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Consumption tradeoff vs. catastrophes avoidance: implications of some recent results in happiness studies on the economics of climate change

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Abstract Recent discussion of climate change focuses on the trade-off between present and future consumption and hence correctly emphasizes the discount rate. Stern (2007) favours immediate and strong actions of environmental protection, but this has been questioned as the discount rate used is much lower than the market or commonly used rates. Focussed only on consumption trade-off, the use of these higher discount rates completely reverses the need for strong actions. However, an even more important problem has been largely neglected. This is the avoidance of catastrophes that may threaten the extinction of the human species. But "we lack a usable economic framework for dealing with these kinds of ... extreme disasters' (Weitzman, J Econ Lit 45(3):703–724, 2007, p. 723). To analyse this, the comparison of marginal utility with total utility is needed. As happiness studies suggest a low ratio of marginal to total utility and as scientific and technological advances (especially in brain stimulation and genetic engineering) may dramatically increase future welfare, immediate and actions stronger than proposed by Stern may be justified despite high discount rates on future consumption, as discount rates on future utility/welfare should be much lower.

1 Introduction

With the publication of the Nicholas Stern (2007) Review, the already hot topic of the economics of global warming has been given another warm-up. Thus, the

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Journal of Economic Literature published two substantive book reviews of the Stern Review by prominent economists (Nordhaus 2007; Weitzman 2007), *Climatic Change* devoted a special issue (August 2008) to the Stern Review, and the *Review of Environmental Economics and Policy* devoted a Symposium to the issue, including an even 'Sterner' review by Sterner and Persson (2008).[1] A central, if not the most, contentious aspect is the appropriate discount rate. Both the Stern Review and its critics mainly use the Ramsey's analysis of intertemporal maximization, trading off current consumption (forgone due to lower production or higher investment now to improve the environment) vs. future consumption levels (made higher due to a better environment) by comparing the marginal utilities of consumption of different periods. While this aspect of intertemporal consumption trade-off is also relevant and important, this paper argues that a more important issue of climate change is that of catastrophes avoidance. For this problem, the relevant comparison is between current marginal utility of consumption and future values of life or total utility. Ways how such a comparison may be done is also suggested, with insights obtained from recent results in happiness studies.

The importance of the appropriate discount rate for climate change issues is not surprising as the bulk of the costs will occur many decades and even centuries from now. For example, a million dollars 200 years from now has a present value of $59,618 if discounted at 1.4% per year (a rate used in one of the simulations in the Stern Review), but has a present value of only $35 if discounted at 5% (a rate used more generally), a difference of 1,700 times! Thus, the use of a more conventional discount rate like 5% could completely reverse the case for immediate and strong actions advocated by the Stern review (and more recently and more strongly by the Garnaut Review for Australia) even if the future damages in monetary terms were many times that of the high estimates. Moreover, results of happiness studies actually suggest that the discount rate on future consumption should be higher than the market rate. This is so because happiness studies suggest that marginal utility decreases very fast with higher consumption level, suggesting that future consumption is likely to have lower marginal utility in comparison to that of the present, assuming a positive growth rate. **If** we confine ourselves to intertemporal consumption trade-off only, we should be less willing to invest now for the benefits of the future. However, this effect is likely to be more than offset by the consideration of catastrophes avoidance emphasized in this paper. Thus, the present paper is not in favour of less and later actions than advocated by the Stern Review. Rather, by focusing on the more important issue of catastrophes avoidance, this paper shows that urgent and strong actions may well be justified more so than suggested by using traditional analysis of consumption trade-off. Briefly, the main points leading to this conclusion are:

- Confined to trading-off current vs. future consumption, the appropriate discount rate on future **consumption** should be rather high, around 5–6% per annum, making immediate and strong actions inappropriate.
- Global warming is more a problem of catastrophes prevention which involves trading-off the marginal utility of current consumption against the total utilities

[1]Sterner and Persson (2008) takes into account the higher price we will be willing to pay for environmental goods as they become scarcer and hence reach a 'sterner' conclusion than Stern.

of people in the future. This involves a very low (less than 0.1% p.a. as argued below) discount rate on future **utility**.

- Despite the failure of traditional economics to provide an adequate analysis of this problem, recent happiness studies suggest that, in most relevant cases, total utilities of lives are high and marginal utilities of additional consumption are low, if still positive. This, together with a low discount rate on future utility, suggests that we should be willing to take immediate and strong actions.
- Moreover, some reasonable expectation regarding advances in science and technology (especially on brain stimulation and genetic engineering) that will increase future welfare by quantum leaps further reinforces the need for immediate and strong actions.
- While high probabilities of our extinction unrelated to environmental disruption and beyond our control should reduce our willingness to sacrifice now for uncertain future benefits, high probabilities of catastrophes due to environmental disruption should increase our willingness to take strong actions as these actions will reduce these probabilities.

It may well be the case that, a hundred years or so from now, we will have invented something that effectively solve the problem of climate change such that our current substantial investment to address the problem may be largely wasted. However, even if there is just a 1% chance that there is a time bomb on the plane, most of us will avoid taking the plane at great costs. We willingly incur such costs knowing that we will almost certainly (99%) be wasting such costs. But it is still better than being on board and having a 1% chance of death! Even just a 1% chance of avoiding or reducing a huge catastrophe of human extinction should require us to be willing to incur immediate and big costs. Similarly, while estimation involving the far future is not very reliable, such uncertainties should bias us towards the precautionary side rather than towards business as usual, as correctly emphasized by Dietz and Stern (2008); see also Barker (2008).[2]

Putting it differently, if we adopt the business as usual policy, growing at 2% per year and after a century the climate change problem turns out to be a non-problem, our grandchildren then will have a per capita income slightly more than 7 times our current one. However, if the climate change problem turns out to be serious, there may be catastrophes, including possible extinction of mankind. On the other hand, if we adopt a vigorous policy of mitigation and reduce our growth rate to say 1.8% (Compare Azar and Schneide 2002), we will reduce our grandchildren income from over 7 times to about 6 times our current level. Would our grandchildren want the potential 20% extra income while subjecting themselves to much higher probabilities of great catastrophes and the significant chance of not even being born at all?

