COMMENTARY

A comment on "Economy-wide estimates of the implications of climate change: Human health"☆

Frank Ackerman, Elizabeth A. Stanton*

Global Development and Environment Institute, Tufts University, 44 Teele Avenue, Medford, MA 02155, USA

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ABSTRACT

In a recent article in this journal, Francesco Bosello, Roberto Roson, and Richard Tol make the remarkable prediction that one degree of global warming will, on balance, save more than 800,000 lives annually by 2050. They introduce enormous, controversial monetary valuations of mortality and morbidity, varying with income; they then focus primarily on modeling the much smaller, indirect economic effects of the changes in health outcomes. Their calculations, large and small, are driven by the huge projected reduction in mortality — an estimate that Bosello et al. fail to substantiate. They rely on research that identifies a simple empirical relationship between temperature and mortality, but ignores the countervailing effect of human adaptation to gradual changes in average temperature. While focusing on small changes in average temperatures, they ignore the important health impacts of extreme weather events. They extrapolate the effects of small changes in average temperature far beyond the level that is apparently supported by their principal sources, and introduce arbitrary assumptions that may bias the result toward finding net health benefits from warming.

1. Introduction

Could a little bit of global warming have wonderful consequences for human health? In their article, "Economy-wide estimates of the implications of climate change: Human health," (*Ecological Economics* 58(3), June 25, 2006, pp.579–591), Francesco Bosello, Roberto Roson, and Richard Tol make the surprising prediction that the first stages of global warming will, on balance, save a large number of lives. As shown in their Table 1 (p.582), Bosello et al. estimate that in the year 2050 a global mean temperature 1.03 °C higher than today's will result in 1,760,000 fewer deaths due to cardio-vascular disease, only partially offset by 910,000 additional deaths due to malaria, diarrheal diseases

and respiratory illness. The net effect is 850,000 avoided deaths, a huge change in worldwide mortality in a single year.

The estimate of reduced mortality is only the starting point for the ambitious set of calculations offered by Bosello et al. They seek to determine both the value of the direct welfare impacts of changes in mortality and morbidity due to climate change, and the indirect economic impacts of those changes in human health, including productivity losses and increased health-care costs attributable to illness. The bulk of their analytical and modeling effort is applied to the relatively small indirect effects, with the direct welfare losses receiving much less attention. Nonetheless, the direct effects are enormous — and, if taken seriously, would have vast, controversial effects on the cost-benefit analysis of climate change.

In their discussion of the direct costs of mortality and morbidity, Bosello et al. write (p.585)

Table 5 also shows the direct costs. Following Tol (2002), we value a premature death at 200 times per capita income, and a year of life diseased at 80% of the annual income. Note that these estimates include the immaterial welfare losses of health impacts only; economic impacts are excluded. The direct costs, expressed as percent of GDP, are much larger than the economic impacts: The direct costs of risks of death and illness outweigh the indirect costs.

Because they find that the first degree of warming will reduce mortality and morbidity in most of the world, they estimate the direct effects as equivalent to a large increase in GDP: specifically, they predict values for direct health effects equivalent to an increase in GDP of roughly 9 to 14% in the U.S.A., EU, Eastern Europe and the former Soviet Union, Japan, and much of the rest of Asia, and more than 4% in China and India. Mortality and morbidity will increase elsewhere, with a value equivalent to a decrease in GDP of about 1% in the "energy exporting countries" and 3% in the rest of the developing world. (Bosello et al., Table 5, column 1.)

Since they have previously made it clear that they are calculating per capita income separately for eight regions of the world,[1] Bosello et al. are in effect valuing deaths quite differently, depending on where they occur. This is an idea that has had a troubled history. In the IPCC's Second Assessment Report, in 1995, economists calculating the monetary value of global warming damages decided to value deaths at $1,500,000 in rich countries, $300,000 in middle-income countries, and $100,000 in low-income countries. When these numbers came to light, governments of many countries were naturally outraged to find their citizens were "worth" only 1/15 as much as Europeans or North Americans. Much of the rest of the IPCC was outraged as well; last-minute disclaimers were inserted into the Second Assessment Report, while the Third Assessment Report, issued in 2001, included a strong recommendation of alternate methodologies that made the value of lives independent of incomes (among many other accounts, see (Ackerman and Heinzerling (2004, 73–74)). The economists involved have continued to defend the income-based valuation of life, suggesting the use of equity weights in cost-benefit calculations to address income inequality (Fankhauser et al., 1997). However, a more common response was expressed by a researcher working in Brazil (Fearnside, 1998, 83):

