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Cost-Benefit Analysis and the environment: The time horizon is of the essence

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ABSTRACT

Cost-Benefit Analysis is a key tool for evaluating welfare gains or losses from an investment. It is now well established that environmental impacts are crucial to consider the full welfare implications of a project. Debate has focussed on approaches to improve the valuation of environmental impacts, and controversy in the discounting of future impacts to present values. The issue of the time horizon of analysis is frequently overlooked. The framing of the time horizon has major implications, as environmental costs and benefits often accrue in the long-term. The technical aspects of setting the time horizon are reviewed, along with updates to practice guidance, noting the longer time horizons now becoming typical. It is demonstrated that the time horizon can have a considerable impact on results, even more substantial than the discount rate. While uncertainty is noted as a technical challenge to longer-term analysis, the use of scenarios and sensitivity testing are noted as an appropriate response. For projects with long-term environmental effects, such as those related to air pollution, climate change and ecosystem damages, it is recommended to use timescales of 100+ years for economic evaluation of the impact. Failing to fully capture these long-term welfare gains and losses will distort analysis with a bias towards those projects that are more carbon-intensive, or environmentally damaging. Such a bias would undermine not only the evaluation, but welfare and sustainable development in general.

1. Introduction

Globally, the landscape of economic analysis of projects and policy has undergone significant change in recent years, a transition in both form and substance. As knowledge has evolved, and public policy priorities have adapted, so the foundations of how economics supports decision-making have shifted. As the ramifications of systemic global environmental phenomena filter through, including the urgency of global heating (IPCC, 2018) and ecological breakdown (IPBES, 2019), there are profound implications for the framing and technical approach to appraisal of public and private investments. Indeed, it has been noted prominently that a particular driver of this process has been the economics of climate change, and the inclusion of the 'environment' in analysing economic welfare (OECD, 2018).

The 2006 OECD review of '*CBA and the environment*' (Pearce et al., 2006) stated that a variety of developments in the theory of Cost-Benefit Analysis (CBA), have altered the way in which economists argue it should be implemented, with 'the environment' central to these. This has restored deeper consideration of the normative foundations of economic analysis itself (Dennig, 2018). The issue of discounting is one such example, where environmental CBA has "*helped shake the conceptual foundations of discounting, in part through novel technical insights but also (and importantly) through renewed debates about ethical underpinnings*" (OECD, 2018: 36). The Intergovernmental Panel on Climate Change (IPCC) have been at the vanguard of clarifying the changes in economics. The Fifth Assessment Report of Working Group III (Kolstad et al., 2014), reviewed the 'limits of economics in guiding decision-making'. It emphasised that while economics can aggregate welfare, this is only one of several criteria that are relevant. Other ethical considerations may not be reflected in an economic valuation, and yet may be extremely important for particular decisions. In the context of global heating, the IPCC in Kolstad et al. (2014) note that particular difficulties are raised for economic methods: as change is non-marginal; the timescale is very long -making the discount rate both crucial and highly controversial; extremes of global distribution of wealth heighten equity considerations; the challenge of measuring non-market values including the very existence of species, ecosystems and cultures; and, uncertainty of outcome, which includes irreversible damages and even a small chance of catastrophe. These are major challenges to the use of standard approaches such as CBA, raising fundamental questions about when it is suitable, and what technical changes are required in implementation. Recent decades have seen strong challenges mounted to the use of CBA

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due to such limitations (Ackerman and Heinzerling, 2004).

The responses to technical challenges within CBA have been evolving in recent years, through prominent reviews and guidance that have modified the requirements of application in practice. A key contributor has been the OECD reports, including the most recent '*Cost-Benefit Analysis and the Environment*' (OECD, 2018). The report included a survey of current practices in member countries, providing insights into state of the art. Other notable resources include the Quinet Report in France (Quinet, 2013), the voluminous UK Treasury '*Green Book,*' and European Commission guidance in Sartori et al. (2014).

This paper provides a brief review of key developments, particularly changes in applied practice, and focusses on an issue that receives scant attention -the time horizon of analysis. Following the introduction, Section 2 provides a short review of the recent evolution of CBA, driven by sustainability science and 'the environment'. Section 3 considers the background to selecting a time horizon in CBA of public projects and policy, and the defining issues -in the form of uncertainty and discounting- followed by a review of changing practices in national and international guidance. This section concludes with a simple quantification of the impact of different time horizons, under alternative social discount rates, on a theoretical flow of costs and benefits. Section 4 discusses the implications and provides concluding remarks.

2. Cost-Benefit Analysis, the 'environment' and sustainability

It is now widely accepted, both in theory and in practice, that economic welfare is deeply dependent and interlinked with the environment and wider human wellbeing in general (Stiglitz et al., 2009; IPSP, 2018; Fleurbaey et al., 2014). This has significant implications for economic appraisal and evaluation. It is now known that neither economic efficiency, nor sound public investment, can actually be delivered without embedding this new reality within the frames of how we consider using and evaluating public monies. If public policy is to meet its remit, and public investment is to deliver value for money, then environmental and social 'externalities,' as the market failures that lead to opportunity costs, must be appropriately included. Where the objective is simply to consider the short-term private financial implications of a project, or indeed the implications for the exchequer, then a simple financial analysis may be sufficient in such limited circumstances. However, if 'economic analysis' is the objective, this intrinsically requires an evaluation of impacts on welfare, and necessarily includes the environment as a core constituent of economic welfare and human wellbeing.

