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Review

Discounting in the evaluation of the cost-effectiveness of a vaccination programme: A critical review

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ABSTRACT

Discounting future costs and health benefits usually has a large effect on results of cost-effectiveness evaluations of vaccination because of delays between the initial expenditure in the programme and the health benefits from averting disease. Most guidelines currently recommend discounting both costs and health effects at a positive, constant, common rate back to a common point in time. A review of 84 published economic evaluations of vaccines found that most of them apply these recommendations. However, both technical and normative arguments have been presented for discounting health at a different rate to consumption (differential discounting), discounting at a rate that changes over time (non-constant discounting), discounting intra-generational and inter-generational effects at a different rate (two-stage discounting), and discounting the health gains from an intervention to a different discount year from the time of intervention (delayed discounting). These considerations are particularly acute for vaccines, because their effects can occur in a different generation from the one paying for them, and because the time of vaccination, of infection aversion, and of disease aversion usually differ. Using differential, two-stage or delayed discounting in model-based cost-effectiveness evaluations of vaccination raises technical challenges, but mechanisms have been proposed to overcome them.

1. Introduction

Economic considerations increasingly drive public investments in vaccines [1]. A key decision-making tool is economic evaluation, which weighs the incremental cost of vaccination against the incremental health and economic benefits that it brings. Since vaccines prevent future disease from occurring, the costs and benefits associated with vaccination usually fall at different times. Economists regard present *consumption* (see Table 1 for definitions of terms in italics) as more valuable than future consumption, because (i) there is an *opportunity cost* to consuming now rather than later, since the money spent could have been invested elsewhere to generate some returns, and (ii) most people simply prefer to consume now rather than later, all other things being equal [2]. The standard approach to collectively capture these preferences for present over future consumption is by *discounting*, which reduces the value of future costs and benefits compared to those in the present [3].

The most common method is to apply a constant (exponential) discounting rate, and to use the same rate for consumption and health. Constant rate discounting is supported by the discounted utility model, which states that the utility derived from consumption at a future time t is the same as the utility now multiplied by a discounting factor $(1+r)^{-t}$. However, this standard model of discounting has been challenged [4–10], particularly for the case of vaccines [11–16], since they have distinct characteristics not shared by many other health interventions and hence their cost-effectiveness can be particularly sensitive to discounting. In light of the importance of discounting to economic evaluations of vaccines, this paper aims to survey the methodological basis and merits of alternatives to standard discounting schemes, as well as to consider how they may apply to vaccination. We first review how discounting is used in current economic evaluations of vaccination, then list the main features of vaccination that distinguish it from other health interventions. We explore how alternatives to the standard discounting model may address these features with respect to four key areas: differential discounting (discounting health at a different rate to consumption), societal preferences, inter-generational effects and the timing of health gains. Finally, we propose solutions

Abbreviations: NICE, National Institute for Health and Care Excellence; WHO, World Health Organization.

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Table 1
Glossary of key economic terms used.

Consumption	The final purchase for use of goods or services by individuals (consumers).
Cost–benefit analysis	A type of economic evaluation in which the incremental costs and benefits of an intervention are both expressed in monetary units.
Cost-effectiveness analysis	A type of economic evaluation in which the incremental costs of an intervention are compared to the incremental outcomes of the intervention expressed in physical units such as cases of disease averted, lives saved or quality adjusted life years gained.
Discounting	Reduction in the value of a future cost or benefit at a pre-specified rate, which depends on its temporal distance from a common time (such as the time at which an intervention like a vaccination programme is initiated).
Externality	Cost or benefit that does not fall on the person producing or consuming a good.
Opportunity cost	The value of the next best alternative use of resources which is foregone when the resources are consumed.
Social rate of time preference	The rate at which society values present over future consumption.
Standard gamble	Method of eliciting the value that individuals place on a health state by asking them their preference between being in a health state, and being in perfect health but with some given risk of instant death.
Stated preference	Method of eliciting individuals' preferences for different options by asking them what they would do in hypothetical situations.
Stationarity	Preference between two outcomes that depends only on the time interval between them and not on when the first event occurs.
Time tradeoff	Method of eliciting the value that individuals place on a health state by asking them their preference between a shorter time spent in perfect health, and a longer time spent in that health state.

to some of the technical issues that may arise with alternative discounting schemes.