[2]Some (e.g. Heal 2009, p. 13, and Henry & Henry cited therein) prefer the use of the precautionary principle, regarding it 'wrong to use standard expected utility theory'. In my view, expected utility/welfare maximization is fine provided the huge losses associated with catastrophes are adequately accounted for, including the contributions of catastrophes avoidance to expected welfare; see the text below. However, for expected utility/welfare maximization that takes only account of intertemporal consumption tradeoff, it may well be misleading. Perhaps, this is the intuitive and implicit underlying reason Heal and Henry regard it as 'wrong' to use standard but inadequate expected utility analysis.

2 Intertemporal welfare maximization by consumption trade-off

The traditional Ramsey's approach maximizes social welfare or the utility of a representative individual through time to infinity as a function of the consumption level of the contemporaneous period only. (The implied simplification of ignoring intertemporal interdependence is followed in this paper except that the utility levels should be the long-term ones. More discussion below.) While utility that represents preference may differ from welfare or happiness (e.g. see Yew-Kwang Ng 1999, 2003), as such divergences do not directly concern the principal point here, we will largely use utility, happiness, and welfare interchangeably.

The well-known Ramsey's equation for the discount rate r is

$$\mathrm{r} = \delta + \eta g \tag{1}$$

where δ is usually called the rate of pure time preference, η is related to the elasticity of marginal utility (percentage decrease in marginal utility of consumption as consumption increases by 1%), and g is the per capita growth rate of consumption. The variable δ is the (per annum) rate of discount on future utility relative to current utility. I agree with Stern and many other researchers in not accepting the ethical position of having a non-zero (either positive or negative) rate of pure time preference. An individual may be myopic, impatient, or otherwise irrational and has a positive rate of pure time preference. However, for the problem of intertemporal maximization associated with problems like global warming, the perspective is presumably that of the whole society/world for both the present and future. Impartiality requires that the utility or welfare of future people be treated similarly as that of the present. Thus, no pure time preference should be entailed. However, there is one valid reason for δ to be positive. Future utility is less certain to be realized. An individual maximizing expected utility (the only rational objective in the presence of uncertainty as argued in Ng (1984)) should weight the utility associated with each state of nature with the probability of its realization. Similarly, the society should weight future utility with the probability of its realization. Since future utility is less certain to be realized, a time discount rate to reflect this uncertainty is fully justified even with impartiality between the present and the future (Ng 2005). In each period, there is a small probability of our becoming extinct such as from celestial collision. This positive probability accumulates over time, making distant future less likely to be realized. A discount rate (which may or may not be constant depending on our estimation of the risk of extinction) to reflect this is rational and ethically justifiable. As suggested by a reviewer, it may be more appropriate (but not done in this paper) to insist on a zero δ and use another parameter to account for the future survival uncertainty discussed here.

The extinction risk is similar to what Bostrom (2002, Section 1.2) calls ‘existential risk’ which he defines as ‘One where an adverse outcome would either annihilate Earth-originating intelligent life or permanently and drastically curtail its potential’. If we would recover from a nuclear war without permanent and drastic curtailment in our potential, as we have recovered from the previous two world wars, even a nuclear war would not be a real extinction risk. ‘These types of disasters [like the two world wars, smallpox, black plague, etc.] have occurred many times and our cultural attitudes towards risk have been shaped by trial-and-error in managing such hazards. But tragic as such events are to the people immediately affected, in the big picture of things—from the perspective of humankind as a whole—even the worst of these catastrophes are mere ripples on the surface of the great sea of life. They haven't significantly affected the total amount of human suffering or happiness or determined the long-term fate of our species' (Bostrom 2002, 1st paragraph of Section 2). Thus understood, the risks of true extinction are likely to be quite small on a, say, per century basis. For example, a 1 km or greater body colliding with Earth has been estimated to occur about once every 500,000 years. By comparison, as Bostrom notes, the Tunguska event in 1908 was caused by a body about 60 m in diameter, without serious threat to our survival. Moreover, in the future, we will probably developed means to avoid such collisions. (On the risks of human extinction and their reduction, see also Matheny (2007)).

The Stern Review adopts an annual uncertainty discount rate $\delta = 0.1\%$. Many critics regard this rate as being too low or prefer using higher rates. (See, e.g. Nordhaus (1994, 2007), Yohe (2006). A rate of δ as high as 3% has been suggested, though this may be based on their preference for inherent utility discounting, not on the high extinction estimates. On the other hand, Heal (2009) prefers a rate of zero for δ. See also Quiggin (2008), Yohe and Tol (2008).) In my view, as the (constant, for simplicity) rate of pure survival uncertainty, the rate of $\delta = 0.1\%$ is VERY excessive. In my view, it should be at least ten times smaller at $\delta < 0.01\%$. At the rate of $\delta = 0.1\%$, the probability of our surviving the next 100 years is 90.48%, with more than 9.5% probability of extinction within the next century; the probability of our surviving the next 1,000 years is 36.77%, with nearly 2/3 chance of extinction within the next millennium. The probability of surviving 5,000 years is much less than 1% (0.672%), and that of surviving 10,000 years is virtually zero at 0.0045173%. Even at the rate of $\delta = 0.01\%$, the probability of our surviving the next 1,000 years is only 90.48%, with nearly more than 9.5% chance of extinction within the next millennium. The probability of surviving 5,000 years is much less than 2/3 (60.65%); the probability of surviving 10,000 years is 36.79% and the probability of surviving 100,000 years is still virtually zero at 0.0045377%. (See Table 1 for further details).

In contrast, if we look back at our history, we now know with reasonable confidence that the Earth has a history of about four and a half billion years, with life on earth about four billion years. Mammals evolved about 200 million years ago, primates about 40 million years ago, great apes about 15 million years ago, and Homo about 2.5 million years ago. Even just counting our species of Homo sapiens, we have a history of about half a million years. Based upon evidence of past extinction rates, Raup (1992) estimates the average longevity of an invertebrate species as between

Table 1 Annual risk of extinction and survival probability

The probability of	Annual value of δ		
survival till next	$\delta = 1\%$	$\delta = 0.1\%$	$\delta = 0.01\%$
100 years	36.6%	90.48%	99.005%
1,000 years	0.004%	36.77%	90.48%
2,000 years	$(10^{-6}) \times 0.186\%$	13.52%	81.87%
5,000 years	$(10^{-19}) \times 0.15\%$	0.672%	60.65%
8,000 years	$(10^{-32}) \times 0.12\%$	0.0334%	44.93%
10,000 years	$(10^{-41}) \times 0.225\%$	0.004517%	36.79%
100,000 years	Virtually zero	$(10^{-41}) \times 0.35385\%$	0.0045377%

4–6 million years and that of vertebrates as between 2–4 million years. Moreover, generalist and geographically dispersed species, like Homo sapiens, usually have a lower rate of extinction than those species relying on a specific habitat. In addition, for our purpose here, these periods are really underestimates since we are really only concerned with real and terminal extinction, not with the evolution into another species.

