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Objective versus subjective assessments: The IPCC treatment of the total economic impact of climate change

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Abstract: I apply restricted Nadaraya-Watson kernel regression to derive the total economic impact as a function of climate change. I restrict the sample to information known at the time of Second, Third, Fourth and Fifth Assessment Reports of the Intergovernmental Panel on Climate Change. There has been no statistically significant change in the estimates over time. Nonetheless, subsequent assessment reports convey different messages in their Technical Summaries, with even greater deviations in the Summaries for Policy Makers. The IPCC should rely more strongly on objective methods.

Key words: IPCC, economic impact of climate change, kernel regression

JEL classification: Q54

1. Introduction

The summary statements of the Intergovernmental Panel on Climate Change (IPCC) attract extraordinary attention in policy and research. It is not always clear how the IPCC arrived at these statements and the confidence expressed. I here consider one particular case: The total economic impact of climate change. I review how the literature developed over time, consistently apply the same statistical method to the data available at the time of writing the last four assessment reports, and compare the results to what was written in those reports.

Much has been written about how the IPCC assesses the literature (Alexander 2007;Gilland 2007;Henderson 2007;Hulme 2010;Hulme and Mahony 2010;Kintisch 2010;Laframboise 2011;McKitrick 2010;Nature 2010;New Scientist 2010;Nishioka 2008;Oppenheimer et al. 2007;PBL 2010;Peiser 2007;Rothman et al. 2009;Schiermeier 2010;Shapiro et al. 2010;Solomon and Manning 2008;Tol 2011;Tonn 2007;van der Sluijs et al. 2010;Wynne 2010;Zillman 2007), and also about the confidence expressed in its conclusions (Budescu et al. 2009;Budescu et al. 2012;Curry and Webster 2013;Moss and Schneider 2000;Narita 2012;Risbey and Kandlikar 2007;Smithson et al. 2012;van der Sluijs 2012). I do not revisit that debate here, but rather discuss one particular instance and one particular estimate.

The summaries of the IPCC contain many complex statements. It is not always clear to which component of the statement the asserted confidence pertains. Successive IPCC reports use comparable but not identical statements. A change in confidence between assessment reports may thus reflect either a change in confidence about the same object or a change in the object that is assessed. I therefore focus on a simple object – the total economic impact of climate change – that has not changed -- although our understanding of the object has.

The paper serves two other purposes. I suggest a simple and objective method to assess the uncertainty about quantified results. I further review progress in the state of knowledge about the total economic impact of climate change, a crucial input into assessments of the desired level of ambition for climate policy.

The paper proceeds as follows. Section 2 discusses the estimates of the total economic impact. Section 3 presents the method, conditional kernel density estimation. Section 4 shows the results. Section 5 compares the objective results to the IPCC findings in four successive assessment reports. Section 6 concludes.

2. Data

There are 19 studies and 21 estimates of the *global* welfare impacts of climate change. Table 1 lists the studies and the estimates. These studies used different methods. (Nordhaus 1994a) interviewed a small number of presumed experts. (Fankhauser 1994;Fankhauser 1995;Nordhaus 1994b;Nordhaus 2008;Tol 1995;Tol 2002a;Tol 2002b) multiplied estimates of the “physical effects” of climate change with estimates of their price, and added up the result. (Bosello et al. 2012;Roson and van der Mensbrugghe 2012) also use estimates of the physical impacts but as input into computing the general equilibrium effects on welfare.

(Maddison 2003;Mendelsohn et al. 2000b;Mendelsohn et al. 2000a;Nordhaus 2006) use observed variations (across space) in prices and expenditures to discern the effect of climate. (Maddison and Rehdanz 2011;Rehdanz and Maddison 2005) use the relationship between self-reported well-being and climate.

There is broad agreement between these studies in three areas (Tol 2009). First, the welfare effect of a doubling of the atmospheric concentration of greenhouse gas emissions on the current economy is relatively small—equivalent to losing a few percent of income. The impact of a century of climate change is roughly equivalent to a year's growth in the global economy.

Second, the initial benefits of a modest increase in temperature are probably positive, followed by losses as temperatures increase further. Figure 1 illustrates this pattern. The initial benefits arise partly from CO_2 fertilization, and partly from reduced heating costs and cold-related health problems in temperate zones. However, the initial warming can no longer be avoided; these are sunk benefits, and do not affect decisions about emission reduction.

