Cost-Benefit Analysis is Problematic When Applied to Social Cost of Carbon

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Abstract

If the 2014 Report by the Intergovernmental Panel on Climate Change (IPCC) is credible, applying cost-benefit analysis (CBA) to climate change, as in calculating the social cost of carbon (SCC), is problematic and potentially dangerous. This essay argues against the possibility of a social cost of carbon by critically examining three fundamental tenets that form the theoretical edifice of CBA in conventional economics: the ideas of scarcity, substitution and discounting. The application of these tenets to climate change by calculating the social cost of carbon exceeds the legitimate scope of CBA in which these concepts were originally formulated. A brief discussion of an alternative approach to CBA for assessing climate change is presented, more applicable to an issue like climate change in which decision-making is urgent, stakes are high, values are in dispute and knowledge is uncertain.

1. Introduction

The social cost of carbon (SCC) is a monetary measure representing the long-term social cost of an increase in a unit of carbon dioxide emission. The SCC approach, usually represented in terms of the discounted marginal cost of climate change damage, falls within the framework of cost-benefit analysis (CBA). CBA seeks to offer a monetary proxy for the evaluation of adaptation and mitigation of climate change. CBA provides decision makers and concerned publics with a guide for future collective discourse and policy formation. However, if the Fifth Assessment Report by the IPCC (2014) is credible, applying CBA to climate change is problematic. This essay draws upon this 2014 IPCC report to argue that CBA and the social cost of carbon cannot be applied to climate change. I develop my argument by discussing the fundamental tenets of *scarcity*, *substitution* and *discounting* that form the theoretical edifice of CBA. The essay argues that applying *scarcity*, *substitution* and *discounting*to climate change exceeds the scope of CBA within which these concepts were originally formulated. I close with a brief discussion of an alternative approach to CBA applied to climate change. Climate change is a typical problem of the post-normal science (Funtowicz and Ravetz 1993)--decision-making is urgent, stakes are high, values are in dispute and knowledge is uncertain.

2. Essential points of the IPCC report

There are five important conclusions from the IPCC Fifth Assessment Report which are crucial for my critique of the social cost of carbon. First, most anthropogenic climate change is pervasive and irreversible on a multi-century to millennial time scale unless there is sustained reduction in greenhouse gas (GHG) emissions. Second, in many regions, changes in precipitation or snow and ice melt have altered hydrological systems including underground water, causing severe climate related impact such as heat waves, droughts, floods, cyclones and wildfires. Such climate variability presents significant danger to ecosystems, particularly in developing countries with low income. Third, marine life such as coral reefs will face progressively lower oxygen levels increased ocean acidification, with associated risks exacerbated by rising ocean temperature. Global redistribution of marine species and reduction of marine biodiversity in sensitive regions will endanger fisheries that rely on healthy ecosystems. Fourth, urban areas are subjected to increased future risks affecting people, assets, economies and ecosystems, including risks from heat stress, storms and extreme precipitation, inland and coastal flooding, landslides, drought, water scarcity, sea level rise and storm surges. Rural areas will likely experience major impacts on water availability and supply, food security, infrastructure and agricultural incomes, including shifts in the production areas of food and non-food crops. And fifth, while adaptation options exist in all sectors, the consequences of implementing those options to reduce potential climate related risks differs across sectors and regions.

The IPCC report implies that unless fossil fuels can be replaced by alternative primary energy sources with no significant GHG emissions, irreversible climate change is likely for centuries. Furthermore, climate change seriously threatens Net Primary Production (NPP) (Vitousek et al., 1986), the most important biophysical basis for biological life on the Earth and which ultimately regulates economic production from agriculture, fishery and forestry. NPP is non-substitutable, and yet human life depends upon it.

3. Reconsidering scarcity, substitution and discounting in conventional economics

3.1 Scarcity

The conventional economic framework dates back to the socioeconomic conditions prevailing in England in the nineteenth century during the industrial revolution. At that time, people started to anticipate that perpetual economic growth could be maintained by a combination of abundant fossil fuels and the expanding economic production. Since then however, limitless desire for goods and money in anticipation of perpetual growth has become the foundation of the *scarcity* concept in conventional economics.