2. Review of discounting in economic evaluations of vaccination

2.1. Methods

We examined how discounting is used in economic evaluations of vaccination reviewed in six recent systematic reviews of economic evaluations of vaccines against human papillomavirus [17] ($n = 12$); *Streptococcus pneumoniae* [18] ($n = 15$), [19] ($n = 10$); rotavirus [20] ($n = 17$); *Haemophilus influenzae* type B [21] ($n = 13$); and seasonal influenza [22] ($n = 18$).

3. Results

In total 84 unique economic evaluations of vaccines published from 1993 to 2014 were examined (see appendix for details).

Of these, 19 (23%) did not discount at all. These included 14 evaluations of paediatric influenza vaccination and two of pneumococcal conjugate vaccination [23,24], where the time horizon over which costs and effects are assessed was less than a year. The time horizons of less than 1 year and the lack of discounting were not inappropriate in most cases, as there were no long-term consequences to consider in the analysis. However, some of these evaluations included considerations of years of life saved beyond the time horizon, which would normally be discounted. One evaluation of rotavirus vaccination had a time horizon of 5 years, which the authors considered short enough to ignore discounting effects [25]. Two others (on *Haemophilus influenzae* type B [26] and pneumococcal conjugate vaccination [27]) had longer time horizons but gave no justification for failing to discount. A further four (5%) discounted benefits alone (and not costs), while 11 (13%) discounted costs alone (and not benefits).

Of the remaining 50 studies discounting both costs and effects, 43 (51%) used the standard discounting scheme of discount rates that are constant over time and equal for both costs and effects (with rates ranging from 3 to 6%). However, one (1%) used stepwise equal rates (reflecting United Kingdom Treasury recommendations [28], see section on "non-constant discounting" for details) and six (7%) used constant rates but discounted costs at a higher rate than benefits. Of the studies with differential discounting, five of them reflected national guidelines (as the United Kingdom prior to 2004, the Netherlands and Belgium recommended differential discounting). However, one (set in France) did not, instead justifying the choice by appealing to the controversy over whether economic evaluations of vaccination should use equal discounting [29].

Of the 84 studies, 52 (62%) involved tracking a single age cohort. A further 16 (19%) tracked a range of age groups, but either only followed outcomes for a year or less, or did not consider the timing of outcomes at all. Of the remaining 16 (19%) studies that tracked multiple cohorts over several years, eight were static or pseudo-dynamic models with no interactions between effects in different cohorts. The remaining eight were dynamic models with inter-cohort effects.

4. Distinctive intertemporal features of vaccination

Vaccination has several distinctive intertemporal features compared to most other health interventions. First, there are often long delays between vaccine administration (when costs are incurred) and disease averted (when benefits are obtained), so benefits are greatly affected by discounting. For example, vaccination against human papillomavirus [15] or hepatitis B [14] involves decades-long delays between initial costs and eventual benefits. In contrast, interventions without long-lasting effects (such as pain relief that provides immediate but short-term relief of symptoms) may be largely insensitive to discounting.

Second, vaccines have positive *externalities*: they not only reduce disease risk in vaccinees but also provide "herd" or community-level protection to others who might otherwise have been infected by vaccinated individuals. The externalities are non-linear with respect to coverage: if a single individual is vaccinated, the health gain to others is small, but if most susceptible individuals are vaccinated, there is a substantial health gain to others. Herd protection from vaccination can persist for years, and indeed indefinitely in the case of eradication. Hence there can be delays between the earlier cost of vaccination and realisation of herd protection effects. Capturing these effects often requires multiple cohort models that stretch further into the future compared to models of non-infectious diseases.

