Chapter 5

Discounting long-term effects of climate change for transport

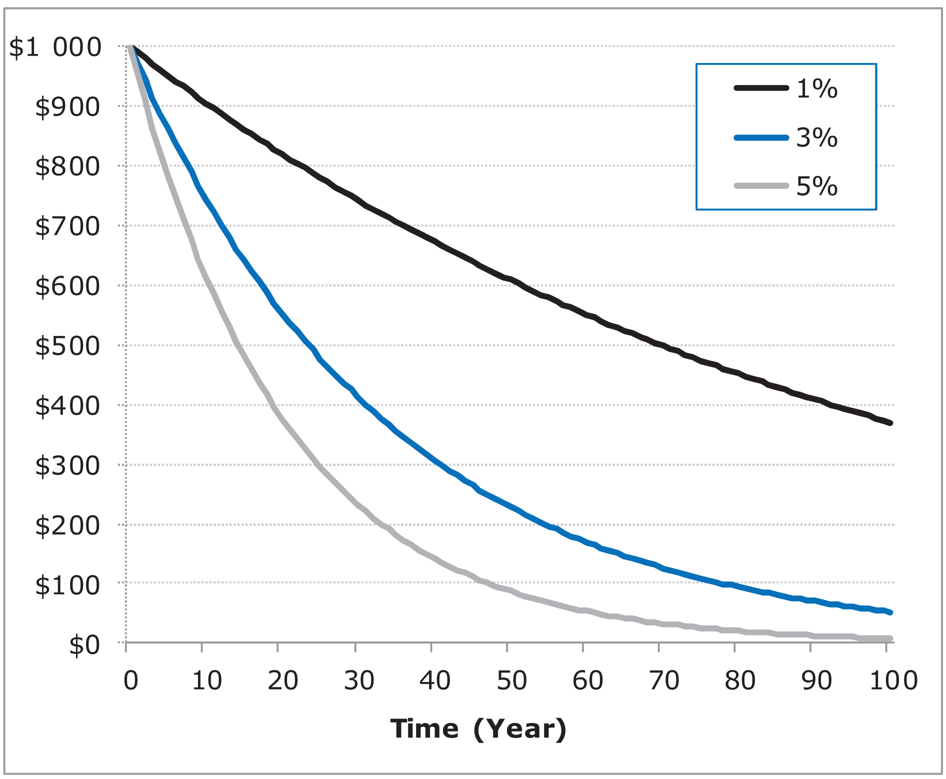
This chapter looks at the theories and approaches to establish a discount rate for assessing long-term projects, discounting under risk and uncertainty and a comparison of how various countries have applied discount rates for climate change projects and policies.

The importance of the discount rate

Discounting is an integral part of any analysis such as cost-benefit analysis (CBA) that considers the costs and benefits over a number of years. Its aim is to express all costs and benefits in terms of their present value by assigning smaller weights to those that occur further in the future than to those that occur more immediately.

The CBA of long-term projects is particularly sensitive to the choice of the discount rate. For example, at an annual discount rate of 3%, the present value of $1 000 in 30 years' time is $412, compared to $231 at 5% and $742 at 1% (Figure 5.1). In 100 years' time, the present value of $1 000 reduces to $52 (at 3%), $8 (at 5%) and $370 (at 1%).

Figure 5.1. **Present value (of $1 000) varies by discount rate and time**



"While everyone agrees that the choice of discount rate is a crucial determinant of the value of public projects, there is less agreement on the appropriate discount rate to use to calculate present value. Academics, cost-benefit guides and textbooks give widely conflicting advice." (Harrison, 2010)

Discount rates and intergenerational concerns

Discounting can be adjusted to address intergenerational problems, which are often emphasised in the climate context. In tackling climate change there is a perceived need for the current generation to sacrifice their well-being in order to preserve the well-being of future generations. There are a number of ways that the current generation can protect the welfare of future generations, including leaving them with physical capital stock or better environmental stock (Harrison, 2010).

The choice of discount rate reflects the level of altruism the current generation has towards future generations. A higher discount rate ascribes future benefits lower weightings. With a high discount rate, few climate policies would pass the CBA test, resulting in less investment to protect future generations from global warming. But a low discount rate can sometimes also encourage counter-productive policies or projects from a climate policy perspective (OECD, 2007). For example, a low discount rate can encourage investment in long-lived coal-fired power stations with low operating costs but long pay-back periods for recovering capital investment instead of investment in gas-fired plants that have the opposite characteristics; high operating costs but a shorter pay-back period. Using a low discount rate also means that the current generation could invest in low-return projects at the expense of investments with higher return and thus make future generation worse off (Harrison, 2010).

There are two main approaches to determine discount rates for projects affecting future generations. They are the “prescriptive” and “descriptive” approaches to discount rate selection (Arrow et al., 1996; Harrison, 2010; Arrow et al., 2013a).

The prescriptive approach directly specifies a discount rate or parameters used in estimating the discount rate based on ethical principles or policy choices. Where the “prescriptive” approach to setting the discount rate is chosen, setting a high discount rate or even a flat discount rate could be seen as “unethical” (e.g. Ramsey, 1928). Under this approach, the social pure time preference becomes a “policy parameter” (Pindyck, 2013), which balances the welfare of current and future generations. If both generations are to be treated equally, the social rate of pure time preference should be lower (or zero), implying a lower discount rate. If the current generation is to be given more weight than the future generation, the rate of pure time preference increases, leading to a higher discount rate.

The descriptive approach, on the other hand, sets the discount rate based on observation of market behaviour (Pearce and Ulph, 1999; OECD, 2007; Kane, 2012). For example, the parameters in the Ramsey formula can be inferred by using empirical evidence to estimate the population’s rate of time preference. Proponents of the descriptive approach suggest that the discount rate should approximate the market interest rates for long-term financial assets (such as government bonds) (Barro and Becker, 1989; Harrison, 2010; Kane, 2012). However, “market rates are conceptually distinct from a social discount rate” and “only reflect the preferences of current individuals, about their current decisions” and “not the interests of future individuals nor the preferences of current individuals about intergenerational matters” (OECD, 2007).