The scarcity refers to the situation in which a persistent gap exists between available goods and limitless wants. The modern world is full of economic goods that allow a reasonable lifestyle, but there are not enough of those goods to satisfy limitless wants (Samuelson and Nordhaus, 2010). Hubin's term (Hubin, 1989), 'moderate scarcity', exactly corresponds to the definition of scarcity given by Samuelson and Nordhaus. The essence of the scarcity concept appears in Existence of an Equilibrium for a Competitive Economy (Arrow and Debreu, 1954). Exactly parallel to the moderate scarcity in conventional economics, they assume that "every individual could consume out of his initial stock in some feasible way and still have a positive amount of each commodity available for trading in the market".

However, an economy must make the best use of its *sufficient* yet limited available resources compared with unlimited wants, i.e., under the condition of moderate scarcity, that brings to the efficiency criterion. This efficiency criterion requires that CBA is used to choose investment projects that maximize the present monetary value of total net economic benefits accruing over a certain time period with a certain discount rate. The scarcity concept in conventional economics does not therefore refer to 'severe scarcity', in which it is very difficult either to satisfy basic needs or else to obtain necessary provisions for subsistence. Often used in CBA, the Contingent Valuation Method (CVM) asks people how much money they are willing to pay for protecting the provision of goods coming from ecosystems. However, in the case of 'severe scarcity', the market mechanism cannot give all individuals an acceptable share of goods, so, the most important question to ask is rather what type of subsistence good is necessary for a decent life. In particular, poor people in developing countries often lack enough purchasing power, so that the monetary value that they report in CVM is necessarily too small, ultimately leading to ruining their subsistence resources for survival. If, as the IPCC report suggests, irreversible climate change threatens NPP, severe scarcity of economic goods must eventually occur. The situation envisioned by conventional economics—that of the moderate scarcity assumed by CBA-- cannot deal with climate change.

3.2 Substitution

In conventional economics, smooth substitution among goods and production factors, one of the pillars of CBA, is essential for price mechanisms to work.

According to Marshall (1920), quasi-constancy of the marginal utility of money-- the change in the satisfaction or benefit, called utility, from an increase in additional money spent--is assumed to be compatible with a society of 'middle-class individuals' in which a substantial part of income is spent on numerous mere conveniences. In relation to total income, most mere conveniences involve marginal expenditures. So, a slight income variation causes one or more such conveniences to disappear from the individual's budget (when income goes down) or to appear as one or more new entries in the budget (when income goes up). In such conditions, it is reasonable to assume that the marginal utility of money for all conveniences is almost the same because individuals are indifferent to buying any one particular convenience. Consequently, substitution between these convenience goods is said to be 'smooth'.

On the other hand, substitution in the production process is much less smooth. Production process is conditioned by the physical properties of material objects for particular purpose, so the complete substitution usually requires a considerable time period. The typical example is the substitution of wrought iron for steel by open hearth furnaces where excess carbon and other impurities are burnt out of pig iron to produce steel. But in conventional economics, substitution is treated as if there were no essential difference between consumer choice and production. In particular, the substitution of primary energy sources in economic production (i.e. renewable energy for fossil fuels) is the key element in mitigating climate change. However, it is striking that IPCC does not seriously investigate the possibility of substituting primary energy sources to replace fossil fuels and reduce GHG emissions. In fact, Working Group III of the IPCC AR5 Report devoted only 3 pages to 7.4.1 Fossil Fuels, 7.4.2 Renewable Energy and 7.4.3 Nuclear Energy, within the full document of 1454 pages.

It is absolutely necessary to understand the nature of the primary energy substitutions that happened in the human history. For this purpose, the concept of *entropy* is introduced. Entropy is a *relative index of the amount of unavailable energy* in a given system. The transition from coal to oil, from high entropy energy to low entropy energy, is atypical. On the other hand, the development process of the coke blast furnace can be regarded as a typical example of primary energy substitution. There occurred a scarcity problem of low entropy resource, wood. A substitutable resource, coal, is of high entropy, so that a roundabout process is needed to remove mixing entropy of coal when burned directly with iron ore due to the poor quality of coal. Unless a particular primary energy source is of low entropy such as oil or there is a possibility of transforming a high entropy resource (i.e. coal) into relatively low entropy resource (i.e. coke), the substitution transition is difficult to achieve. We must recognize that technology is only a 'catalyst' to induce the latent ability of energy resources to emerge.

There are formidable barriers to achieving the smooth substitution of primary energy sources that is assumed within the theoretical basis of CBA. Three of these barriers are heavily dependent on fossil fuels to generate electricity; the insufficient reserves of uranium 235 and the difficulty in creating commercial nuclear breeder reactors; and the limited supply of silver for multi-crystalline silicon wafer-based solar cells in the Photovoltaic (PV) systems. These three barriers will be discussed in turn.