In practice, the environmental applications of CBA to policy and project evaluation have become some of the most important and controversial (Ackerman and Heinzerling, 2004; Masur and Posner, 2011).[1] The full significance of the environment comes into focus when the complete panorama is viewed. To achieve this, it must be recognised that addressing the challenge of 'the environment in CBA' is not simply about the appraisal of 'environmental projects', or indeed the inclusion of environmental impacts in analysis. The environment is fundamental to appropriate framing of analysis of public investment in general. The environment provides ecosystem services to human systems that are often not substitutable (Drupp, 2018), therefore development itself must be sustainable if collapse is to be avoided. This necessitates aggregate analyses of planetary boundaries (Steffen et al., 2015), and the contribution of national development pathways to maintaining society within these boundaries (IPCC, 2018). However, if there is to be consistency, this must have real consequences for development in general, and at project and policy level in particular.

It is with this in mind that the Quinet Report (Quinet, 2013) recommended that the new French CBA guidance be established within the frame of '*ecological transition*'. Where schedules of project analysis are undertaken without analysing systemic changes, there are concerns that such a 'weak sustainability' interpretation would leave high levels of local or global damages to fall outside of the scope of CBA (Bullock, 2017), and thus amplify systemic risks. The OECD (2018) are unequivocal that 'strong sustainability' guidance from the natural sciences must be the focus of the process of CBA. This necessitates integration across system levels (international-national-regional-local), and a holism from sustainability science to account for environmental impacts. Following this, appropriate methods for valuations of these impacts is necessary, this includes applying forms of valuation that can account for irreplaceable natural and social capital -such as a stable climate and resilient social and ecological systems. It also requires that the limits of CBA are repeatedly flagged, noting that marginal gains in economic efficiency at the project level, cannot be traded for an unsustainable pathway at the aggregate level.

At the aggregate national or system level, in a status quo where appraisals do not accord sufficient value to dimensions of the environment, this will favour more carbon-intensive and environmentally damaging growth. In addition to these environmental externalities, this causes ripples that will be felt in weakening economic competitiveness, and increase exposure of the State to damage and compliance costs. The Global Commission on the Economy and Climate[2] (GCEC, 2016) recognise this as an urgent need to steer public finance and investment away from high-carbon, 'maladaptive infrastructure,' that is no longer appropriate to the needs of the 21st century. The aim is to deliver 'sustainable development paths' (Sathaye et al., 2007), to guide policy and investment away from lock-in to what the World Bank (2013) term 'brown-growth',[3] or carbon-intensive development. The long lifetime of infrastructure is one of the determinants that cause lock-in to carbon-intensive brown-growth. From a strategic perspective, this also results in lost economic opportunities through 'green growth' (World Bank, 2013). The GCEC report is clear that shifting public investment and addressing price distortions of carbon are key to tackling a number of interrelated goals; reigniting and sustaining growth, transitioning to low carbon development, delivering on sustainable development and reducing climate risk. On a more general front, the European Commission guidance on CBA is unequivocal that "*Not taking into account environmental impacts will result in an over- or underestimation of the social benefits of the project and will lead to bad economic decisions*" (Sartori et al., 2014: 322).

The use of CBA is encouraged by organisations such as the OECD (2018) and the European Commission (2016) to deliver not just efficiency and improved economic welfare, but also for the 'integration of the environment into economic policies.' Yet, the implications of sustainability and systemic change must filter through national policy and strategy for sustainable development, the related vision that informs project selection and design, and the guidance and practice of economic

[1] Ackerman and Heinzerling (2004) suggested that in practice CBA was being used as a political tool to avoid regulation. On the other hand, Masur and Posner (2011) cited a Ninth Circuit Court of Appeals ruling that struck down a light truck fuel economy standard set by the US Department of Transportation, because the CBA had failed to take account of the benefits of reducing greenhouse gas emissions. See: Ctr. For Biological Diversity Biological v. Nat'l Highway Traffic Safety Admin., 538 F.3d 1172,1198–203 (9th Cir. 2008).

[2] The Global Commission on the Economy and Climate, and its flagship project '*The New Climate Economy*,' were set up to help governments, businesses and society make better-informed decisions in the context of achieving economic prosperity and development, while also addressing climate change. The New Climate Economy was commissioned in 2013 by the governments of seven countries: Colombia, Ethiopia, Indonesia, Norway, South Korea, Sweden and the United Kingdom.

[3] 'Brown growth' describes economic development that relies heavily on fossil fuels. Brown growth tends not to consider the negative side effects that economic production and consumption have on the environment (World Bank, 2013), remaining as un-priced externalities.

analysis in CBA itself. This 'mainstreaming' of sustainability within government institutions is necessary to support sustainability transition as per the IPCC (Sathaye et al., 2007).

The OECD (2018) have noted key changes that are relevant to CBA guidance and practice, including; the implications of sustainability and the limits of CBA, but also the practical changes in discounting, externality valuations and the inclusion of equity and co-benefits. Social discount rates are a key controversy for CBA, often described as 'the tyranny of discounting'. The OECD note a general trend towards lower discount rates, declining discounting and consideration of the need for 'dual discounting,' in the form of even lower discount rates for non-substitutable natural and social capital. Table 1 illustrates some of the declining discount rates and longer time horizons for selected OECD countries, adapted from OECD (2018). It specifically illustrates the difference between short to medium-term and long-term discounting, and that the time horizon intended by 'long-term' is multi-decade to multi-century.