Regardless of how much sense such a procedure may make to GDP-oriented economists, it is morally unacceptable to most of the world and needlessly damages efforts to build support for any global warming mitigation and adaptation strategies that may be proposed.

Although Bosello et al. do not include the direct cost estimates (i.e., the values of death) in their indirect-cost

analysis, they have lent additional academic credibility to these huge, and unequal, hypothesized values for reduction in mortality. Even without such inequity, monetization of death and illness is a controversial and unsettled area, inevitably involving problematical hypotheses about the value of life and well-being (Ackerman and Heinzerling, 2004).

For their detailed analysis, Bosello et al. use a computable general equilibrium (CGE) model to evaluate the effects of indirect health costs – losses of labor productivity, and health care expenditures – that are in the same direction as the direct costs (by region) but of a much smaller magnitude. The absolute value of these indirect cost impacts ranges from 0.014 to 0.101% of GDP, values that are well within the margin of error of any estimate of costs or benefits of climate change more than 40 years into the future.

Our concern in this note is not the magnitude of those small indirect effects, but rather the large underlying estimates of the reduction in human mortality resulting from climate change. Whether one accepts the direct cost estimates from Bosello et al., or other standards of evaluation, an annual reduction of 850,000 deaths is bound to loom large in the analysis of climate change.

The issue is important because of the large role of near- and medium-term events (which, in the multi-century scope of the climate problem, includes outcomes through 2050), both in political decision-making about climate policy and in cost-benefit analyses. At a high discount rate, near- or medium-term benefits may outweigh enormous long-term damages when expressed in present value terms, creating a cost-benefit argument against vigorous emissions reduction efforts (Ackerman and Finlayson, 2006). It is, therefore, crucial to be sure that any reported benefits of warming are reliable and well supported. This does not appear to be the case with the purported mortality reduction from the first degree of warming.

We have three criticisms of the analysis of mortality and temperature in Bosello et al.:

- They rely on research that identifies a simple empirical relationship between temperature and mortality, but ignores the countervailing effect of human adaptation to gradual changes in average temperature.
- While focusing on small changes in average temperatures, they ignore the important health impacts of extreme weather events such as heat waves, droughts, floods, and hurricanes.
- They extrapolate this pattern far beyond the level that is apparently supported by their principal sources, and introduce an arbitrary assumption that may bias the result toward finding benefits from warming.

2.   The "minimum-mortality temperature"

For estimates of cardio-vascular and respiratory deaths, Bosello et al. rely on a simple empirical relationship between temperature and mortality: studies in many areas have found that there is a daily temperature that minimizes mortality; more deaths tend to occur when the temperature is either

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[1] See their statement on p.582 that they are "using the projected per capita income growth of the 8 GTAP-EF regions for the countries within those regions." The regions include U.S. and EU, at one extreme of income, and China and India, and "Rest of World" (other non-oil-exporting developing countries) at the other extreme.

higher or lower. That is, a graph of mortality versus daily temperature is V-shaped, where the point of the V represents the minimum-mortality temperature.[2]

Bosello et al. represent at least a third generation in the studies of this relationship. In parts of their work, including the treatment of cardio-vascular and respiratory mortality, they adapt the results of Tol (2002), which in turn estimates worldwide impacts of temperature changes by extrapolating from research by Martens (1998).[3] A fundamental problem with this line of research can be seen in the original study by Martens.