The interaction between time differences and generational differences can be complex. They are illustrated in Table 2 for four vaccines:

- Considerable expense was spent on smallpox eradication until it was achieved in 1979. Today, expenditure on smallpox vaccination is virtually zero, but we continue to receive benefits from having eradicated smallpox (which was estimated to cost the world $1.35 billion a year in 1967 [30]). Note that even in the 1970s there were generational differences in benefits of vaccination: children were protected from disease, while their parents were already immune due to prior vaccination or infection.
- Human papillomavirus vaccination protects current adolescents from future cervical cancer. It has a smaller effect on current adults because the vaccine is only prophylactic, and many of them

Table 2
Temporal and generational timing of benefits from four vaccines.

Vaccine	Benefits	
	Present generation (present adults)	Future generations (present children)
Smallpox		
Present (1970)	Very small	Large
Future	Very small	Very large
Human papillomavirus		
Present (2010)	Small	Small
Future	Small	Large
Varicella		
Present (2010)	Very small	Medium
Future	Possibly negative	Large
Paediatric influenza		
Present (2010)	Large	Small
Future	Very small	Very small

have already been infected with human papillomavirus. Hence, there are fewer inter-cohort effects, but time delays between costs (vaccination) and benefits (preventing cervical cancer) are important.

- Varicella vaccination protects current children from varicella, and years later, protects them from zoster, a more severe disease caused by reactivation of varicella in people who have recovered. In current adults though, vaccination could actually result in higher zoster incidence [31]. Hence, there are important inter-cohort effects, with benefits to cohorts receiving the vaccine but detriments to older cohorts.
- Paediatric influenza vaccination directly protects children from influenza, and indirectly protects adults through herd immunity. In developed countries, children are the main influenza transmitters, but older adults are the most susceptible to influenza complications [32]. However, the present year's influenza vaccine offers few benefits to either children or adults in future years, since the influenza virus will no longer genetically match the vaccine in the future. Hence, there are important inter-cohort effects, but time differences are less important.

These inter-cohort effects change the nature of the decision problem. Non-infectious diseases are usually modelled with a single age cohort only, because intervening in that age-cohort is not expected to bring important health effects to other age-cohorts. Hence, a decision made for the present cohort would be equally valid to future cohorts unless conditions change. Equally, if it was reversed in the future it would simply return future cohorts to the status quo prior to the decision. In contrast, decisions about vaccines affect multiple cohorts over several years. Hence, economic evaluations of vaccination are often based around transmission dynamic models which consist of several interacting age-cohorts in order to capture the inter-generational externalities of vaccination [1].

5. Discounting health

Future costs are often discounted at the *social rate of time preference*, which has three components [2,28,33,34]: (i) pure time preference or "myopia", an individual preference for consumption now instead of later due to impatience, (ii) time preference due to uncertainty about the ability to consume in the future, and (iii) decreasing marginal utility of consumption, as economic growth causes future consumption to exceed present consumption. These effects relate to time preferences of individuals, but can arguably be extended to justify discounting societal investments [28,35]. From this perspective, the discount rate has been expressed as the rate at which society is willing to tradeoff consumption today for consumption in the future. This can arguably be captured, for example, by the long-term interest rate on government bonds which measures the market rate at which the government is able to make this tradeoff.

Health economic evaluations involve estimates of health effects as well as costs (consumption). Most health economic guidelines, including the Washington Panel on Cost-effectiveness in Health and Medicine [36] and the World Health Organization (WHO) [35], recommend discounting both costs and health effects at an equal rate. Only three countries (Poland, the Netherlands, and Belgium) recommend differential discounting in their base case [37]. WHO also recommend sensitivity analyses including discounting health at a lower rate than consumption [35] and using a nonconstant discount rate when evaluating effects over long time-scales [38]. The UK National Institute for Health and Care Excellence (NICE) initially recommended discounting health at a lower rate than costs, but switched to equal discounting in 2004 in a move that prompted robust debate [4,39].