In a traditional transport appraisal framework, the discount rate is often assumed to be constant over time. Having a constant discount rate means individuals are time-consistent and that their later preferences confirm earlier preferences (Frederick et al., 2002). The theory of a declining discount rate was first developed by Weitzman (1998) and subsequently by Gollier and Weitzman (2010) and Freeman (2010). A key conclusion from those studies is that when future discount rates are uncertain, then the “effective” (or certainty-equivalent) discount rate must decline over time towards its lowest possible value (Gollier and Weitzman, 2010; Freeman, 2010 and USG, 2010).

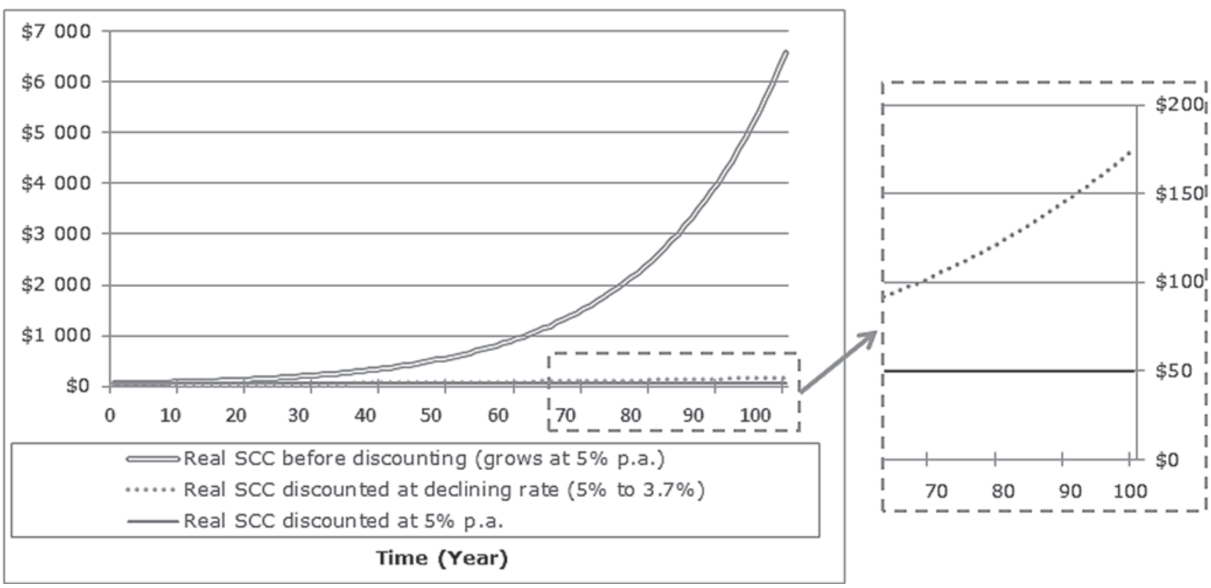
Empirical literature seems to conform to the theory that discount rates are not constant over time (OECD, 2007 or Frederick et al., 2002). In their literature review, Frederick et al. (2002) found some empirical regularities regarding to discount rate including: asymmetric preference between gains and losses (gains are discounted more); small amounts are discounted more than large amounts and people seem to have a preference for spreading consumption over time. In addition, results from experiments[1] suggest that the discount function at the individual level declines over time (OECD, 2007).

Typical arguments for a declining discount rate include: falling economic growth rates, the uncertainty associated with future growth in per capita consumption and economic conditions, shocks to consumption due to catastrophic risks, changes to or heterogeneity in future preferences and intergenerational equity (OECD, 2007; Gollier and Weitzman, 2010; Arrow et al., 2014).

To illustrate the effects of discount rate on real SCC, Figure 5.2 provides a stylised illustration of the effect where real SCC grows at 5% per annum. Assuming the real SCC in year 0 is $50 per tonne of CO_2, it increases to around $6 600 after 100 years (before discounting).

If these values were discounted at a constant 5% per annum (i.e. same as the rate of increase in real SCC), the present value of real SCC will remain unchanged over time (at $50 in this example). On the other hand, if the estimates were discounted at a declining discount rate (e.g. from 5% reducing to 3.7%), the real SCC in present value after 100 years would be much higher. In this stylised example, it is around $175 per tonne of CO_2.

Figure 5.2. **Stylised interpretation of the effect of discounting on carbon value (t/CO_2)**



Discount rates for long-term projects

Discounting is a means for assessing outcomes over time by reference to individual, market or social preferences (especially for decisions that affect a long time-horizon). There are two commonly cited arguments for why this is necessary – positive time preference and the opportunity cost of investment (Harrison, 2010). These two arguments vary by the assumption as to whether private consumption or private investment will be displaced by public investment decisions. The marginal social cost of capital approach[2] based on the Capital Asset Pricing Model framework is a common approach to establish a discount rate to account for the displacement of private investment. This approach has been used by some countries (e.g. New Zealand and Japan) to determine the public sector discount rate. However, the pure time preference and the displacement of private consumption approach have received most attention in the current social discount rate literature due to its relevance to the assessment of the welfare of future generations (e.g. Weitzman, 2012 and Armtiage, 2014). The following chapters briefly outline three such approaches.

Ramsey formula

The positive time preference argument asserts that most individuals have a "pure preference" for the present, and also expect that as incomes increase over time the marginal utility of consumption declines and therefore they would prefer to consume now than to consume in the future. Otherwise, they would have to be compensated (e.g. through interest on savings) for delaying the consumption until the future.

The approach used to determine the discount rate under the positive time preference argument is the **social rate of time preference (SRTP)**. This approach reflects the impact of savings and investment on domestic consumption and the time preference individuals have on consumption today over the same level of consumption at a later date. It suggests the correct discount rate should be the rate at which a society is willing to postpone current consumption in exchange for future consumption without any change in overall wellbeing.