Third, the uncertainty is vast and right-skewed. Undesirable surprises are more likely than desirable surprises of equal magnitude. For instance, the climate sensitivity – the equilibrium warming due to a doubling of the atmospheric concentration of carbon dioxide – is bounded from below by the laws of physics but it is hard to put an upper bound on its value. It is relatively easy to paint disastrous pictures of the impacts of climate change – rapid sea level rise in the Bay of Bengal leading to mass migration and nuclear war – but difficult to imagine that climate change would make the world prosperous and peaceful. Most estimates are for 3°C of global warming or less, but climate change may well go beyond that. The uncertainties about the impacts are compounded by extrapolation (Tol 2012). These uncertainties are, of course, an argument for more stringent climate policy.

3. Method

I use kernel regression to estimate the relationship between climate change and total economic impact. I use a bivariate normal kernel (Nadaraya 1964;Watson 1964); and use the (Silverman 1986) rule-of-thumb to set the bandwidth equal to $h=1.06\Sigma^{-0.5}n^{-0.2}$, where Σ is the sample covariance matrix and n is the sample size. I limit support of the kernel to the range from the lowest observation minus four times the standard deviation to the highest observation plus four times the standard deviation.

Standard kernel regression (Takezawa 2006) does not impose any functional form on the impact function. Indeed, that is one of its main strengths. However, by construction, zero climate change has zero impact. I therefore constrain the kernel regression to go through the origin by adding a 22nd observation with $h^*=h/10$. The division by ten is ad hoc, chosen by experimentation. If the bandwidth of the restriction is too large, it is not met in expectation; if the bandwidth is too small, the restriction holds only locally and the kernel function loses its smoothness. See (Tol 2013) for more detail.

Typical kernel regression is focused on the conditional mean, in this case, the expected impact conditional on (as a function of) the change in the global mean surface air temperature. The conditional mean is, of course, the mean of the conditional distribution. I here use the entire distribution as that reveals the confidence bounds.

4. Results

Figure 1 shows the restricted Nadaraya-Watson kernel regression and its 95% confidence interval for the studies published before the Second Assessment Report, the Third, the Fourth and the Fifth, respectively. Before AR4, estimates of the impact of were limited to warming of 2.5°C and 3.0°C. The kernel regression is therefore valid only for a limited range of climatic changes. This range shrinks between AR2 and AR3 as the number of observations rises from 4 to 9, and the standard deviations shrink accordingly.

In all four cases, the expected impacts cross zero somewhere between 1°C and 2°C of global warming – suggesting net positive impacts for milder warming for AR2 and AR3, and showing such for AR4 and AR5. Impacts get progressively more negative for greater warming, but only become statistically significantly different from zero somewhere between 3°C and 4°C.

Figure 2 repeats some of the information in Figure 1, but reorganized so as facilitate comparisons. For 1.7°C of warming, there is no statistically significant difference between the assessment reports. The same is true for the impacts of 2.5°C and 3.5°C of warming. Furthermore, there is no statistically significant difference between the impacts of 1.6°C and 3.5°C of warming for any of the four assessment reports.

5. IPCC

The above assessment of our knowledge of the impact of climate change reveals that we knew little in 1995 and have not learned a whole lot since. So what did the successive IPCC assessment reports make of this?

The technical summaries report the following:

AR2 "damages for developed countries […] between 1% and 2% of GNP for a 2xCO2 climate […] damage in different developing regions range from a minimum of 2% of GNP to a maximum of 9%" (Pearce et al. 1996)

AR3 "with a small [2°C] temperature increase, there is medium confidence that aggregate market sector impacts would amount to plus or minus a few percent of world gross domestic product (GDP), and there is low confidence that aggregate nonmarket impacts would be negative. […] Most studies of the aggregate impacts find that there are net damages at the global scale beyond a medium temperature increase [3°] and that damages increase from there with further temperature increases." (Smith et al. 2001)

AR4 “[t]here is some evidence that initial net market benefits from climate change will peak at a lower magnitude and sooner that was assumed for [AR3], and it is likely that there will be higher damages for larger magnitudes of global mean temperature increases than was estimated in [AR3]” (Schneider et al. 2007)

AR5 “Globally aggregated economic impacts of global warming are a small fraction of income up until 3°C [10.9.2, *medium evidence, high agreement*]. A global mean average temperature rise of 2.5C may lead to global aggregated economic losses between 0.2 and 2.0% of income (*medium evidence, medium agreement*) and losses increase with greater warming. Little is known about aggregate economics impacts above 3°C.” (Arent et al. 2014)

Compared to the state of knowledge at the time, AR2 was overconfident. AR3 more accurately reflected the uncertainties, but peculiarly suggested that the best guess at the time was zero impact with a symmetric confidence interval. AR4 stresses the differences with AR3, which are in fact insignificant. If anything, AR4 should have been more optimistic about the impact of larger warming. AR5 omits the initial benefits, shows the 67% confidence interval (rather than the 95% one as in Figures 1 and 2), and admits to ignorance about the impacts of larger climate change.