We encountered many dangers, tragedies, even catastrophes. However, life managed to survive and proliferate over 4 billion years and we Homo sapiens managed to survive and prosper for about half a million years.[3] It is true that with modern technology and massive production, the living environment is being threatened. While more opportunities are open up, the danger that we are digging our own graves may entail a higher probability of extinction. However, unless we insist on or are stuck with the extreme position of business as usual, it is highly likely that we would be able to tackle the problems created by global warming, even if only imperfectly. Moreover, it is important to note the following important distinction.

On the one hand, it is true that the higher probability of extinction due to factor (such as celestial collision) unrelated to global warming should increase our uncertainty discount rate δ and hence decrease our willingness to sacrifice our present consumption for future benefits (as those future benefits are less likely to be realized). In contrast, the higher probability of extinction due to global warming itself should increase our willingness to sacrifice our present consumption to avoid or reduce global warming. This is so since our sacrificing of the present consumption, if done in appropriate ways to effectively reduce global warming, will help to reduce the probabilities of extinction. Thus, at least for measures that help to reduce/avoid catastrophes, the value of δ should not be taken as given but should be a function of our investment and other measures (like taxing pollutants) in environmental protection. To my knowledge, no analyst seems to have taken account of this. If δ is taken as given, the problem is then simply a matter of intertemporal consumption trade-off. Then, the higher the time preference or uncertainty discount rate δ, the less willing we should be to sacrifice current consumption for future consumption.

Let us consider this important difference further. If we just concentrate on intertemporal consumption trade-off, taking δ as given, then, as suggested by a reviewer of this paper, 'low-lying islands states likely to be inundated with rising sea levels would have a *higher* discount rate and therefore lower effort to mitigate climate change, which is contrary to intuition and understanding'. This reasonable 'intuition and understanding' should thus include the point (emphasized in this paper) that the effort to mitigate climate change should help to reduce δ, a point missed out in most, if not all, analyses. The more your house is threatened by bush fires, the less you are willing to make improvements (like interior decoration) to your house that do not reduce its chance of being destroyed by fire, but the more you are willing to make improvements (like installing external clearance and using less fire-prone materials) to your house that **do** reduce its chance of being destroyed by fire.

[3]It is true that, due to the anthropic principle or selection bias (that we have survived to make the current observation), our past length of survival may have to be suitably qualified. However, saying that 'our past success provides no ground for expecting success in the future' (Bostrom 2002, towards the end of Section 8.3) seems overstated.

Though the expert is well familiar with it, the part ηg in the Ramsey equation above may be briefly explained intuitively. Due to diminishing marginal utility, the higher the consumption level, the lower the marginal utility of consumption. The higher the rate of growth g in per capita (real) consumption, the higher will future consumption level be higher than the present one. Thus, the annual growth rate g multiplied with the responsiveness of marginal utility to consumption level gives how much lower the marginal utility of a dollar of consumption is less than that of a year before. This is of course based, as the whole Ramsey analysis does, on the intertemporal comparability of utility and an unchanged utility function. Though many economists do not accept this, it may still be accepted as necessary simplification as the changes/differences may be difficult to discover and can go either way. In the absence of further evidence to improve the estimation, this may be accepted as a starting benchmark. (However, see the Section 3 on how this benchmark may be partially improved by adopting an additional parameter α to reflect the increase in future welfare due to scientific and technological improvements.)

The Stern Review takes $\delta = 0.1\%$, $\eta = 1$, and $g = 2\%$, giving a discount rate of $r = 2.1\%$. Most commentators regard this rate of r as being too small. For example, Nordhaus (2007, p. 694) prefers a rate of 5.5% (from $\delta = 1.5\%$, $\eta = 2$, and $g = 2\%$); Weitzman (2007, p. 707) prefers a rate of 6% (from 'a trio of twos', i.e. $\delta = 2\%$, $\eta = 2$, and $g = 2\%$). At noted above, at least if viewed purely as an uncertainty discount, even $\delta = 0.1\%$ is excessively high. A δ of 1% gives the ridiculous result that we are nearly 2/3 certain of not being able to survive the next 100 years and 99.996% certain of not being able to survive the next 1,000 years. On the other hand, the value $\eta = 1$ is likely to be biased towards the low side. It implies that total utility equal the log of consumption, with a doubling of consumption halving the marginal utility of consumption and a consumption level of 1,000 times the current one increasing total utility by three times and decreasing marginal utility also by 1,000 times. These figures look excessively pessimistic to economists. However, at least over the survival/comfort level, recent happiness studies suggest no significant increase in welfare at least at the social level (after the relative competition effects between individuals cancel out) with higher consumption. This suggests an η value much higher than one. With $\eta = 1$, total utility goes to infinity as consumption goes to infinity. This is obviously impossible as no one is capable of infinite happiness no matter how high is consumption, due to biological limitations. Thus, Weitzman (2007, p. 707) finds $\eta = 3$ reasonable. This, even with $\delta = 0$, still gives $r = 6\%$ (with $g = 2\%$). This rate of discount is even larger than the one used by Nordhaus. However, while most commentators appear to find a growth rate of $g = 2\%$ acceptable, it is really excessively high for the problem of maximization through to infinity used in the Ramsey approach. (However, the high value of g in fact increases the importance of catastrophes avoidance relative to that of consumption trade-off both by decreasing the importance of future consumption by increasing the discount rate on future consumption and by increasing the utility in the future. Thus, the following point on the likely declining value of g in the far future is not really essential to the argument of this paper.)

