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## Disentangling the Stern/Nordhaus Controversy: Beyond the Discounting Clash

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## Summary

The Stern/Nordhaus controversy has polarized the widely disparate beliefs about what to do in order to tackle the climate challenge. To explain differences in results and policy recommendations, comments following the publication of the Stern Review have mainly focused on the role played by the discount rate. A closer look at the actual drivers of the controversy reveals however that Stern and Nordhaus also disagree on two other parameters: technical progress on abatement costs and the climate sensitivity. This paper aims at appraising the relative impacts of such key drivers of the controversy on the social cost of carbon and climate policy recommendations. To this end, we use the flexible integrated assessment model RESPONSE which allows us to compare very diverse worldviews, including Stern and Nordhaus' ones within the same modelling framework and map the relative impacts of beliefs on the three key drivers of the controversy. Furthermore we appraise quantitatively, by means of a linear statistical model, the impacts on results of an extended set of core parameters of RESPONSE. We show that beliefs on long term economic growth, technical progress, the form of the climate damage function and the climate sensitivity have an impact as important as beliefs on pure time preference. Hence, we can qualify the role played by the discount rate in the Stern/Nordhaus controversy and more broadly in the definition of climate policies.

**Keywords:** Integrated Assessment Model, Discount Rate, Social Cost of Carbon, Abatement Policy, Worldview

**JEL Classification:** Q54, Q58, C61

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July 5, 2012

**Abstract**

The Stern/Nordhaus controversy has polarized the widely disparate beliefs about what to do in order to tackle the climate challenge. To explain differences in results and policy recommendations, comments following the publication of the Stern Review have mainly focused on the role played by the discount rate. A closer look at the actual drivers of the controversy reveals however that Stern and Nordhaus also disagree on two other parameters: technical progress on abatement costs and the climate sensitivity. This paper aims at appraising the relative impacts of such key drivers of the controversy on the social cost of carbon and climate policy recommendations. To this end, we use the flexible integrated assessment model RESPONSE which allows us to compare very diverse worldviews, including Stern and Nordhaus'ones within the same modelling framework and map the relative impacts of beliefs on the three key drivers of the controversy. Furthermore we appraise quantitatively, by means of a linear statistical model, the impacts on results of an extended set of core parameters of RESPONSE. We show that beliefs on long term economic growth, technical progress, the form of the climate damage function and the climate sensitivity have an impact as important as beliefs on pure time preference. Hence, we can qualify the role played by the discount rate in the Stern/Nordhaus controversy and more broadly in the definition of climate policies.

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# 1 Introduction

There is now a consensus among climate economists to consider climate change as a global externality that must be compensated for to recover economic optimality. Hence, basic public economics wisdom requires some mitigation efforts (IPCC, 2007). The issue gets controversial however when we try to answer the “when” and “how much” questions. In a nutshell, the dynamic puzzle arising from a long-standing debate originated in the early 1990s, is about whether we should act strongly now or gradually and later. Those two polar climate policies could be referred to as the Stern (2006)/Nordhaus (2008) controversy. While Stern promotes sharp early abatement as a precautionary measure to prevent potential future catastrophic damage, Nordhaus argues that it is more economically sound to postpone abatement efforts (following a so-called “policy-ramp”) and tolerate higher climate risks given that those risks would be better borne by supposedly richer future generations than relatively poor present ones.

Fine tuning of mitigation efforts over time directly derives from the appraisal of society’s willingness and ability to tackle the climate issue. Within an optimal control framework, such a quality should depend on the value of the climate externality known in the literature as the Social Cost of Carbon (SCC). The computation of the SCC over the next century is a symmetric issue to the timing of climate policies. Along an optimal path of growth and carbon emission reduction, the SCC is the value equating at each date the discounted sum of the marginal abatement costs with the discounted sum of remaining marginal climate damages (Nordhaus, 2011; Pearce, 2003; Tol, 2008). This optimality rule makes it possible to delineate the efficient border of mitigation efforts.

Similarly to the timing dispute, there is no academic consensus about the value of the SCC and published literature provides a very wide range of values. Indeed the most recent Intergovernmental Panel on Climate Change (IPCC) report gives a SCC range of $\$-3/tCO_2$ to $\$95/tCO_2$ (IPCC, 2007). Tol (2005) gathers 103 estimates and finds out that the median estimate is $\$4/tCO_2$, the mean $\$26/tCO_2$ and the 95 percentile $\$97/tCO_2$.

The debate following the Stern Review (Dasgupta, 2007; Nordhaus, 2007; Weitzman, 2007; Yohe and Tol, 2007) has reopened the “when/how much” controversy and eventually exacerbated irreducible differences in results and policy recommendations. This was due to a heavy focus on the discounting clash between Stern and Nordhaus’ approaches and a surprising disregard for the lessons learned from the 1990s in the so-called “when” flexibility controversy about the roles of inertia, uncertainty on the optimal emission target (Ambrosi et al., 2003; Ha-Duong et al., 1997; Manne and Richels, 1992), irreversibility (Chichilnisky and Heal, 1993; Kolstad, 1996; Ulph and Ulph, 1997; Ha-Duong, 1998; Pindyck, 2000), learning and technical change (Goulder and Mathai, 2000). The alarmist results found by Stern would be mainly driven by the unusual low pure time preference (0.1%) retained in his model, while a more conventional rate (2%) would have given smoother “Nordhaus-like” results. Indeed, in a deterministic framework, it is easy to figure out how the rate of pure time preference may critically impact models’ results as it balances the relative value of future damage (that will mostly arise after 2050) against present costs of emission reductions. Then the higher the discount rate the lower the present value of discounted future damage. This insightful dispute has raised fundamental intergenerational ethical questions, however ruling out other critical drivers of the controversy such as beliefs on climate damage, climate sensitivity[1], long term economic growth, and abatement costs. We focus in this paper on this forgotten drivers.

