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How do we evaluate the cost of carbon emission ?

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HOW DO WE EVALUATE THE COST OF CARBON EMISSION?

Title

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Abstract

The Social Cost of Carbon (SCC) estimates damage in social consumption or GDP caused by one extra ton of carbon dioxide (CO_2) emission each year. It is monetary terms of social impact of a ton of CO_2 emission. Its calculation could be discounted-utilitarian or non-discounted. The dominant social welfare functions in policy making is discounted-utilitarian. The principal objective of this study is recognizing the way economists' measure cost of carbon emission, wherever and whoever emits. With supportive objective of updating very recent carbon cost estimate using different assumptions for wide-ranging parameters explicitly discount rate. Besides, considerate attention had given to outlooks about Integrated Assessment Models (IAM's) approaches. To attain these objectives the paper had look into numerous published and unpublished literatures. Thus, empirical literature shows, choice of discount rates are major deriver of variation in social cost of carbon estimates. As shown, in the discussion, United States Government Interagency Working Group (2010) estimated SCC values are: $6.8, $ 26.3, $ 41.7, & $ 80.7 (2007$/metric ton CO2) for 5%, 3%, 2.5% and 95 percentile hard case respectively in 2020. However, the Interagency Working Group revised result in (2013, 2016), the SCC values are: $12, $42, $62, & $123 (2007$/metric ton CO2) for 5%, 3%, 2.5% and 95 percentile hard case respectively for the same year considering. The literature also shows the frequently used IAMs' have generated different estimates. Taking FUND and PAGE, with absolutely contrasting on assumptions to "Catastrophes" and GDP endogenous empirical finding shows largest deviation in estimate for same level of discount rates. There are also researches employed in developing countries using Ricardian cross-section. The author recommends that more integrated mega level multidisciplinary studies needs to be financed. Further scientific research by scholars who developed the existing models needed to look work more on challenges.

***Key words**: CO_2, Social Cost of Carbon, Discount rate, Integrated Assessment Model*

1. Introduction

Greenhouse gases (GHG) that every company, household release are the most significant driver of climate change (Apata T.G. etal, 2009). Carbon dioxide emission contributes 72% of global greenhouse gas emissions excluding emissions from land use. Land use amplifies greenhouse gas emission by about 0.5% to ±1% (PBL, 2017). Energy-related CO2 emission represents roughly 85% of global CO2 emissions. It continued to rise and remained as major global agenda calling for collaborative actions. For example 2018 IPCC report agreed to achieve Paris goal of 2015 which is keeping global temperature at 1.5–2°C amplification. It has also vision of reaching net-zero CO_2 emissions between 2045 and 2080. This shows every other year scholars and politicians around the globe sit together to deal about carbon emissions.

Climate change is one of the major global concerns since industrial revolution (Tol, 2005; Stern, 2006). IPCC confirmed that globe is hard hit by climate change due to increased temperatures, fall in precipitation, change in sea level, and other extreme climate variables. Climate change aggravates existing global economic problems (IPCC, 2007a). It is one of the causes for the wide ranging market failure that we encounter today (Stern, 2006). An emission led climate change causes substantial welfare losses, drop in consumption global economy, depletion of biodiversity and other unwanted effects. Impact of climate change already reduce length of growing seasons in some parts and are expected to get worse unless, appropriate policy measures have put in place. However, effort made to shrink CO_2 emissions to reduce its effect is limited.

It has paramount importance to measure how much society costs for a unit increase in carbon emission. For example (Pezzey, 2017) claimed measuring carbon cost would inform us welfare cost of future global climate change produced by emitting extra ton of CO_2 in each year. As described by (Dell M. etal., 2013) in this process four broad components are involved: 1) path for greenhouse gas (GHG) emissions projecting model, 2) a model that mapping GHG emissions into climatic change, 3) a damage function that calculates economic costs of climatic change, and 4) a social welfare function for aggregating damages over time and potentially across space.

Using these components together external cost of carbon damage can be estimated. Economists use two main tools in relation to valuing carbon: Social cost of Carbon (SCC) or Marginal Abatement Cost (MAC). For MAC, measures cost that has spent for reducing emissions whereas SCC estimates cost for damage (Ibrahim N. & Kennedy C., 2016).

Therefore, the paper seeks to address policy oriented empirical questions: How do we measure the social cost of carbon emission? How much is the cost of carbon per ton of carbon emission? To what extent does discount rate affect level of social cost of carbon? Collectively, the study has three broad objectives: explore contemporary empirical evidences, how economists' measure cost of carbon emission, updating challenges in cost estimation and discourse empirical findings using wide-ranging parameters' with due emphasis on discount rates.

2. Measuring Cost of Carbon

Recently, measuring cost of carbon emission is center of discussion among economists. Different approaches have been used to measure emission damages and/or benefits. Wide-ranging methods which convey analogous result had been used. Economists use two main tools to inform policy decision-making in relation to valuing carbon: SCC or the Marginal Abatement Cost (MAC).

In marginal abatement cost targeted emission level by specific project as prerequisite to fund. And estimation would held using policy aimed at reducing emissions. Policy maker exert efforts on emission reduction instead of spending money for struggling carbon damage example, Adler M. et.al, (2017) used marginal abatement cost technique to estimate cost of reducing emissions.

Marginal abatement cost, measures cost that has spent aimed at reducing emissions (University Ottawa, 2011). The University derived MAC solely built using expert opinions, discount rate, assumptions about emissions growth, investment and operating costs, and emission reduction potential and cost of various technologies. However, valuation based on personal opinion is biased. Accordingly, wide-ranging estimate is derived (£30–90/t CO_2) in 2020, £60 per ton gap between the least and large estimate. Therefore, the main drawback of the estimate is subjectivity of inputs used. In addition, Ibrahim N. & Kennedy C., (2016) used bottom-up methodology for marginal abatement cost applicable to sampled global cities, requires initially a compilation of mitigation programs and policies. By these the finding was efficient in cost. However, they made strong assumptions for example for them savings include financial saving only which is not the case for some of sample cities. Furthermore, co-benefits are not considered in their analysis, in reality carbon emission is the biggest externality in which it positively affect agents outside the market when reduced, the reverse is true.