NICE have issued special discounting guidance for cases in which "treatment restores people who would otherwise die or have a very severely impaired life to full or near full health, and when this is sustained over a very long period (normally at least 30 years)" [40], initially recommending differential discounting and subsequently amending the guidance to an equal rate lower than the standard reference case rate. Paulden and O'Mahony have criticised these conditions (in their original application to differential discounting) as inconsistent and discriminatory, because they appear to exclude interventions that are preventive or which need to be maintained over time. Hence, there are disease conditions where different interventions that decrease their impact (such as preventive and curative ones) would be evaluated with different discount rates [41].

As previously discussed, discounting future health has a pronounced effect on vaccination because of the long delay between costs and benefits. Bonneaux has argued that this disparity may reflect the "law of cure" [42] or "rule of rescue" that, in McKie and Richardson's formulation [43], leads people to prioritise saving lives of identifiable individuals facing imminent death over "statistical lives" that can be saved through preventive measures like vaccination. McKie and Richardson suggest that "identifiability" may be defensible on utilitarian grounds because it supports "people's belief that they live in a community that places great value upon life", but is still a morally dubious criterion for discrimination. NICE has explicitly excluded using the rule of rescue as a decision-making criterion [44].

6. Equal vs. differential discounting

Equal discounting of costs and health effects is supported by several arguments. One is Weinstein and Stason's consistency thesis [45]: equal discounting ensures that two programmes initiated at separate times but with identical cost and health consequences (when measured over the same period of time following initiation) receive equal priority when the value of health is constant over time. Williams [46] elucidates the reasoning behind equal prioritisation: on a societal level, marginal investment in consumption can be substituted with marginal investment in health. Hence, a steady state relationship should exist between consumption and health, i.e. the (consumption) value of health should remain constant over time.

A second argument is Keeler and Cretin's postponement paradox [47]. They argue that if health is discounted at a lower rate than costs, then the cost-effectiveness of a health investment will improve further in the future if it is postponed, resulting in health investments being "paralysed" into infinite postponement. This argument has been criticised as being usually irrelevant since decision makers are typically choosing between competing priorities to fund from a fixed annual budget, rather than the optimal timing of a given investment. Hence, the issue of cohorts of patients in different years competing for the same resources never arises [7,10,48,49].

The last argument is made by Lipscomb et al. [36] from the perspective of horizontal equity. Equal discounting preserves "time neutrality" by giving equal treatment to potential beneficiaries who are alike in every respect except for their position in time relative to the decision time. The counter-argument is that these beneficiaries are not actually equal because they live in societies with different income levels, available health technologies and hence valuations of health [5].

These arguments assume that the value of health is constant over time. If the relative value of health increases as society becomes wealthier, then Gravelle and Smith showed that the discount rate for health should be approximately the discount rate for costs less the growth rate in the value of health [7]. More recently, Claxton et al. [9] developed Gravelle and Smith's framework further by suggesting that the validity of differential discounting depends on whether the decision maker is seeking to maximise welfare or health itself, whether the budget for health care is fixed and whether the value of health changes over time. They show that the differential between the discount rate for costs and health can be informed by growth in either the value of health, or the cost-effectiveness threshold.

7. Individual vs. societal preferences

Individuals have time preferences that can be elicited using different methods, including empirical *stated preference* studies. The social rate of time preference relates to preferences of society as a whole for present over future consumption. The appropriate way to establish this rate, and in particular how it relates to the time preference of individuals, is not straightforward [2,6]. One approach is simply to treat it as the average of individual time preferences. However, stated preference studies often [50] (but not always [51]) find that individual discount rates exceed societal rates. Hence, Olson suggests that such studies, if they are to be used at all, should ask individuals to prioritise based on their preferences about the temporal distribution of health in society, without foreknowledge about what their position in that society is [52]. Nevertheless, some economists believe that social decision making should reflect the aggregation of individual rather than social preferences to avoid overriding the choices that people make in their individual decisions (the principle of consumer sovereignty).