The issue of valuations has accelerated in the last three decades. Valuation studies on the benefits of biodiversity, and on the services provided by different ecosystems, or ESS, have been growing at an exponential rate (Markandya and Pascual, 2014). Sartori et al. (2014) cite major advances in developing unit values for non-market impacts in recent years, and it is generally accepted throughout the CBA literature that unit values of environmental externalities must increase in value over the life cycle of the project.[4] Best practice internationally for the identification of costs and benefits is achieved through applying the frame of '*ecosystem services*.' This is not a new appraisal process, but a comprehensive and systematic way to think about environmental impacts, as the entire range of environmental effects that entail from a proposed policy or project. This has been recommended by Sartori et al. (2014:61) '*Considering that ecosystem services change is one of the vital aspects of welfare, this should be always taken into account as potential for any project.*' The approach is also endorsed by the UK's HM Treasury 'Green Book' (Dunn, 2012) and by the OECD (2018). Maddison and Day (2015) describe how ecosystem services are a form of 'natural capital' that facilitates valuation of intangibles such as amenity, recreation, water quality and air.

The 'Total Economic Value' (TEV) approach has been recommended by the OECD (Pearce et al., 2006), and by Sartori et al. (2014), for identification and valuation of environmental impacts. The TEV approach is an umbrella that seeks to represent a comprehensive economic valuation of the marginal change of all environmental effects of a project, or in the underlying ecosystem services which are impacted by it. TEV is favoured as an approach as it is useful as a comprehensive framework for thinking, and for the identification of the environmental effects. However, it has been argued that the moniker 'total' in TEV may be something of a misnomer. The OECD (2018) explain that it is not possible to fully describe the 'total value' of any ecosystem. Changes in ecosystems are non-linear and can lead to collapse, so marginal change is not an accurate representation of the processes occurring. In addition, as ecosystems operate as interrelated 'complex adaptive systems' (CAS), they are greater than the sum of their parts. This means that the value of any one service is inter-linked with the value of the other services of that ecosystem. It also means that environmental and social capital are not fully substitutable with other forms (EEA, 2015), so financial capital cannot compensate. This is a further representation of the importance of the 'strong sustainability' framing previously outlined, as is implied by the 'dual discounting' approach to place a lower discount rate on irreplaceable natural capital (Weikard and Zhu, 2005).

In addition to environmental costs, the environmental benefits of avoided damages are important in the analysis of environmental improvement projects. Some of these may occur outside of the original goal of the project or policy, such as reduced air pollution and greenhouse gases from energy efficiency and renewable energy projects, and the reduced fuel consumption and greenhouse gases from shifting transport to rail and active modes of mobility. It must be noted that 'co-benefits,' sometimes termed 'complementary benefits' or 'ancillary benefits' in CBA literature, can have significant impacts on the outcome of analysis. As noted by the IPCC in Sims et al. (2007), while co-benefits of mitigation, to reduce greenhouse gas emissions, can be important decision criteria for policymakers, they were often neglected in analyses. There are many cases where the net co-benefits are not monetised, quantified, or even identified by decision-makers and businesses. As usefully emphasised by Hamilton et al. (2017), while the benefits of mitigation can be global and long-term, co-benefits such as reduced air pollution are relatively certain, short-term and accrue within the country making the efforts. Reductions in damages from local and regional air pollution tend to be the largest category of co-benefit that arise with greenhouse gas mitigation. The World Bank (2016) has estimated the air pollution co-benefit estimate for the EU, for each tonne of greenhouse gas emissions reduced, at an additional $200. Deng et al. (2017) noted that while the co-benefits of mitigating GHG can serve as an input to CBA, perhaps more importantly, it could provide information and rationales for taking action to mitigate GHG emissions that are more persuasive to some policymakers or to the public at large.

Table 1
Discounting rate guidance in selected OECD countries, adapted from OECD (2018).

Country	Short to medium-term	Long-term
United Kingdom	3.5% all projects and regulatory analysis	Declines to 1% after 300 years
United States	3–7% CBA project and regulatory analysis, depending on source of funding	- Lower rate for intergenerational projects recommended by US Office of Management and Budget - 2.5% recommended by USEPA
United States	2% for Cost Effectiveness Analysis	No guidance on long-term
France	2.5% for risky projects	Risk free rate declines to 1.5% for 75 year horizon
Norway	3% for risky projects and regulatory analysis	Risk free rate declines to 1% after 100 years
Netherlands	3% for all projects and regulatory analysis	Apply declining discount rates, considering type of capital and risk

Another crucial issue that has presented across CBA in general is that of equity considerations, in the distribution of costs and benefits across extremes of wealth and poverty. The Intergovernmental Panel on Climate Change Fifth Assessment Report notes a consensus that because of the necessity of the ethical considerations of equity, CBA is only applicable in very specific circumstances, and with introduction of equity weights (Fleurbaey et al., 2014). It is now hard to find discussion where it is claimed that CBA has no responsibility to comment on the distributional impacts of projects (OECD, 2018). The UK guidance in the Treasury Green Book explicitly recognises that distributional considerations arise within CBA (HM Treasury, 2011), firstly because projects have potential distributional impacts, but also secondly, because government policy has committed to distributional objectives.