In general looking into its features, MAC is supply side approach, referred in earlier literature as conservation supply curve (Ibrahim N. & Kennedy C., 2016) links emission abatement to an emission cost being a CO2 tax or a CO2 price. It takes existing policies that create a cost per unit of emission for regulated agents, initiated either by emission tax or tradable permits scheme that establishes equilibrium price for emitters. Hence, MAC is designed to meet specific emissions target (Watkiss P., 2005) raised bold however, true proposition, "White Paper analysis", mainly benchmarked government target values against wider literature. In this case we can call estimate by (Gillingham K. & H. Stock 2018) found tremendously wide ranging results, from less than \$10 per ton up to \$1,000 per ton, as such wind production tax credit have estimated carbon abatement costs ranging from \$2 to more than \$260.

However, MAC is imperative, allow policy-makers to make critical decisions: what emission reduction should target, efficient way to achieve it, and how much each projects cost. As such, the Paris agreement policy target of keeping global warming below 2°c (UN, 2015) can be taken as an example of policy target.

It also expressed using graph (Gillingham K. & H. Stock, 2018). In a graph, a point on MAC curve represents marginal cost of abating additional unit of emissions (Ellerman, D.A., Decaux, A., 1998). It reflects marginal costs relative to baseline (choices of technology and behavior under 'business as usual'), it doesn't take into account any low carbon policy interventions (Tilbur et.al, 2010). Its marginal costs curve to achieve a cumulative level of emissions abatement required to bring emissions reductions that allow specific stabilization pathway (Watkiss P., 2005). Furthermore, curve will equal to all emitters to reach a given target reduction, that is ailment for cost-effective policy (Adler M, et.al, 2017).

The social cost of carbon demonstrates how much society or a company is willing to pay to reduce damages arising from climate change. On the other hand, MAC represents the cost of abating next unit of emissions for a given target level, and informs decisions about emission targets, as well as the design and cost of policy to reduce emissions.

Following aforementioned information, MAC focuses on existing target while SCC requests the willingness to pay of a household or firm. Expert pose a question of transparency on MAC.

Henceforth, due to resource and time restraint I did explained MAC briefly. And the following few pages are discussions about social cost of carbon as well as estimates, basically intention of this paper,

2.1. Social Cost of Carbon

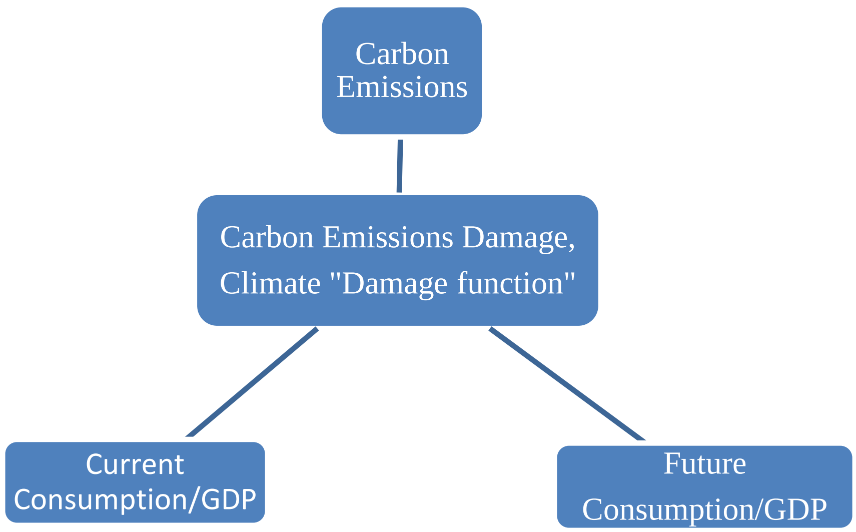
Definition: The net present value of future global climate change impacts from one additional net global metric ton of carbon dioxide emitted to the atmosphere at a particular point in time.

2.2. Conceptualizing Social Cost of Carbon

Social Cost of Carbon has three scenarios (Pezzey, 2017). Scenario one, maximizes the sum of discounted benefits minus costs; another achieves some physical policy target like keeping global warming below 2°C UN, 2015; and a third type is a baseline, with no additional climate policies (Rose et.al, 2017). The first two scenarios are modeled for carbon emission induced economy as such (Gilligham K. & H. Stock, 2018) evaluated along an arbitrary emissions trajectory, marginal damage costs referred as social cost of carbon. On the other hand, optimal or "policy" SCCs estimate used as carbon prices to guide some policies example, U.S. government used it to satisfy cost–benefit analysis of climate-related regulations requirements (Pizer, 2017). Both arbitrary and policy guide emission reduction target have shortcoming. In case in case of arbitrary target may endorse subjectivity. And policy target emission has shown prevalence of strong political influence.

Accordingly, conceptual framework has built following works done by University of Ottawa, (2011). The adopted figure (1) has link two key variables: carbon emission and output change. Obviously, it is intuitive for economists to look for consumption and GDP changes under carbon emission induced economy as compared to business as usual scenarios. The figure shows the way carbon emission links current consumption to future consumption. In this case calculation involves estimating future consumption and/or GDP and emissions damage over the course of hundreds of years, and then discounting it back to the present. In effect accumulated emissions discounted to the reference time period for example today's emissions could have damage may be in the future several years later. Therefore, we discounted back to a given year considered. Thus, figure (1) below shows loss in GDP/Consumption for carbon emission induced economy.

Figure One: Estimating the Social Cost of Carbon



Source: Own sketched adopted from University of Ottawa (2011): The Value of Carbon in Decision-Making: The Social Cost of Carbon and the Marginal Abatement Cost.

As seen in figure 1 above, SCC to estimate future GDP damage and/or consumption loss over the course of hundreds of years, and then discounting it back to the present. It is clear that composite consumption or national income is measured as welfare cost of future global climate change compared to some reference carbon emission scenario.

Of course, calculation of SCC might be discounted-utilitarian or non-discounted (Adler M. et al., 2017). However, dominant social welfare functions in policy making is discounted-utilitarian, individuals' well-being are summed and valued on behalf of generations will be discounted since emissions released today would have impact after hundred years later even more. However, some such as (Adler M. et al., 2017) argue discounting violates ethical axiom of impartiality and ignores distribution of wellbeing between generations.

Putting aside these critics, estimating using SCC is quite essential for improving carbon cost calculation techniques and designing damage reduction policy.