Building on the emblematic Stern/Nordhaus controversy, we disentangle the drivers of the controversy in order to explain the reasons for such wide differences in SCC and climate policy recommendations. We argue that Stern and Nordhaus do not only dramatically disagree on the pure time preference to pick, but also on two other key parameters, namely the climate sensitivity and the evolution of abatement costs. The calibration of those parameters basically rests on "beliefs" because there is no decisive argument to pick one value rather than another. Eventually the calibration results from an irreducible subjective choice within reasonable ranges provided by most advanced research. The combination of beliefs on these parameters constitutes what we call a "worldview".

This paper aims at appraising the relative impact on results of those beliefs and qualifying the impact of pure time preference on climate policies. To carry out this analysis we use RESPONSE (Ambrosi et al., 2003; Perrissin-Fabert et al., 2012) which has the same basic modelling structure as DICE (Nordhaus' model) and PAGE (Stern's model) and thus makes it possible to compare Stern and Nordaus' worldviews within a unique consistent framework. We show that the rate of pure time preference has a significant impact on the SCC but cannot alone account for differences in climate policies recommendations. It is only a key parameter among a broader set of parameters including the climate sensitivity and the technical progress on abatement costs. RESPONSE allows us to map the relative impacts of beliefs on these key parameters. In addition to this graphical disentangling of the controversy, we provide a quantitative appraisal of the relative impacts of core parameters of RESPONSE over time, such as the rate of long term economic growth, the forms of both the climate damage and abatement cost functions, and the three key drivers of the Stern/Nordhaus controversy. To do so, we carry out a broad sensitivity analysis over those core parameters that make up a worldview. Then we apply to the grid of results a linear statistical model in order to compute mean elasticities over time, and therefore the relative impacts, of critical parameters.

In section 1 we present the controversy within the framework of RESPONSE. In section 2 we draw a mapping of the Stern/Nordhaus controversy that decomposes the impacts of discounting, abatement costs and climate sensitivity on abatement and SCC trajectories. We present in section 3 the results of the econometric analysis which makes it possible to rank the core parameters of RESPONSE according to their relative impacts on the SCC and abatement levels. This allows us to show that beliefs on pure time preference do matter although beliefs on technological progress, the climate sensitivity or long term economic growth are also very important. We also believe that our approach could provide the climate debate with a useful transparent framework to better understand the impact of modelling choices on the assessed SCC and climate policy recommendations.

# 2 Accounting for The Stern/Nordhaus Controversy

## 2.1 A comparison of Stern and Nordhaus' modelling frameworks

We examine in this section the differences between DICE (Nordhaus, 2008) and PAGE (Stern, 2006; Hope, 2006).

[1] The climate sensitivity is the temperature increase implied by a doubling of preindustrial level of $CO_2$ concentration.

DICE and PAGE have very close modelling frameworks. They are both dynamic integrated assessment models that couple a macroeconomic optimal growth model[2] with a simple climate model. Carbon emissions are considered as an inevitable product of the production. They are responsible for a concentration increase in the atmosphere and thus for climate damage. As climate damage negatively impacts part of the production, the optimization process consists in allocating the optimal share of the output among consumption, abatement and investment, in order to maximize an intertemporal social utility function composed of the consumption of a composite good.

They both use an isoelastic social utility function $U(C) = \frac{C^{1-\alpha}}{1-\alpha}$, with $C$ the consumption of the composite good, and $\alpha$ the elasticity of marginal utility which is set at 2 in DICE and 1 (leading to $U(C) = \log(C)$) in PAGE.

They both account for a one-shot decision process and do not examine sequential decision-making.

Stern and Nordhaus share a same belief about long term economic growth ($g$ = 1.3% per year over the next century).

The most striking difference between Stern and Nordhaus' worldviews lies in the choice of the rate of pure time preference. Based on the Ramsey's formula, the discount rate $r$ writes: $r = \rho + \alpha g$, with $\rho$ the rate of pure time preference, $g$ the rate of long term economic growth, and $\alpha$ the elasticity of the marginal utility of consumption. Nordhaus advocates a positive approach to determine $\rho$ and suggests $\rho = 1.5\%$ in order to match an observed value of interest rate of 4.1% ($1.5 + 2 \times 1.3 = 4.1$). Conversely, Stern makes the case for a normative setting of the rate of pure-time preference. He argues following Ramsey (1928); Sen (1961); Solow (1974) that the only legitimate argument for placing less value on the utility of future generations is the possible extinction of mankind in the future. Then, the ratio $\frac{1}{(1+\rho)^t}$ should be interpreted as a rough estimate of the probability of extinction of mankind making $\rho = 0.1\%$ the most sound choice[3].

Although Stern and Nordhaus consider the same ranges of values provided in IPCC reports to calibrate key parameters such as climate sensitivity and the evolution of mitigation costs, they differ in the choice of the value of the parameter within those ranges. Regarding climate sensitivity they both refer to the range [1.5 °C ; 4.5 °C] given in (IPCC, 2007). While Nordhaus integrates in DICE the mean value of 3 °C, Stern deals with a so-called "high+" climate scenario (Stern, 2006, p.156, Box 6.2) in order to explore possible consequences of amplifying natural feedbacks that would rise climate sensitivity up to the range [2.4 °C ; 5.4 °C] (Murphy et al., 2004). Instead of integrating a mean value into the model, he runs PAGE with the whole spectrum of values and then computes the 5 and 95 percentiles of climate sensitivity estimates as well as the mean case to exhibit estimates of climate damages for instance[4].

Nordhaus has a rather pessimistic belief on the evolution of mitigation costs. He defines for instance a backstop price ($BK$)[5] at \$1, 200 /t$CO_2$ in 2005 which barely decreases down to \$950 /t$CO_2$ in 2100. Conversely, Stern has a rather optimistic belief on technological progress. He does not set explicitly a backstop price but estimates that mean cost of mitigation will dramatically decrease from \$61 /t$CO_2$ (for an abatement

[2]such as Ramsey-Cass-Koopmans' models (Ramsey, 1928; Koopmans, 1963; Cass, 1966).