In considering this list of technical updates to CBA, a defining issue that has received little attention is that of the time horizon of the analysis itself. The time horizon frames the analysis, and limits the inclusion of environmental costs and benefits, which by definition accrue in the long-term. An analysis on shorter time periods can truncate inclusion, for environmentally damaging projects this will undervalue true costs, and by definition overvalue net benefits. For environmentally beneficial projects this would undervalue true welfare benefits, and distort the net benefit calculation by failing to counter the influence of the capital investment costs at the beginning. This defining issue of the

[4] The inter-temporal elasticity of environmental externalities to GDP per capita growth can be used in order to take into account of unit prices. These are usually expressed for a given base-year, and must increase over the project lifecycle (Sartori et al., 2014) to reflect increasing scarcity.

time horizon is the focus of the next section.

3. The time horizon of analysis, and the importance of the long-term

3.1. Considering the time horizon in context

The World Health Organisation (WHO) have observed the time horizon of the analysis can significantly affect the outcome of results of CBA (WHO, 2006). The time horizon becomes of increased relevance where the analysis concerns long term impacts (OECD, 2018), such as the emission or avoidance of greenhouse gases from energy and transport projects. It is particularly pertinent for emissions mitigation and climate adaptation projects, which may have high initial capital investment, but generate long-term streams of benefits. The time horizon often practically limits the forecasting of demand, which is necessary to analyse long-term cost and benefit flows, such as those related to emissions of greenhouse gases.

There are three time horizons concepts that could be discerned for CBA; the *financial analysis period* which tends to be assessed in timelines of up to 30 years (DG Regio, 2008), the *technically useful or physical lifetime* of the project, as a longer representation of typical infrastructure and its lifespan,[5] and lastly, the *welfare impact horizon* of costs and benefits. Theoretically, the welfare impact horizon, in terms of flow of costs and benefits, has a far longer timespan than either financial analysis, or indeed technical analysis, as the impacts are essentially infinite (CPB/PBL, 2013). CBA seeks to understand the welfare impacts of public investments due to the impacts of a project's cost and benefit flows. Rather than just a financial analysis, this necessitates a sufficiently long time horizon to adequately capture future impacts on welfare, but also to ensure that the analysis is not biased towards the present generation, and it's consumption preferences.

A projects impacts could be direct and immediate, such as the safety and efficiency benefits of a rail transport project. However, there are also delays and inertia in some of the most important costs and benefits. Impacts do not always present immediately, and apart from standard operational phase emissions and impacts, may even outlive the technical life of the project. Prominent examples include the health impacts due to air pollution from roads projects[6] (WHO, 2015) which may take decades to present as illness or disease for those who were exposed. The indirect regional development or distributional benefits of a project may also require decades to materialise. Measures to prevent disasters, such as climate adaptation and flood protections, may only provide notable benefits on significant timescales when a threat finally emerges. The long-term impacts of greenhouse gases released by human activities such as burning fossil fuels, can continue as the impacts of climate change for centuries after the activities which released them have ceased[7] (IPCC, 2001). The air and water pollutants from the decomposition of waste in a landfill may not emerge until after the landfill has been decommissioned (Nordic Council of Ministers, 2007). Permanent or irreversible impacts on welfare and the economy include climate change damages and biodiversity loss (IPCC, 2001). These are some of the long-term impacts that are outside of the oft-cited example of nuclear waste. Nuclear waste has a multi-century or multi-millenia impact time horizon to account for impacts.

The actual impacts of a project depend not only on what it is, and how it is designed,[8] but into what receiving context it is placed, and the economic, social and environmental qualities and vulnerabilities this context or receptor has. The OECD 2006 review noted that in the early years, when CBA was confined to assessing the financial worth of investment projects, the time horizon – the point beyond which costs and benefits are not estimated – was set by the physical or economic life of the investment (Pearce et al., 2006). However, recent years have seen changes in the orthodoxy of how CBA in general is applied as noted by the OECD (2018), due to the long-term nature of environmental costs and benefits, and their ethical implications. While some earlier practices noted by Pearce et al. (2006) suggested that there were 'no hard and fast rules' for setting the time horizon, it has now become clear that long time horizons must be applied to estimate welfare impacts. These must continue sufficiently into the future to capture important long-term costs and benefits to welfare, rather than to just centre on the financial implications of an investment choice. If the analysis is to be a CBA rather than an exchequer expenditure or financial analysis, it must theoretically capture all future costs and benefits to welfare, a crucial principle for CBA is therefore the application of long time horizons. Ignoring or excessively discounting the long-term impacts has been seen as ethically indefensible for many decades.