We find a growth rate of 2% reasonable because we have been accustomed to similar growth rates since the industrial revolution, especially (in per capita terms) after the demographic transition. In the last 100 years, we have been growing at more than 2% per year. We are now growing at significantly more than 2%. The expectation

Table 2 The number of times future output will be larger than our current one

After	Annual g = 1%	Annual g = 2%
100 years	2.7048	7.245
200 years	7.316	52.485
500 years	144.77	19,956.57
1,000 years	20,959.16	$10^8 \times 3.98265$
2,000 years	$10^8 \times 4.39286$	$10^{17} \times 1.58615$
5,000 years	$10^{21} \times 4.04454$	$10^{43} \times 1.00198$
10,000 years	$10^{43} \times 1.63583$	$10^{86} \times 1.003963$
20,000 years	$10^{86} \times 2.676$	$10^{172} \times 1.00794$

that we may grow at 2% or even higher in the next 100 years is not unreasonable. However, for problems involving intertemporal maximization through to infinity, the feasibility of maintaining a growth rate of 2% indefinitely must be called into question. As shown in Table 2, the number of **times** the output in the various future years will be that of our present output growing at the rate of 1% and 2% per year respectively becomes astronomically large after thousands of years. Either growing at 2% for the next 10,000 years or at 1% for nearly the next 20,000 years, the output will exceed 10^{86} **times** our present level. If one wish to know how big is 10^{86}, it is 100 trillion trillion trillion trillion trillion trillion trillions. We know that our Sun is immensely larger than our Earth, our Milky Way (which contains about 400 billion sun-like stars) is immensely larger than our Sun, and our visible universe (which contains hundreds of billions of galaxies) is immensely larger than our galaxy. We also know that there are many times more cells (in trillions) in a person's body than there are stars in our galaxy; there are even more atoms (many trillions) in a single cell. However, there are only about 10^{80} atoms in our visible universe, a million times smaller than 10^{86}!

It is true that the growth in productivity needs not solely be manifested in physical production but may consist in services and leisure. Still, with productivity in the order of 10^{172} times that of our current one implies that a single worker would be able to produce the value of output many quintillion times more than the value of the weight of the whole universe in gold in less than a tiny fraction of a second! Optimist as I am, I do not think that this would ever be possible, not to say in 20,000 years from now. Thus, while economic growth may be at the level of 2–3% for many more decades, it must eventually slow down. Taking g = 2% indefinitely is thus misleading.

Some economists take the method of truncating the time horizon, looking say at only the next 100 or 200 years. Though the probability that we will survive more than 200 years should be much higher than 50%, this simplification is not too misleading, **if** the problem is **just** that of intertemporal consumption tradeoff, especially if the discount rate is around or more than the more common value of about 5%. [However, for the main point here of the avoidance of catastrophes, this approach of considering a few centuries only does not work adequately as the reduction of the probabilities of extinction increases welfare expected to realize possibly thousands and even millions of years into the future, such that a small reduction in this probability now may have rewarding contributions only if the far future is taken into account.] Thus, a stream of value worth $100 in real terms from the year 201 (counting the current year as year 0) **every year** through to infinity, discounted at 5%, has only a present value of 11 and a half cents ($0.1156) **in total**! At such discount rates, even astronomical losses centuries from now have virtually negligible present values. This again underlines the misleading nature of focusing on intertemporal consumption tradeoff for problems like global warming that have long-lasting effects and that may lead to catastrophic outcomes threatening our very survival. For the problem of intertemporal consumption tradeoff, it is difficult to reject a rate of discount in the order of about 5% at least for the next couple of centuries when growth rate may be expected to remain high. (Prominent economists like Nordhaus and Weitzman favour rates higher than 5% as already noted above.) On the other hand, after discounting at about 5% for a couple of centuries, no reasonable future values after that will have significant present values. Thus, if we focus mainly on intertemporal consumption tradeoff, we end up with the conclusion of no strong immediate action (such as by Nordhaus) or having to use not very reasonable parameters (such as $\eta = 1$, and $g = 2\%$ indefinitely) to justify a very low discount (such as by the Stern Review).

Weitzman (2007) correctly mentions that, in dealing with global warming, the expected growth rate should have 'a thick left tail' (p. 718), but acknowledges that 'we lack a usable economic framework for dealing with these kinds of thick-tailed extreme disasters' (p. 723).[4] The next section attempts to provide an outline of a method in dealing with such catastrophes. As just a preliminary attempt, it is not ambitious in trying to provide a precise and definite cost–benefit analysis with conclusive figures. Rather, it is meant to be more illustrative and attempts mainly to show how such an analysis may proceed.

3 Towards an economic analysis of catastrophes avoidance

Nearly two decades ago, I discussed 'decisions (e.g. nuclear power development, environmental protection, genetic engineering) that may affect the probabilities of the continued survival of the human race' (Ng 1991, p. 79). However, that paper focused on the dilemma created if our expected welfare into the indefinite future sums to infinity, as may be the case if either our rate of population growth (if we go for the classical utilitarian objective of aggregate welfare) and/or our per capita welfare increases at a rate exceeding the pure uncertainty discount (not likely to exceed 0.01% as mentioned in the previous section). No matter how tiny (but positive) a fraction of infinity is still infinite. Thus, even if we are partial towards our current welfare and value our future welfare only at a fraction α $(1 > \alpha > 0)$ that of our present welfare, we should be willing to suffer enormously now to prevent no matter how minute a reduction in the probability of our continuing survival. We should then behave as if perfectly morally ($\alpha = 1$) with respect to factors that threaten our survival. How then could the present generation put its bias towards its own welfare into practice?

The Ramsey's model in fact involves an infinite expected welfare. He used the ingenious method of minimizing the shortfall from a posited bliss level of welfare to

[4]Weitzman (2009) has made some interesting analysis. However, his most remarkable conclusions like unbounded welfare sensitivity (p. 6), the dismal theorem (p. 10), and the required willingness to sacrifice 100% of our current consumption are based both on the possibility of an infinite expected welfare (argued below and in Ng (1991) to be impossible) and the ignoring of the fact that some significant amount of positive consumption is essential for our present survival and hence the realization of future welfare.

avoid the problem of comparing different streams of infinite values. However, for the problem of castastrophes avoidance involving changes in the probabilities of our survival, we cannot use this method of shortfalls from bliss. Thus, if our expected welfare is infinite, the problem is intrinsically intractable. However, I argued in my 1991 paper that our expected welfare is finite. [Basically, we are finite and even our universe, or at least that part of the universe reachable in finite time even at the speed of light, is finite and hence unable to provide the material basis of infinite welfare.] Taking this position, we may then proceed with the cost–benefit of catastrophes avoidance.