The summaries for policy makers (SPM) have the following language:

AR2 “aggregate estimates [of total damages from 2-3˚C warming] tend to be a few percent of world GDP, with, in general, considerably higher estimates of damage to developing countries” (Bruce et al. 1996)

AR3 “when aggregated to a global scale, world gross domestic product (GDP) would change by ± a few percent for global mean temperature increases of up to a few ˚C (*low confidence* [5-33]) and increasing net losses would result for larger increases in temperature (*medium confidence* [33-67])” (McCarthy et al. 2001)

AR4 “[f]or increase in global mean temperature of less that 1-3˚C above 1990 levels, some impacts are projected to produce benefits in some places and some sectors, and produce costs in other places and other sectors. It is very likely that all regions will experience either declines in net benefits or increases in net costs for increases in temperature greater than about 2-3˚C […] global mean losses could be 1-5% GDP for 4˚C warming” (Parry et al. 2007)

AR5 “With these recognized limitations, the incomplete estimates of global annual economic losses for additional temperature increases of ~2°C are between 0.2 and 2.0% of income (±1 standard deviation around the mean) (*medium evidence, medium agreement*). Losses are *more likely than not* to be greater, rather than smaller, than this range (*limited evidence, high agreement*). Losses accelerate with greater warming (*limited evidence, high agreement*), but few quantitative estimates have been completed for additional warming around 3°C or above.” (Field and Canziani 2014)

Compared to the technical summary, the SPM of AR2 softens the quantitative information. The first clause in the SPM of AR3 is garbled: Welfare impacts are presented as changes in the scale of economic activity. The range of impacts is identified as the 5-33% confidence interval, suggesting that most of the probability mass lies outside a few percent. Because AR3 seems to write about impacts (rather than damages), this would imply that there is 67% probability of benefits greater than "a few percent". The second clause in AR3 is a shortened version of the technical summary. The SPM of AR4 is more circumspect about the net benefits of initial climate change than the technical summary, and has more quantified information about the net damages – including for a 4˚C warming, for which no estimates had been published at the time (cf. Table 1). The SPM of AR5 starts with caveats, removes the quantitative information for warming beyond 2.5°C[1] (although it does sketch the shape of the impact curve), and adds that the uncertainty is asymmetric.

The comparison of the language in the technical summaries to a standardized analysis of the state of knowledge suggests that there is a lack of consistency in IPCC assessments. This is particularly pronounced when comparing successive reports: Although there has been little advance in knowledge over the 19 year period between AR2 and AR5, the IPCC suggests otherwise. Where the technical summaries have difficulty in consistently capturing what is known, the summaries for policy makers add further distortions – in one case changing the interpretation and in another adding unsupported statements.

6. Discussion and conclusion

I gathered estimates of the total economic impact of climate change, and split the sample according to the timing of the four latest assessment reports of the IPCC. I applied the same statistical method to the subsamples, and found that, although the number of estimates increased over time, the information contained in those estimates added little to the stock of knowledge. The technical summaries of the successive assessment reports do not consistently reflect the underlying information, and the summaries for policy makers further distort what is known.

Others have argued that the IPCC should become more systematic in its assessment (see references in the introduction). The above results lend further support to that conclusion. The inconsistencies found can probably be explained by the different compositions of the author teams and a desire to say something new and different than the previous assessment report.

This paper also offers a method to assess relationships and their uncertainties. There are of course many such methods, but kernel regression stands out for having few restrictive assumptions and standardized ones at that. Methods like these should be applied – and data archived between assessment reports to allow systematic comparison.

The results on the total economic impact of climate change are threefold. It is sobering that there has been so little progress over 20 years; and that the impacts do not statistically deviate from zero until well above 3°C of global warming. Estimated impacts are relatively small, but do justify greenhouse gas emission reduction.

[1] The SPM of AR5 refers to temperature increases relative to "recent times" which is 0.6°C above pre-industrial.