[3]Indeed with $\rho = 0.1\%$, the expectation of a human race surviving 100 years is 0.905, while it turns out to be only 0.223 with $\rho = 1.5\%$ which looks, by far, too pessismistic

[4]The computation of these estimates are based on a probability distribution over the range of climate sensitivity which gives a greater weight to high values of climate sensitivity, with a 20% chance that climate sensitivity could be greater than 5 °C (in the "high+" case), in comparison to a normal distribution.

[5]The backstop price is the price of the technology that makes it possible to abate one hundred percent of $CO_2$ emissions

**Table 1:** Differences and similarities in Stern's and Nordhaus' models

| | Nordhaus | Stern |
|---|---|---|
| Type of model | IAMs based on an intertemporal optimal growth model | |
| Utility function | $U(C) = \frac{C^{1-\alpha}}{1-\alpha}$, with $\alpha = 2$ in DICE, $\alpha = 1$ in PAGE | |
| Decision framework | One-shot decision | |
| Economic growth | $g = 1.3\%$ | |
| Climate dynamics | Simplified carbon and temperature dynamics | |
| Discount rate | $\rho = 1.5\%$ leading to $r_N = \rho + \alpha.g = 4.1\%$ | $\rho = 0.1\%$ leading to $r_S = 1.4\%$ |
| Abatement cost | $BK = \$1,200$ /t$CO_2$ in 2005, $BK = \$950$ /t$CO_2$ in 2100 | Average cost of mitigation: from \$61 /t$CO_2$ in 2015 to \$22 /t$CO_2$ in 2050 |
| Climate sensitivity | 3 °C as the mean value of [1.5 °C ; 4.5 °C] | High+ climate scenario [2.4 °C ; 5.4 °C] with a fat tail probability distribution |
| Damage | [1% ; 5%] of GDP loss for a 4 °C increase | additional estimates including non market impacts. |

level of 7.5% of the baseline scenario) in 2015 to \$22 /t$CO_2$ in 2050 (for an abatement level of 75% of the baseline scenario). His cost estimates are mostly based on technological bottom up studies.

Regarding climate damage, Stern and Nordhaus use a quite similar quadratic damage function as for a given level of increase in temperature, PAGE and DICE give close estimate of damage amounting to few percentage points of GDP (between 1% and 5% of GDP loss for a 4 °C increase). In addition to these "mainstream" damage estimates, Stern also provides more original estimates including non market impacts which roughly double climate damage.

While the controversy mostly focused on the discounting issue as it appears as the most obvious line of division between the two approaches, this comparison of Stern and Nordhaus' worldviews suggests that differences of beliefs on climate sensitivity and abatement costs may also have an impact on results. RESPONSE allows us to disentangle and map those impacts.

## 2.2 An introduction to RESPONSE

RESPONSE belongs to the same type of IAMs as DICE and PAGE, based on an intertemporal optimization growth model coupled with a climate model[6].

The intertemporal maximization program between $t_0 = 2010$ and $T$ (with $T = 2200$)

[6] A comprehensive description of RESPONSE is provided in (Dumas et al., 2012) http://www.centre-cired.fr/IMG/pdf/CIREDWP-201241.pdf

simply writes:

$$V = \max_{A_t, C_t} \sum_{t=t_0}^{T} N_t \frac{1}{(1+\rho)^{t-t_0}} u\left(\frac{C_t}{N_t}\right), \tag{2.1}$$

where $u(.)$ is the standard logarithmic utility function, $N_t$ is the population at $t$, which is assumed to grow at an exogenous rate, $C_t$ is the consumption of a composite good at $t$, $A_t$ is the abatement of emissions at $t$ and $\rho$ is the rate of pure time preference.

This program is solved under a set of constraints.

The capital dynamics writes:

$$K_{t+1} = (1-\delta)K_t + Y(K_t, L_t) - C_t - C_a(A_t) - D(\theta_t), \tag{2.2}$$

where $K_t$ is the capital at $t$, $\delta$ is the parameter of capital depreciation (equal to 3% per year), $L_t$ is an exogenous factor of labor (adjusted with exogenous technical progress) that enters $Y$ the traditional Cobb-Douglas function of production, $C_a$, the abatement cost function, $\theta_t$, the increase in temperature in comparison to preindustrial temperature, and $D$ the quadratic damage function.

Total amount of emissions abatement $A_t$ lies in the range[0 - $E_t$], with $E_t$ the level of potential emissions which simply writes:

$$E_t = \sigma_t Y(K_t, L_t), \tag{2.3}$$

$\sigma_t$ is the carbon intensity of production.

The abatement cost $C_a$ depends on abatement $A_t$:

$$C_a(A_t) = \frac{1}{(1+\gamma)^{t-t_0}} \left(A_t\zeta + (BK-\zeta)\frac{A_t^{\nu}}{\nu}E_t^{1-\nu}\right). \tag{2.4}$$

The abatement cost is thus a sum of a linear function and a power function (with $\nu = 4$). The rate $\gamma$ of technical progress in abatement technologies is exogenous. At $t = t_0$, $\zeta$ is the marginal cost of first abatement: $C_a'(A_{t_0} = 0) = \zeta$. $BK$ stands for the price of backstop technology, which is, by definition, the marginal cost of abatement when abatement amounts to emissions $E_t$: $C_a'(A_{t_0} = E_{t_0}) = BK$.

The quadratic damage function D writes,

$$D(\theta_t, K_t) = \chi\theta_t^2 Y(K_t, L_t), \tag{2.5}$$

where $\chi$ stands for the curvature of the quadratic function.

The model also incorporates the linear three-reservoir model of carbon cycle by Nordhaus (Nordhaus and Boyer, 2003) and a temperature model resembling Schneider and Thompson's two-box model (Schneider and Thompson, 1981) in the same fashion as (Ambrosi et al., 2003; Nordhaus, 2008). At each step, temperature is a function of previous temperature and carbon stocks, and carbon stocks are functions of previous carbon stock and emissions after abatement ($E_t - A_t$).