Estimating SCC is a difficult exercise, there are thoughtful uncertainties, including uncertainties about science (warming from emissions of CO_2 and environmental changes accompanying warming, such as precipitation changes and sea level rise) and uncertainties about economic impact of climate change Bowen A. (2011). Economists give much attention for some critical parameters (discount rate, time preference, risk aversion, income elasticity) (Watkiss P. & Downing T., 2018; Pezzey, 2018).

As per the scope of the paper concerned, I would prefer to emphasis on choice of discount rate and its implication on carbon cost estimate. Of course, (Pezzey, 2018) argued discount rate is more importance than other parameters and even combined parameters. Hence, it answers the inter-generational linkage question, implicate the extent to which current generation cares about their offspring.

It determines the fate and carbon cost share of unborn generations, how much weight should place impacts of climate change on unborn generations, compared with equivalent impacts today (Bowen A., 2011; IPCC, 2018).

Thus, determining discount rate is most important part in shaping cost of carbon. Accordingly, discount rate has given emphasis, in which justifying discounting and the magnitude of social cost of carbon for different discount rate are discussed below.

2.3. Why Discounting?

Welfare maximization across generations' needs inter-temporal allocation, life time consumption need to be distributed evenly along time paths. Therefore, discounting is standard practice where economists used in calculating costs and benefits over time. Because a certain unit money today is more valuable than same unit money in the future due to interest and economic growth, dollar today is not equal to a dollar received in the future.

A Senior Research Fellow for Energy Economics and Climate Change (Kreutzer D., 2016) said "discounting is a critical component of cost-benefit analysis, especially when the costs and benefits occur at separate and temporally distant points" where it is orthodox in emission damage function.

Hence, discounting can smooth consumption across generation and cost of carbon emissions that will allocated equally. In broader term it measures the relative importance in societal decisions of the welfare of future generation relative to that of current generation.

General discourse, discount rate for emission damage, reflects balance between present & future wellbeing. This makes discount rate key parameter in damage estimation. Thus, discount rate which used in SCC derivation and SCC estimated values are discussed below.

2.4. Choice of Discount Rate

The US National Academies of Science, Engineering and Medicine (NAS), states discount rate could adjust current cost or benefit with future cost or benefit. Choice of discount rate has a principal role in determining share of carbon cost across generations. Economists used different determination approaches, Pindyck (2017) warrants there is no consensus regarding choice of discount rate. Having this, some common selection mechanism are discussed below.

There are important analytic components that need to be considered in selecting discount rate: pure rate of time preference, a measure of relative risk aversion, and rate of growth of per capita consumption (Anthoff et.al, 2009). In damage function (Kellehera P. & Wagner G., 2018) explain climate change damage through emission is a long-term problem, consumption discounting is appropriate. For example US Working Group claimed discounting using “consumption” discount rate, reflects how much households willing to sacrifice consumption today in order to have more in future, or how much they are willing to pay to borrow from future consumption. Clearly, it relays on how much impatient individuals are, size of their incomes now versus what they expect them to be in the future, and the risk of default perceived by lenders for a given type of asset. Explicitly decision-making incorporate how welfare of future generations should be weighed against that of the present generation.

Though, discussion has shown discount rate is central in SCC computation and no consensus is made on selection criteria, US Working Group had been chosen three discount rates, largely upon empirically observed interest rates, of 2.5%, 3%, and 5 %. The 3 % rate had been and is taken as central rate, that chosen on basis of average “risk-free” savers and borrowers use to discount future consumption, approximated the long-term return on 10 year. It shown as consistent with economics literatures of consumption rate of interest. The 2.5% selection was based upon historical data. Furthermore, 5% selection has been justified as some borrowers are willing to pay higher interest rates than risk-free rate: “high interest rates credit-constrained individuals accept suggest that some account should be given to discount rate revealed by their behavior” (US Government 2010) as it is sighted by (Johnson L. & Hope C., 2012). The interagency group also celebrated 95th percentile at a 3% discount rate, representing higher expected economic impacts.

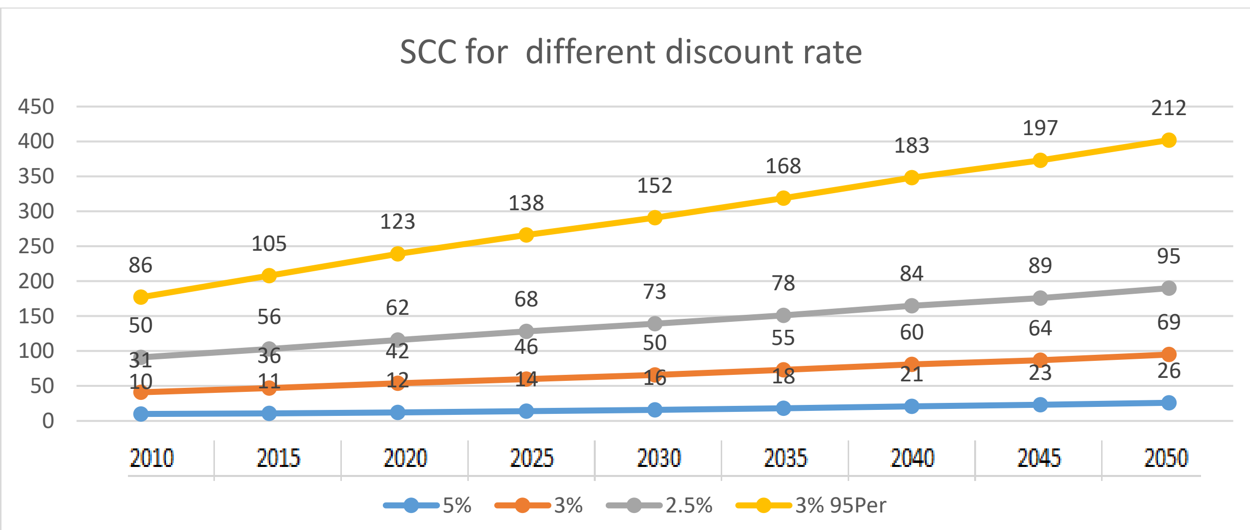
However, most (perhaps all) policy decision maker are influenced by Interest group usually government as such referring National Academies of Science of US Auffhammer M. (2018) notified that the recent highly ranged 3% to 7% discount rate of carbon damage by Trump administration rule makings has been suggested. This revision may drives cost of carbon to be down below $10 per ton of carbon emission, gap between smallest and largest cost of carbon will magnificently widen. Clearly, higher discount rates, reflect a higher risk that future value of money will diminished, bring lower values and lower discount rate produce huge value. Hence, new policy revision suggestion under Trump administration will likely affect people’s attitude of fighting emission discharge. In the following section, we will see the effect of discount rate in changing volume of social cost of carbon.