Box 5.1. **Ramsey formula**

The Ramsey formula, which has led academic research since the 1920s (Ramsey 1928) defines the discount rate (ρ_t) as follows:

$$\rho_t = \delta + \eta\, g_t.$$

δ	represents pure time preferences, which reflects individuals' preference for consumption now rather than in the future
η	the absolute value of the elasticity of marginal utility of consumption
g_t	the expected growth rate in per capita consumption between now and time t.
$\eta\, g_t$	represents the wealth effect related to the idea that future generations will be better off compared to present generations.

Although literature has suggested using the after-tax rate of return of low-risk marketable securities (such as government bonds) to approximate SRTP, the commonly used approach is the formula developed by Ramsey in 1928 (Box 5.1). The Ramsey formula has two key components, the pure time preference (δ) and the diminishing marginal utility of consumption over time ($\eta\, g_t$). The elasticity of marginal utility of consumption (η) represents the curvature of the utility function, a measure of aversion to interpersonal inequality and a measure of personal risk aversion[3] (Weitzman, 2007).

In the Ramsey formula, the discount rate is expressed as a function of expected growth rate in per capita consumption, therefore the resulting discount rate is not constant over time. If future consumption growth will be positively correlated with economic cycles (i.e. cyclical), the discount rate should vary with the economic cycles (OECD, 2007).

Extended Ramsey formula

The Ramsey formula has often been used as a basis for intergenerational discounting by including an extra term to account for the precautionary effect around future rate of growth in consumption (Box 5.2) (Gollier, 2002; Weitzman, 2007; OECD, 2007; Arrow et al., 2013b and Cropper et al., 2014). According to this formula, the precautionary effect gets bigger as the variance of future consumption increases and therefore results in a lower discount rate.

Box 5.2. **Extended Ramsey formula to account for precautionary effect** (note)

The modified Ramsey formula is given by:

$\rho_t = \delta + \eta\, g_t - \frac{1}{2}\eta^2 \sigma_g^2$

where:

ρ_t, δ, η and g_t are defined as in Box 5.1.

σ_g^2 variance of consumption at time t, and

$\frac{1}{2}\eta^2 \sigma_g^2$ a precautionary effect.

Note: This formula assumes growth rate in consumption is independently and identically distributed over time (i.e. it follows a random walk or arithmetic Brownian motion).

Systemic risk-adjusted Ramsey formula

Although there has been no consensus on the discount rate for public sector appraisal, there is some consensus on the need to account for the uncertainty associated with the linkages between future project benefits and future macroeconomic conditions (e.g. Weitzman, 2007 & 2012; Quinet, 2013; Gollier, 2013 & 2014). Related literature mentions another conceptual version of the Ramsey formula, the systemic risk-adjusted SRTP[4]. This approach is similar to the extended Ramsey formula with an extra term that links project benefits and costs with Gross Domestic Product (GDP).

In this approach, the discount rate is expressed as the sum of the risk-free interest rate plus the product of the risk premium[5] (φ) and the correlation between project benefits and economic activity (β) (Box 5.3). The risk-free interest rate is the same as the extended Ramsey formula (Box 5.2). This systemic risk-adjusted Ramsey formula is referred as the consumption-based CAPM by Gollier (2014) because of its similarity to the standard CAPM[6]. Gollier (2014) shows that systemic risk premium increase with uncertainty over time and therefore the risk-adjusted discount rate can increase over time if the beta is higher than $\eta/2$.

Box 5.3. **Systemic risk-adjusted Ramsey formula** (note)

The systemic risk-adjusted social rate of time preference is given by:

$r = r_f + \varphi \beta$

where:

r is the risk-factored discount rate specific to the project

r_f is the risk-free rate (i.e. the extended Ramsey formula);

$r_f = \delta + \eta g_t - ½ \eta^2 \sigma_g^2$

φ is the general risk premium, a parameter common to all projects, that measures the amplitude of the long-term systemic risks linked to macro-economic trends;

$\varphi = \eta \sigma_g^2$

β is beta, a project-specific parameter that measures the correlation between project benefits and economic activity.

Note: This formula assumes the evolution of economic activity is independently and identically distributed over time (i.e. it follows a random walk or arithmetic Brownian motion).

The key rationale of this approach is that each project entails various types of risk, including those that are associated with the future overall macroeconomic conditions (i.e. φ). If the project's benefits are positively correlated with the macro-economic conditions (i.e. β is positive), the risk on project returns gets amplified, particularly in the case of large-scale transport projects in which the returns would be unexpectedly lower under bad macro-economic outcomes.

For transport projects, key benefits (such as time savings) are typically subject to uncertainty. There is also a risk around unexpected change in travel demand. Facing this risk, investors (including governments) would be more cautious in their decision making, leading them to increase the discount rate: whenever future travel demand is heavily affected by the macroeconomic conditions, the distribution of future outcomes becomes more spread, hence inducing a positive risk premium.

For climate policy, on the other hand, the issue is more complicated as the correlation between the returns from climate policy and the risk at the macro-economic level is unclear. As the economy grows, more activities, including transport, produce more GHG. This implies a positive correlation between GHG emissions and the macroeconomic conditions. However, emissions may also have a negative impact on economic growth, as climate impacts may cause significant damages to the economy. Due to the presence of this feedback effect, the overall effects are ambiguous.

One benefit of this systemic risk-adjusted SRTP is that it allows calculation of the discount rate project by project (Quinet, 2013). Since the discount rate is determined by three factors (the risk-free rate, the beta correlation between projects and the economy, and the risk premium), it can be constant or it can vary over time-period depending on the values of the parameters chosen.

Discounting under risk and uncertainty

There are two broad categories of uncertainty that affect the choice of discount rate. They are the uncertainty around future interest rates and/or the components of the social discount rate (such as growth) and the uncertainty around future benefits[7] due to project risks.