We use the software GAMS to solve this maximizing program and compute optimal paths of abatement and optimal trajectories of SCC. We define the SCC in the same fashion as in (Nordhaus, 2008) as "the additional damage caused by an additional ton of carbon emissions. In a dynamic framework, it is the discounted value of the change in the utility of consumption denominated in terms of current consumption". To get the value of this SCC we use the shadow prices associated to the $CO_2$ concentration dynamic and the capital dynamic which are directly computed by GAMS.

## 2.3 The Stern/Nordhaus controversy reframed by RESPONSE

Our analysis of the differences between DICE and PAGE has pointed out that three main beliefs distinguish Stern and Nordhaus' worldviews: the rate of pure-time preference, abatement costs and climate sensitivity. We now show how we integrate their differences in beliefs in RESPONSE:

**Pure-time preference rate** The discount rate amounts to 4.1% in Nordhaus' setting and 1.4% in Stern's one (with the growth rate equal to 1.3% in both cases). As RESPONSE uses a logarithmic utility function, the elasticity of the marginal utility of consumption is 1 (as in PAGE) instead of 2 as in DICE. Then to recover the same overall discount rate as in DICE we are obliged to inflate the parameter of pure time preference up to 2.8. This operation is justified as Nordhaus (2008) asserts that alternative calibrations of consumption elasticity and pure time preference are allowed as long as they lead to the same real interest rate.

**Abatement costs** Nordhaus specification of abatement cost are readily put into RESPONSE. As suggested in (Nordhaus, 2008) we choose $BK$ to be $\$1,200\,/tCO_2$ in 2005 and an annual rate of technical progress of $\gamma = 0.0025\%$ over the next century in order to reach a backstop cost of $\$950\,/tCO_2$ in 2100. We choose $\zeta = \$0\,/tCO_2$ as abatement function in DICE is a power function which does not integrate any linear part. For the Stern-like setting of the abatement function, we decide to take the same backstop price $BK = \$1,200\,/tCO_2$ in 2005 and calibrate the other parameters ($\gamma$ and $\zeta$) of the function so that they fit with Stern's belief on mean cost of mitigation in 2050. Mean cost $MC$ writes:

$$MC(A_t) = \frac{C_a(A_t)}{A_t} = \frac{1}{(1+\gamma)^{t-t_0}}\left(\zeta + (BK-\zeta)\frac{A_t^{\nu-1}}{\nu}E_t^{1-\nu}\right). \qquad (2.6)$$

As abatement $A_t$ is a fraction of potential emissions $E_t$, we can replace $A_t$ with $a_tE_t$, with $a_t$ the relative level of abatement expressed as a fraction of potential emissions (i.e. $a \in [0,1]$). This leads to:

$$MC(A_t) = \frac{1}{(1+\gamma)^{t-t_0}}\left(\zeta + (BK-\zeta)\frac{a^{\nu-1}}{\nu}\right).$$

Then we solve a system of two unknowns and two equations given that, according to Stern mean cost of abatement decreases from $\$61\,/tCO_2$ in 2015 for an abatement level ($a$) of 7.5 percent to $\$22\,/tCO_2$ in 2050 for an abatement level of 75 percent, and eventually get the annual rate of technical progress $\gamma = 0.0522$ and the linear cost $\zeta = \$101\,/tCO_2$ in 2005.

**Climate sensitivity** We choose a climate sensitivity of 3 °C for Nordhaus as he explicitly retains this value in DICE. For Stern, we use the "high+" range of climate sensitivity [2.4 °C - 5.4 °C] to determine his climate sensitivity. The only information we have about the probability distribution over this range is that the mode is 3.5 °C and there is a 20% chance that climate sensitivity could be greater than 5 °C. We then set Stern's climate sensitivity at 4 °C. This difference in climate sensitivity leads to higher temperature increase for the same level of emission so that with the same BAU emission scenario climate damage hits almost 4% of total wealth in 2100 in the Stern's approach while it amounts to 2.5% of GDP in DICE.

**Table 2:** The three variables accounting for Stern and Nordhaus' differences in worldviews

| | Nordhaus | Stern |
|---|---|---|
| Pure time preference | $\rho$ = 2.8% | $\rho$ = 0.1% |
| Abatement cost in 2005 | $BK$ = \$1,200 /t$CO_2$ with low rate of decrease ($\gamma$ = 0.25% per year) and no initial marginal cost $\zeta$ = \$0 /t$CO_2$ | $BK$ = \$1,200 /t$CO_2$ with high rate of decrease ($\gamma$ = 5.22% per year) and an initial marginal cost $\zeta$ = \$101 /t$CO_2$ |
| Climate sensitivity | 3 °C | 4 °C |

To account for the Stern/Nordhaus controversy, we thus calibrate RESPONSE with two sets of beliefs as described in Table 2. Note that the purpose is not to exactly reproduce Stern's and Nordhaus' results but instead to appraise within a common modelling framework the relative impact on results of those two emblematic worldviews[7].

# 3 Mapping the Relative Impacts of Key Drivers of the Controversy

As Stern and Nordhaus mainly disagree on three parameters which can take two values each, we run RESPONSE with eight (= $2^3$) possible sets of parameters. Inside the space defined by the two polar Stern/Nordhaus worldviews there are thus six other scenarios corresponding to a mix of Stern and Nordhaus' beliefs on the discount rate, climate sensitivity, and abatement costs.

To recognize the underlying beliefs of a given worldview we define the graphical code presented in Table 3.

**Table 3:** Graphical code used in Figure 1

| | | |
|---|---|---|
| circle | (○ or ●) | low climate sensitivity |
| triangle | (▲ or △) | high climate sensitivity |
| filled | (● or ▲) | high $\rho$ |
| empty | (○ or △) | low $\rho$ |
| line | (-○- or -△-) | fast technical progress |
| no line | (○ or △) | slow technical progress |

[7]In fact, the calibration à la Stern gives results that fits quite well with Stern's recommendations in terms of SCC and abatement, while the calibration à la Nordhaus tends to underestimate by a factor of two Nordhaus's recommendations.