If a change in our current consumption/investment affects the probabilities of our survival, either with respect to the whole mankind or a subset thereof, an appropriate cost–benefit analysis involves the comparison of the marginal utility of current consumption against the total utility or expected total welfare of our life. This may be done using either one of the following methods, starting with the life of an individual. First, we may estimate the willingness to pay for a marginal improvement in the safety of life by observing actual individual choices under different situations. For example, other things being equal, how much is an individual willing to pay more for an airline with a better safety record? Secondly, we may directly ask a representative sample of individuals their willing to pay for life safety, i.e. reduction in the risk of death. Thirdly, we may postulate a reasonable cardinal utility/welfare function and estimate the resulting willingness to pay for life safety accordingly. (Utility, which represents preference, may differ from welfare in the presence of ignorance, non-affective altruism, and irrationality; see Ng (1999). For issues where these divergences are not being focused on, we may use utility and welfare interchangeably, as done here.)

Perhaps partly due to their normal analysis being mostly only concerned with actual choices, economists are usually very skeptical of the reliability of the latter two methods. To put it crudely, economists typically trust people's pockets (actual willingness to pay) rather than their mouths (cheap talks). This suspicion/reservation certainly has much validity. That a person says that he is willing to pay a lot for something does not necessarily mean that he is actually willing to do that in reality. However, recent results in behavioral economics have shown that, even actual willingness to pay may not be very a reliable indication of the actual welfare of the people making the payment. This problem is less serious for things like apples and bread that we consume every week. However, the willingness to pay to reduce the risk of death is likely to be affected by a number of difficulties/irrationalities. First, no one has experienced death. Secondly, there is the likely common irrational fear of death. The fear of death needs not be irrational, but excessive fear beyond the point the maximization of expected utility/welfare is irrational. We tend to have excessive fear of death as this promotes our survival. Evolution is dictated by survival and reproduction, not by expected welfare maximization. (See Ng 1995). Thirdly, our attitudes towards death may also be significantly affected by our cultural, especially religious, backgrounds/beliefs.

While there may be no perfect method to measure the ratios of total to marginal utility/welfare, a combined use of the several imperfect methods may give a reasonable guide. In particular, the third method of postulating a reasonable cardinal utility/welfare function (of consumption) may be helped by results in happiness studies. Alternatively, the ratio of total to marginal utility/welfare may directly be estimated from results in happiness studies, as discussed in the first paragraph of Section 4. However, care must be exercised in this estimation. For one thing, cross-sectional or intertemporal results need not reflect causal effects of consumption on welfare. However, given sufficient data, economists may be able to give a reasonably good estimate of the causal effects. The actual estimation of this is beyond the scope of this paper. Rather, the next section gives a simplified case illustrating the contrast between intertemporal consumption trade-off and catastrophes avoidance.

4 Consumption tradeoff vs. catastrophes avoidance: an illustrative example

In this section, a simple model is used to illustrate the point that the need for catastrophes avoidance may overwhelm the importance of consumption tradeoff even if a high interest/discount rate is used for consumption tradeoff. As it is meant to be no more than illustrative, simplicity is emphasized over realistic representation.

As mentioned in the previous section, our current high growth rates cannot be expected to last indefinitely. Thus, decreases in the annual growth rate g of consumption c are allowed. For simplicity, a three-stage modelling is used. The growth in consumption is taken to equal g from now (time $t = 0$) to time T (=100 years from now in the numerical simulation), and will equal g' from time T to time T' (=200 years from now in the numerical simulation), and will equal g'' from time T' to infinity. Thus, in Fig. 1, the growth in consumption c is depicted as the curve that consists of three linear sections (as the vertical axis is ln c instead of c), starting at the present level of $c = c_0$.

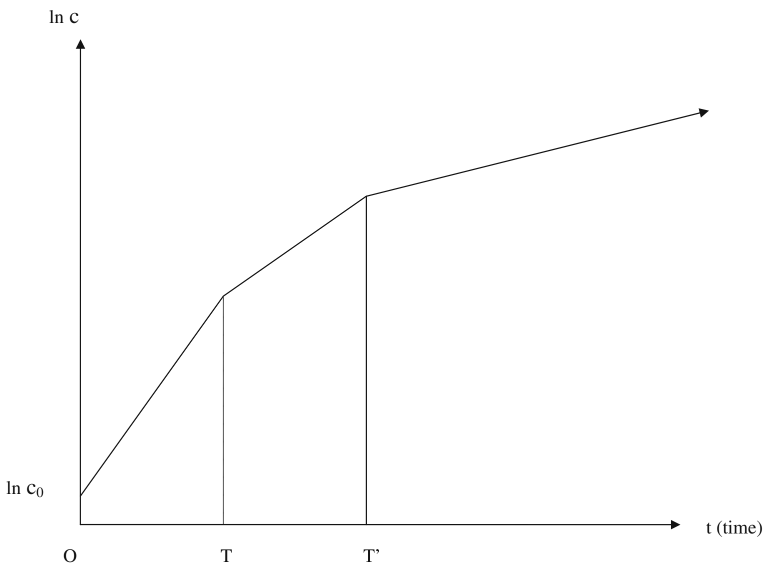

Fig. 1 Consumption over time

Following Ramsey, Stern and others, I take the constant elasticity form of utility function (if the constant term $\overline{A}$ below is ignored). However, since the constant η is allowed to be larger than one, a positive constant term $\overline{A}$ is added to the utility function. ($\overline{A}$ is taken as unity in the numerical simulation; it has no relationship to A used below.) We thus have the 'basic' utility level $u = \overline{A} + \left(\frac{c}{1-\eta}\right)^{1-\eta}$. (The actual utility level may go beyond the basic one with utility-enhancing technological advance; see below.) Recent results of happiness studies indicate a very limited contribution of consumption to happiness.[5] Also, common sense suggests that utility does not go to infinity as consumption goes to infinity, given the technological level. These two considerations suggest that the relevant values of η are larger than one. For this reasonable range of η, $\overline{A}$ represents the maximum value that the 'basic' utility level may reach. However, even given the consumption level unchanged, utility may be increased beyond its basic level through technological progress over time. Also, given the per-capita consumption and utility levels, if the number of people enjoying that level is higher, social welfare may be higher. We use the variable α to indicate the combined growth rate in social welfare due to these two effects.