Uncertainty without project risk

Without project risks, a risk neutral social planner will adopt a discount rate close to the risk-free rate (based on the extended Ramsey formula). When the discount rate is unknown, the literature suggests using different choices of discount rate to derive the certainty equivalent (CE) discount rate (e.g. Weitzman, 1998 and Gollier and Weitzman, 2010). The key argument of this approach is that what should be probability-averaged are not the future discount rates at various time periods but the future discount factors (Weitzman, 1998; Freeman, 2010 and Traeger, 2013). Discount factors are the factors by which future cash flows must be multiplied to obtain the present value, i.e., if the discount rate is d, the discount factor for year i is represented by $\frac{1}{(1+d)^i}$.

To illustrate the approach, Table 5.1 shows how discount rates can be combined. The average discount factors for 3% and 7% discount rates are higher than the discount factors for a 5% discount rate (i.e. average of 3% and 7%). The implicit discount rate derived from the average discount factors is called the certainty-equivalent (CE) discount rate (Weitzman, 1998). In this example, the CE discount rate declines over time and approaches the low-end of the discount rate range over time. Thus, the risk-free rate may decline over time due to uncertainty.

Table 5.1. **Numerical example of a declining certainty-equivalent discount rate**

Year	Discount factor for a 3% rate	Discount factor for a 7% rate	Certainty-equivalent discount factor (average) - note	Certainty-equivalent discount rate
1	0.971	0.935	0.953	5.0%
10	0.744	0.508	0.626	4.8%
20	0.554	0.258	0.406	4.6%
30	0.412	0.131	0.272	4.4%
40	0.307	0.067	0.187	4.3%
50	0.228	0.034	0.131	4.1%
60	0.170	0.017	0.093	4.0%
70	0.126	0.009	0.068	3.9%
80	0.094	0.004	0.049	3.8%
90	0.070	0.002	0.036	3.8%
100	0.052	0.001	0.027	3.7%
200	0.003	1.33E-06	0.001	3.4%
300	1.41E-04	1.53E-09	7.04E-05	3.2%
400	7.33E-06	1.76E-12	3.67E-06	3.2%

Note: This example assumes the probability for the two discount rates to occur is the same. If the estimates of probability for different discount rates (could be more than two) are available, the probability-weighted average should be used. These probability-weights can differ between time periods (Gollier and Weitzman, 2010).

The CE approach is one way to gauge what the average discount rate would be at different points in time. However, for the CE approach to be valid, it is necessary for the discount rate to be persistent (i.e. period of low or high will tend to be followed by further periods of low or high rates). Literature has found evidence to support this persistency in interest rate (e.g. OECD, 2007; Groom et al., 2007; Freeman et al., 2013).

Uncertainty with project risk

According to Arrow and Lind (1970) the total risk of public investment can be shared between a large number of individuals and therefore the risk burden to individuals for inclusion in CBA becomes negligible. Due to transaction costs and market imperfections, however, the risk premium for a public investment is not zero. It has been suggested (e.g. Sandmo, 1972; Weitzman, 2012; Quinet, 2013 and Gollier, 2014) that the public sector's discount rates should include a risk premium. With project risks, project benefits become uncertain. In theory, the risk premium is likely to increase with uncertainty. As noted, while the risk-free rate may decline over time due to uncertainty, the risk premium is likely to increase over time. Therefore, the systemic risk-adjusted discount rate (e.g. using the systemic risk-adjusted Ramsey formula) can increase or decrease over time, depending on the relative force of the two effects (Gollier, 2014).

Risk and uncertainty

To account for the preceding treatment of uncertainty with and without project risk in CBA, a common approach would be to apply objective probability distributions (of risk) to economic growth and project returns, taking account of correlations. Theoretically speaking, however, such an approach only considers risk but not Knightian uncertainty. As distinguished by Knight (1921), measureable uncertainty (i.e. risk) is "so far different from an unmeasured one that it is not in effect an uncertainty at all". Since uncertainty is not measureable, it is simply not possible to assign a probability or statistical distribution to estimate the expected outcomes. In practice though, the magnitude of the macro-economic risk premium captures a certain degree of uncertainty. This risk premium may be supported by probability distributions of growth scenarios, and in Quinet (2013) by a more general subjective description of the magnitude of the uncertain macro-economic risk. In the latter case, risk and uncertainty are mingled together and their combined consequences are captured to a certain degree, which overstates low risk and small Knightian uncertainty but understates extreme risks and high Knightian uncertainty.

In recent literature (e.g. Klibanoff et al., 2005 and Traeger, 2014), there are models that attempt to examine how ambiguity (one of the multiple forms of uncertainty) affects the discount rate. These models apply a subjective probability distribution over objective probability distributions to capture the uncertainty about the correct objective probability distribution (Traeger, 2014). Results show that "a decision-maker who is more averse to ambiguity than to risk will lower the discount rate more for [ambiguity] than for [risk]" (Traeger, 2014). As the wide area of research currently being developed beyond the classical expected utility maximising framework produces results and improves over time, practical steps to account for some aspect of Knightian uncertainty may become possible.

International comparison

This section briefly summarises discount rate practices from the partial survey of OECD member countries. Box 5.4 provides more details on each country's approach.

Currently, different countries apply different discount rates in CBAs (Table 5.2). The marginal social opportunity cost of capital and the social rate of time preference are the two key approaches used by most jurisdictions to estimate discount rates. The former methodology tends to result in a higher discount rate. Differences in preferences, term structure of interest rate, correlation between projects and economic conditions also contribute to the observed differences in the discount rates chosen.

The United Kingdom and Norway adjust the discount rate[8] for the risk associated with long-term effects by adopting a declining schedule. The Netherlands, Germany and the United States instead adopt a lower but constant discount rate.