One component of the social discount rate is uncertainty about the possibility of being able to enjoy the benefits of future consumption. This uncertainty stems from several kinds of risk: (i) catastrophe risk, the risk that society itself will no longer exist in a form that will allow these benefits to be enjoyed [28]; (ii) unanticipated risks which may lead to future benefits of a particular programme not materialising, such as obsolescence due to technological innovation [28]; (iii) the risk that individuals will not enjoy the future benefits because of death or another personal catastrophe [5]. The rest of this section discusses some of the challenges in estimating these risks.

Of these risks, catastrophe risk is clearly relevant to society, but likely to be smaller than the risks operating on an individual level. Murray and Acharya suggest it may not exceed 0.1% a year [53]. Programme-specific risks are also relevant to society, but it would seem difficult to estimate them by asking individuals to quantify the actual risk (rather than their subjective perception of that risk). Tinghög suggests that individual preferences should be overridden in a case of "myopic preference failure", where individuals are cognitively unable to process the information necessary for welfare maximisation, even if the information is technically available [6]. Parfit [54] suggests that if the reason for discounting is uncertainty about the future, then the discount rate should be varied based on the risk involved with the particular programme. Lipscomb et al. [36] argue that programme-level uncertainty has no place in the discount rate at all, but instead should be incorporated into the expected outcomes of the cost-effectiveness analysis.

The third risk is that of individual risk of death or catastrophe. Brouwer et al. [5] suggest that this risk is irrational at a societal level, because some (usually predictable) proportion of individuals will always live to receive health benefits. Indeed, this risk may be particularly irrelevant for vaccination programmes due to their positive externalities. As Tasset et al. [11] point out, individuals may discount future health benefits because they fear not being able to enjoy them, but the time period in which they were protected from infection still contributes to societal (herd) protection, and future generations can continue to enjoy this benefit regardless of whether individuals in the previous generation survive.

8. Intra- vs. inter-generational tradeoffs

As previously mentioned, the long-term effects of vaccines can raise issues around the distinction between intra- and inter-generational time tradeoff. This distinction has been made more widely. In Gravelle and Smith's terminology [7], a distinction should be made between comparison of health effects of an individual of age a at time t with the same individual of age $a+1$ at time $t+1$ (intra-generational discounting), and of an individual of age a at time t with another individual of age a at time $t+1$ (inter-generational discounting). Discounting will reduce the value of not only any future health and consumption gains of the current generation, but also the total value of all the health and consumption of a future cohort compared to the present one.

This distinction is particularly important for vaccines. Most economic evaluations of interventions against non-infectious diseases need only account for the cohort receiving the intervention, whereas economic evaluations of vaccination often extend the analysis to include future cohorts in order to better capture indirect benefits (and detriments) such as herd protection. The health gains of future cohorts through herd protection are contingent on decisions taken in earlier cohorts. In contrast, for evaluations of treatment, health gains in future cohorts are independent of decisions made in earlier cohorts.

Intra-generational discounting might legitimately be based on individual time preferences, while inter-generational discounting involves wider issues of fairness. Future generations cannot participate in present decisions that will affect them. Schelling argues that pure time preference measures "emphatic distance", our preference for people closer to us in time as they are more familiar and likely to be more similar to us [55]. However, Tinghög argues that it would be unfair to disadvantage them purely because "it will benefit "us" instead of them" [6]. Sen [56] takes this further (albeit in the context of energy policy) and argues that future generations have rights to resources that we should not take away, even if their utility loss is compensated by our gains.

To incorporate this distinction, Lipscomb [8] proposes "two-stage discounting" in which health effects in the same individual are discounted back to a common age using an estimate of individual time preference, then the individually discounted health effects across all individuals are discounted back to a common time using the social rate of time preference (which is lower than the private rate of time preference).