2.5. Discount Rate and Social Cost of Carbon

Social cost of carbon estimates may range from a few dollars to several hundreds of dollars per ton of carbon emission" for small variation in discount rate (Pezzey, 2018). This hypothesis confirmed by figure two below, summary of SCC estimation by (EPA, 2013) that has been revised in 2016 by "Technical Update of Social Cost of Carbon for Regulatory Impact Analysis under Executive.

In the plane social cost is in the vertical axis whereas discount rate and time are presented in the horizontal axis. The values are presented for five years interval from 2010 to 2050 calculated for frequently discount rate (5%, 3%, 2.5% and 95th percentile hard scenario, based on (2007$/ ton CO2).

Figure 2: SCC for different discount rate



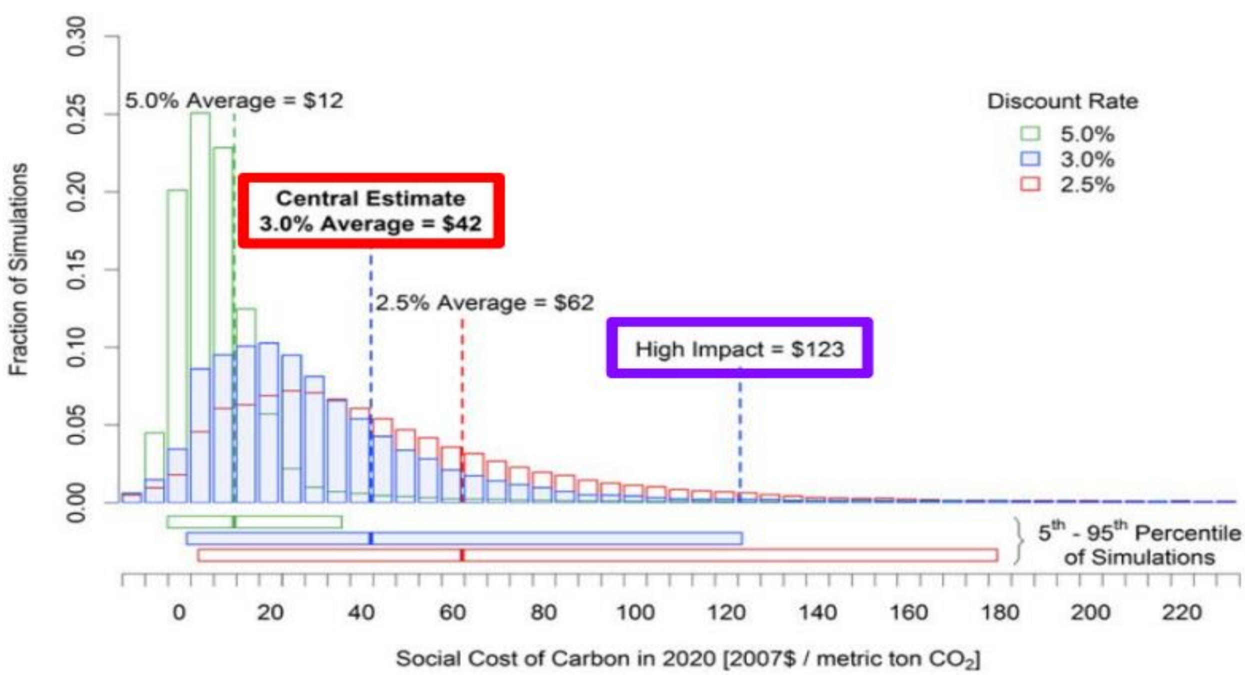
Source: Own sketched using "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866."(U. S. Government Interagency Working, Group on Social Cost Carbon, 2016).

As shown, in their result, minor deviation in discount rate could brought about huge volume of damage cost. Let alone the hard case scenarios, the lowest discount rate (2.5%) costs $62, higher discount rate (5%) costs $12 in 2020. We can notice that choice of discount rate strongly affects the social cost of carbon. The SCC at a 2.5% discount rate is five times the SCC at 5% discount rate. In which values in the graph tells us doubling discount rate cuts cost of emission by more than triple. On the same period a movement from 3% to 2.5% increases carbon cost exactly by \$20. Putting together, the SCC values are: \$12, \$42, \$62, & \$123 (2007\$/ ton CO2) for 5%, 3%, 2.5% and 95 percentile hard case respectively in 2020.

In conclusion, lower discount rate generate higher social cost of carbon that confirm (Philibert C., 2003) idea of low discount rates makes future generations to become welfare maximizer in expense of current generations. Here, we can understand how much assumptions about discount rate make carbon cost estimation complex. Furthermore, compared to remaining scenarios extreme scenario (95th percentile) need huge money to contest one ton of extra carbon emission, indicate the potential for less likely, but more extreme, impacts.

Trend shown in figure 2 has a distribution plotted in figure 3 below. Vertical axis is simulations, horizontal axis is the cost of carbon estimated across discount rate considered. The cost of carbon evaluated at \$2007 using updated report of 'Interagency Working Group on Social Cost of Carbon, United States Government' 2016 revision. Hence, figure three below presented to show for entire distribution.

Figure 3: Distribution of SCC Estimates for 2020 (in 2007\$ per metric ton CO2)



Source: Rose et.al. (2017) sketched using "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866."(U. S. Government Interagency Working, Group on Social Cost Carbon, 2016).