In the practical process of implementing a CBA, the time horizon needs consideration early, at the scoping and screening stage. It is at this stage that the potential effects on the environment are identified, characterised and quantified, in advance of the economic evaluation. This will include priority environmental externalities, such as air pollution and greenhouse gas emissions, climate change adaptation and damage to ecosystems and the services they provide. The HM Treasury Green Book (2020) provides useful guidance on identifying and quantifying effects.[9]

3.2. The influence of uncertainty and discounting on the choice of time horizon

In practice there are two factors that have influenced the rationale of the choice of time horizons, the first is forecast uncertainty in future costs and benefits, while the second is the impact of the discount rate. As CBA is often based on forecasting future demand outcomes -that lead to impacts in the form of costs and benefits- and as forecasting is subject to uncertainty, some advocate limiting time horizons to 20–30 years. It is known from ex-post analysis that all kinds of forecasting approaches encounter uncertainty, even in the short-term (Armstrong, 2001). This led to recommendations from O'Mahony (2014) to employ scenario approaches that explicitly explore key uncertainties.[10] Within CBA, the Dutch guidance specifically recommends employing existing scenario studies and sensitivity analyses of key uncertainties (CPB/PBL, 2013). Established scenario-based approaches to managing and responding to uncertainty are therefore embedded in the Dutch approach, to actively engage with uncertainty. In general, applying short time horizons to long-term impacts, in defensive response to uncertainty, appears

[5] Which could range from five years or less in the case of information technology such as computer hardware, to 100 years or more for transport infrastructure and housing.

[6] Estimated at 600,000 premature deaths across the EU in 2010, with the cost of mortality and morbidity at $1.575 trillion (WHO, 2015).

[7] Which leads to the multi-century timeline employed in the Social Cost of Carbon 'damage cost' approach to carbon pricing.

[8] The German federal infrastructure programme 'FTIP' uses the physical lifetimes of the typical components of the infrastructure to arrive at the time horizon for each project. This could involve five years planning, ten years construction and up to 90–100 years for the lifetime of some particular physical components in the case of transport projects.

[9] This includes a recommendation to go beyond marginal effects and consider impacts on the stocks of natural capital. See HM Treasury (2020: 75-76).

[10] Rather than *forecasting* or *projecting* historical trends which fail to capture the dynamic uncertainty into the future, *scenarios* explore alternative outcomes in different combinations of driving forces.

empirically unsound. O'Mahony (2018) highlighted that short-term time horizons will inevitably skew the analysis against projects or impacts that have long-term implications, and improving foresight and modelling of future demand and impacts is preferred. The World Health Organisation (WHO, 2006) note that in CBA in general, the time horizon is central to the outcome of the analysis;

> *"Traditionally, CBA evaluates investment projects, where intervention costs are front-loaded (i.e. principally incurred at or near the beginning of the project) and benefits tend to be delayed and spread over a longer period. Therefore, the time horizon of the CBA can be central to the outcome of the analysis. For example, a CBA with a short time horizon would tend to reduce the benefit–cost ratio of the intervention."* (WHO, 2006: 20)

In practice, the WHO response in CBA is to use a 100-year time horizon, and cite the example of the long-term health impacts of air pollution as justification (WHO, 2006).[11] The WHO note another justification that may lead an analyst to seek to apply a short term time horizon. That is where there are high discount rates being applied. High discount rates can render long-term impacts, even of significant magnitude, to become negligible when calculated in present values. However, as the need for declining discount rates have been generally accepted in the literature for a number of years (Pearce et al., 2006), this renders null this argument to avoid longer time horizons. Declining discounting is itself a concept derived from recognising long-term impacts, and the value of future generations, while cognisant of uncertainty (Weitzman, 1998). A pragmatic approach is required that balances the need to consider the long-term, with the technical challenge of the growth uncertainty that occurs as the scope of the analysis extends further into the future. Best practices that have emerged internationally offer examples of how this can be achieved.

3.3. National and international practices

The theoretical background is clear in the requirement for long-term time horizons to capture long-term environmental costs and benefits, a key question lies in what is practicable? The Quinet Report (Quinet, 2013) established CBA recommendations for *France* that extended the time horizon from previous practice. The French time horizon now stands at 2070 for all projects, and up to 2140 for residual costs and benefits including greenhouse gas emissions (Ministère de l'écologie, 2014). This updated French national guidance adopted virtually all of the Quinet recommendations for 'ecological transition'. Quinet noted the beginning of transitions in society; "*transitions of various natures regarding ecology, global warming, biology and the digital revolution*," (Quinet, 2013: 9), and that these transitions necessitate a long term perspective to be applied.

The central guidance of the *United Kingdom* Green Book (2018) recommends a time horizon of 10 years for many interventions. But, in acknowledging that there are long-term projects and long-term impacts, it further notes that in some cases including 'significant assets' such as buildings and infrastructure, up to 60 years are required. For significant costs and benefits such as those related to climate change risks, even longer periods are required; "*where intervention is likely to have significant social costs or benefits beyond 60 years…include immunisation programmes, the safe treatment and storage of nuclear waste or interventions that reduce climate change risks*." (HM Treasury, 2018: 24). The UK Green Book details a declining discount rate that is to be applied to issues of intergenerational wealth transfer,[12] for up to 125 years, while the previous guidance for the UK detailed rates up to 300 years. The Department of Energy and Climate Change guidance for the UK (DECC, 2011), as an addendum to the Green Book, specifically addresses the long-term impacts of projects on emissions of GHG. DECC highlight that emissions must be accounted for on a timescale that is further into the long term than 2050; "*However, some government projects have a significant impact well beyond 2050. There is thus a need to extend the new carbon valuation approach until 2100 to ensure that such analysis is taken forward in a transparent and consistent way*" (DECC, 2011: 2). The 'lifetime of the intervention,' that is employed in the UK has conceptual links with the 'lifespan of the physical components of the infrastructure' used in Germany. In German transport CBA this may be up to 100 years for some components (Federal Ministry of Transport and digital infrastructure, 2016: 53–55).