Martens performed a meta-analysis of eight earlier studies of the effects of small changes in temperature on cardio-vascular and respiratory mortality. These eight studies look at trends in mortality in a few areas around the world – most of them in cold climates – and report evidence of a "V-shaped" relationship between temperature and mortality. The point of this V – the minimum-mortality temperature – turns out to fall within the normal range of local temperatures, such that some months are generally below it and some above. In Martens' model, as temperatures warm, fewer days will be spent below the minimum-mortality temperature and more will be spent above it. The left, or cold, side of the V is generally steeper than the right, or warm, side. That is, the reduction in mortality for 1° of warming in cold months is greater than the increase in mortality for 1° of warming in hot months. So as countries move 1° to the right across the V, the reductions in mortality in cold seasons will tend to outweigh the increases in warm seasons. This is the basis for the health benefit of warming in Martens and in those who have built upon his work.

A fundamental problem with this analysis is the implicit assumption that the position of the V, i.e. the minimum-mortality temperature, does not change. As Martens himself observes, people adapt to changing temperatures over time: "Acclimatisation may occur in several days, although complete acclimatisation may take up to several years." (Martens, 1998, 338) Indeed, the minimum-mortality temperature is not a constant, but varies widely around the world. Martens mentions that it varies from 16.5 °C in Amsterdam to as much as 29 °C in some studies for Taiwan. A later study of cities in the eastern U.S. found that the minimum-mortality temperature is 9 °C higher in Miami than in Chicago (Curriero et al., 2002).

Although Martens discussed adaptation to temperature changes, and tempered his conclusions on that basis, Tol uses fixed-coefficient equations estimated directly from Martens' data (Tol, 2002, 60, Eqs. (3)–(7)) and never mentions either "adaptation" nor "acclimatization". Bosello et al., in turn, adopt the temperature-related mortality estimates from Tol 2002, without significant modification, save for one possibility discussed below.

Yet adaptation does matter. Except in the very hottest parts of the world, it is reasonable to expect that people can adapt to gradual increases in average temperature. Since the minimum-mortality temperature varies widely around the world, and appears strongly correlated with average temperature, it seems likely that gradual warming will lead to gradual change in the minimum-mortality temperature as well. If this is the case, then rigid projections from Martens' data are mistaken, since there will be little or no mortality change from the first degree of warming based on the V-shaped relationship between temperature and death rates. To uphold projections based on the V-shaped relationship, in the manner of Martens and (particularly) his successors, it would at least be necessary to defend the hypothesis that the point of the V never moves, even as temperatures slowly rise. We have not found any such argument in the literature.

3.   Extreme weather

Models of climate change predict not only increases in average temperature, but also increased variability of weather conditions and more extreme weather events: more droughts and floods, more heat waves, more powerful storms (IPCC, 2001). According to one study, recent climate change has made extreme heat waves two to four times more likely, and over the next 40 years, these extreme heat events will become 100 times more likely (Epstein and Mills, 2005).

With moderate changes in temperature and precipitation – such as the average changes forecast for the next few decades – there are good opportunities for human populations to adapt. When it comes to cardio-vascular cold and heat stress, however, it isn't the average temperature that kills, it's temperature extremes. As our climate warms, the most important impact of temperature on mortality is unlikely to be avoided cold stress. Rather, human populations will adapt to new minimum-mortality temperatures, so that temperatures below the prevailing average will be experienced as causing cold stress, while temperatures above the average cause heat stress, especially in elderly or infirm people who have difficulty adjusting to rapid swings in temperature.

Average temperatures tell us nothing about the frequency of extreme divergences, hot or cold, from the local minimum-mortality temperature. Mounting evidence from climate scientists, however, indicates not only that recent temperatures have been more variable with more extremely hot temperatures, but also that the variability of temperatures and the frequency of heat waves is likely to accelerate in the coming decades (IPCC, 2001). While Bosello et al. (2006) exclude the impact of extreme weather, Martens' original study took care to acknowledge it: "[C]limate change is likely to increase the frequency or severity of heat waves…although this study focused on the long-term influence of climate changes upon health risk…research on heat wave-related mortality suggests an increase in predominantly cardiorespiratory mortality and illness" (Martens, 1998, 342). It is, of course, notoriously difficult to predict the magnitude or precise rate of change of extreme weather events. But this does not mean that zero is a good estimate of the effects of extreme weather — as is implicitly assumed in a climate analysis that ignores such events.