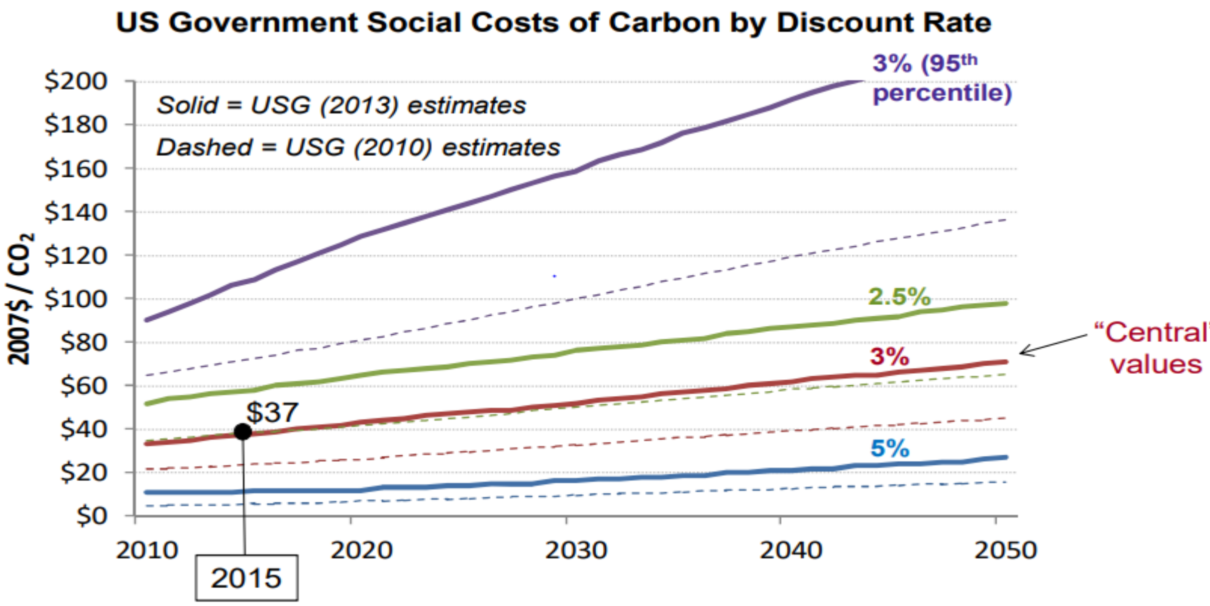
The figure shows simulation compressed for central discount rate. This is realistic distribution because central estimate is the average of included discount rate scenarios. Implies probability of laying at 3% discount rate is approximately equal for all scenarios. In this specific case, SCC for 3% discount rate is close to median of the SCC distribution. If we look at dispersion of high impact discount rate carbon cost to the mean and 5% discount rate to the mean are at equal distance. Therefore, central discount rate represents the simulation accurately.

In addition, the 5% discount rate estimated cost is skewed to the left, relatively less responsive for time. Of course, over 40 years, it increased by 16 dollars only. This increasement from 10 in 2010 to 26 in 2050, is exactly equal with half of the 2010, SCC value evaluated at 3% discount rate. Furthermore, figure 3 illustrates, variance in SCC for discount rate assumed, distributions are also skewed to the right and have long tails, it speaks a fact that the lower discount rate, the longer the right tail of distribution that have been taken as standard.

Moreover, Working Group 2010 estimated SCC value: $6.8, $ 26.3, $ 41.7, & $ 80.7 (2007$/metric ton CO_2) for 5%, 3%, 2.5% and 95 percentile hard case respectively are lower than the 2013 estimates for same level of climate projection and discount rates. The figure 3 below presents work done by Rose (2014) who had compared 2010 and 2013 SCC estimates of US government. On the other hand, figure four shows 2020 SCC estimates report of 'Interagency Working Group on Social Cost of Carbon, United States Government' May 2013 revision corresponding four updated SCC estimates of $12, $43, $64, and $128 (2007$) for 5%, 3%, 2.5% and 95 percentile hard case respectively.

In figure 4 below carbon cost across time noted bold line as 2013 estimates with corresponding discount rates. The dashed line represents trend in social cost of carbon in 2010 with same rate of discounting with 2013 estimates. Both lines are valued at $2007.

Figure 4: The 2010 and 2013 US Government Social Costs of Carbon



Source: Rose (2014): Understanding the Social Cost of Carbon: A Technical Assessment, Energy & Environmental Analysis Research Group, EPRI: U.S. Energy Association.

As shown in figure above, in 2015 ton of CO_2 for emissions costs $37 for 2013 Working Group estimate which was $20 for the same year indicated in 2010 estimation of the group. Nordhaus WD. (2015) revisiting social cost of carbon found $31.2 per ton of CO2 for emissions, with the discounting rate of 2.5% per year. The 2010 and 2013 carbon cost deviation presented in figure above is a result of three updates, including the representation of damage from sea level rise, which would have been updated assumptions on adaptation and a revision in the treatment of potentially abrupt shifts in the climate. These updates has potential to change SCC, as such, inclusion of sea level would increase volume of carbon cost per ton of emissions. In addition, exclusion of adaptation would lead to underestimation in cost of carbon. In combination damage reduction is expensive in 2013 than it was in 2010 for all discount rate used. Moreover, further investigation and multidisciplinary assessment by economists and hard science scholars would come up other possible reasons, that are not evidently increases the social cost of carbon with a three year short time span.

Given all uncertainty, challenges and generation of varied carbon cost estimate for same unit of emission in fractional discount rate variance, still SCC is prominent approach to compute carbon cost. IAM played vital role in calculation of this number typically combining climate change with monetized benefits, costs (Svante M., 2010) and thereby produce an input as guidelines for optimal policy.

Therefore, it is intuitive to look IAM and make argument on peculiar features of each IAMs. Basically, three most–cited models, which are William Nordhaus' DICE model recently RICE, (Yale University), Richard Tol's FUND model (Sussex University), and Chris Hope's PAGE model (Cambridge University) have many things to share. They have also some shared by two of them for example GDP is exogenous in FUND and PAGE but, it is the solution of the model itself for DICE. Due to this fact, in DICE, temperature affects both consumption and investment, possibly make carbon cost estimation extreme scenario. In PAGE, consumption-equivalent damages in each period calculated as a fraction of GDP, depending on temperature in that period relative to preindustrial average temperature. In FUND, damages in each period also depend on the rate of temperature change from the prior period. The other critical difference among such models is their view about adaptation.

3. Integrated Assessment Models (IAM)

Integrated assessment models conglomerate human behavior & climate systems so as to able to make predictions about future climatic change and its consequences (Dell M. et.al, 2013). It links physical impacts to economic damages for the purposes of estimating SCC (Michael G. et.al, (2010); Tol, 2008).

