250 million below 1 meter."

1) Source Nature Communications report: https://www.nature.com/articles/s41467-019-12808-z

2) Climate Central Org analysis: https://climatecentral.org/pdfs/2019CoastalDEMReport.pdf

3) BBC Article: https://www.bbc.com/news/science-environment-50236882

4) Guardian Article: https://www.theguardian.com/environment/2019/oct/29/rising-sea-levels-pose-threat-to-homes-of-300m-people-study?CMP=Share_iOSApp_Other

BREAKING NEWS:

(Relevant news articles I've not yet fully researched and/or verified)

Missing Economic Risks in Assessments of Climate Change Impacts

Grantham Research Institute, Columbia University - September 2019 [1, 2]

"Economic assessments of the potential future risks of climate change have been omitting or grossly underestimating many of the most serious consequences for lives and livelihoods because these risks are difficult to quantify precisely and lie outside of human experience."

"Some of these impacts involve thresholds in the climate system beyond which major impacts accelerate, or become irreversible and unstoppable."

"Many of these impacts could exceed the capacity of human populations to adapt, and would significantly affect and disrupt the lives and livelihoods of hundreds of millions, if not billions, of people worldwide."

1) Source report: http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2019/09/The-missing-economic-risks-in-assessments-of-climate-change-impacts-2.pdf

2) New York Times article: https://www.nytimes.com/2019/10/23/opinion/climate-change-costs.html?smid=nytcore-ios-share

The Paris Summit thus leaves the door open to catastrophic change

That fall 2015 meeting declared a goal of no more than **2°C** warming by 2100

A goal that is supported by (at best) weak commitments & enforcement

But climatologist Hansen and his colleagues have now predicted that

1.5°C might be enough to trigger collapse of Arctic or Greenland ice sheets [7]

Which would make STRONG corrective measures imperative!

But we have now see that while:

Early economic studies suggested Social Cost of Carbon of ~ 12$ / tonne CO_2

Which is far less than 50-100$ / tonne CO_2 value that I estimated

would be adequate to SHOVE power production away from fossil fuels

Newer studies, consistent with the economists' own earlier doubts,

suggest that revised Social Cost of Carbon **MAY** be ~ 50-100$ / tonne CO_2

7) http://www.atmos-chem-phys-discuss.net/15/20059/2015/acpd-15-20059-2015-print.pdf

Putting this all together:

A carbon tax of about $100 per tonne of CO_2 (equivalent) emitted:

WOULD offset current cost disadvantages of emerging energy alternatives

DOES apparently represent the true hidden costs of fossil fuel emissions

Which means that Carbon Taxes **DO** meet David McKay's closing call for:

An idea that DOES add up!

Leaving us with David's remaining calls to:

"Stop staying no and start saying yes!" (to this, or alternatives)

And to start working toward implementation of such ideas

Bringing me to end of this class, with just one more thing to add:

THANK YOU DAVID

IN MEMORIAM – APRIL 2016

Obituary (The Guardian)

Credits / Acknowledgements

Some materials used in this class were developed under a National Science Foundation "Research Initiation Grant in Engineering Education" (RIGEE).

Other materials, including the WeCanFigureThisOut.org "Virtual Lab" science education website, were developed under even earlier NSF "Course, Curriculum and Laboratory Improvement" (CCLI) and "Nanoscience Undergraduate Education" (NUE) awards.

This set of notes was authored by John C. Bean who also created all figures not explicitly credited above.