No single weather event can be unambiguously linked to climate change, since there have always been climate

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[2] We are not addressing the estimates of temperature impacts on vector-borne diseases and diarrhea, also presented in Bosello et al. These raise separate analytical issues, and, except in Africa, the impacts of other diseases are generally small in comparison to cardio-vascular and respiratory disease.

[3] Tol (2002) also cites (EuroWinter, 1997) as a source for this relationship, but that appears to be a misreading: the Eurowinter study focuses solely on the pattern of impacts of cold weather on different parts of Europe, with no comment on or comparison to heat-related deaths or illnesses.

fluctuations and occasional extremes. But climate change is increasing the frequency and intensity of extreme weather, causing a sharp upswing in weather-related deaths (Hales et al., 2003). As many as 50,000 people may have died in the 2003 heat wave in Europe (Brücker, 2005). The U.S. suffered 1800 deaths from Hurricane Katrina in 2005,[4] and more than 700 fatalities from a 1995 heat wave in Chicago (Klinenberg, 2002). The heat waves of summer 2006 killed at least 1000 in the Netherlands and 200 in the US.[5] Heat waves in India, in which temperatures sometimes reach 49 °C, have killed more than a thousand people on several occasions in recent years (De et al., 2005).

Bosello et al. base their model on small changes in average temperature, not extreme weather events. Following Martens, they use average monthly temperatures instead of the daily temperature range, as employed by other researchers on this topic (Campbell-Lendrum et al., 2003, 142). Average monthly temperatures have little value in predicting whether or not the temperature on a given day will diverge very far from the minimum-mortality temperature and therefore cause cold or heat stress. It is the extremes in local temperature variation that are of concern in predicting changes in cardio-vascular stress, not averages over the course of a month.

4.   Unexplained differences

Even if one accepts that the early stages of warming will lead to a reduction in mortality, based on the V-shaped relationship, the magnitude of the effect is quite different in Martens (1998), Tol (2002), and Bosello et al. (2006) — and generally much larger in Bosello et al. than in the earlier studies. The problem is particularly severe for China and India, but affects the worldwide estimates of Bosello et al.

Martens does not produce worldwide estimates, but projects the effect on cardio-vascular and respiratory mortality from a 1.2 °C warming in 20 major cities located in 17 countries. Assuming that the cities are typical of the countries as a whole, he offers projections for the 17 countries. For China, where his projection is based on data for Beijing and Guangzhou, he estimates a mortality reduction of 4 per 100,000 population. For China's population of roughly 1.25 billion, this implies 50,000 avoided deaths from 1.2 °C warming. Likewise, we calculate that his estimate implies roughly 60,000 avoided deaths in the U.S., and 10,000 avoided deaths in Japan.[6]

Tol extrapolates Martens' forecasts to the rest of the world, to obtain global estimates. As shown in Table 1, his estimates for changes to cardio-vascular mortality from a degree of warming in OECD-America (excluding Mexico) and OECD-Pacific (excluding South Korea) are roughly in line with Martens' estimates for the U.S. and Japan, respectively. However, his projection for "centrally planned Asia," which is almost entirely China, is

Table 1 – Cardio-vascular mortality changes from 1.0–1.2 °C of warming

Martens	China	−50,000
Tol	Centrally planned Asia	−80,000
Martens	US	−60,000
Tol	OECD-America	−50,000
Bosello et al.	US	−170,000
Martens	Japan	−10,000
Tol	OECD-Pacific	−10,000
Bosello et al.	Japan	−70,000

Source: Martens, 1998; Tol, 2002; Bosello et al., 2006; Martens' estimates are our calculations from Martens' rates per 100,000 population.

much higher than Martens' China estimate. Since Martens modeled a larger temperature change (1.2 °C versus 1.0 °C), Tol's China estimate is roughly twice as large as Martens' when adjusted to a comparable amount of warming.