TABLE 1

		Coal	Oil	Natural Gas	Nuclear	Hydro	Bio& Waste	Others
USA	**2008**	**52**	**1.4**	**18**	**23**	**2.3**	**1.3**	**2**
	2015	**34**	**1**	**32**	**19**	**6**	**2**	**5**
France	**2008**	**4.4**	**1.6**	**4.1**	**84**	**4**	**0.4**	**1.6**
	2015	**2**	**0**	**4**	**78**	**10**	**1**	**5**
China	**2008**	**89**	**0.8**	**0.9**	**2.3**	**6.5**	**0.1**	**0.1**
	2015	**70**	**0**	**2**	**3**	**19**	**1**	**4**
India	**2008**	**82**	**4**	**6.7**	**1.7**	**4.2**	**0.5**	**0.5**
	2015	**83**	**2**	**5**	**3**	**1**	**2**	**4**
Japan	**2008**	**28**	**12**	**24**	**30**	**3**	**1**	**2**
	2015	**34**	**10**	**40**	**0**	**8**	**4**	**4**
World	**2008**	**47**	**6**	**21**	**16**	**6**	**2**	**3**
	2015	**39**	**4**	**23**	**11**	**16**	**2**	**5**

Table 1. Percentage Share of Primary Energy Sources for Electricity Generation in 2008 and 2015, compiled from data in EDMC(2011) and EDMC (2018) *Handbook of Energy & Economic Statistics*, Energy Conservation Center, Tokyo

Although electricity is considered to be the cleanest form of energy, electricity generation depends heavily on fossil fuels with two thirds of the world electricity in 2015 being generated this way (Table 1). To generate sufficient electricity without using fossil fuels is crucial for mitigating climate change. Unfortunately coal, the most intensive source of GHG emissions, still contributes almost 40% of electricity generation. Thanks to shale oil gas production, the USA reduced coal-fired electricity generation from 52% in 2008 to 34% in 2015. However, that reduction is likely temporary. Along with the USA and despite government claims, China and India remain heavily dependent on coal-fired electricity generation.

In relation to nuclear energy, Table 1 shows that electricity generation in France comes mainly from nuclear power generation. Yet total uranium-235 supply does not satisfy current world demand.

Uranium oxide product (U_3O_8) cannot directly fuel nuclear reactors without reprocessing. Only 0.7% of U_3O_8 is fissile. The proven reserve of uranium-235 is surprisingly limited at about 7.6 million tonnes (2015 estimate). If nuclear energy were to supply the total world primary energy consumption of 2008, the U_3O_8 reserve would last less than 8 years (Nuclear Energy Agency, 2016).

Under these limiting circumstances, supporters of nuclear power generation have been trying to establish a fast breeder reactor that uses Mixed Oxide consisting of Plutonium dioxide and Uranium dioxide. But developing a commercial fast breeder reactor involves four phases: (i) experimental reactor; (ii) prototype reactor; (iii) demonstration reactor; and (iv) commercial reactor. Japan, for example, has only reached the second phase of such development, then abandoned the plan for the Manju breeder and started its decommissioning in 2016. Overcoming this barrier to energy substitution seems unlikely in the foreseeable future.

A third barrier to smooth substitution in the energy sector concerns solar PV. Direct use of solar energy such as PV systems is considered to be a good candidate for a globally available renewable primary energy source to substitute for fossil. PV installations based on first generation multi-crystalline silicon wafer-based solar cells represents the most widely adopted technology worldwide, with a market share of about 95% (Fraunhofer Institute for Solar Energy Systems, 2018). Indeed, despite development of second generation (thin-film) and third generation solar cells, the share of crystalline silicon wafer-based solar cells holds firm with no apparent sign of decline.

Silver is used in a specialized paste for the contact metallization of silicon wafer-based cells. Although the decrease of silver consumption per cell has been remarkable in recent years, down to 36 mg/W on average in commercial technologies in 2014, in the case of a solar PV deployment to cover 30% of the current yearly global electricity demand (4.6TW of new installations), the total silver usage could reach 33% of the currently estimated world silver reserves (Lo Piano and Mayumi, 2017). The silver requirement for a large-scale electricity generation by PV systems is a formidable problem and again challenges the principle of substitution that is central to the operation of CBA.