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Table 1. Estimates of the welfare loss due to climate change (as equivalent income loss in percent); estimates of the uncertainty are given in bracket as standard deviations or 95% confidence intervals.

Study	Warming (˚C)	Impact (%GDP)
AR2		
(Nordhaus 1994b)	3.0	-1.3
(Nordhaus 1994a)	3.0	-4.8 (-30.0 to 0.0)
(Fankhauser 1995)	2.5	-1.4
(Tol 1995)	2.5	-1.9
AR3		
(Nordhaus and Yang 1996)[a]	2.5	-1.7
(Plamberk and Hope 1996)[a]	2.5	-2.5 (-11.4 to -0.5)
(Mendelsohn et al. 2000a)[a,b,c]	2.5	0.0[b] 0.1[b]
(Nordhaus and Boyer 2000)	2.5	-1.5
AR4		
(Tol 2002a)	1.0	2.3 (1.0)
(Maddison 2003)[a,d]	2.5	-0.1
(Rehdanz and Maddison 2005)[a,c]	1.0	-0.4
(Hope 2006)[a,e]	2.5	-0.9 (-2.7 to 0.2)
(Nordhaus 2006)	3.0	-0.9 (0.1) -1.1 (0.1)
AR5		
(Nordhaus 2008)	3.0	-2.5
(Maddison and Rehdanz 2011)[a]	3.2	-11.5
(Bosello et al. 2012)	1.9	-0.5
(Roson and van der Mensbrugghe 2012)	2.9 5.4	-1.8 -4.6
(Nordhaus 2013)	2.9	-2.0

[a] Note that the global results were aggregated by the current author.

[b] The top estimate is for the “experimental” model, the bottom estimate for the “cross-sectional” model.

[c] Mendelsohn et al. only include market impacts.

[d] Maddison only considers non-market impacts on households.

[e] The numbers used by Hope are averages of previous estimates by (Fankhauser 1995) and (Tol 2002a); Stern *et al*. (2006) adopt the work of Hope.