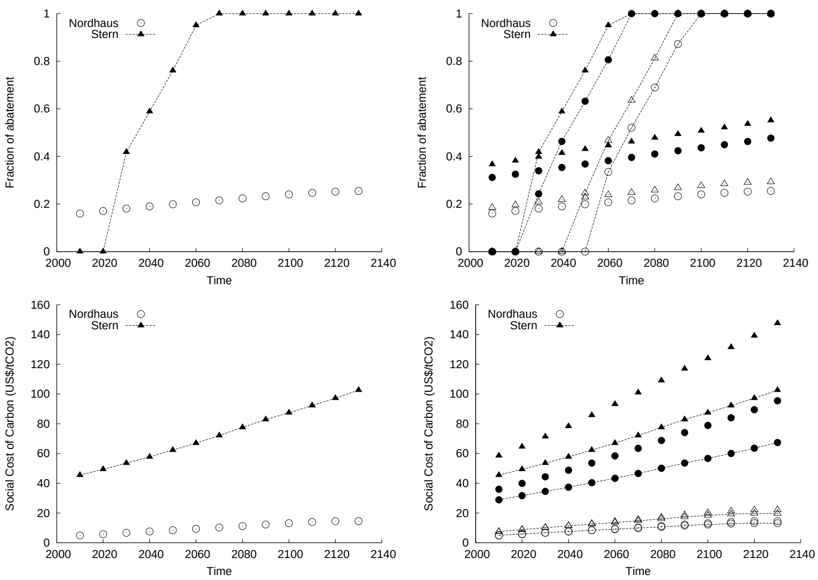


**Figure 1:** Abatement and SCC trajectories from 2010 to 2130 for Stern and Nordhaus only first and then for the six other possible worldviews resulting from a combination of Stern and Nordhaus' beliefs. Empty circles without line stand for Nordhaus trajectories. Full triangles with line stand in turn for the time profile of the Stern's optimal position.

## 3.1 Analysis of abatement and SCC trajectories

Figure 1 compares trajectories of abatement and SCC over the period 2010 - 2130. The two charts on the left side of the figure only compare Stern and Nordhaus' worldviews plugged into RESPONSE while the two charts on the right side compare eight worldviews.

Stern and Nordhaus' abatement profiles differ radically. While Stern's optimal path consists in decarbonizing the economy in a very short period of 50 years between 2020 and 2070, Nordhaus' results are much smoother with abatement effort starting in 2010 at 16 percent and then slightly increasing till 2130 up to 25.5 percent. Extending the comparison to the six other worldviews makes it possible to point out the impact of beliefs on abatement profile. Starting from the Stern profile, it happens that increasing the rate of pure time preference and/or reducing the value of the climate sensitivity does not qualitatively change the form of the abatement path. Full decarbonization is still reached in a short period of fifty years, while the very moment of mitigation efforts take-off is postponed so that abatement only starts in 2050 for instance when pure time preference is high and climate sensitivity is low. The trend of abatement changes dramatically however when beliefs on abatement costs shift from the Stern's setting of the abatement cost function to the Nordhaus'one. Indeed, in all cases with a low rate of technical progress mitigation efforts start since 2010 and keep increasing gradually over time. Pure time preference and climate sensitivity impact the initial level of abatement[8].

Regarding the SCC, all trajectories are steadily increasing. The interpretation of Nordhaus' results is quite straightforward. The SCC follows an increasing trend in

[8]The higher the climate sensitivity the higher the initial level. Conversely, the higher the rate of pure time preference, the lower the initial level of abatement

relatively low ranges of values from \$5 /t$CO_2$ in 2010 up to \$14.5 /t$CO_2$ in 2130 which directly results from the smooth trend of the mitigation path. In the Stern case the SCC increases at a higher rate from \$45 /t$CO_2$ in 2010 up to \$103 /t$CO_2$ in 2130. The steady growth during the decarbonization period from 2020 to 2070 is driven by the evolution of the marginal abatement cost. When full abatement is reached, the SCC is no longer driven by the marginal damage caused by incremental $CO_2$ emissions. As for the other intermediate worldviews, we notice that mitigation cost does not impact the form of the trajectory while pure time preference and climate sensitivity impact the level of the SCC. The higher the rate of pure time preference the lower the SCC, the higher the climate sensitivity the higher the SCC.

## 3.2 Reframing the controversy in the abatement/SCC space

The striking results that arise from figure 1 is that technical progress on abatement costs has a critical impact on abatement paths while the rate of pure time preference significantly impacts the SCC, although both parameters cannot alone account for the whole difference between Stern and Nordhaus worldviews.

With low rate of technical progress, abatement levels never exceed 55% by 2130, while, with high rate of technological progress, abatement always ends up at 100% by 2100. In turn, beliefs on the climate sensitivity have both an impact on abatement and the SCC.

A Nordhaus run with a Stern-like discount rate (filled circles with no line) yields at first glance quite similar levels of SCC as in the Stern run (from 36 to \$95 /t$CO_2$). We argue however that these respective Stern and Nordhaus SCC must not be confused as they result from totally different levels of abatement. In the Nordhaus case abatement barely reaches half of the emissions in 2130, while in the Stern case full abatement is reached since 2050. Symmetrically, the change of pure time preference in the Stern run has a significant impact on results as the SCC lowers dramatically down to the range [\$7 – 20 /t$CO_2$] while the abatement trajectory does not change qualitatively as mitigation take-off is only postponed to 2050 and reaches 100 percent in 2090. This suggests that comparing levels of SCC alone, and therefore rates of pure time preference, is not policy relevant as similar SCC or rates of pure time preference can be related to very different mitigation trajectories. Then beliefs on abatement costs and climate sensitivity must also be considered to compare results from different worldviews. Starting from the Nordhaus' case for instance, it is possible by construction to recover Stern's results by changing in turn Nordhaus' beliefs till recovering Stern's set of beliefs and *vice versa*. Running Nordhaus' worldview with high climate sensitivity slightly increases results both in terms of SCC and abatement. The combination of low discount and high sensitivity leads to much higher results (full triangles with no lines) that exceed Stern's results in terms of SCC while abatement increases slower and ends up at a much lower level than in the Stern's run. Then changing abatement costs makes it possible to recover Stern's time profile.