Table 5.2. **Transport sector discount rate in different countries**

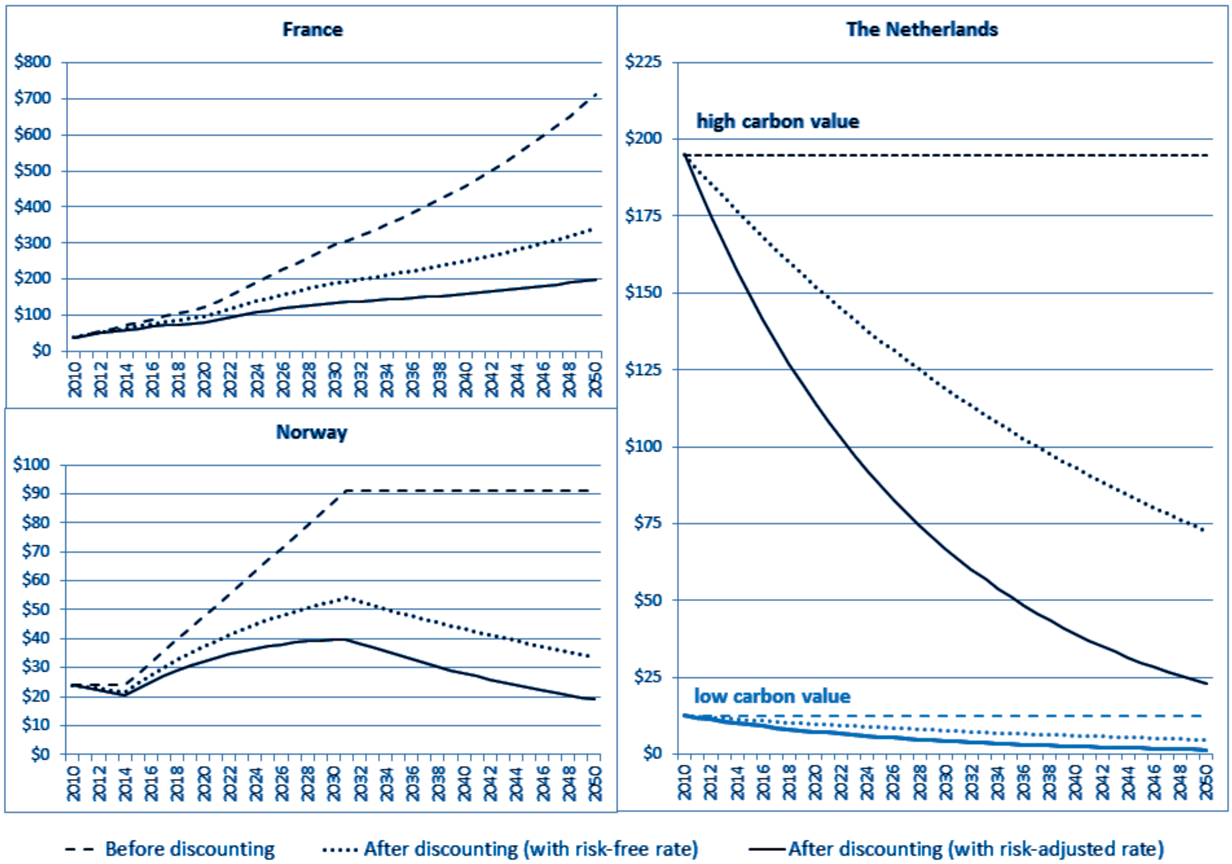
Country	Method	Discount rate		
France	Risk-adjusted SRTP	Constant: 4.5% or project specific rate		
The Netherlands	Risk-adjusted SRTP	4% for climate change effects and 5.5% for other effects		
Norway	Risk-adjusted SRTP	<40 years: 4%	40-75 years: 3%	>75 years: 2%
UK	SRTP	0-30 years: 3.5%	31-75 years: 3%	Reducing to 1% for over 300 years
Sweden	SRTP	Constant 3.5%		
Germany	SRTP	Constant 1% for long-term climate change effects, 1.5% for other effects and 3% for short term effects (0-20 years)		
US	Certainty equivalent	Constant: 2.5%, 3%, and 5% (for estimation of SCC)		
Japan	SOC	Constant 4%		
New Zealand	SOC	8% as recommended by NZ Treasury (6% used by NZ Transport Agency)		

Note: SOC – Marginal social cost of capital; SRTP – Social Rate of Time Preference (based on variants of the Ramsey formula).

Source: A preliminary OECD survey of carbon values in selected countries (Chapter 5).

To illustrate the impact of risk-adjusted discounting on the final carbon value used in CBA, the carbon values used by France, The Netherlands and Norway are discounted first using the risk-free component of the risk-adjusted discount rate and then by the additional risk-premium (i.e. the risk-adjusted discount rate) (Figure 5.3). The effects of risk-adjustment are not insignificant.

Figure 5.3. **Carbon value with risk-adjusted discounting for selected countries (in USD 2013 values/tCO_2)**



Source: ITF calculations based on OECD survey of selected member countries.

Box 5.4. **Discount rates: International practices**

United States

Government agencies in the United States traditionally used constant discount rates of 3% and 7% in their CBAs. However, after considering intergenerational issue, the interagency group ultimately chose three certainty-equivalent constant discount rates: 2.5%, 3%, and 5% per year (Greenstone et al., 2013).

France

In France, the discount rate is based on the systemic risk-adjusted SRTP approach to take into account systemic risk with a risk-free rate of 2.5% (falling to 1.5% from 2070) and a risk premium of 2% (rising to 3% from 2070) multiplied by a sector specific (or, when available, a project specific) beta value (Quinet, 2013). The increasing risk premium reflects the increase in project-specific systemic risks as the time horizon extends. With a beta of 1, the standard discount rate is 4.5%. However, the discount rate can vary between projects as the beta value varies.

United Kingdom

The UK uses Social Rate of Time Preference to set the discount rate. Because of the uncertainty about the future values of time preference, a certainty equivalent rate taking into account the range of this uncertainty was calculated (HM Treasury, 2011). In the end, the UK Green Book recommends the following discount rate for different time periods (Table 5.3).