The difference between Martens' and Tol's results might reflect Tol's surprising assumption that cardio-vascular heat-related deaths occur only in urban areas, whereas cold-related deaths occur in both rural and urban areas (Tol, 2002, 60). The asymmetric treatment of rural areas has little effect on heavily urbanized societies such as the U.S. and Japan, but has a major impact on China with its huge rural population. The assumption of no heat-related cardio-vascular deaths in rural areas is introduced by Tol without citation or justification, and appears to bias his results toward finding net benefits from warming.[7] Tol's assumption might be inspired by the more limited, well-known conclusion that the same regional temperature can be more painful in urban areas, due to urban "heat island" effects. While the negative effects of heat on health can be exacerbated in urban areas, it in no way follows that these effects are negligible in rural areas. The evidence on India's frequent heat waves should be studied carefully before assuming that rural death rates are so little affected by heat (De et al., 2005).

The estimates by Bosello et al. for the U.S. and Japan, also shown in Table 1, are sharply higher than either Martens or Tol. One difference is that Bosello et al. are modeling impacts in 2050, when the world's population will be larger and a greater proportion of the population will be elderly and, therefore, more susceptible to cold and heat stress. Tol, on the other, is modeling the effect of a static temperature increase on today's world. This is important to the results of these models because almost all temperature related mortality – 80 to 90% in most countries – is attributable to people 65 and over, and this group is expected to more than double in size by 2050 (Martens 1998; UN-DESA 2004).[8]

The difference between the estimates by Tol and Bosello et al. is explored further in Table 2, highlighting the puzzling nature of the estimates for China and India. Tol's "south and southeast Asia" region encompasses more than India, of course, but his two Asian regions, shown in the table, provide an approximate match to the Bosello et al. "China and India"

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[4] As of August 2, 2006, the Louisiana Department of Health and Hospitals reported 1,464 deaths in Louisiana, and 346 deaths in other states, due to Hurricane Katrina. http://www.dhh.louisiana.gov. Accessed 22 September 2006.

[5] Heidi Cullen, "Heat Wave Death Toll Numbers Trickling In," http://www.weather.com/blog/weather/8_10348.html. Accessed 22 September 2006.

[6] We have rounded off all mortality figures to the nearest 10,000 in order to avoid spurious precision and to focus on the overall magnitudes of these projections.

[7] Tol (1997) made a similar assumption, again without citation or justification.

[8] Since the population that will be over 65 in 2050 was born in 1985 or earlier, its size is dependent only on death rates between now and 2050. That is, it is not dependent on demographic forecasts of future birth rates.

Table 2 – Change in mortality in China and India per degree of warming		Cardio-vascular	Respiratory
Tol	Centrally planned Asia	−80,000	60,000
	South and SE Asia	−50,000	140,000
	Subtotal, 2 Asia groups	−130,000	200,000
Bosello et al.	China and India	−810,000	90,000
Source: Tol, 2002; Bosello et al., 2006.			

Table 3 – Changes in temperature-related mortality from 1.0–1.2 °C of warming, with demographic transition		
Martens (extrapolated to 2050)	China and India	−400,000
Bosello et al.	China and India	−810,000
Martens (extrapolated to 2050)	US	−130,000
Bosello et al.	US	−170,000
Martens (extrapolated to 2050)	Japan	−30,000
Bosello et al.	Japan	−70,000
Source: Martens, 1998; Bosello et al., 2006; Martens' estimates are our calculations from Martens' rates per 100,000 population.		

region. For Tol, the two Asian regions together experience 130,000 fewer cardio-vascular deaths per year, per degree of warming, offset by an increase of 200,000 in respiratory deaths. For Bosello et al., China and India experience 810,000 fewer cardio-vascular deaths, but only 90,000 additional respiratory deaths. The coming demographic shift in India and China explains part, but not all, of the difference between the estimates by Tol and Bosello et al.: India and China's joint over-65 population is expected to quadruple, but Bosello et al. estimate cardio-vascular mortality six times that of Tol. In addition, if a growing and aging population is meant to explain the difference between the results reported by Tol and Bosello et al., we would expect the change in respiratory mortality to be larger, not smaller, in Bosello et al. (see Table 2).

Using Martens' temperature-related change in deaths per 100,000 for the population under and over 65, we extrapolated to 2050 using the appropriate size and shares of the under- and over-65 population (see Table 3).[9] The estimated reduction in mortality using this method was 400,000 in India and China, 130,000 in the US, and 30,000 in Japan — still much smaller than the Bosello et al. results.