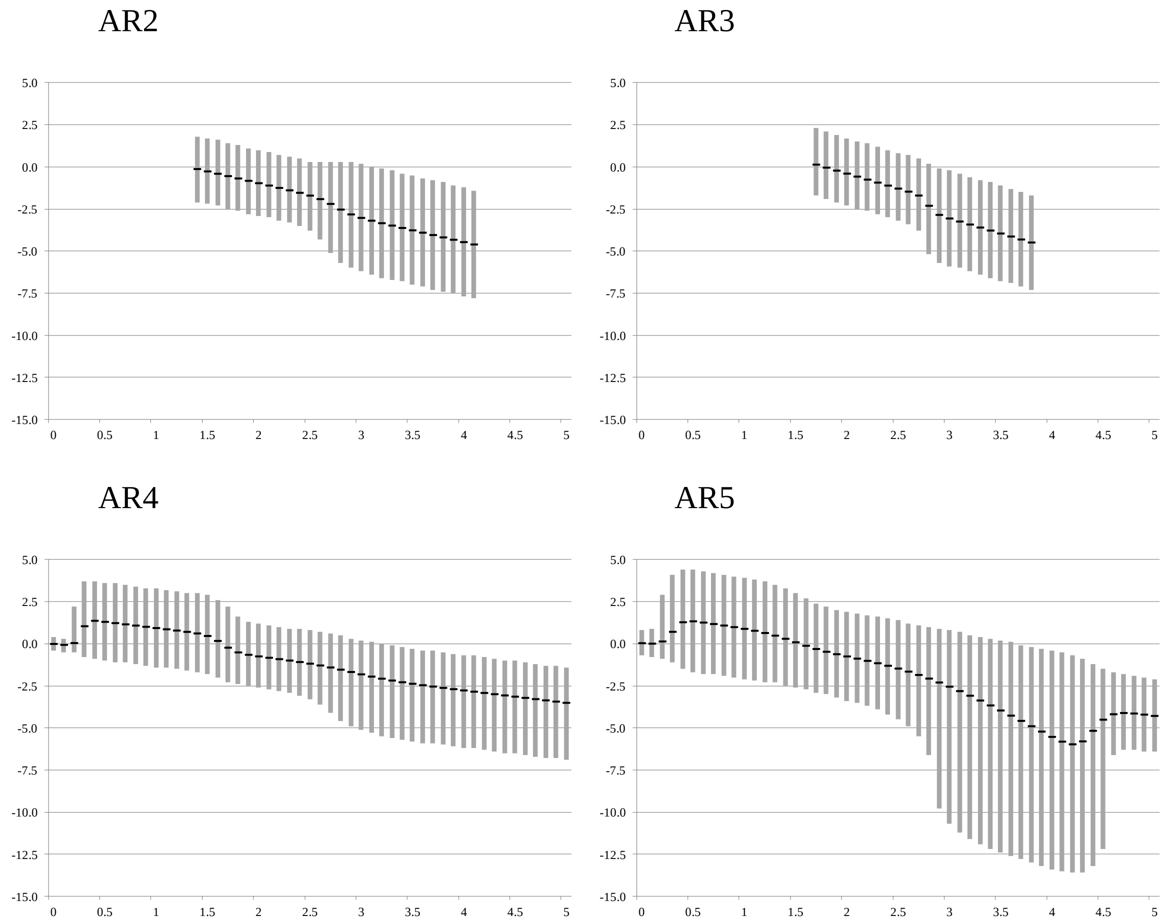

Figure 1. Restricted Nadaraya-Watson kernel estimates of the impact (welfare-equivalent income loss, percent, vertical axes) of climate change (increase in the global mean surface air temperature, degree Celsius, horizontal axes) for studies published before the Second (AR2), Third (AR3), Fourth (AR4) and Fifth (AR5) assessment report of the Intergovernmental Panel on Climate Change.

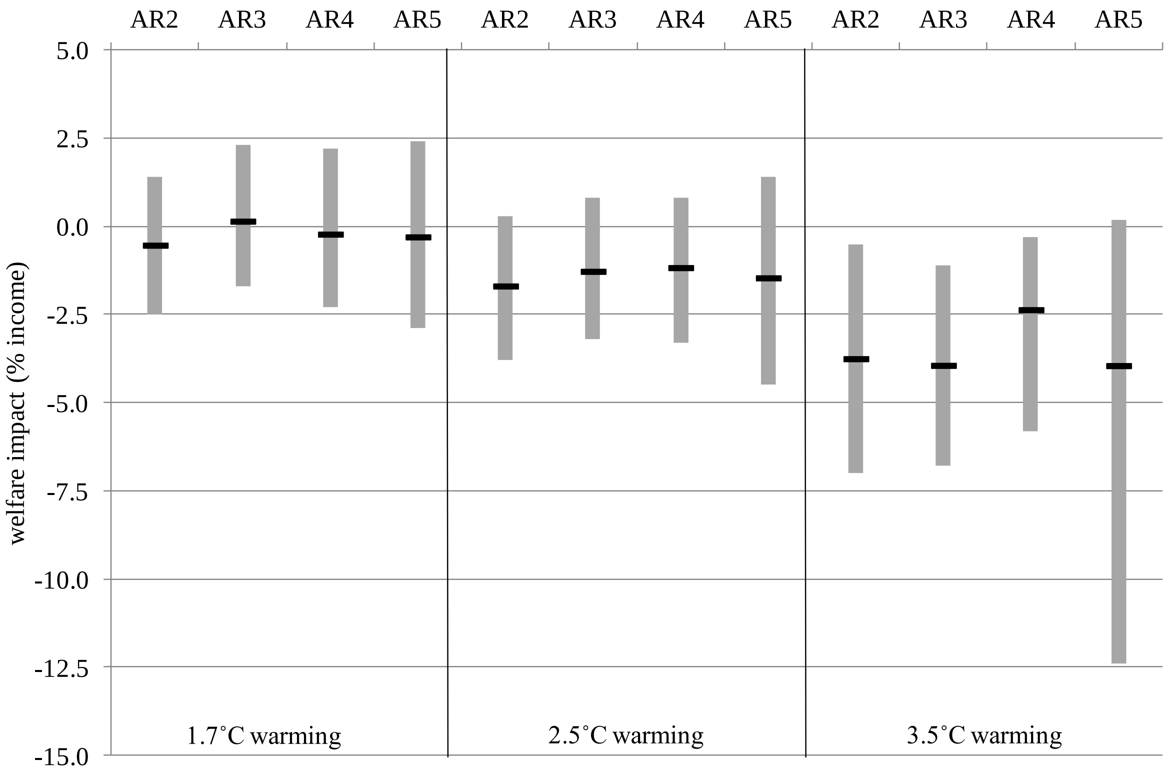

Figure 2. Restricted Nadaraya-Watson kernel estimates of the impact of climate change