Though, it is in expense of detailed representation of underlying climatic & economic systems, IAM's has advantage of using single integrated framework (Michael G. etal., 2010). As described above, it joins climate processes, economic growth and feedbacks in single modeling framework. Most commonly used techniques are Dynamic Integrated Climate Economy (DICE), Climate Framework for Uncertainty Negotiation and Distribution (FUND), and Policy Analysis of Greenhouse Effective (PAGE).

3.1. Dynamic Integrated Climate Economy (DICE)

The DICE model is an optimal growth model based on a global production function with an extra stock variable (atmospheric carbon dioxide concentrations). The DICE damage function links global average temperature to overall impact on world economy. Currently, it includes regional version named RICE models (Nordhaus and Sztorc 2013). Damages reduce investment in that year, it disseminate forward in time and reduce GDP in future years appreciating investment as major GDP component. Then, GDP is endogenous in DICE. In contrast, GDP is exogenous in Climate Framework for Uncertainty Negotiation and Distribution (FUND) and Policy Analysis of Greenhouse Effective (PAGE), damages in any given year do not propagate forward.

DICE analytical model that signifies economies, policy and scientific features of climate change, which basically follows neoclassical theory of climate change economics. Consequently, Solow growth model economies make investments in capital, education, and technologies, thereby reducing consumption today, in order to increase future consumption (Nordhaus, 2014).

The model extends the approach by including “natural capital” of the climate system. It views GHGs concentrations as negative natural capital and emission reductions as investments that raise quantity of natural capital. In this model emission reductions treated as analogous to investment in “natural capital.” Investing in natural capital through reductions in emissions implying reduced consumption harmful effects of climate change can be avoided and future consumption thereby increased.

There has been improvement in DICE, for example 2010 version includes some modifications on 2007 version, and the 2013 version includes the regional dynamics analysis (RICE). The model changes that are relevant for SCC estimates developed by interagency working group include:1) updated parameter values for carbon cycle 2) obvious representation of sea level dynamics 3) a re-calibrated damage function that includes an explicit representation of economic damages from sea level rise. Changes were also made to other parts of DICE model including the equilibrium climate sensitivity parameter, the rate of change of total factor productivity, and elasticity of marginal utility of consumption but these components of DICE are superseded by interagency working group’s assumptions and so will not be discussed here. More details on DICE2007 can be found in Nordhaus (2008) & DICE2010 in Nordhaus (2010).

A new feature of DICE2010 is an explicit representation of dynamics of global average sea level anomaly to be used in the updated damage function (discussed below). This section contains a brief description of the sea level rise (SLR) module; a more detailed description can be found on the model developer's website. Average global sea level is modeled as sum of four terms that represent contributions from: 1) thermal expansion of oceans, 2) melting of glaciers and small ice caps, 3) melting of the Greenland ice sheet, and 4) melting of Antarctic ice sheet.

Following updated features and innovative DICE model produce an estimate different from what have been and will produced by remaining IAM's methods. Let alone other approaches, it also produced contrasting outcomes even within itself for instance (Nordhaus WD., 2015) have had shown SCC of $32 per ton of CO_2 emission in year 2015 however, this ranges from $7 to $77 for 10th to 90th percentile with 2.8 ratio of 95th percentile to average. Let discuss about FUND's feature and circumstance that makes model vary from the remaining methods.

3.2. Climate Framework for Uncertainty Negotiation and Distribution (FUND)

In FUND, impacts of climate change are assumed to depend on impact of previous year, thereby capturing adaptation to climate change. In contrast to other integrated assessment models in its detailed representation of sectorial and regional economic impacts. FUND model has been assumed GDP growth as exogenous. In addition, agricultural CO2 fertilization, cooling demand, adaptation have taken strong attention.

However, it always reflects its developer's world views. It is therefore regularly contrary to the rhetoric of politicians, and occasionally politically incorrect.

The US Interagency Working Group on Social Cost of Carbon report shows FUND incorporated adaptation by allowing damages by climate change happens more slowly. Inclusion in adaptation can compromise net effect of CO_2 fertilization in agricultural sector, positive impacts to some regions from higher temperatures, and sufficiently slow increases in temperature across these sectors can result in negative economic damages from climate change.

3.3. Policy Analysis of Greenhouse Effective (PAGE)

PAGE is the third IAM which calibrated for 8 regions, and therefore cannot be run as a singular, global routine. It is most standard approach that would accustom initial "learning investment" required would substantially reduce the unit costs of CO_2 abatement as compared to a business as usual scenario. PAGE09 represents climate change impacts, abatement costs and adaptation costs that result from abatement and adaptation policies specified by the user. Thus, Changes in utility, so that risks can be fully considered. In PAGE model GDP is exogenous, whereas adaptation has been included.

Kopits E. (2015) summarized number of regions, damage function specification, uncertainty treatment, consideration of adaptation, catastrophes and endogenous nature of GDP for IAM's done by US Interagency Working Group, in the table instantaneous characteristics of IAM's (DICE, PAGE, and FUND) is clearly presented.