The French and UK CBA guidance both refer to long-term uncertainty in society, particularly the impact on welfare of environmental challenges, that require use of declining discount rates, and also long-time horizons. As discussed previously, the approach in the Netherlands is theoretically even more long-term than in France or the UK, as in principle the timeline is infinite. In practice, two years are chosen in the Netherlands, these denote the beginning year y, and the end year for analysis $y^{(x)}$, where $y^{(x)}$ is the final year with relevant data available. This allows determination of baseline conditions, and the effects in the distant future year, when impacts become 'structural in nature' (CPB/PBL, 2013). The determination of the impacts in the intervening years, between y and $y^{(x)}$, are then interpolated as a growth curve.

The central guidance for CBA in *Norway* suggests that the analysis should seek to capture all relevant effects of the measure under consideration, including those that are in the distant future (Norwegian Ministry of Finance, 2012). This guidance notes recommendations for the transport sector in Europe in the 'HEATCO project' (HEATCO, 2006), which cited difficulties in providing specific estimates more than 40 years into the future. On this basis the Swedish Transport Administration recommended a 40-year analysis period for transport projects, this was then followed by Norway, but with a 75-year period used in the case of rail projects. In responding to these longer timeframes the Norwegian guidance noted the challenge of uncertainty and recommended i) the splitting of the technical lifespan into an 'analysis period' and a 'residual period,' and, ii) scenario and sensitivity analysis. The residual period intends to capture long term effects based on the evolution of costs and benefits during the analysis period. However, where the residual value period is long, or the impacts are subject to considerable uncertainty, the Norwegian Ministry states that sensitivity analysis and scenario analysis should be used.

The *New Zealand* CBA guidance (New Zealand Treasury, 2020), describes 'periods' for which cost and benefits should be estimated. This suggests a 'whole of life costs' approach and details up to the year 2070 in its online software tool 'CBAx'.[13] In the *United States*, the Department of Transportation (US DOT, 2017) proposes that the useful lifetime of a transport project may exceed 50 years. In the context of long-term uncertainty it then suggests that the time horizon should be up to 40 years. In contrast, the USEPA (2010) propose that there is little theoretical guidance on the time horizon of economic analyses. They suggest that the economic analyses should have timeframes that reflect major impacts on welfare, that is, the time horizon should be long enough that the net benefits for all future years become negligible. The USEPA has applied times horizons such as 36 years for power plants, but up to the year 2300 for the social costs of carbon, and even up to 10,000 years for

[11] Following an intervention to reduce coal use, the related reductions in morbidity and mortality from lung cancer only become apparent after a long latency period.

[12] Where the possible effects of an intervention under appraisal are long term and involve very substantial or irreversible wealth transfers between generations.

[13] http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/cbax

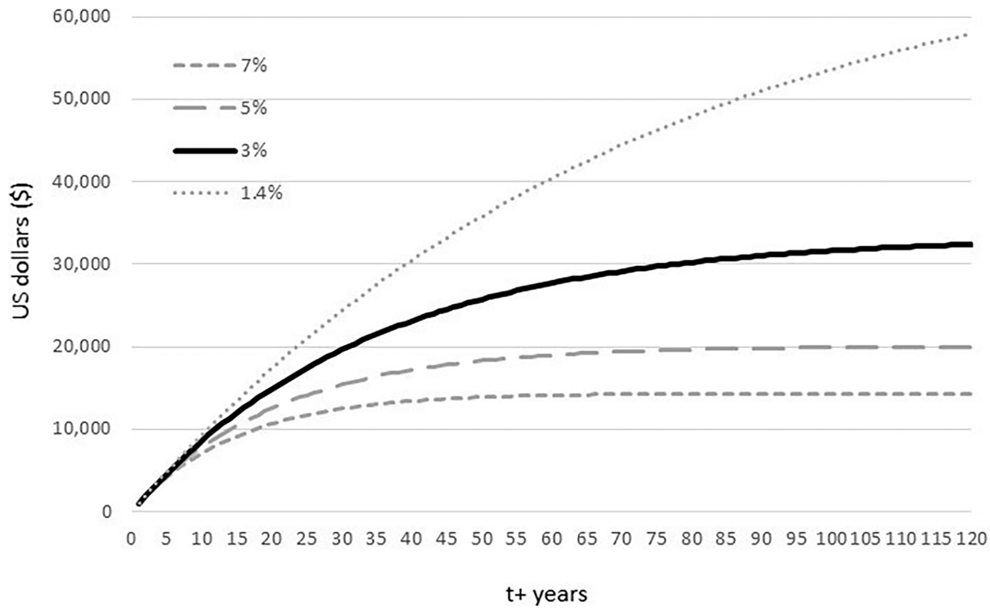

Fig. 1. Effect of time and discount rates on constant flow of $1000 USD per annum

a radioactive waste facility.

The Directorate General for Regional and Urban Policy of the *European Commission* have been employing shorter time horizons (Sartori et al., 2014). This EU guidance has been applying an approach since at least the 1990's, based on a financial analysis survey from 1994 (DG Regio, 2002). This earlier report noted that "*The choice of time horizon may have an extremely important effect on the results of the appraisal process*" (DG Regio, 2002: 24). The current guidance, Sartori et al. (2014), employs the same time horizons as the previous guidance iterations from 2002 and 2008, and with the same rationale. The time horizons detailed range from 10 years for productive industry, 25 years for roads and 30 years for rail. However, it must be noted that these time horizons are financially defined rather than defined by the technical lifetime or by the impacts on welfare; "*in project analysis it is convenient to assume reaching a point in the future when all the assets and all the liabilities are virtually liquidated simultaneously*" (DG Regio, 2008: 37), and "*The choice of time horizon…may also affect the determination of the co-financing rate*" (DG Regio, 2002: 24).