To sum up, these results allow us to qualify the role played by the discount rate in the Stern/Nordhaus controversy as only a broader set of beliefs must be considered to account for differences in worldviews and thus in climate policies recommendation. In the next section we go beyond this graphical rationale and use a linear econometric model to measure the respective impact of beliefs on the key drivers of the SCC and mitigation efforts.

## 4 Disentangling the Relative Impact of Key Drivers of the Controversy: a Quantitative Analysis

A comprehensive sensitivity analysis on six key parameters of RESPONSE (taking five values each in ranges summarized in table 4) allows us to fill up a grid of results with 15625 scenarios. The grid is built so that each scenario appears on a single row where the values of both the SCC and abatement are given for 13 consecutive dates from 2010 to 2130. Hence, the whole set of scenarios can be considered as a single cross-section of scenarios and is suitable to a sound statistical analysis which will allow us to quantitatively appraise the respective impact of core parameters of RESPONSE on the SCC and abatement.

**Table 4:** Sensitivity analysis over 6 key parameters of RESPONSE

| | |
|---|---|
| Growth rate ($g$) | 1% - 2.1% |
| Pure time preference ($\rho$) | 0.1% - 2.8% |
| Climate sensitivity ($\vartheta$) | 2 °C - 6 °C |
| Climate damage (curvature parameter $\chi$) | 0.00116 - 0.00452 |
| Linear cost ($\zeta$) | \$0 /t$CO_2$ - \$229 /t$CO_2$ |
| Annual rate of technical progress ($\gamma$) | 0.25% - 5.22% |

Here, we describe step by step the methodology. We first estimate regression equations for the two variables of interest, namely the SCC and abatement, with both ordinary least squares (OLS) and corrected heteroskedasticity generalized least-squares (GLS) estimators. Regression equations are composed of six explanatory variables, namely the rate of pure time preference, the rate of technical progress on abatement cost, climate sensitivity, the rate of long term growth, and the forms of both the climate damage and abatement cost functions.

The regression equations expressions at each date are thus given by:

$$SCC_t = \beta_{0t} + \beta_{1t}\rho + \beta_{2t}\gamma + \beta_{3t}\zeta + \beta_{4t}\vartheta + \beta_{5t}g + \beta_{6t}\chi,$$

and

$$Abat_t = \alpha_{0t} + \alpha_{1t}\rho + \alpha_{2t}\gamma + \alpha_{3t}\zeta + \alpha_{4t}\vartheta + \alpha_{5t}g + \alpha_{6t}\chi,$$

with $\alpha_i$ and $\beta_i$ the regression coefficients.

The linear form of the models is satisfactory because the fits are very high for such large cross-sections. Figure 2 shows that $R^2$ computed at each date are comprised between 0.54 and 0.90 for both *Abat* and *SCC*. These rather unusually high levels of fit suggest a very good adjustment of the linear models. Note however that the values of the $R^2$ is not constant over time. In the case of abatement the $R^2$ starts from its lowest level (0.54) in 2010, then culminates in 2070 at 0.90 and eventually slightly decreases down to 0.78 in 2130. Regarding the SCC, the $R^2$ is rather constant till 2050 around 0.7, and then on decreases down to 0.56 in 2130.

Results show that the six parameters are important and the regression coefficients $\alpha_i$ and $\beta_i$ are significantly non null.

Coefficient standard errors which were computed by the delta method (Greene, 2011) are very small. Then t-stats are highly significant as none of them yield results

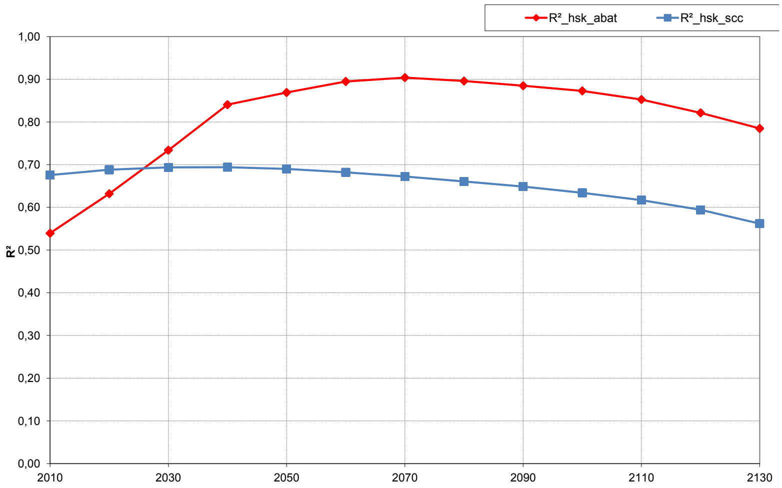


**Figure 2:** The chart represents the evolution over the period 2010 - 2030 of the $R^2$ computed for both *Abat* and $SCC$

below several tens.[9] Still, residuals show some uncorrected heterogeneity that obliges us to interpret them cautiously. It seems that the residuals are affected by very large outliers which were not corrected in the present results and may be the principal source of heterogeneity in the models.

Second we derive from each estimated coefficient $\alpha_i$ and $\beta_i$ at each date the corresponding mean point elasticity $\eta_i$ and $\gamma_i$ according to the following formula (Greene, 2011):

$$\eta_i = \alpha_i \frac{\overline{x}_i}{\overline{SCC}},$$

and

$$\gamma_i = \beta_i \frac{\overline{x}_i}{\overline{Abat}}$$

where $\overline{x}_i$ is the mean of the explanatory variable $x_i$, and $\overline{SCC}$ and $\overline{Abat}$ the mean of the explained variables, i.e. the SCC and the abatement at each date[10].