Table one: features of IAM's models

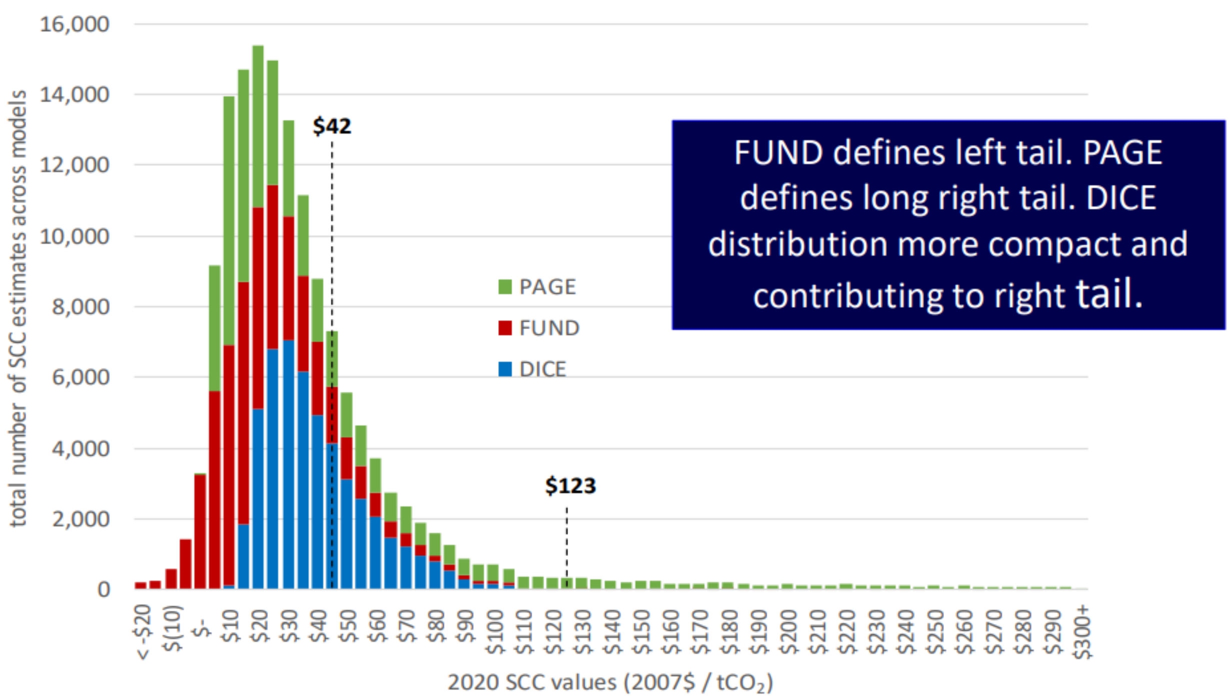
IAM's Components	DICE(2010)	PAGE (2009)	FUND (v3.8)
Regions	1	8	16
Damage Categories	2: sea level rise (SLR); aggregate non-SLR	4: SLR, economic, non-economic, "discontinuity"	11 market and non-market sectors
Damage specification: SLR Non-SLR	- quadratic function of global SLR - quadratic function of global temperature	- power function of global SLR -power function of regional temperature	- based on internal model of optimal coastal adaptation - sector specific
Model treatment of Uncertainty	Deterministic	Most parameters Probabilistic	Most parameters Probabilistic
Adaptation	Implicitly included in Choice of some	Generally included in specification of	Explicitly included for some sectors

	underlying studies	“tolerable” temp change	
“Catastrophes”	Yes	Yes	No
GDP endogenous	Yes	No	No/Yes

Source: Kopits E (2015): The Social Cost of Carbon for Regulatory Impact Analyses: Interagency Working Group on Social Cost of Carbon; Presentation on Assessing Approaches to Updating the Social Cost of Carbon.

Thus, using approaches mentioned above different results for same level of discount rates are obtained. Even for FUND and PAGE, which have similar asumption on “Catastrophes”, GDP endogenous, and treatment of uncertainty. These are assumptions would bring huge difference in damage functional presentation. However, look in to result distribution reported in figure five by Rose et.al (2017) distribution varied for all IAM’s.

Figure Five: DICE, FUND, and PAGE estimate distribution for 2020 with a 3% discount rate



Source: Rose et al (2017) sketched using “Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866: U. S. Government Interagency Working, Group on Social Cost Carbon.

The figure is constructed using U. S. Government Interagency Working, Group "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis revision in 2016. The unit is U.S dollar at 2007 exchange rate.

As seen in the figure above, the distribution for "PAGE" is long right tail, because PAGE model has been introduced adaptation in all sectors fully and it take in to account the under estimated cost of carbon. As well as damages in each period are calculated as a fraction of GDP, depending on temperature in that period relative to preindustrial average temperature would hikes estimated cost. The diagram also showed estimate value for DICE is compacted and placed in between values of the remaining IAMs. Hence, DICE counted GDP as a solution of a model, affects both consumption and investment, its carbon cost estimate is larger than FUND estimates. But, may be due to fully inclusion of adaptation PAGE generates an extreme scenario estimate which is by far higher than what has been estimated using DICE model. In general, the distribution confirms most of features of each model presented in table one.

Besides distribution, carbon cost estimate difference often seen in these approaches example https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5321009/table/t03/ proves an average SCC $45 2020, in which $40 for DICE-2010, $74 for PAGE and $22 for FUND. This result asserts assumptions included in each model creates critical influence on value of carbon cost. In combination carbon cost estimation is complex & uncertain. In next section evaluation technique for economic impact of climate change focused on partial cross-sectional analysis is presented.

4. Evaluating Economic Impact of Climate Change

Empirical studies on impact of climate change can broadly divided into two categories partial equilibrium mostly used by earlier studies and Computable General Equilibrium where several recent studies have applied. Hence, discussing general equilibrium modeling needs resource and time that is beyond scope of this project I will focus on partial equilibrium, often used by economists to estimate damage function in climate change induced economy. Some studies employed panel regression example, Kabubo J. etal, (2015) others like (Zhai et al., 2009; Zhai and Zhuang, 2009) used crop-simulation that make use of controlled experiments on crops grown in a field or laboratory. Those, models do not include farmers' adaptation to changing climate conditions in the estimates. As a result, they tend to overestimate damages as well as such experiments are costly and narrowly defined locations can only be tested.

Overall, partial equilibrium analysis suffers or fails to consider price variations that causes bias in welfare calculations (Mendelsohn and Nordhaus, 1996; Cline, 1996). For example Ricardian model has examined only change in net revenue, and spillover effect of net revenue shock hasn't been researched. Both panel regression and crop-simulation also focus on single market; considers optimization process with and without climate change for a single market with no heed for the spillover effect of shocks. Herewith, below rough discussion made about Ricardian cross-sectional model most used by economists.

4.1. Ricardian Cross-Sectional Model

The Ricardian approach depends on perceptions initially built by David Ricardo and further developed by analysts like Palmquist (1989). They noticed that each parcel of land has countless characteristics that vary across various zones. The parcel proprietor can change a portion of the qualities like fertility and drainage erosion control in light of data and motivating forces while others like soil type, soil depth, climate and landscape cannot be for all intents and purposes modified. Ricardian model is familiar that used to build and examine impact of climate change on economy often crop revenue.

In this perspective, proposed model followed two procedures in calculating economic impact of climate change. Firstly, model includes only linear and quadratic terms of climate variables (temperature, precipitation, sea level and others) and linear terms of plot soil types. Secondly, letting to control adaptation measures include linear terms plot characters (plot area & plot elevation) & relevant household and socioeconomic variables. Furthermore, different regressions will run: for entire sample crop farms and each crop types. Thus, overall net crop revenue with climate change estimated example, (Deressa T. & R. Hassan, (2009) applied to quantity effect of climate change on crop production in Ethiopia.