The most recent European Commission guidance on CBA gives an example of a rail project which has a time horizon that is defined by its 'economically useful lifetime' at 30 years, yet the financial and economic flow calculated in residual value are estimated for a further 52 years (Sartori et al., 2014:117). The guidance notes that the resulting financial and economic residual values are very different, reflecting the very different profiles of the financial, and the economic flows that include long term impacts on welfare.

In determining standard practices internationally, it is useful to note the OECD (2018) report which surveyed practices in OECD countries. In transport CBA, of the 15 respondents a considerable majority of 74% used 40, 50, 100 year or even longer time horizons. Only 26% used either 20 or 30 year time horizons. For energy investments, 70% use time periods of up to 30 years and 30% use periods of 100+ years. Policy assessments tend to be shorter, with 36% up to 10 years, but with 27% using 100+ years. A quantification of the impact of longer-term time horizons, that are applicable to environmental costs and benefits, are considered in the next section.

3.4. Quantifying the impact of different time horizons

To quantify the actual impact of the variety of the time horizons discussed above, the example of a constant annual benefit flow of $1000 is projected up to 120 years, in line with Quinet et al. To value these future benefits in the present, Social Discount rates of three, five and seven per cent, similar to the Congressional Budget Office (2003), are applied in a constant form. Added to this is a 1.4% discount rate, as applied to climate change by Stern (2007), and presented in Fig. 1. In Table 2, a zero rate discount is also added which explores the extreme, and could be attributed to non-substitutable natural and social capital consistent with strict interpretation of Hotelling's rule.[14] In both cases, the measurements are in US dollars for illustration.

Table 2
Effect of time horizon and discount rates on constant long-term flow of $1000 USD per annum.

Year (t+)	7%	5%	3%	1.4%	0%
25	11,719	14,142	17,442	20,985	25,000
50	13,866	18,304	25,759	35,799	50,000
100	14,335	19,896	31,628	53,656	100,000
120	14,347	19,990	32,402	57,974	120,000

As would be expected, it can clearly be seen that the impact on the discounted net benefits are considerable when changing discount rates. Table 1 previously detailed the discount rates in application in selected OECD nations, adapted from OECD (2018). Over a 25-year period, moving from 7%, as the risky rate on private returns in the US, to their regulatory appraisal rate of 3%,[15] increases net benefits by $5,723, or by 48.84%. Moving to the Stern discount rate of 1.4, or a zero discount rate, increases the discounted net benefits to $20,985 and $25,000 respectively. The estimated net benefits, are therefore increased by 79.07% and 93.92%, when moving to these lower discount rates, from the risky private discount rate of seven.. This in line with standard commentary

[14] Hotelling's rule is used to define the price path, as a function of time, while maximising the economic rent when fully extracting a non-renewable natural resource. Known as 'Hotelling rent' or 'scarcity rent' it is the maximum rent that could be obtained while emptying the stock of the resource. In an efficient exploitation of a non-renewable resource, the percentage change in the price per unit of time should equal the discount rate, to maximise the present value of the resource capital over the extraction period.

[15] Based on the real rate of return on long-term government debt (Spackman, 2017). A 3% rate is the risky project return in Norway, and closer to the standard rate of 3.5% in the UK (OECD, 2018).

on the impact of discounting. However, the impact of the time horizon, in the case of the low single digit discount rates, is even more significant than further reducing the discount rates. A constant 3% rate extended from 25 to 50 years, has more impact on the results than moving from 3% to 1.4%, or even to a zero discount rate. This has major significance, as low single digit discount rates of ≤3.0%, are now standard across many advanced economies, for regulatory analysis, public projects and evaluation of environmental impacts (OECD, 2018).

Moving to longer time horizons of analysis, to account for more complete long-term impacts on welfare, such as France (120 years), or 100 years with the WHO (2006) and as included in Germany's infrastructure lifetime, has a major impact on the accounting for the benefit flows that accrue from public projects. It is entirely plausible that for some major public investments, such as low-carbon transition or expansion of rail networks, this additional impact could be significant enough to modify a net welfare loss, a benefit ratio of <1, to a net benefit >1. The consequences of time horizon length, for the economic analysis of public policies and projects, are therefore defining. These may be even greater than those in the now well-rehearsed debates on discounting that have unfolded in many economically advanced nations. Conservatively, the theoretical example given did not apply the now common declining discount rates, or any increase in benefits, which are applied in constant form. Both factors would further increase the quantity of net benefits calculated across longer-time horizons. This adds support to the conclusion that longer time horizons are required for the economic analysis of environmental benefits, and avoided damages.