Table 5.3. **Green Book discount rates**

Years from current year	Discount rate
0-30	3.5%
31-75	3.0%
76-125	2.5%
126-200	2.0%
201-300	1.5%
301 and over	1.0%

Source: HM Treasury (2011).

Norway

In Norway, the discount rate has two components – a risk-free rate and a risk premium. For evaluation periods under 40 years, Norway uses a risk-adjusted rate of 4%, which is the sum of a 2.5% risk-free rate and a 1.5% risk premium. Based on a declining risk-free rate and a declining risk premium, the discount rate in Norway reduces to 3% for years from 40 to 75 and to 2% from year 75 onwards (Table 5.4).

Table 5.4. **Discount rate in Norway**

Discount rate	Years 0 -40	Years 40 -75	From year 75
Risk-free rate	2.5%	2%	2%
Risk premium	1.5%	1%	0%
Risk-adjusted rate	**4.0%**	**3%**	**2%**

Source: Norwegian Ministry of Finance (2012: 78-79).

Box 5.4. **Discount rates: International practices** *(cont.)*

Japan

Japan uses the SOC approach to determine discount rate for CBA. The current discount rate is set at 4%, and it is constant throughout the evaluation period (maximum 50 years). More details of Japan's approach are provided in Annex A.

Netherlands

The discount rate for the Dutch government CBA has two components – a fixed risk-free rate based on information obtained from the capital market (of 2.5%) and a risk premium (of 3%) to account for relative risk in the future. Therefore the discount rate is set at 5.5%. However, for external effects that are irreversible (such as climate change), the risk premium is 1.5% (instead of 3%), giving a discount rate for climate change effects of 4%. More details of the Netherlands' approach are provided in Annex B.

Sweden

Sweden uses social rate of time preference (SRTP) and the Ramsey formula to set the social discount rate. After considering the arguments for a declining discount rate due to increasing risk over time, Sweden chose to set a discount rate at a lower level to approximate a declining schedule with a single average figure. The discount rate in Sweden is currently set at 3.5%.

Germany

The standard social discount rate (based on SRTP) in Germany for cross-generational valuations is 1.5%. For long-term climate change effects, UBA recommends a constant discount rate of 1%. This corresponds to a more conservative estimate of an annual economic growth rate of 1% over the next 100 years. In Germany, the constant discount rate applies to the entire evaluation period. More details of Germany's approach are provided in Annex C.

New Zealand

Prior to 2008, the public sector discount rate used in New Zealand was set at 10%. In 2008, following a review of discount rate methodologies and parameters for establishing the discount rate, the NZ Treasury recommended an 8% discount rate (after tax, real) for use in transport investment decisions. This estimate was based on the social opportunity cost of capital (SOC) approach and used industry data to estimate the parameters. Following the 2008 update, NZ Transport Agency also amended the discount rate to 8% in the same year. In 2013, NZ Transport Agency reviewed the parameters used in the SOC formula and decided to use a 6% discount rate instead.

At present, transport infrastructure projects that are funded by NZ Transport Agency are assessed using a 6% discount rate (and a 40-year evaluation period). However, for investment decisions that require Crown funding (e.g., the decision on whether to build a new ferry terminal at Clifford Bay to replace an existing ferry terminal at Picton) and for policy decisions (e.g. whether to reduce the adult legal blood alcohol concentration limit), the NZ Ministry of Transport adopts NZ Treasury's 8% discount rate.

Source: OECD survey of selected member countries.

Notes

1. The shape of the discount function can be constructed by asking people to choose between a set of delayed rewards, such as money and sweets (OECD, 2007).

2. The marginal social cost of capital (SOC) can be simplified into three key terms: the after-tax real risk-free interest rate (r^f), an asset beta (β) and a (tax-adjusted) risk premium (R^p). The formula is given by: $r = r^f + \beta R^p$ (see for example: Spackman, 2008; NZ Treasury, 2008; Weitzman, 2012 and Armitage, 2014). A major criticism of the SOC approach is the lack of a logical mechanism to derive the risk premium for a public project as the standard approach is based largely on the financial markets (Spackman, 2008). Furthermore, SOC does not consider the interest of future generations and how the current generation sees intergenerational matters (OECD, 2007 and Armitage, 2014).

3. There are three categories of risk preference: risk aversion, risk-neutral and risk-taking. The utility function under a risk aversion assumption is concave, whereas it is linear and convex under the risk-neutral and risk-taking assumptions respectively.

4. By considering the correlation between the increased output of the project and returns to the economy as a whole, Weitzman (2007) demonstrated that discount rate at time t can be expressed as $r_t = \beta r_e + (1-\beta) r_f$ (where r_e is the expected return from investment for the economy as a whole and r_f is the risk-free rate). By substituting the standard risk premium expression $r_e - r_f = \eta\sigma_g^2$, the discount rate equation reduces to $r_t = r_f + \beta \eta\sigma_g^2$. One result of Weitzman's discount rate equation is that the discount rate declines monotonically over time to approach the risk-free rate (Weitzman, 2007 p.711 and Weitzman, 2012 p.25).

5. In this case, the risk premium measures the amplitude of the long-term systemic risks linked to macro-economic trends.

6. Capital Asset Pricing Model.

7. In transport appraisal, uncertainty occurs in many areas, such as the level of emissions due to changes in technological advancement and/or modal changes, which will affect the expected project benefits.

8. Term structure of interest rate (also known as the yield curve) is financial term that describes the relationship between interest rates and time to maturity (known as the "term").

References

Armitage, S. (2014), "Discount rates for long-term projects: the cost of capital and social discount rate compared", September 2014, The University of Edinburgh Business School, http://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID2505150_code102554.pdf?abstractid=2505150&mirid=1

Arrow, K.J. and Lind R.C. (1970), "Uncertainty and the evaluation of public investment decisions", *The American Economic Review*, Vol. 60(3), Jun, pp.364-378.

Arrow, K.J. et al. (1996), "Intertemporal Equity, Discounting, and Economic Efficiency." In *Climate Change 1995: Economic and Social Dimensions of Climate Change*, Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change, edited by J.P. Bruce, H. Lee, and E.F. Haites. Cambridge: Cambridge University Press.