9. Non-constant discounting

Another approach is "slow" or non-constant discounting [57] in which the discount rate decreases over time, so that it has less effect on distant benefits, which accrue mainly to future generations. This is motivated from inter-generational concerns [53] and empirical studies showing that individuals have declining rates of time preference as outcomes become more distant in time [51,58–61]. The resulting calculations are analytically simpler than two-stage discounting, albeit at the cost of being a more indirect (and less accurate) way of addressing inter-generational equity. Time-dependent functions proposed for the discount rate include stepwise, proportional [57], hyperbolic [58], and quasi-hyperbolic [62].

The UK Treasury recommends stepwise discounting to all public sector bodies [28], but at a very slowly declining rate (3.5% for the first 30 years, declining to 3.0% from year 31 and with further declines from year 76); this will only make a perceptible difference in analyses with effects that span several generations. Murray and Acharya propose an exponentially declining rate in the short term to reflect concern for proximal generations, and then a constant (but extremely low) rate thereafter [53]. Westra et al. [15] examined the cost-effectiveness of human papillomavirus vaccination using different several different discounting models.

One objection to "slow discounting" is that it would violate the *stationarity* property [63]. Stationarity ensures preference stability i.e. someone's time preference for an event will not change as time advances. However, stationarity is not always observed in stated preference studies [64,65], and may anyway be practically irrelevant if decisions are binding for the future. Harvey [57] suggests that individuals can have "multiple selves" in behavioural decision theory (i.e. consider versions of themselves at different time points to be separate entities) and hence, experience different time preferences. However, even though individuals may change their mind as an event draws near, the practical consequences of reflecting this in decision rules have yet to be clarified, and it has yet to be considered appropriate for policy makers to adopt such a position.

10. Timing of risk reduction vs. utility reduction

Vaccination involves three events separated in time: risk of infection, risk of mortality, and change in life expectancy. Bos et al. [14] has argued that health improvements following vaccination (and other preventive interventions) should be discounted from the time of infection risk reduction to the time of the intervention, rather than from when actual life years or health utilities are gained (i.e. when disease manifestations are prevented). The rationale is that vaccination is a good consumed for the sake of averting future risk exposure, and the stream of life years saved as a result is simply a statistical construct. Hence, health benefits should be discounted when the good (vaccination) is used. However, these recommendations have yet to be adopted in guidelines or used in economic evaluations.

Going a step further, Lowenstein and Prelec [66] developed the concepts of "savouring and dread", anticipated pleasure or pain, to explain why people often prefer to delay pleasant outcomes and hasten unpleasant ones. Cohen [67] uses these ideas to suggest that part of the benefit of preventive interventions includes not only averting future disease, but also gaining "utility in anticipation", or anxiety reduction due to decreased risk of a future event. Since few health risks are certain to occur and individuals are rarely aware of what would have occurred if a preventive measure had not been taken, he argues that the primary motivation for taking preventive actions is to reduce the anxiety associated with a risk, rather than to avert the risk itself. Drummond et al. [16] suggest that at least part of the utility gain from vaccination should take place from the time of vaccination rather than the time of disease averted.

The possibility of losing utility from dread may imply negative pure time preference for health, because averting future health detriments may be valued more highly the further away from the present they are (because they are accompanied by a longer period of dread). Indeed, stated preference studies have found that some people do have zero or negative time preference [68], particularly for health states perceived as more severe. Others report high positive time preference, sometimes even higher for health than for consumption [50,51], but this may reflect "status quo bias" [69] since a person's stock of health declines over time [7]. Furthermore, even if a person's pure time preference is negative, the overall preference may be positive as a result of the uncertainty component.