3.3 Discounting

A third tenet of CBA, and hence of the calculation of the social cost of carbon, is the notion of discounting. It is customary to calculate the present monetary value of an investment without considering the origin or justification of discounting.

Unlike all other material objects, money defies the first and the second laws of thermodynamics. Defying the *first* law, money can be created out of nothing by national banks and financial agents. Defying the *second* law, money does not decay functionally, even though the physical structure of a coin, for example, decays. Every material object has a material structure, i.e. a *structural component* and every material object has a particular purpose for use, i.e. a *functional component*. As the structural component of a material object decays due to the second law of thermodynamics, its functional component also decays. The material object becomes unsuitable for the particular purpose for which it was originally intended (Mayumi and Giampietro, 2018). However, money is different. Even if its physical structure decays, money still functions as its originally intended purpose. As US law stipulates: "Lawfully held mutilated paper currency of the United States may be submitted for examination in accord with the provisions in this subpart. Such a currency may be redeemed at face value if sufficient remnants of any relevant security feature and clearly more than one-half of the original note remains" (Legal Information Institute, 2017). A decayed banknote still functions as a banknote.

Thus, the function of money does not change over time. *A qualitative gap* expands as money maintains its original purpose while material objects lose original purpose. Only money grows quantitatively over time as interest emerges. In this way, discounting monetary value is justified in conventional economics. The superiority of money is supported institutionally and legally, allowing the owner of money to dictate in principle the timing of transactions with people who have to sell goods in order to limit structural decay of those goods.

Money is usually regarded as the wealth of an individual. Money is also a debt for the whole community because money entails a promise to pay the bearer in term of existing goods or the production of future goods. Consequently, money puts the whole community into long-term biophysical debt. Economic production entails a deficit in terms of entropy (Georgescu-Roegen, 1971) because useful energy and materials are consumed irrevocably, resulting in fewer exhaustible resources remaining. Therefore, money has a dual nature: as a form of wealth from an individual perspective, but as a manifestation of debt from a communal perspective (Mayumi and Giampietro, 2018).

Other financial assets also have such dual nature. As used in CBA, maximizing the present monetary value represents an individual perspective. Bromley (1990) properly states: "*it is a value judgement* for the economist to claim that economic efficiency *ought to be* the decision rule for collective action". Considering monetary evaluation according to an individual perspective is not suitable for facing climate change. W. S. Jevons (1965), a founder of conventional economics explicitly states that discounting should not take place. Concerning the time horizon to be considered in conventional economic analysis, Stiglitz (1997) declares that economic analysis is concerned with only 'the next 50–60 years'. It must be emphasized, however, that the power of discounting *even in monetary value* is remarkable. The present value of $1 decreases over time horizon of 50 years to $0.61 at 1% discount rate, to $0.087 at 5%, and to just $0.0085 at 10%.

4. An alternative way to deal with climate change

The risks of climate change have a number of unique features that cannot adequately be captured by the calculation of its economic externality, i.e., the social cost of carbon, whether this value is 1,19 or 1,500 euro per ton of CO_2 emitted. The real challenge does not consist in calculating the social cost of carbon in monetary terms but in considering how to distribute the related inter-generational and intra-generational burdens and gains that result from climate change in a sustainable and equitable way. As noted by Tainter et al. (2015), there is a more modest and practical approach to dealing with sustainability problems such as climate change which avoids CBA and the social cost of carbon. This approach asks four questions: (i) what is to be sustained?; (ii) sustained for whom?; (iii) sustained for how long?; and (iv) sustained with what kinds of gains and sacrifices?

Based on such an approach, four elements are crucial for mitigating climate change:

(i) reaching a constructive agreement through deliberation and cooperation on what should be sustained;
(ii) discussing seriously the local, regional and global distribution issues related to intra-generational and inter-generational equity;
(iii) educating ourselves in such discussions to look further ahead than in most current economic analysis:
(iv) itemizing, as far as possible, the gains and sacrifices that are achievable in a hierarchically organized world in which socioeconomic conditions are skewed.

5. Conclusion

I have based my argument on three points. First, scarcity in conventional economics cannot be applied to situations such as climate change where severe scarcity prevails. Therefore, using the social cost of carbon to deliver an efficient allocation of resources cannot be achieved. Second, to mitigate climate change, alternative primary energy sources to fossil fuels are essential, yet as shown above, nuclear energy and PV systems are not hopeful candidates. In other words, the smooth *substitution* of energy generation assumed in CBA cannot be guaranteed. Third, *discounting* the future value of money may be justified for individual monetary decisions. However, if the criterion of maximizing present monetary value is adopted for the problem of allocating a given amount of an exhaustible resource, for example, the physical quantity of that resource to be allocated for successive periods *must decrease over time*. So, *discounting* is very difficult to be accepted for collective decisions. Using the social cost of carbon to determine the long-term cost of climate change is based on the individual perspective and thus far from satisfactory.