Arrow, K.J. et al. (2014), "Should governments use a declining discount rate in project analysis", *Review of Environmental Economics and Policy*, Advance access July 2014. http://reep.oxfordjournals.org/content/early/2014/07/16/reep.reu008.full.pdf .

Arrow, K.J. et al. (2013a), "Determining benefits and costs for future generations", *Science*, Vol. 341(6144), 349-350.

Arrow, K.J. et al. (2013b), "How should benefits and costs be discounted in an intergenerational context?", *Working Paper Series*, 5613, Department of Economics, University of Sussex.

Barro, R. and Becker, G. (1989), "Fertility choice in a model of economic growth", *Econometrica*, Vol. 57(2), March, pp. 481-501.

Cropper, M., Freeman, M., Groom, B., and Pizer, W. (2014), "Declining discount rates", *American Economic Review*, Vol. 104(5), pp. 538-43.

Frederick, S., Loewenstein, G. and O'Donoghue, T. (2002), "Time discounting and time preference: A critical review", Journal of Economic Literature, Vol. XL, June, pp.351-401.

Freeman, M. (2010), "Yes, we should discount the far-distant future at its lowest possible rate: A resolution of the Weitzman-Gollier Puzzle", *Economics: The Open-Access, Open-Assessment E-Journal*, Vol. 4, 2010-13, April.

Freeman, M. et al. (2013), "Declining discount rates and the Fisher Effect: inflated past, discounted future?", Centre for Climate Change Economics and Policy and Grantham Research Institute on Climate Change and the Environment, http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2014/02/WP109-discount-rates-fisher-effect.pdf

Gollier, C. (2014), "Discounting and growth", *American Economic Review*, Vol. 104(5), pp. 534-37.

Gollier, C (2013), *Pricing the future: The economics of discounting in an Uncertain World*, Princeton University Press.

Gollier, C (2010), "Expected net present value, expected future value, and the Ramsey rule", *Journal of Environmental Economics and Management*, Vol. 59(2), March, pp. 142–148.

Gollier, C (2002), "Time horizon and the discount rate", *Journal of Economic Theory*, Vol. 107, pp. 463-473.

Gollier, C. and Weitzman, M. (2010), "How should the distant future be discounted when discount rates are uncertain?", *Economics Letters*, Vol. 107, pp.350-353.

Groom B. et al. (2007). "Discounting the Distant Future: How Much Does Model Selection Affect the Certainty Equivalent Rate?", *Journal of Applied Econometrics*, Vol. 22, pp. 641-656.

Harrison, M. (2010), "Valuing the future: the social discount rate in cost-benefit analysis", Visiting Research Paper, Productivity Commission, Australian Government.

HM Treasury (2011), "The Green Book: Appraisal and evaluation in central government", London, United Kingdom.

Kane, M. (2012), "Disagreement and design: An arbitration of the climate change and intergenerational discounting debate", New York University Law and Economics Working Papers, Paper 306 http://lsr.nellco.org/nyu_lewp/306.

Klibanoff, P., Marinacci, M. and Mukerji, S. (2005), "A smooth model of decision making under ambiguity", *Econometrica*, Vol. 73(6), pp.1849-1892.

Knight, F. (1921), *Risk, uncertainty and profit*, Boston, MA: Hart, Schaffner & Marx; Hougton Mifflin Company.

New Zealand Treasury (2008), "Public sector discount rates for cost benefit analysis", New Zealand Treasury, 2008.

Norwegian Ministry of Finance (2012), "Cost-benefit analysis", Official Norwegian Reports NOU (2012), October, Norway.

OECD (2007), "Use of discount rate in the estimation of costs of inaction with respect to selected environmental concerns", Working Party on National Environmental Policies, OECD, Paris, drafted by Hepburn, C., www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?doclanguage=en&cote=env/epoc/wpnep(2006)13/final.

Pearce, D.W. and Ulph. D, (1999), "A social discount rate for the United Kingdom", in D. W. Pearce, *Environmental Economics: Essays in Ecological Economics and Sustainable Development*, pp. 268–285, Edward Elgar, Cheltenham.

Pindyck, R.S. (2013), “The climate policy dilemma”, *Review of Environmental Economics and Policy, Association of Environmental and Resource Economists*, Vol. 7(2), pp. 219-237, July.

Quinet, E. (2013), "Factoring Sustainable Development into Project Appraisal: A French View", *International Transport Forum Discussion Papers*, No. 2013/31, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/5jz40rncm222-en

Ramsey, Frank P. (1928), "A mathematical theory of saving", *Economic Journal*, Vol. 38(152), pp. 543–559.

Sandmo, A. (1972), “Discount Rates for Public Investment Under Uncertainty”, *International Economic Review*, Vol. 13(2), June, pp. 287–302.

Spackman, M. (2008), “Time preference, the cost of capital and PPPs”, Conference on ‘Discount rates for the evaluation of Public Private Partnerships’, Queen’s University, Ontario, http://jdi-legacy.econ.queensu.ca/Files/Conferences/PPPpapers/Spackman-081002-final.pdf

Traeger, C.P. (2014), “Why uncertainty matters: discounting under inter-temporal risk aversion and ambiguity”, *Economic Theory*, Vol. 56(3), pp.627-664.

Traeger, C.P. (2013), “Discounting under uncertainty: disentangling the Weitzman and the Gollier effect”, CUDARE working paper no. 1121, UC Berkeley. http://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID2270459_code1081099.pdf?abstractid=2270459&mirid=1

USG (2010), “Technical support document: Social cost of carbon for regulatory impact analysis - Under executive order 12866”, Interagency Working Group on Social Cost of Carbon, United States Government, February.

Weitzman, M.L. (2012), “On risk-adjusted discount rates for long-term public investments”, Department of Economics, Harvard University, http://nyttekost-web.sharepoint.com/Documents/120908_RiskAdjustedDiscountRate.pdf .