It is true that the introduction of population size as a variable raises ethical questions that economists and moral philosophers have no accepted answers. In particular, should we maximize average utility (utility per head on average) or aggregate/total utility (average utility times the number of persons). Classical utilitarians were in favour of the latter while most economists (including John Harsanyi and Paul Samuelson) are in favour of the former, though some economists like Meade and Stern are in favour of aggregate utility. The maximization of average utility violates the compelling Mere Addition Principle (the mere addition of happy individuals without reducing the welfare of existing individuals should be a good thing, a sort of an extended Pareto Principle). On the other hand, the maximization of aggregate utility may lead to the Repugnant Conclusion (with a huge number of individuals each enjoying a very small amount of net welfare). Neither one is acceptable to most philosophers. I proposed a resolution of this dilemma by accepting aggregate utility at the level of pure morality, arguing that the Repugnant Conclusion is not really repugnant at this level but allowing for our possible partiality towards our own welfare in refusing to accept the Repugnant Conclusion if our own welfare has to be reduced to a tiny level. (See Ng 1989). For the issue of this paper, it is not very important how the population problem is resolved. To the extent that future population may be expected to be higher and to the extent that we give some positive weight to population size, the case of this paper on the importance of catastrophes prevention is strengthened. However, even if we ignore the population problem or go for average utility maximization, the case for the importance of catastrophes prevention may still be made. (In terms of the simulation below, it just means that the value of α may be somewhat lower than it otherwise would be.)

[5] Most happiness studies uses happiness levels of pre-assigned ranges and this may partly explain the limited contribution of consumption. There are also problems of reliability and comparability. Thus, further studies are needed. However, the result of the limited contribution of consumption beyond some certain level and given the technological level is unlikely to change much. On measurement and comparability issues that at least partly address this problem, see Ng (1996, 2008). On the role of technological advance, see the text below.

To get a precise numerical picture, we will assume precise numerical values for the relevant variables. Let us consider three cases. Case 1 is the so-called 'business as usual', with unabated high emissions of green-house gases. Case 2 is one of immediate emission reduction that is assumed to reduce current growth in consumption (from now to time T), to increase future growth in consumption (from T to time T′), but having no effects on the probabilities of catastrophes/extinction. Case 3 is stronger emission reduction that reduces the probabilities of catastrophes/extinction. Taking $T = 100$, $T' = 200$, $\overline{A} = 1$, $c_0 = 1$, $\eta = 2$, $\alpha = 0.01$, $\alpha' = 0.001$, $\alpha'' = 0.0001$, $\delta = 0.0001$, $g'' = 0.0001$ for all the three cases, (consumption growth rate until T) $g = 0.02$ for Case 1, $= 0.015$ for Case 2, and $= 0.014$ for Case 3; $g' = 0.01$ for Case 1, $= 0.0152$ for Case 2, $= 0.016$ for Case 3; $\delta' = 0.0003$ for both Cases 1 and 2, and $= 0.0002$ for Case 3; $\delta'' = 0.0004$ for both Cases 1 and 2, and $= 0.0003$ for Case 3. In other words, we do not vary the three time periods 0–T, T–T′ and T′–infinity between the three cases, nor the values of $\overline{A}$, c_0, η, δ and the α's. Rather, if we take Case 1 "business as usual" as the base case, Case 2 of emission reduction reduces the current (0–T, i.e. the next 100 years) consumption growth rate g from 2% (for Case 1) to 1.5%, but increase the growth rate g′ for the next period (year 101 to 200 from now) from 1% to 1.52%. This is a case of consumption trade-off between this coming century and the future. We have, the expected utility (all evaluated now at $t = 0$) for first two cases as,

$$EU_1 = 107.88 + 94.77 + 3,208.87 = 3,411.52;$$

$$EU_2 = 92.50 + 91.80 + 3,211.33 = 3,395.63.$$

where EU_i is the expected utility of Case i which consists of the sum of the expected utilities for the three periods concerned. (The mathematics behind the simulation is given in the Appendix.)

At least for the current simulated values, we see that, taking only the effects of consumption trade-off, emission reduction actually reduces our expected utility from 3,411.524 to 3,395.63. This reduction may be explained. In terms of real consumption, the reduction in the first century will in fact be more than offset by the increase in the second century and after (though growth rate will be unchanged from the third century, the larger increase in growth rate over the second century over the reduction in growth rate in the first century will give a higher base consumption at the beginning of the third century). However, the higher consumption in the future has to be subject to both the Ramsey discount ηg (about 2% to 4% in the simulation) or for conversion into utility terms and to the pure uncertainty discount δ (between 0.01% to 0.03%). The many times increase in future real consumption then becomes of lower expected utility value in present value. Thus, not only does the expected utility value for the first century decreases from Case 1 to Case 2 (from 107.88 to 92.50), that for the second century also decreases (from 94.77 to 91.80). Though the expected utility for the third period increases somewhat, it is not sufficient to offset the decrease in the first century. Thus, the total expected utility for the three periods together decreases from 3,411.52 to 3,395.63.

However, the situation is quite different when the probabilities of extinction differ due to the avoidance or reduction of catastrophes. Thus, for Case 3, we have,

$$EU_3 = 88.80 + 91.43 + 4,834.04 = 5,014.27$$

which gives an expected utility value very much higher. Though there is a significant reduction in consumption growth rate g for the first century from 2% (for Case 1) to 1.4%, and this loss cannot be made up by the corresponding increase in growth rate g′ for the second century from 1% to 1.6% (as seen in the previous comparison between Case 1 and 2 above), the annual risks of extinction for the second period (T to T′) and the third period (T′ to infinity) have been reduced by 0.01% (from 0.0003 to 0.0002 for δ' and from 0.0004 to 0.0003 for δ''). This catastrophes reduction has a huge effect on expected utility because it increases the survival probabilities from the second century on indefinitely into the future. To put it differently, if we (the whole human species) becomes extinct in year x, we lose not only the expected utility in that year, but those for all years after x. Catastrophes prevention is thus very important.

In fact, as argued in the next section, as advances in science and technology are likely to dramatically increase the welfare of our descendants if we do not spoil the game by polluting our planet to extinction, the significance of catastrophes prevention in increasing our expected utility should be much higher than suggested by the simulation above. In other words, the values of alphas may be much higher. For example, if we just increase the values of alphas somewhat to, $\alpha = 0.015$, $\alpha' = 0.0015$, $\alpha'' = 0.0002$, while holding the values of all other parameters the same as above, we have,

$$\mathrm{EU}_1 = 151.34 + 97.24 + 3,208.87 = 3,458.45$$

$$\mathrm{EU}_2 = 131.18 + 94.24 + 3,211.33 = 3,316.75$$

$$\mathrm{EU}_3 = 126.04 + 93.87 + 9,751.07 = 9.860.98.$$

This increases the significance of catastrophes prevention enormously. This point is not just true for the particular simulation in question. It is true in general as it is not difficult to show that the higher the values of α's, the higher the contribution of reducing the values of δ's to expected utility.