The Ricardian approach investigate a cross section of farms under various climatic conditions and looks at the relationship between the value of land or net revenue and agro-climatic variables (Mendelsohn et al.,1994). The most vital advantage of Ricardian model is its capacity to include private adaptations. The farmers' reaction includes costs, creating economic damages that are reflected in net revenue. Along these lines, to completely represent the cost or advantage of adaptation, important dependent variable ought to be net revenue or land value (capitalized net revenue), and not yield. Ricardian approach considers by measuring economic damages as decreases in net revenue or land value induced by climatic variables.

The Ricardian approach regressed farmland values against climate economic and components to estimate the economic effects of climate change and different variables on farm performance (Mendelsohn and Dinar, 1999). The assumption is that in a well-functioning market framework, the estimation of a parcel of land ought to reflect its potential benefit. As the outcome it ought to be conceivable to estimate significant climate-land value relationship by indicating a multivariate regression model whereby the assessed coefficients for climate factors would reflect economic estimation of climate in farming, holding other factors constant.

Ricardian approach is criticized on some of its features example, lacks sensibly controlled experiment across farms. Farms diverge across space agro-ecology, it cannot guarantee all factors have been taken into account in analysis; some may not even be measured at all (Cline, 1996; Mendelsohn and Dinar, 1999). Since it uses precipitation and temperature only, fail to execute carbon fertilization effects (Cline, 1996; Mendelsohn and Tiwari, 2000).

Absence of explicit inclusion of irrigation in the model (Cline, 1996; Darwin, 1999) has been also raised as criticism. It doesn't measure true cost of farming in an economy where climate is changing with irrigation. Furthermore, the model fails to consider effects of transition costs. For instance, if farmer introduces new crop or technology, he/she will face reduction in his /her farm agricultural output until he/she adapt new crop or technology, but, approach does not consider this transition in analysis Kurukulasuriya et al., 2008a).

Agreed in the contributions and drawbacks of the approach, let see empirics in some developing countries, where major economic sectors are reactive for climate change variables (precipitation and temperatures). There is country and continent level analysis for instance, Kabubo-Mariara and Karanja (2007), measures economic impact of climate change on Kenyan crops. The finding shows among climate variables changes in temperature affect more than changes in precipitation. Similar study has employed in Zimbabwe (Nhemachena and Mano, 2007). The study regresses net farm revenue against various climates, soil, hydrological and socio-economic variables. The result also revealed that CGM2, HadCM3 and PCM showed that by 2100 net farm revenues would decrease across all farms by respectively $0.8 billion, US$1.3 billion and $1.4 billion. Where: CGM2 (Coupled global Climate Model): PCM (Parallel Climate model), and HadCM3 (extreme scenario) for detailed illustration refer https://www.researchgate.net/figure/Climate-predictions-of-SRES-models-for-2020-2060-and-2100_tbl2_228109215

This analysis has employed for selected 11 African countries (Kurukulasuriya and Mendelsohn, (2008a). Finding showed African farms are sensitive to climate specifically for temperature; hence, 10% increase in temperature leads to a 13% drop in Africans farm net revenue and precipitation elasticity is estimated to be 0.4. Out of Africa, A Study by Seo and Mendelsohn, (2008c) used a Ricardian approach analysis to measure impacts of climate change on South American farm lands. Accordingly, their finding indicated that farmland values will decrease as temperature increase, also as rainfall increase except for the case of irrigated farms. Furthermore, their prediction analysis indicate that both rain fed and irrigated farms will lose their incomes by more than 50% by 2100, with slightly more severe damage to irrigated farms. A study by (Kassahun, 2009) in Nile basin. The uniform climate scenario the review used 2.5°c and 5°c increase in temperature level and 7% and 14% decrease in precipitation level. In like manner, crop net incomes will decline to all farms under the four uniform climate scenarios aside from irrigated farm for a 2.5°C increment in temperature. At long last the review concludes that agriculturists in the review area knew about climate change and adjusting to the change in the study area.

Furthermore, those studies considered lump sum of agriculture particularly crop agriculture into one category. Climate change affects different crops in different way; effects of climate change are different for each crop types with independent regressions. For example in case of Nile basin we can take Ethiopia as a sample and she has crops in the North western part of the country produces cotton demand high temperatures where as in the central part, produced Teff (Ethiopian staple crop) needs moderate temperatures and some others are known in the production Barley are require low temperatures. This also true for South America, Kenya and African countries.

5. Policy Implications

Having, deep difficulties in social cost of carbon calculation discoursed so far, many economists still used it and I would like to forward the following points. Economic policy makers have to make strong effort in developing economic model to estimate carbon emission and to be able to save world from far-reaching carbon emissions impact. It is imperative if countries are led by well-informed politician who can possibly understand scholars in the area and able to implement various policy packages or sets of measures validated by experts for example intervention in setting discount rate shall be limited. I also indorses that more disaggregated regional data and programing needs to be publicly available so that interested scholars would learn more, so that are able to contribute for improvement in sector.

6. Summary

Existing literature on cost of carbon dioxide emission has seen well studied more organized. What problem the carbon emission dispute has coming and what earlier scholars has doing and methodological approach were less talked. Literature supports that studies about carbon emission is complex than any other externality. Methodology that model cost of carbon emission are SCC & MAC. As per SCC concerned, estimates cost of carbon emission damage reduction is modeled. The choice of discount rates has seen a major driver for uncertainties. As shown, in the discussion in 2020, United States Government Interagency Working Group (2010) estimated SCC values are: \$6.8, \$ 26.3, \$ 41.7, & \$ 80.7 (2007\$/metric ton CO_2) for 5%, 3%, 2.5% and 95 percentile hard case respectively. However, the Interagency Working Group revised result in (2013, 2016), the SCC values are: \$12, \$42, \$62, & \$123 (2007\$/metric ton CO_2) for 5%, 3%, 2.5% and 95 percentile hard case respectively. The literature also shows the frequently used IAM's have generated different estimates. Taking FUND and PAGE, their track is absolutely contrasting on assumptions to "Catastrophes" GDP endogenous empirical finding shows largest deviation in estimate for same level of discount rates. There are also challenges and uncertainty both in SCC estimation and IAMs. Both have problem of uncertainty on discount rate and time preference and carbon concentration on the atmosphere.

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