11. Addressing technical difficulties

Because economic evaluations of vaccination often involve models with multiple interacting cohorts, a number of technical difficulties arise when using differential, two-stage or delayed discounting. O'Mahony et al. [70] demonstrated that the cost-effectiveness of introducing vaccination improves as the number of age-cohorts modelled increases under differential discounting, but not under equal discounting. The issue arises because each successive age-cohort receives vaccination 1 year later and so is not "start time neutral", so cost-effectiveness improves with each successive cohort, all else equal. Hence, vaccination will be less cost-effective in a given cohort compared to previous cohorts when discounted back to the same year.

Furthermore, zero or negative time preference for health would result in infinite benefits at finite costs for disease eradication [53], hence, justifying virtually unlimited reprioritizing of investments towards eradication. Indeed, zero or negative time preference would have the same effect for any successful vaccination programme, unless the time horizon was finite, since the discounted costs and health effects from an infinite number of cohorts need to be summed up. Setting a finite time horizon is an unsatisfactory solution as it is equivalent to having a 100% discount rate after a certain time; there does not seem to be any empirical or methodological justification for this. When time preference for both consumption and health is positive, an infinite time horizon does not pose methodological difficulties since the marginal change in discounted costs and health effects with each additional cohort rapidly diminishes. This problem is a special case of Parfit's "argument from excessive sacrifice" [54], in which the lack of positive time preference for benefits may cause the present generation to sacrifice all its consumption for the sake of future generations. Parfit's solution is not to impose a positive time preference, but to incorporate an equity criterion by which benefits are equitably shared between generations, so that no generation is asked to make too great a sacrifice for the sake of another. For instance, a boundary condition could be introduced such that the health of any given generation would not be allowed to fall below a certain threshold as a result of health resource allocation decisions.

Both these problems (cost-effectiveness depending on the number of cohorts modelled, and infinite benefits for finite costs) can be avoided by using a modification of Lipscomb's two-stage discounting [8]: discount costs and health effects in each cohort back to the common age of vaccination using a differential rate, and then discount them for each cohort back to a common time using the same (possibly negative) societal discount rate. A difficulty arises because with vaccination, health effects can fall on different cohorts from those receiving the intervention, so they can be attributed either to the cohort receiving the vaccine, or the cohort benefitting from the effects. The latter is both technically simpler (avoiding the need to determine which cohort benefits from which vaccine) and easier to justify, since benefits are then discounted at the rate received by the cohort in which they fall. A disadvantage of two-stage discounting is the added complexity of the procedure, especially in multi-cohort models. In environmental and energy policy, simple formulations to achieve the same effect have been proposed. For instance, Schelling [55] suggests that the pure time preference element of discounting is removed when considering intergenerational issues. However, equivalent formulae in health economics are not obvious because improving the health of the present generation does not reduce the stock of health for future generations in the way that may happen with natural resources [53].

O'Mahony et al. suggest a more convenient solution that can be applied to health: adjust the cost-effectiveness threshold in multi-cohort models based on the (discounted) incremental cost-effectiveness ratio of a hypothetical comparator which is just at this threshold when undiscounted [71]. They also show that the resulting solution is equivalent to the two-stage discounting scheme described above.

12. Conclusion

Most economic evaluations of vaccination still discount both costs and health at a positive, constant, common rate back to a common time. Obviously, any adjustment in the way vaccine evaluations are discounted needs to be consistent with guidelines for health economic evaluations in general, while being cognisant of particular consequences for vaccines due to their distinctive features. Differential discounting appears to be technically sound, more equitable from an inter-generational perspective than equal discounting, and is already accepted in some countries as appropriate to all health economic evaluations. Other adjustments, such as a decreasing rate of discounting or altering the time at which health is discounted, may also reflect our concern for inter-generational equity and avoiding anxiety due to a potential future health detriment. Hence, there are sound empirical, theoretical and ethical justifications for considering other departures from standard discounting, although the technical implications of these adjustments are less well explored compared to those for differential discounting. Since economic evaluations of vaccination are particularly sensitive to discounting, future work to explore such alternatives should consider vaccination-specific issues as part of that enquiry.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.vaccine.2015.06.084

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