These elasticities at each point in time allow us to appraise the evolution of the respective impact of the six explanatory variables on the SCC and the level of abatement. Elasticities' results should be read that way: an elasticity of $-0.68$ of the parameter $\rho$ in 2040 for instance means that a one percent increase of the rate of pure time preference in 2040 implies a $-0.68$ percent decrease in the SCC in 2040. All computations were performed in the GRETL econometrics software (Cottrell and Lucchetti, 2011).

[9]t-stats are considered as significant as they yield results above 2

[10]Note that the use of a log-linear model would have made it possible to directly interpret regression coefficients as elasticities. However, as some of the scenarios give nil values for abatement levels at the beginning of the period, the log-linear form was not suitable. Indeed it would have obliged us to remove those undefined values from the grid and therefore to lose relevant information.

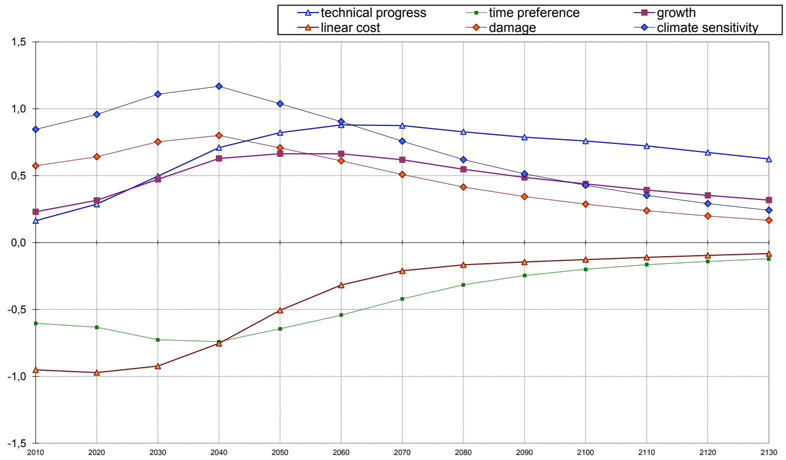


**Figure 3:** The chart represents the evolution over the period 2010 - 2130 of mean point elasticities of abatement

For all of these results, given that the GLS estimator is consistent, standard errors of the elasticities are too small to be reported. Hence our results are highly significant at the usual levels and we only plot the elasticities themselves.

Time profiles of the elasticities over the period 2010 - 2130 are plotted in Figures 3 and 4.

Restricting[11] the analysis to the three key drivers of the Stern/Nordhaus controversy (namely pure time preference, technical progress and climate sensitivity), we note that technical progress has opposite impacts on the SCC and abatement, driving up abatement and driving slightly down the SCC while pure time preference and climate sensitivity have respectively negative and positive impacts on both the abatement and the SCC.

Over the period 2010 - 2130 the three variables have a growing impact on abatement that peak in 2040 for pure time preference and climate sensitivity and in 2070 for technical progress. From 2060 the impact of technical progress becomes preponderant as the impacts of both climate sensitivity and pure time preference decrease steadily till 2130. Note that from 2050 on the impacts of both technical progress and climate sensitivity outweigh the impact of pure time preference.

Regarding the impacts on the SCC, a different pattern comes up in Figure 4. Elasticities curves are flat (except for the rate of long term economic growth) which means that elasticities are constant over time. Technical progress on abatement cost has a much lower impact (with an elasticity of $-0.07$) on the SCC than on abatement. As in the abatement case, climate sensitivity and pure time preference have opposite impact,

[11] As the same analysis performed on a reduced statistical model only composed of the three variables that distinguish Stern and Nordhaus yielded the same pattern of elasticities profiles and did not alter either the sign nor the ranking of the respective impact of variables on results we only present the complete statistical model.

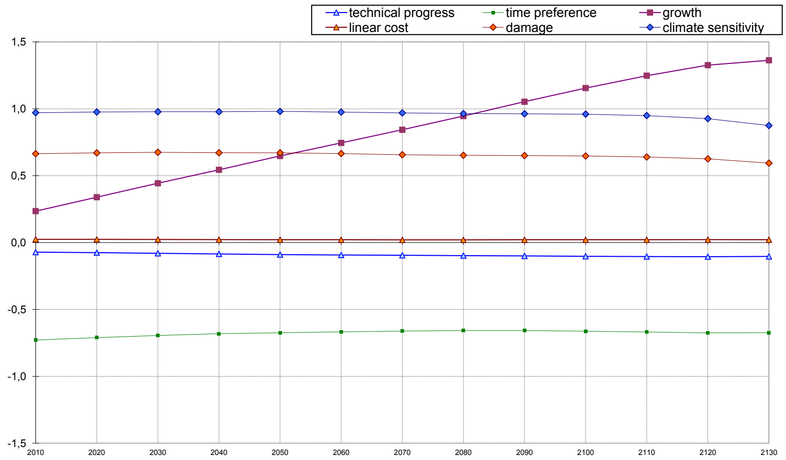


**Figure 4:** The chart represents the evolution over the period 2010 - 2130 of mean point elasticities of the SCC

the elasticities of the former (around 1) being greater than the ones of the latter (around $-0.7$).

In both cases, the striking result is that the impact of beliefs on pure time preference is not preponderant and that the impacts of beliefs on technological progress and climate sensitivity are also important. Those results clearly make the case for qualifying the actual role of the discounting issue in the Stern/Nordhaus controversy.

Eventually, extending the analysis to other core parameters of RESPONSE, it turns out that the rate of long term economic growth and the form of the climate damage function have significant impacts. Elasticities of $\zeta$ (the linear part of the abatement cost function) however is either close to zero in the SCC case, or decreasing over time and tending to zero in the abatement case (due to technological progress). Note that the elasticity of economic growth $g$ has an increasing profile in the SCC case and ends up with a very high value of mean elasticity of 1.4.