It is true that in both the above simulations, the case of rigorous emission reduction (Case 3), while increasing our expected utility enormously through catastrophes prevention, the increase occurs from the third century. The expected utilities for first two centuries actually decrease. This is so partly because we do not allow for the benefits of emission reduction for the first century, especially in improving the quality of the environment and in reducing the probabilities of mini catastrophes that may cause losses of millions of lives but not the extinction of the whole human species. If we have allowed for these, expected utilities for the first two centuries may also be higher under Case 3. We have not done this more complete reckoning because the point here is mainly to emphasize the importance of major catastrophes prevention versus consumption trade-off.

5 Concluding remarks: the relevance of happiness studies and technological advances

Happiness studies show that, beyond a moderate level of income, higher income contributes little if anything towards happiness at the social level. Even at the individual level, the contribution of extra consumption/income is small in the long run due to the adaptation effect. When one is used to high levels of consumption, it becomes no longer exciting. This small contribution of consumption is further reduced or eliminated at the social level due to relative competition between individuals and the environmental disruption effects of production and consumption. (For detailed discussion, see, e.g. Clark et al. 2008; Di Tella and Macculloch 2006; Easterlin 1974, 2002; Frey and Stutzer 2002; Inglehart and Klingemann 2000; Kahneman and Krueger 2006; Layard 2005; Ng 2003).[6] On the other hand, happiness studies also reveal that, for most people in most countries, the happiness levels are positive and high, averaging well in excess of the level of neutrality, at 7 or more out of 10, even for many economically poor countries. These results suggest that the marginal utility of consumption is low relative to the total utility. In terms of the Ramsey analysis, it suggests that the value of η (which is related to the elasticity of marginal utility with respect to consumption) is high, especially for utility calculation at the social level. In non-technical terms, this means that higher consumption is of little significance in comparison to saving lives and avoiding extinction. Thus, this finding in happiness studies increases the importance of catastrophes prevention emphasised in this paper.

Another factor that increases the importance of catastrophes avoidance is the reasonable expectation that the advance in science and technology may increase the happiness levels of future people by quantum leaps. This may be suspected especially since the strong adaptation effect may largely nullify the short-term utility gains in the long run just as happened before with respect to, for example, the introduction of television. While the adaptation effect will no doubt dilute the welfare significance of such innovations as web-surfing, there are at least two areas of expected future advance that will not be significantly subject to the satiation (applying at the moment of consumption) and adaptation (applying in the longer run) effects.

First, there is brain stimulation of the pleasure centres. Positive reward associated with brain stimulation was discovered by Olds and Milner (1954) when they observed that a rat returned to the place where it received direct electrical stimulation of certain parts of its brain. The pleasure from brain stimulation is not subject to the adaptation effect. Common methods of enjoyment through the stimulation of our senses (through the peripheral nervous systems) like eating delicious food and having sex is, after some point, subject to fast diminishing marginal utility due to satiation and adaptation. This is so because we are programmed through natural selection to protect us from over-eating, etc. Thus, our ordinary biological capacity for happiness is rather limited. However, in our eons of evolution, our brain was not stimulated intracranially (bypassing the peripheral nervous systems) and hence there has been no need to program diminishing marginal utility directly within the pleasure centres in our brain. Thus, brain stimulation promises high happiness due to the absence of satiation and adaptation.

Another expected advance that will lead to dramatic leaps in happiness may be expected in genetic engineering. It is true that here we have to be even more

[6]Such analyses suggest that traditional analysis focusing on monetary costs and benefits such as Mendelsohn (2008) may be incomplete. On the other hand, the emphasis on the importance 'to pay attention to the difference between human suffering and losses of gross domestic product' (Jaeger et al. 2008) is on the right track.

careful than in brain stimulation to avoid being counter-productive. Nevertheless, with care and sufficient safeguards, genetic engineering promises great leaps because it may transform our capacity for enjoyment itself. Short of the extremes like brain stimulation and starvation, the happiness level of a person depends more on the subjective factors than the objective circumstances. The subjective factors are however shaped by our upbringings, education, social contacts, and a host of other factors. However, these factors affect mainly the waves of happiness around a set point. The level of this set point for each person is largely genetic (Lykken and Tellegen 1996; Lykken 1999). This does not mean that we cannot affect our happiness levels at all. Even Lykken (1999) who has established the high degree of association of happiness and a host of other things with genetic factors through the study of identical twins (including those reared apart), believes that we can learn to become happier by affecting the waves of happiness. Nevertheless, the dominance of the genetic factors in determining the set points remains. This suggests that a way to increase happiness by a quantum leap more important than brain stimulation is through genetic engineering. Of course, a very high degree of care has to be taken for such an endeavour. Is it too risky nevertheless? While there are some risks, they could be reduced by sufficient safeguards. Moreover, the risks involved are far less than those created by our current path of high growth without sufficient environmental protection. The returns of this high growth are just some chance (that problems like climate change turn out to be of no significance) of higher output that contributes virtually nothing to happiness. The risks are high chance of environmental disasters including human extinction. In contrast, genetic engineering promises a very high chance of huge quantum leaps in our happiness, at negligible and avoidable risks if adequate safeguards are adopted. Why do many people still feel comfortable with the former and not with the latter? Irrational fear of the unfamiliar is probably at work.

Even if we shun technological advances like brain stimulation and genetic engineering, the argument of this paper is not overturned (just not enhanced much further). This is so since the value of alphas used in the above simulations are very small and hence does not really take into account such dramatic technological advances. However, the reasonable expectation that advances in science and technology may dramatically increase the welfare of future generations means that catastrophes avoidance is even much more important, as the aggregate utility that could be sacrificed by our extinction will be much higher. In terms of the simulation in the previous section, it means that the values of alphas may be much higher, increasing the contribution of lowering the risk of extinction to aggregate expected utility.

To put it more emphatically, it may be said that mankind is facing the greatest cross-road in its entire history: We may choose to ignore the threat of global warming and choose business as usual and go to Hell (extinction), or we may adequately solve the problem of environmental disruption and ensure our road to Heaven (survival and quantum leaps in the welfare of our offspring). The human species had faced the threat of extinction before. Yet the current cross-road is more remarkable than previous ones for two reasons. First, the current threat is man-made and could be undone by us. Second, if we could avoid the current threat, we will have very good chance of going to Heaven (quantum leaps in welfare). The difference has never been greater!