It is instructive to conclude this essay with the following consideration. William Nordhaus, one of the founding fathers of the SCC and a Nobel Prize Winner in economics, once presented an equation for calculating the cost of climate change (Nordhaus,1992, 1316): $d(\mathrm{t}) = 0.0133[\frac{T(t)}{3}]^2$, where $d(t)$ is the fractional loss of global output from greenhouse warming in period t. $T(t)$ is the temperature in period t, usually measured in degrees Kelvin. Because $d(t)$ is a dimensionless number, the relation does not make sense unless appropriate dimensions are assigned to both constants in the equation, 0.0133 and 1/3. It is depressing to see that the procedure adopted by the economist to calculate the social cost of carbon is nothing but a curve-fitting practice, completely ignoring the dimension of variables. The social cost of carbon results in a formalism nonsense (Mayumi and Giampietro, 2012).

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References

[1] Arrow, K. J. and Debreu, G. (1954) 'Existence of an equilibrium for a competitive economy', *Econometrica*, vol 22, pp 265–290

[2] Bromley, D. W. (1990) 'The ideology of efficiency: searching for a theory of policy analysis', *Journal of Environmental Economics and Management*, vol 19, pp86-107

[3] Fraunhofer Institute for Solar Energy Systems (2018) *Photovoltaics Report*.

[4] http://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/photovoltaics-report-in-englischer-sprache.pdf

[5] Funtowicz, S. O. and Ravetz, J. R. (1993) 'Science for the post-normal age', *Futures*, vol 25, no 7, pp735-755

[6] Georgescu-Roegen N. (1971) *The Entropy Law and the Economic Process*. Harvard University Press, Cambridge, Mass.

[7] Hubin, D. C. (1989) 'Scarcity and the demands of justice'. *Capital University Law Review*, vol 18, no 2, pp185-199

[8] IPCC (2014) *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, Geneva, Switzerland

[9] Jevons, W. S. (1965) *The Theory of Political Economy*, fifth edition. Augustus M. Keller, New York

[10] Legal Information Institute (2017) *The Code of Federal Regulations*, https://www.law.cornell.edu/cfr/text/31/subtitle-B

[11] Lo Piano, S., and Mayumi, K. (2017) 'Toward an integrated assessment of the performance of photovoltaic power stations for electricity generation', *Applied Energy*, vol 186, pp167-174.

[12] Marshall, A. (1920) *Principles of Economics*. 8th edn, Machmillan, London

[13] Mayumi, K., and Giampietro, M. (2012) 'Response to "Dimensions and logarithmic function in economics: A comment"', *Ecological Economics*, vol 75, pp12-14

[14] Mayumi, K. and Giampietro, M. (2018) 'Money as the potential cause of the tragedy of the commons', *Romanian Journal of Economic Forecasting*, vol 21, no 2, pp151-156

[15] Nordhaus, W. D. (1992) 'An optimal transition path for controlling greenhouse gases', *Science*, vol 258, pp1315-1319

[16] Nuclear Energy Agency (2016) *Uranium 2016: Resources, Products and Demand*, OECD. NEA. No. 7301

[17] https://www.oecd-nea.org/ndd/pubs/2016/7301-uranium-2016.pdf

[18] Samuelson, P. A. and Nordhaus, W. D. (2010) *Economics*, 19th edn, MacGraw-Hill, New York.

[19] Stiglitz, J. E. (1997) 'Reply: Georgescu-Roegen versus Solow/Stiglitz', *Ecological Economics*, vol 22, pp269–270

[20] Tainter, J. A., Taylor, T. G., Brain, R. G. and Lobo, J. (2015) 'Sustainability', In R. Scott and S. Kosslyn (eds) *Emerging Trends in the Social and Behavioral Sciences*. John Wiley & Sons, New York

[21] Vitousek, P. M., Ehrlich, P. R., Ehrlich, A. H., and Matson, P. A. (1986) 'Human appropriation of the products of photosynthesis', *BioScience*, vol 36, no 6, pp368-373

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