One further innovation can be seen in the more recent study. Bosello et al. mention, in a single sentence unsupported by citation or evidence, that they assume there are no heat-related deaths in rural areas (p.583). This suggests that they have extended Tol's asymmetric treatment of rural areas to respiratory deaths — assuming that the rural population suffers only cold-related, but never heat-related, respiratory as well as cardio-vascular deaths.[10] Since China and India include a large fraction of the world's rural population, the effects would show up most markedly in these countries, reducing the number of heat-related respiratory deaths included and increasing the estimates of avoided deaths reported by Bosello et al. As with Tol's more limited version of the same assumption, this

introduces a bias toward finding net benefits of warming — and needs to be tested against empirical evidence on heat waves in countries such as India.

To summarize this intricate comparison, Tol appears to be consistent with Martens on developed country estimates, but has roughly doubled Martens' estimate for China, perhaps due to his unsupported assumption of no heat-related cardio-vascular deaths in rural areas. Bosello et al. have increased Tol's estimates by a factor of almost four for cardio-vascular deaths avoided by warming for most of the world, and by a factor of six in China and India, a difference that can only partially be explained by demographic transition. At the same time, they have sharply reduced Tol's estimate of the increased respiratory deaths in China and India due to warming, perhaps as a result of the combination of extending Tol's unsupported assumption about the absence of heat-related rural deaths to respiratory diseases and the Tol (1997) urbanization scenario. Quite apart from our skepticism about the validity of Martens' assumption of a constant minimum-mortality temperature discussed above, justification of the dramatic changes in the estimated impacts from one study to the next would require a fuller description of methodology on the part of Bosello et al.

5.   Conclusions

The analysis presented by Bosello et al. predicts that the number of lives saved by climate change will be far greater than the number of lives lost, and uses this prediction to estimate direct and indirect economic impacts. Although the indirect economic impacts, modeled in detail by Bosello et al., are quite small, the underlying change in mortality is huge. The estimate that 1° of warming will result in 850,000 fewer net deaths in 2050 seems to rely heavily on three faulty assumptions. First, human populations are assumed to be unable to adapt to new climatic conditions, continuing to respond as they do today even as average temperatures gradually climb. Second, the focus on slow changes in average temperatures ignores the important issue of mortality and other impacts of extreme weather events related to climate change. Third, the incidence of increased heat-related cardio-vascular and respiratory mortality is restricted to urban areas while decreases in cold-related cardio-vascular mortality are assumed to occur in both urban and rural areas. Even with these assumptions, however, we could not reproduce the huge estimates made by Bosello et al. We urge them to produce a transparent explanation of the calculations behind their mortality estimate.

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[9] We used demographic projections from the UN-DESA's World Population Prospects database. For India, Martens' deaths per 100,000 in China were applied. Since Martens finds generally lower rates in tropical countries, this is likely to be an over-estimate for India. For China's mortality in the under-65 group – absent from Martens' results – we inferred an estimate of 1 death per 100,000 population, which appears roughly consistent with his other data. As noted above, the over-65 population is much more important for mortality estimates, and is easier to predict.

[10] Bosello et al. use an urbanization scenario taken from Tol (1997), which assumes that the urban share of population will grow to 95% by 2200, but does not describe the size of the urban population in 2050. In general terms, the slower the assumed rate of urbanization, the fewer the heat-related deaths in the total population (since such deaths are assumed by Bosello et al. to occur only in urban areas).

Like other predictions of benefits to be derived from climate change, estimates of reduced mortality from warming have an importance outside of the scholarly realm. Policy-makers around the world respond to such predictions when making decisions regarding the type and extent of institutions created to combat climate change; predictions of large benefits from warming inevitably suggest that the problem is not so urgent to address. A model that accurately predicts the likely effects of climate change on mortality is essential to the formulation of climate and energy policies in countries around the world and to the future of international agreements regarding limits to the production of greenhouse gases. False optimism about climate impacts could have dangerous and long-lasting consequences.

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