Mathematical appendix

As mentioned at the beginning of Section 3 in the text, we have the 'basic' utility function $u = \overline{A} + \left(\frac{c}{1-\eta}\right)^{1-\eta}$ that grow (from either population growth or technological advance) at the rate alpha, on top of the possible growth in consumption c. After being discounted by the pure uncertainty of survival δ, we may express the expected utilities for the three periods (depicted in Fig. 1 in the text) below as A, B, and C respectively. The aggregate expected utility is just the sum of A, B and C. From the following equations, the simulations reported in Section 3 may then be calculated.

$$A = \int_0^T \left[\overline{A} + \frac{\left(c_0 e^{gt}\right)^{1-\eta}}{(1-\eta)}\right] e^{(\alpha-\delta)t} dt$$

$$= \frac{\overline{A}}{(\alpha-\delta)}\left[e^{(\alpha-\delta)T} - 1\right] + \frac{\overline{c}}{(1-\eta)\,g + (\alpha-\delta)}\left[e^{[(1-\eta)g+(\alpha-\delta)]T} - 1\right],$$

$$\text{where } \overline{c} = \frac{c_0^{1-\eta}}{1-\eta}.$$

$$B = \int_T^{T'} \left[\overline{A} + \frac{\left(c_0 e^{gT} e^{g't'}\right)^{1-\eta}}{1-\eta}\right] e^{(\alpha'-\delta')t'} dt$$

$$= \int_T^{T'} \left\{\overline{A} + \frac{\left[c_0 e^{gT} e^{g'(t-T)}\right]^{1-\eta}}{1-\eta}\right\} e^{(\alpha'-\delta')(t-T)} dt$$

$$= e^{-(\alpha'-\delta')T} \int_T^{T'} \left[\overline{A} + \overline{c}\, e^{[(g-g')T+g't](1-\eta)}\right] e^{(\alpha'-\delta')t} dt$$

$$= \frac{\overline{A} e^{-(\alpha'-\delta')T}}{(\alpha'-\delta')}\left[e^{(\alpha'-\delta')T'} - e^{(\alpha'-\delta')T}\right] + \overline{c}\, e^{[(g-g')(1-\eta)-(\alpha'-\delta')]T} \int_T^{T'} e^{[(\alpha'-\delta')+(1-\eta)g']t} dt$$

$$= \frac{\overline{A}}{(\alpha'-\delta')}\left[e^{(\alpha'-\delta')(T'-T)} - 1\right] + \overline{c}\, e^{[(g-g')(1-\eta)-(\alpha'-\delta')]T} \int_T^{T'} e^{[(\alpha'-\delta')+(1-\eta)g']t} dt$$

$$= \frac{\overline{A}}{(\alpha'-\delta')}\left[e^{(\alpha'-\delta')(T'-T)} - 1\right] + \frac{\overline{c}\, e^{[(g-g')(1-\eta)-(\alpha'-\delta')]T}}{(\alpha'-\delta') + (1-\eta)\,g'}$$
$$\times \left\{e^{[(\alpha'-\delta')+(1-\eta)g']T'} - e^{[(\alpha'-\delta')+(1-\eta)g']T}\right\}$$

$$= \frac{\overline{A}}{(\alpha'-\delta')}\left[e^{(\alpha'-\delta')(T'-T)} - 1\right] + \frac{\overline{c}\, e^{g(1-\eta)T}}{(\alpha'-\delta') + (1-\eta)\,g'}\left\{e^{[(\alpha'-\delta')+(1-\eta)g'](T'-T)} - 1\right\}$$

$$C = \int_{T'}^{\infty} \left[\overline{A} + \frac{\left(c_0 e^{gT} e^{(T'-T)g'} e^{g''t''}\right)^{1-\eta}}{(1-\eta)} \right] e^{(\alpha''-\delta'')t''} dt$$

$$= \int_{T'}^{\infty} \left[\overline{A} + \frac{\left(c_0 e^{gT} e^{(T'-T)g'} e^{g''(t-T')}\right)^{1-\eta}}{(1-\eta)} \right] e^{(\alpha''-\delta'')(t-T')} dt$$

$$= e^{-(\alpha''-\delta'')T'} \int_{T'}^{\infty} \left[\overline{A} + \frac{\left(c_0 e^{gT} e^{(T'-T)g'} e^{g''(t-T')}\right)^{1-\eta}}{(1-\eta)} \right] e^{(\alpha''-\delta'')t} dt$$

$$= \frac{\overline{A}\left(e^{-(\alpha''-\delta'')T'} e^{(\alpha''-\delta'')\cdot\infty} - 1\right)}{(\alpha''-\delta'')} + \bar{c}\, e^{-(\alpha''-\delta'')T'}$$

$$\times \int_{T'}^{\infty} e^{\left[gT+(T'-T)g'+g''(t-T')\right](1-\eta)+(\alpha''-\delta'')t} dt$$

$$= \frac{-\overline{A}}{(\alpha''-\delta'')} + \bar{c}\, e^{-(\alpha''-\delta'')T'} \int_{T'}^{\infty} e^{\left[(g-g')T+(g'-g'')T'\right](1-\eta)+\left[g''(1-\eta)+(\alpha''-\delta'')\right]t} dt$$

$$= \frac{-\overline{A}}{(\alpha''-\delta'')} + \bar{c}\, e^{\left[(g-g')T+(g'-g'')T'\right](1-\eta)-(\alpha''-\delta'')T'} \int_{T'}^{\infty} e^{\left[g''(1-\eta)+(\alpha''-\delta'')\right]t} dt$$

$$= \frac{-\overline{A}}{(\alpha''-\delta'')} + \frac{\bar{c}\, e^{\left[(g-g')T+(g'-g'')T'\right](1-\eta)-(\alpha''-\delta'')T'}}{g''(1-\eta)+(\alpha''-\delta'')}$$

$$\times \left\{ e^{\infty\cdot\left[g''(1-\eta)+(\alpha''-\delta'')\right]} - e^{\left[g''(1-\eta)+(\alpha''-\delta'')\right]T'} \right\}$$

$$= \frac{-\overline{A}}{(\alpha''-\delta'')} + \frac{\bar{c}\, e^{\left[gT+g'(T'-T)\right](1-\eta)}}{g''(1-\eta)+(\alpha''-\delta'')} \left\{ e^{-\infty} - 1 \right\}$$

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