Weitzman, M.L. (2007), “A review of the Stern Review on the economics of climate change”, *Journal of Economic Literature*, Vol. XIV, September, pp.703-724.

Weitzman, M. L. (1998), “Why the far-distant future should be discounted at its lowest possible rate”, *Journal of Environmental Economics and Management*, Vol. 36(3), pp.201-208.

Further reading

Ackerman, F. and Bueno, R (2011), "Use of McKinsey abatement cost curves for climate economics modelling", Stockholm Environment Institute, Working paper WP-US-1101.

Delink, R., Lanzi, E., Chateau, J., Bosello, F., Parrado, R., and de Bruin, K. (2014), "Consequences of climate change damages for economic growth: a dynamic quantitative assessment", *OECD Economics Department Working paper*, No. 1135, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/5jz2bxb8kmf3-en

DECC (2013b), "Updated short-term traded carbon values used for UK public policy appraisal", September, Department of Energy and Climate Change, United Kingdom.

Gollier, C (2010), "Expected net present value, expected future value, and the Ramsey rule", *Journal of Environmental Economics and Management*, Vol. 59(2), March, pp. 142–148.

Heal, G. and A. Millner (2013), "Scientific Ambiguity and Climate Policy", *Environmental Resource Economics*, Vol. 55, pp.21-46.

Hope, C., J. Anderson and P. Wenman (1993), "Policy analysis of the greenhouse effect: An application of the PAGE model", *Energy Policy*, Vol. 21(3), pp. 327-338.

IPCC (2013), "Climate Change 2013: The physical science basis - summary for policy makers", Contribution of Working Group I.

Kesicki, F. and Ekins P. (2012), "Marginal abatement cost curves: a call for caution", *Climate Policy*, 12(2), pp. 219-236.

Kimball, M. (1990), "Precautionary saving in the small and in the large", *Econometrica*, Vol.58, No. 1 (Jan 1990), pp.53-73.

Meunier, D. (2012), "Towards a sustainable development approach in transport assessment", *Procedia-Social and Behavioral Sciences*, 48, 3065-3077.

Meunier, D. and Quinet, E. (2014), "Valuing GHG emissions and uncertainty in transport cost benefit analysis", European Transport Conference 2014, Frankfurt, Germany, September.

Millner, A. (2013), "On welfare frameworks and catastrophic climate risks", *Journal of Environmental Economics and Management*, 2013, http://dx.doi.org/10.1016/j.jeem.2012.09.006

Nordhaus, W. D. (1992), "The 'DICE' Model: Background and Structure of a Dynamic integrated climate-economy model of the economics of global warming", Cowles Foundation Discussion Papers 1009, Cowles Foundation for Research in Economics, Yale University.

Nordhaus, W. D. (2009), "An analysis of the dismal theorem", *Cowles Foundation Discussion Paper*, No. 1686, Yale University.

Nordhaus, W. (2011), "The economics of tail events with an application to climate change", *Review of Environmental Economics and Policy*, Vol. 5(2), pp. 240–257.

OECD (2006), *Cost-Benefit Analysis and the Environment: Recent Developments*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264010055-en.

Proost, S. and Van Dender, K. (2011), "What long-term road transport future? Trends and policy options", *Review of Environmental Economics and Policy*, Vol. 5(1), pp. 44-65.

Proost, S., E. Delhaye, W. Nijs, and D. Van Regemorter (2009), "Will a radical transport pricing reform jeopardize the ambitious EU climate change objectives?", *Energy Policy*, Special Issue, Vol. 37(10), pp. 3863-71.

Rienstra, S. (2008), "*De rol van kosten-batenanalyse in de besluitvorming*" (The role of cost-benefit analysis in decision making), Kennisinstituut voor Mobiliteitsbeleid.

Small, K. A. (1991), "Transportation and the environment," in Roland T. (Ed.), *The Future of Transportation and Communication*, Swedish National Road Administration, pp. 217-230.

Stern, F. et al. (1999), "Summary of experimental uncertainty assessment methodology with example", Iowa Institute of Hydraulic Research, College of Engineering, The University of Iowa, IIHR Technical Report No. 406 http://user.engineering.uiowa.edu/~cfd/pdfs/References/uncert.pdf.

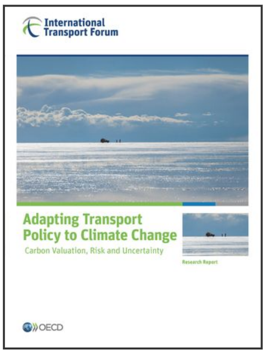
Tol, R.S.J. (1996), "The climate framework for uncertainty, negotiation and distribution", in: K.A. Miller and R.K. Parkin (Eds.), *An Institute on the Economics of the Climate Resource*, University Corporation for Atmospheric Research, Boulder, pp. 471-496.

van Dender, K. and M. Clever (2013), "Recent Trends in Car Usage in Advanced Economies – Slower Growth Ahead?: Summary and Conclusions", *International Transport Forum Discussion Papers*, No. 2013/09, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/5k46n4121k5d-en

Vielle, M. and Bernard A. L. (1998), "La structure du modèle GEMINI-E3", *Économie et Prévision*, Vol. 136(5), pp. 19-32.

Warner, J.T. and Pleeter, S. (2001), "The personal discount rate: evidence from military downsizing programs", *American Economic Review*, Vol. 91(1), pp. 33–53.

Young, L (2002), "Determining the discount rate for government projects", New Zealand Treasury, Working Paper, 02/21.



From:

Adapting Transport Policy to Climate Change

Carbon Valuation, Risk and Uncertainty

Access the complete publication at:

https://doi.org/10.1787/9789282107928-en

Please cite this chapter as:

International Transport Forum (2015), “Discounting long-term effects of climate change for transport”, in *Adapting Transport Policy to Climate Change: Carbon Valuation, Risk and Uncertainty*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/9789282107928-7-en