4. Discussion and concluding remarks

The recent history of Cost-Benefit Analysis has established that CBA is not suitable for some questions, while the traditional issue of its' normative foundations has also re-emerged. Yet the inclusion of the environment, and by that an increasing influence of sustainability sciences, has seen major changes to the technical approaches to analysis, and the resulting public guidance that supports its practical application in project evaluation. This has included an explosion of studies on refining the valuation of externalities, increased inclusion of co-benefits, new equity weightings and major changes to discounting practices. Discounting has evolved towards a reduction in the standard Social Discount Rate, the introduction of declining discounting and application of dual discounting for social and natural capital. In spite of these changes, an issue that has received little attention is the issue of the time horizon applied to the analysis itself.

The work of Flyvberg has frequently been cited as identifying an 'optimism bias,' in failing to account for cost overruns and demand shortfalls in public projects (Flyvbjerg, 2007). However, the issue of short time horizons shows that there is a major risk of a new bias category, in the form of a 'pessimism bias' for environmentally beneficial projects, and an 'optimism bias' for those that are environmentally damaging. This will occur where there is a failure to adequately include environmental costs and benefits, through applying shorter, more financially-defined time horizons. Shorter time horizons truncate the necessary inclusion of long-term flows in the analysis. This is particularly important for projects which generate damages, including through greenhouse gas emissions and impacts on biodiveristy, which are defined by the long-term. It is also significant for projects seeking environmental improvement, in transition and adaptation. Public investment projects, that seek improvement often involve high up-front capital investments, with benefits to welfare spread out over the long, and very long-term.

In response to this variety of challenges, a review of Ireland developed what it termed a '*CBA sustainability package*,' a parcel of related measures recommended for update of CBA (O'Mahony, 2018). These address the 'technical building blocks' of CBA and point towards: a wider scope of costs and benefits (through application of frameworks that support analysts in identification and in providing money valuations); an increase in the shadow price of carbon (through changes in how it is set, accompanied by improvement in accounting practices for GHG emissions); a lower discount rate (with application of the declining discounting and dual discounting methods); and an extension to the time horizon (with application of techniques that improve the handling of uncertainty). While Hulme (2009) suggests that the discount rate is *the issue* when it comes to considering emissions mitigation and the impacts of climate change. Hulme also suggests that the time horizon could potentially be even more significant in public project analysis. A simple theoretical analysis, using a constant flow of benefits, under different constant discount rates, shows that even a limited extension of the time horizon can be more significant. Moving from 25 to 50 years, on a 3% discount rate, has a greater impact than moving from 3%, down to the Stern et al. 1.4%, or even a zero rate, −when remaining on a shorter 25 year analysis period.

The common defence for employing shorter time horizons, framed as the challenge of forecast uncertainty or as the impact of discounting, do not provide appropriate grounds to justify shorter time horizons. A review of national and international practices clearly shows that time horizons are tending to lengthen, either through extending the analysis period, or capturing the long-term externalities in a residual calculation, with the explicit objective of responding to environment and sustainability considerations. The survey of CBA practices in OECD countries shows that lengthened time horizons have become the norm in project appraisal (OECD, 2018).

Approaches vary across different countries, French transport CBA approaches up to 2140, to include both the analysis period to 2070 and a residual period to 2140. Caution is required in using a residual period, as the time horizon sets the period for demand forecasts which are required for accurate calculation of costs and benefits. Therefore, it is not sufficient to retain the short appraisal time horizon and seek to bundle all long-term impacts into a residual. The first approach must always be a longer analysis period, a residual is the option of last-resort with respect to including long-term impacts.

For the United Kingdom, the approach to assessing issues of intergenerational wealth transfer, such as the impacts of climate change, is represented by a 300 year period. Project analysis CBA in the UK will likely be implemented on shorter timescales, such as 60 years for transport, and potentially up to 2100 for valuation of energy and GHG emissions. The Dutch approach is indicative of a period of analysis that reflects the actual impacts on welfare, and to use scenarios and sensitivity analysis to address uncertainty. In practice, this analytical period may be limited by the data available from relevant studies, yet the intention to consider a long time horizon is clear.

Adopting time horizons for including environmental impacts, similar to the technical lifetimes of long-lived infrastructure projects, are now justified. The 'lifespan of the physical components of the infrastructure' in Germany may be up to 100 years. This corresponds with the World Health Organisation's 100-year time horizon, that captures the long-term health impacts of air pollution (WHO, 2006). It is also similar in scale to the approach that is recommended by Quinet, to extend the time horizon of environmental costs and benefits to 2140 (Quinet, 2013). It is necessary to consider the appropriate timescale of each environmental effect early in the analysis, during identification and characterisation, and before the economic evaluation. It is recommended to consider time horizons of 100+ years, dependent on the type of environmental damage that a project leads to, including priority costs and benefits such as air pollution, greenhouse gas emissions, climate change and damages to ecosystems and the services they provide.

Adopting this approach can provide the appropriate balance between the need to capture long-term impacts on welfare, with the technical challenge of the long-term forecasts that are necessary to achieve this. The process of implementing longer time horizons for significant environmental impacts, requires early consideration, during scoping and screening, to identity and quantify the environmental impacts. Due to its roots in the orthodoxy of microeconomics, CBA cannot fully incorporate complex systemic environmental change, such as that the global level. However, it can remain a useful tool for project appraisal and policy analysis. This is conditional on its enhancement and improvement to respond to the growing urgency of environmental challenges, in keeping with the robust conclusions of sustainability science. Following the related changes to the technical building blocks of analysis that are now common, it is also necessary to encompass long-term time horizons for analysis of environmental costs and benefits, if CBA is to remain pertinent to sound analysis of public projects.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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