# 5 Toward a Transparent Modelling Framework to Negotiate Climate Policies

Disentangling the Stern/Nordaus controversy requires to go beyond the discounting clash that has been heavily commented. Accurate review of the calibration of both DICE and PAGE reveals at least two other major lines of division between Stern and Nordhaus on the climate sensitivity and technical progress on abatement costs. RESPONSE makes it possible to map the relative impact of these three key drivers of the controversy. While technical progress has a critical impact on optimal abatement path, pure time preference has a significant impact on the level of the SCC. Still, we show that similar levels of SCC can be related to very different climate policies. This indicates that pure time preference alone cannot account for the whole gap of results. This is undoubtedly due to the interplay of the other beliefs that compose each worldview.

Then, by means of a statistical analysis over the results of a broad sensitivity analysis on the key parameters of RESPONSE, we point out the mean elasticities of this key parameters at different points in time. Our results clearly suggest that the rate of pure time preference has a significant impact on both abatement and the SCC although other beliefs on technical progress, climate sensitivity, the rate of long term economic growth and the form of climate damages also significantly matter.

Hence, if a Social Cost of Carbon were to be negotiated among countries, the take-away message of this analysis for decision-makers would be that they should not focus too much on the setting of the discount rate which is only one driver of the results. Instead, a more comprehensive analysis of each component of the worldviews expressed in the debate would better reveal the stumbling blocks of negotiations or conversely indicate the possible ways toward an agreement.

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## References

Ambrosi, P., Hourcade, J., Hallegatte, S., Lecocq, F., Dumas, P., and Ha-Duong, M. (2003). Optimal control models and elicitation of attitudes towards climate damages. *Environmental Modeling and Assessment*, 8(3):133–147.

Cass, D. (1966). Optimum growth in an aggregative model of capital accumulation: A turnpike theorem. *Econometrica: Journal of the Econometric Society*, 34(4):833–850.

Chichilnisky, G. and Heal, G. (1993). Global environmental risks. *The Journal of Economic Perspectives*, 7(4):65–86.

Cottrell, A. and Lucchetti, R. (2011). gretl user's guide–gnu regression, econometrics and time-series library.

Dasgupta, P. (2007). Commentary: The stern review's economics of climate change. *National Institute Economic Review*, 199(1):4–7.

Dumas, P., Espagne, E., Perrissin-Fabert, B., and Pottier, A. (2012). Comprehensive description of the integrated assessment model RESPONSE. Working Paper CIRED.

Goulder, L. and Mathai, K. (2000). Optimal CO2 abatement in the presence of induced technological change. *Journal of Environmental Economics and Management*, 39(1):1–38.

Greene, W. H. (2011). *Econometric Analysis*. Prentice Hall, 7th edition.

Ha-Duong, M. (1998). Quasi-option value and climate policy choices. *Energy Economics*, 20(5-6):599–620.

Ha-Duong, M., Grubb, M., and Hourcade, J. (1997). Influence of socioeconomic inertia and uncertainty on optimal CO2-emission abatement. *Nature*, 390(6657):270–273.

Hope, C. (2006). The marginal impact of co2 from page2002: An integrated assessment model incorporating the ipcc's five reasons for concern. *Integrated assessment*, 6(1):19–56.

IPCC (2007). *Climate change 2007: Mitigation. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, UK and New York.

Kolstad, C. (1996). Fundamental irreversibilities in stock externalities. *Journal of Public Economics*, 60(2):221–233.

Koopmans, T. (1963). Appendix to'on the concept of optimal economic growth'. Cowles Foundation Discussion Papers.

Manne, A. and Richels, R. (1992). *Buying greenhouse insurance: the economic costs of carbon dioxide emission limits*. The MIT Press.

Murphy, J., Sexton, D., Barnett, D., Jones, G., Webb, M., Collins, M., and Stainforth, D. (2004). Quantification of modelling uncertainties in a large ensemble of climate change simulations. *Nature*, 430(7001):768–772.

Nordhaus, W. (2007). A Review of the" Stern Review on the Economics of Climate Change". *Journal of Economic Literature*, 45(3):686–702.

Nordhaus, W. (2008). *A question of balance*. Yale University Press.

Nordhaus, W. (2011). Estimates of the social cost of carbon: Background and results from the rice-2011 model. Cowles Foundation for Research in Economics.

Nordhaus, W. and Boyer, J. (2003). *Warming the world: economic models of global warming*. the MIT Press.

Pearce, D. (2003). The social cost of carbon and its policy implications. *Oxford Review of Economic Policy*, 19(3):362.

Perrissin-Fabert, B., Dumas, P., and Hourcade, J.-C. (2012). What social cost of carbon? a mapping of the climate debate. *FEEM NOTA DI LAVORO*.

Pindyck, R. (2000). Irreversibilities and the timing of environmental policy. *Resource and energy economics*, 22(3):233–259.

Ramsey, F. (1928). A mathematical theory of saving. *The Economic Journal*, 38(152):543–559.

Schneider, S. and Thompson, S. (1981). Atmospheric co2 and climate: importance of the transient response. *Journal of Geophysical Research*, 86(C4):3135–3147.

Sen, A. (1961). On optimising the rate of saving. *The Economic Journal*, 71(283):479–496.

Solow, R. (1974). The economics of resources or the resources of economics. *The American Economic Review, Papers and Proceedings of the Eighty-sixth Annual Meeting of the American Economic Association*, 64(2):1–14. Papers and Proceedings of the Eighty-sixth Annual Meeting of the American Economic Association.

Stern, N. (2006). *The Economics of Climate Change. The Stern Review*. Cambridge University Press.

Tol, R. (2005). The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties. *Energy policy*, 33(16):2064–2074.

Tol, R. (2008). The social cost of carbon: trends, outliers and catastrophes. *Economics: The Open-Access, Open-Assessment E-Journal*, 2(25):1–22.

Ulph, A. and Ulph, D. (1997). Global warming, irreversibility and learning. *The Economic Journal*, 107(442):636–650.

Weitzman, M. (2007). A review of the Stern Review on the economics of climate change. *Journal of Economic Literature*, 45(3):703–724.

Yohe, G. and Tol, R. (2007). The stern review: implications for climate change. *Environment: Science and Policy for Sustainable Development*, 49(2):36–43.

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